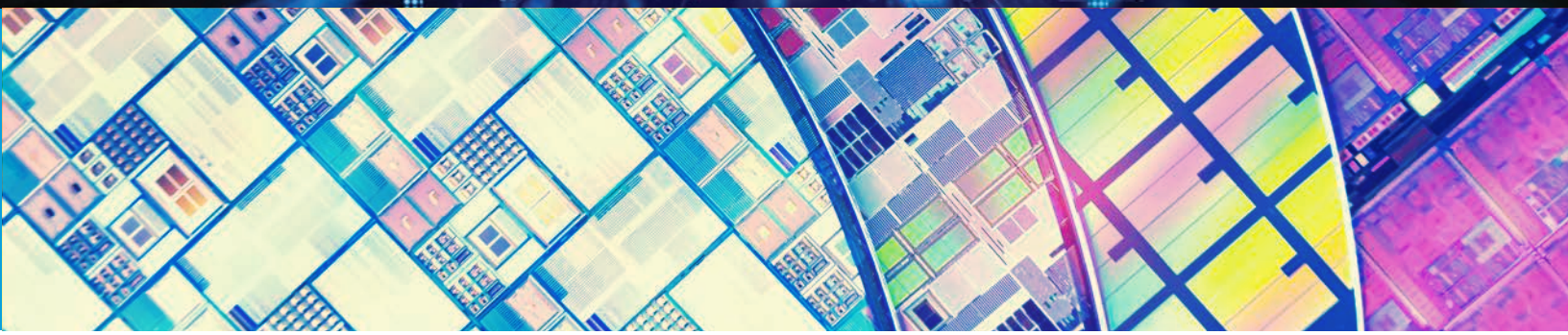
GLOBAL VALUE CHAIN DEVELOPMENT REPORT 2023

RESILIENT AND SUSTAINABLE GVCS IN TURBULENT TIMES



UIBE 1951 · ADB · IDE-JETRO · WORLD TRADE ORGANIZATION

GLOBAL VALUE CHAIN DEVELOPMENT REPORT 2023

RESILIENT AND SUSTAINABLE GVCS IN TURBULENT TIMES

UIBE 1951 ADB IDE-JETRO WORLD TRADE ORGANIZATION

Creative Commons Attribution-NonCommercial 3.0 IGO license (CC BY-NC 3.0 IGO)

© 2023 Research Institute for Global Value Chains at the University of International Business and Economics, Asian Development Bank, the Institute of Developing Economies–Japan External Trade Organization and the World Trade Organization.

This work is a product of the Research Institute for Global Value Chains at the University of International Business and Economics, Asian Development Bank, the Institute of Developing Economies–Japan External Trade Organization and the World Trade Organization. It is based on joint research efforts to better understand the ongoing development and evolution of global value chains and their implications for economic development. The views expressed in this work are those of the individual chapter authors and do not necessarily reflect the views and policies of the copublishing partners, their boards of executive directors or governors, or the governments they represent, nor that of the institutions with which the individual authors may be affiliated. The opinions expressed and arguments employed herein are not intended to provide any authoritative or legal interpretation of the provisions of the WTO agreements and shall in no way be read or understood to have any legal implications whatsoever.

The copublishing partners do not guarantee the accuracy of the data included in this work and accept no responsibility for any consequence of their use. The mention of specific companies or products of manufacturers does not imply that they are endorsed or recommended by the copublishing partners in preference to others of a similar nature that are not mentioned.

By making any designation of or reference to a particular territory or geographic area, or by using the term "country" in this work, or the boundaries, colors, denominations, and other information shown on any map in this work, the copublishing partners do not intend to make any judgments as to the legal or other status of any territory or area.

This work is available under the Creative Commons Attribution-NonCommercial 3.0 IGO license (CC BY-NC 3.0 IGO) https://creativecommons.org/licenses/by/3.0/igo/. By using the content of this publication, you agree to be bound by the terms of this license. Please contact the Research Institute for Global Value Chains at the University of International Business and Economics (email: rigvc@uibe.edu.cn) if you have questions or comments with respect to content, or if you wish to obtain copyright permission for your intended use that does not fall within these terms.

For any copyright materials in this publication that are attributed to a source other than any of the copublishing partners, please contact the copyright owner or publisher of that source for permission to reproduce it.

The copublishing partners cannot be held liable for any claims that arise as a result of your use of those materials.

Note: ADB recognizes "China" as the People's Republic of China; "South Korea" as the Republic of Korea; "Laos" as the Lao People's Democratic Republic; "Russia" as the Russian Federation; and "Vietnam" as Viet Nam. "Taipei,China" is a member of ADB; "Chinese Taipei" is a member of WTO. Chapters of the report contributed by ADB use ADB's member designation.

Cover design by Mike Cortes.

Contents

Tables, Figures, and Boxes vi
Foreword xiii
Publishing Partners xv
Contributors xvi
Acknowledgments xviii
Abbreviations xix
Editorial and Advisory Committee xxv
Key Messages and Findings xxvi
Executive Summary xxviii

Chapter 1: Examining Global Value Chains in Times of International Shocks 1

1.1 Introduction 1
1.2 Global Value Chains During Periods of Shocks 3
1.3 Dollar Prices and Global Value Chains 12
1.4 Potential Bottleneck Products in International Trade 17
1.5 Geographic Concentration in Value and Frequency of Trade 21
Concentration in Foreign Value-Added Sources 21
Concentration in Frequency of Engagement 24
1.6 Adjusting to Shocks 28
Prospects for Global Value Chain Reconfiguration 30
Localization Policies in the People's Republic of China 39
Conclusion 43
References 45

Chapter 2: Impacts of Trade Tensions and COVID-19 on Global Value Chains 49

2.1 Introduction 49
2.2 Sources of shocks and their propagation in Global Value Chains 50
Sources of Shocks and Mechanisms of Propagation 51
Propagation of Shocks through Tariff Measures in GVCs 52
Propagation of Shocks through Non-Tariff Measures in GVCs 54
2.3 Patterns of Restructuring and Regionalization of Global Trade 56
Global Trade Picture 56
Trade Diversion 57
Reshoring and Regionalization 59
2.4 Trade Tensions and Global Value Chains 62
Trade Among the Major Economies 62

Triangular Trade between the PRC, the US and Third Countries 64

2.5. COVID-19, GVCs and Digitalization 67

The Impact of COVID-19 on Reshaping Global Value Chains 67

Counterfactual Analysis of the Impact of the COVID-19 Pandemic on GVCs 67

Digitalization, Resilience and Recovery 72

Conclusion 76

Appendix 78

1: Changes in the Average Global Value Chain Production Length as a Result of the US–PRC Trade Tension 78

2: Top Five Trading Partners of the World's Main Economies 79

3: Gross Trade between the US and ASEAN Countries 80

4: CGE Model Construction and Scenario Setting 81

5: The Impact of Digital Policy on Global Value Chains 84

References 85

Chapter 3: Toward a Secure and Resilient Energy Supply Chain 90

3.1 The Impact of Rising Geopolitical Tensions on the Rules Underpinning the Multilateral Trading System 91

Why are GVCs, Including Energy Value Chains, Vulnerable to an Erosion of WTO Norms through Geoeconomics? 91

How Geopolitical Crises are Eroding the Legal Fabric of the MTS and of Global Value Chains: The Effects of the Russian War in Ukraine on Energy Supply Chains 93

"Trade Weaponization" and Trade Sanctions are Escalating 94

Possible Legal Responses to Protect the MTS and Global Value Chains Against Geoeconomics 95

3.2 New Dynamics of Global Energy Supply Chains 99

The COVID-19 Shock to Energy Supply Chains 99

The US-PRC Trade Tensions and Its Impact on Energy Supply Chains 100

Geopolitical Tensions and Their Impact on Energy Supply Chains: Energy Geopolitics 101

The Energy Crisis and Energy Security 102

3.3 Geopolitical Changes and New Evolution of Energy Supply Chains 104

Historical Evolution of Energy Domination and Energy Geopolitics 104

The Dynamic Evolution Global Energy Supply Chains 106

CGE Simulation Analysis for the Impact of the Energy Supply Chains Re-Shaping 113

3.4 Renewable Energy and the Future Directions of Energy Supply Chains and Energy Trade 118

Carbon Neutrality, Energy Transition, and Renewable Energy Development 118

Renewable energy supply chains and the new world energy market and trade 119

Challenges facing to renewable energy supply chains 120

3.5 Potential Impact of the Energy Dynamics on the Emission Goals 122

Conclusions 125

References 127

Chapter 4: From Fabless to Fabs Everywhere? Semiconductor Global Value Chains in Transition 132

4.1 Introduction 132

4.2 Semiconductor Global Value Chains: Segments and Value Added Structure 136

4.3 Semiconductor Global Value Chains: Major Economy Participants 141

4.4 Changing Fortunes in the Global Semiconductor Industry: From Integrated Fabs to the "Fabless Revolution" 145

The Rise of the Fabless Firms 148

The Rise of the Dedicated Foundry 151

Overall Specialization in the Semiconductor Market 153

4.5 The Role of the Government in the Development of the Semiconductor Industry 155

Support in Advanced Economies for Semiconductor Production 155

Rise of the East Asian Tigers 156

4.6 The Rise of East Asia in Semiconductor Global Value Chains 164

4.7 Techno-Nationalism: Must Real States Have Fabs? 170

Conclusions 178

References 183

Chapter 5: Tracing Carbon Dioxide Emissions along Global Value Chains 188

5.1 Historical CO_2 Emissions and Climate Change Challenges 189

5.2 Visible Impacts of Climate Change 190

5.3 Historical CO_2 Emissions and Challenges Towards the Achievement of Carbon Neutrality 190

5.4 CO_2 Emissions and Their Responsibilities along Global Value Chains 194
5.5 Tracing CO_2 Emissions in Global Value Chains 194
5.6 Production- vs Consumption-Based Emissions and Emissions Transfers along GVCs 196
5.7 Sharing CO_2 Emissions Responsibilities Across Economies along Global Value Chains 198
5.8 Tracing CO_2 Emissions of Multinational Enterprises in Global Value Chains 201
5.9 Measuring the CO_2 Emissions of MNEs in GVCs 201
5.10 Changing Trends in MNEs' CO_2 Emissions 203
5.11 Decomposing MNEs' CO_2 Emissions by Trade Patterns 205
5.12 Measuring the Carbon Footprints of MNEs in GVCs 208
5.13 Component Structure of MNEs' Carbon Footprints, A Producer Perspective 210
5.14 Component Structure of MNEs' Carbon Footprints, A Consumer Perspective 210
5.15 Re-evaluating the Carbon Mitigation Responsibilities of MNEs in Global Value Chains: From a Factor Income Perspective 212
5.16 Environmental Costs and Economic Benefits of MNEs 213
5.17 Possible Incentive Fund Led by MNEs 219
Conclusion and discussion 220
References 224

Chapter 6: Greening Global Value Chains: A Conceptual Framework for Policy Action 228
6.1 Introduction 228
6.2 The Driving Factors of Global Value Chain Greening 231
6.3 Types of Environmental Innovation 240
6.4 Actors Involved in Environmental Innovation 243
6.5 The Enabling Mechanisms of Environmental Innovation 245
6.6 The Outcomes of Global Value Chain Greening 247
6.7 A Three-Pronged Strategy for GVC Greening 249
Conclusion 253
References 256

Chapter 7: Global Value Chains for Inclusive Development 261
7.1 Introduction 261
7.2 GVCs can Improve the Performance of MSMEs in Developing Economies 263
The Context: MSMEs' Role in Developing Economies and Trends in their GVC Participation 264

GVCs Facilitate Access to International Markets 266
GVCs Facilitate the Transfer of Good Management Practices 267
GVCs Facilitate Quality Upgrading 269
GVCs Facilitate Technology Transfers and Innovation 272
GVCs Facilitate Access to Trade Finance for MSMEs 273
7.3 GVCs Can Help Workers in Developing Economies 275
GVCs Can Support a Shift to Formal Employment 276
GVCs Can Improve Job Quality 278
GVCs Tend to Widen Wage Inequality 280
GVCs Can Support Gender Equality 283
GVCs Can Reduce the Incidence of Child Labour 288
7.4 The Future of Inclusive GVCs 289
Digital Platforms and GVCs 290
Automation and Outsourcing 291
AI and Services GVC 292
7.5 Main Messages and Lessons for Policymakers 293
Conclusion 297
References 299

Appendix

Background Paper and Chapter Authors' Workshop for the Global Value Chain Development Report 2023 313

Tables, Figures, and Boxes

TABLES

1.1 Criteria for Classifying Product Categories as Potential Bottlenecks 19

1.2 Top Exporters of Potential Bottleneck Products, 2000–2021 21

1.3 Domestic Value-Added in Processing Exports v Normal Exports, People's Republic of China; 2007, 2012, 2017 (%) 42

A1 Scenarios in the CGE Modeling 81

A2 Projected Impacts of Digital Input and Technological Improvements on GVC Activities in 2025 84

3.1 Change in Oil Trade Flows Under the Combined Scenario (% Changes Relative to the Baseline) 117

4.1 Domestic/Regional Value Added in the Semiconductor Value Chain by Activity, 2021 (in percent) 143

4.2 Changing Fortunes in the Global Semiconductor Industry: Key Trends and Drivers, 1959-2022 147

4.3 World's Top Semiconductor Lead Firms by Type, Revenue, and Share, 2000-2020 (in US$ billions and Percent of Semiconductor Market) 150

4.4 Evolving Domestic and Institutional Contexts of Industry Development in Selected East Asian Economies, 1980-2022 159

4.5 Geography of World Semiconductor Manufacturing by Fab Location, Product Applications, and Capacity, 2000-2018 (foreign owned in parentheses) 168

4.6 World's Top Semiconductor Manufacturers by Fab Capacity, Main Applications, Fab Locations, and Markets, 2010 and 2018 169

5.1 Sharing Emission Responsibilities along GVCs 200

5.2 Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies in Selected Industries through MNEs (2016) 220

6.2 Biophysical Outcomes of Global Value Chain greening 248

6.3 A Three-Pronged Strategy for GVC greening 250

FIGURES

1.1 Decomposition of World Exports, 2007–2022 4

1.2 Backward and Forward Global Value Chain Participation Rates, World, 1995–2022 5

1.3 Global Value Chain Participation of Economies, 2007–2010 and 2018–2022 7

1.4 Global Value Chain Production Lengths by Sector, World, 2007–2010 and 2018–2022 8

1.5 Global Inflation Rates, 2000–2022 (%) 12

1.6 Differences in Backward and Forward Global Value Chain Participation Rates, Nominal vs Real, 2007–2022 14

1.7 Discrepancy, Variability, and Divergence of Real and Nominal Global Value Chain Participation 15
1.8 Export Value and Share of Potential Bottlenecks in the World, 2000–2021 20
1.9 Backward Dependence on Value-Added, Top 20 Economies and Rest of the World ($ million) 23
1.10 Trade in a Directed and Unweighted Network 25
1.11 Pass-Through Indices, Top 20 Economies and Rest of the World 29
1.12 Herfindahl-Hirschman Indexes of Economies, 2007–2010 and 2018–2022 32
1.13 Agglomeration Classes of Economies, 2007–2010 and 2018–2022 36
1.14 Backward and Forward Agglomeration of Selected Economies, 2019, 2020, 2021 38
2.1 The Change of the Average Cumulative Input Tariffs 53
2.2 The Trend of Global Tariff and NTMs 55
2.3 Trade Facilitating and Restricting NTMs during COVID-19 55
2.4 Global Export of Merchandise and Service 56
2.5 Global Trade of Intermediate and Final Products in 2021 57
2.6 Change in Gross Exports in 2017–2019 and 2019–2022 58
2.7 The Domestic Value-Added Share in the Total Export 60
2.8 Changes in Developing Asian Economies' Value-Added Trade in Intermediate Goods 60
2.9 Changes in Sectoral Production Length of the PRC and the USA 61
2.10 Top Three Trade Partners in Merchandise of the US 62
2.11 PRC-US Trade in High-Tech Products 63
2.12 US Export to PRC Subject to US's Government Export Control 64
2.13 Indirect Import of Intermediate Inputs from the PRC to the US through Third Regions 65
2.14 The Ratio of Indirect Intermediate Import of the US from the PRC through ASEAN and USMCA Countries 66
2.15 The Share of Total, Simple and Complex GVC Activities 68
2.16 Changes in Value-Added Activities in 2020 (%) 71
2.17 Growth rates of GVC items in the PRC, the US, Mexico, and India 72
2.18 Counterfactual Outputs of ICT and non-ICT Industries During the COVID-19 74
2.19 Potential GDP Changes (%) and Digital Infrastructure 75
2.20 Changes in the Average Global Value Chain Production Length as a Result of the US–PRC Trade Tension (%) 78
2.21 ASEAN Exports to the US as a Share of Total Exports (2017–2021) 80
2.22 Intermediate Imports from the PRC as a Proportion of ASEAN Total Intermediate Imports by Country (2017–2021) 80
2.23 The GVCGE Framework 82
2.24 The Effects of Policy Shocks on Economic Variables 83
3.1 Changes of Global CPI Due to Energy Shock 103

3.2 Historical Evolution of Energy Domination and Energy Geopolitics 105
3.3 The Dynamic Evolution of Energy Supply Chains and Geopolitics 107
3.4 Change in US LNG Exports 108
3.5 Change in US Gas Exports 109
3.6 The Diamond Energy Supply Chain in Asia-Pacific 109
3.7 Change in Russian Oil Exports.....110
3.8 The West and East Pipeline of Russia to Asia 111
3.9 Real GDP Impact of Energy Supply Chain Restructuring (% Changes Relative to the Baseline).....115
3.10 Changes in Gas Trade Flows Under EU-US Energy Supply Chains Scenarios (% Changes Relative to the Baseline) 116
3.11 Changes in Gas Trade Flows Under Eurasian Energy Supply Chains Scenarios (% Changes Relative to the Baseline) 116
3.12 Change in Primary Energy in the Future.....124
3.13 CO_2 Emissions from Combusted Fuels in the Future.....125
4.1 The Basic Structure of Semiconductor Value Chains.....137
4.2 Semiconductor Value Added by Activity, 2019 (in percent) 142
4.3 Semiconductor Global Value Chains and the Production Networks of ICT End Products.....142
4.4 Breakdown of the Global Wafer Fabrication Capacity by Region, 2019 (in percent).....144
4.5 Price to Book Ratios of Leading American Semiconductor Firms, 2013-2022 149
5.1 Visualization of Climate Change Impacts 191
5.2 Major Economies' Historical CO_2 Emissions from 1830 to 2021 and their Targeting Years for Carbon Neutrality 191
5.3 Smile Curve of Value-Added vs Crying Curve of CO_2 Emissions along GVCs 193
5.4 GVC-Based Accounting Framework for Tracing Emissions.....195
5.5 Developed and Developing Economies' CO_2 Emissions along GVCs. 197
5.6 Changing Trends and Decompositions of MNEs' CO_2 Emissions (2005-2016) 203
5.7 Changing Trends and Decompositions of MNEs' CO_2 Emissions in Selected Countries.....205
5.8 Decomposition of MNEs' Export-Embodied Emissions (2005-2016).....206
5.9 CO_2 Emissions of MNEs in the Textile Sector of Top 10 Economies (2016) .207
5.10 Decomposition of Third-Country-Induced Emissions of MNEs in the Textile Sector of Selected Economies (2016) 208
5.11 Component Structure of MNEs' Carbon Footprints, a Producer's Perspective (2016) 211
5.12 Component Structure of MNEs' Carbon Footprints in Selected Economies, A Consumer's Perspective (2016).....211

5.13 CO_2 Emissions Measured by PBA and FIBA between 2005 and 2016 (Mt) ... 214
5.14 Value-Added Calculated by PBA and FIBA between 2005 and 2016 (Billion USD) ... 215
5.15 PBA and FIBA MNEs' CO_2 Emissions and Value-Added of Selected Economies (2005 and 2016) ... 216
5.16 PBA and FIBA MNEs' CO_2 Emissions and Value-Added of the Basic Metals Sector in Selected Economies (2016) ... 218
5.17 Cumulative Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies through MNEs (2005-2016) ... 219
6.1 Overview of Greenhouse Gas Emissions Across the Value Chain ... 230
6.2 Sri Lanka's Performance in Textile and Clothing Manufacturing, 1990–2021 ... 234
6.3 The Plan A Model Eco-Factories ... 235
6.4 A Purse Seine Net ... 238
6.5 Leather Production in an Arzignano Tannery ... 241
7.1 Share of Employment by Firm Size in Developing Economies (%) ... 265
7.2 Growth in the Share of Firms Participating in GVC in the Recent Decades (2006–2022) ... 266
7.3 Quality of Management Practices and GVC Participation ... 268
7.4 Management Quality and Language Similarities between Host and HQ Country ... 270
7.5 Trade Finance Rejections ... 273
7.6 GVC Participation and Formal Share of Employment ... 277
7.7 Gender Wage Gap and GVC Participation ... 286

BOXES

1.1 Characterizing Economies Based on Differences in Current and Constant Price Estimates ... 16
1.2 Deriving the Number of Times a Supply Chain Passes Through a Sector ... 27
1.3 Calculating the Value-Added Agglomeration Index ... 35
1.4 Standard and Extended Input-Output Models ... 41
2.1 Changes in Global Trade Patterns – The Rise of Electric Vehicles and the Auto Industry ... 67
2.2 GVC activities with FDI heterogeneity ... 69
4.1 ASML and the Dominant Supplier of Semiconductor Lithography Equipment ... 140
4.2 Intel and the American Dominance in Integrated Device Manufacturing ... 146
4.3 Qualcomm and the "Double Revolution" of Fabless and Smartphones in the US ... 154
4.4 Singapore's Chartered Semiconductor Manufacturing and Failed State-Led Catching Up ... 160

4.5 Republic of Korea's Samsung as a Successful Product of the Developmental State? 162
4.6 HSMC and the Problems of Industrial Policy Implementation....164
4.7 TSMC and Technological Innovation in Chinese Taipei....166
4.8 The Impacts of US Sanctions on Huawei....177
5.1 Accounting for CO_2 Emissions of MNEs in Global Value Chains 202
5.2 Sectoral Level Analysis: Textile Industry 207
5.3 Accounting for Carbon Footprints of MNEs in Global Value Chains....209
5.4 The Concept of Trade in Factor Income and its Relationship with Gross Trade Volume and Trade in Value-Added (using US exports to PRC as an example)....213
6.1 The (Un)Willingness to Pay for Green: Textile Suppliers in Sri Lanka....234
6.2 The "Tuna-Dolphin Problem" and the Drivers of Global Value Chain Greening 238
6.3 Environmental Innovation in Industrial Clusters—The Arzignano Tannery District 241
6.4 Valcucine A Mentoring-Driven Approach to Product Innovation....242
6.5 When private actors and government come together: The Hawassa Industrial Park....244
7.1 The Importance of Language Skills for Knowledge Diffusion....270
7.2 GVCs and Returns to Education 287

Foreword

The *Global Value Chain Development Report 2023: Resilient and Sustainable GVCs in Turbulent Times*, the fourth in this biennial series, is released at a critical juncture in the evolution of Global Value Chains (GVCs). It first provides an update on trends in GVCs highlighting that international production networks remain a central part of globalization despite mounting pressures. The report then turns to its main theme which is informed by the fact that the intricate networks of international flows of goods, services, capital, and technology are currently facing exceptional challenges arising from geopolitical complexities and the impacts of climate change in the Post-COVID era.

Recent pandemic-related disruptions have revealed long-standing vulnerabilities in GVCs, especially those associated with over-concentration and over-dependence on a single economy or region for the supply of critical products — a circumstance exacerbated by recent geopolitical tensions. However, the current structure of GVCs is complex and has led to significant benefits for firms and consumers globally. It minimizes costs and maximizes scale economies since it allows economies to specialize in finely defined tasks, hyper-exploiting the concept of comparative advantage.

This makes reconfigurations costly and challenging. Importantly, it also leads to significant interdependencies that limit the scope for the weaponization of trade. For example, the global semiconductor value chain is a highly efficient and innovative network resulting from the delicate division of labor and specialization, where no single economy can competitively maintain a complete semiconductor supply chain on its own. Hence, self-sufficiency, de-coupling and de-globalization are far from being viable options for enhancing the resilience of semiconductor GVCs in the long term.

In parallel, the urgency of making GVCs greener has increased sharply with accelerating climate change. At present, more than 130 economies and regions have announced their carbon neutrality targets. A global consensus has emerged on the need to address climate change and promote green development. This trend has a great impact on the direction and pattern of GVCs through both institutional and technological innovation and collaboration. The report provides a comprehensive carbon emission accounting framework that allows tracing emissions through GVCs before proposing a conceptual framework that can help business and policymakers in their efforts to green GVCs.

Resilience and sustainability cannot be achieved without inclusiveness. Since the impacts of shocks tend to be unevenly distributed within economies, it is important that all parts of society are able to recover quickly for the economy as

a whole to be resilient. Integrating into GVCs leads to substantial benefits for workers and firms in developing economies, but the gains from integration are not always fairly distributed. To ensure that GVCs support inclusive development, barriers to integration must continue to be lowered and measures must be put in place that prevent firms from exploiting their market power at the expense of small suppliers.

The *GVC Development Report 2023* examines all these developments and highlights how GVCs are critical factors in the megatrends shaping today's global economy. It is a joint effort of four institutions: the Research Institute for Global Value Chains at the University of International Business and Economics, the Asian Development Bank, the Institute of Developing Economies - Japan External Trade Organization, and the World Trade Organization. As the Asian Development Bank did in the previous report, the Research Institute for Global Value Chains at the University of International Business and Economics has taken the lead this time. The report benefits from extensive collaboration among GVC researchers worldwide. Over 60 authors from more than 30 research institutions in 20 economies contributed 37 background papers that form the basis for this report. We look forward to expanding this research joint venture by including more partner institutions in the future.

We hope that the *Global Value Chain Development Report 2023* will contribute to a deeper understanding of the recent development of GVCs and help build consensus to maintain an open, sustainable, and resilient global trading system in the service of human well-being.

Zhongxiu Zhao
President of UIBE

Masatsugu Asakawa
President of ADB

Kyoji Fukao
President of IDE-JETRO

Ngozi Okonjo-Iweala
WTO Director General

Publishing Partners

The *Global Value Chain Development Report 2023: Resilient and Sustainable GVCs in Turbulent Times* is jointly published by the Research Institute for Global Value Chains at the University of International Business and Economics (RIGVC-UIBE), the Asian Development Bank (ADB), the Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO), and the World Trade Organization (WTO).

RIGVC-UIBE is the first research institute to focus on global value chain (GVC) research. The institute is a platform for promoting GVC research by integrating research efforts and resources of universities and other research institutions, government agencies, and firms across the world. It runs training and degree programs on GVCs, and its resources are open to all researchers.

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 68 members—49 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

IDE-JETRO is a research institution affiliated with the Japan External Trade Organization (JETRO), an incorporated administrative agency under the Ministry of Economy, Trade, and Industry of Japan. IDE-JETRO does research on the economics, politics, and societies of developing countries and regions. Through its research, IDE-JETRO contributes to knowledge and a better understanding of developing economies.

WTO is the only global international organization dealing with the rules of trade. Its main function is to ensure that trade flows as smoothly, predictably and freely as possible. It also provides a forum for its members to negotiate trade agreements and to resolve the trade problems they face with each other. The overall objective of the WTO is to help its members use trade as a means to raise living standards, create jobs and improve people's lives.

Contributors

Coeditors

Yuqing Xing, professor, National Graduate Institute for Policy Studies, and oversea academic dean, Research Institute for Global Value Chains, University of International Business and Economics (UIBE)

Ran Wang, associate professor, Research Institute for Global Value Chains, and deputy director of the Global Value Chain Laboratory, UIBE

David Dollar, senior fellow, John L. Thornton China Center at the Brookings Instiution

Chapter authors

D'Maris Coffman, professor, The Bartlett School of Sustainable Construction, University College London

Youyi Deng, doctoral student, School of International Trade and Economics, UIBE

Yuning Gao, associate professor, School of Public Policy and Management, Tsinghua University, and external expert group member of Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO)'s GVC research project

Elisabetta Gentile, senior economist, ADB, and fellow, Global Labor Organization

Shaopeng Huang, assistant professor, Research Institute for Global Value Chains, UIBE

Christian Regie Jabagat, consultant, ADB

Rasmus Lema, associate professor, United Nations University, UNU-MERIT and Professor GES 4.0, University of Johannesburg

Meng Li, assistant professor, School of Environmental Science and Engineering, Shanghai Jiao Tong University

Angelo Jose Lumba, consultant, ADB

Kathryn Lundquist, economic affairs officer, WTO

Mahinthan Joseph Mariasingham, senior statistician, Asian Development Bank (ADB)

Bo Meng, senior researcher, Development Studies Center, IDE-JETRO and visiting professor, Collaborative Innovation Center for Emissions Trading System Co-constructed by the Province and Ministry, Hubei University of Economics

Sang Hyun Park, research economist, WTO

Roberta Rabellotti, professor of economics, Department of Political and Social Sciences, Università di Pavia

Yves Renouf, counsellor, World Trade Organization (WTO)

Dalila Ribaudo, lecturer, Aston Business School, Aston University

Xunpeng Shi, professor, Australia-China Relations Institute, University of Technology Sydney

Victor Stolzenburg, research economist, WTO

Kejuan Sun, lecturer, School of Economics, Henan University of Finance and Law

Qian Sun, post doctor, School of Economics and Business, Tsinghua University

Enxhi Tresa, economist, Organization for Economic Co-operation and Development (OECD)

Ran Wang, associate professor, Research Institute for Global Value Chains, and deputy director of the Global Value Chain Laboratory, UIBE

Yuqing Xing, professor, National Graduate Institute for Policy Studies, and oversea academic dean, Research Institute for Global Value Chains, UIBE

Jinjun Xue, professor, Nagoya University and Tsinghua University

Henry Wai-chung Yeung, distinguished professor and co-director, Global Production Networks Centre, National University of Singapore

Meichen Zhang, assistant professor, Research Institute for Global Value Chains, UIBE

Tao Zhang, doctoral student, School of Public Policy and Management, Tsinghua University

Acknowledgments

The *Global Value Chain Development Report 2023*, the fourth in the series, draws on contributions from 37 background papers presented and discussed at the First Authors' Workshop for the Global Value Chain Development Report 2023 hosted by the World Trade Organization (WTO) during 7–11 November 2022 (Appendix 1). The drafts of the report's seven chapters were presented at the Chapter Authors' Workshop for the Global Value Chain Development Report 2023 hosted by the Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO) in Japan during 5-6 June 2023 (Appendix 2). The editors thank the authors of these papers and the chapters, and the discussants and participants at the two workshops, for their insightful comments and suggestions.

Special thanks go to the discussants of the chapter drafts: Michele Ruta, International Monetary Fund (IMF); Etel Solingen, University of California at Irvine; Aya Okada, Nagoya University; Mari Tanaka, Hitotsubashi University; Jiantuo Yu, China Development Research Foundation (CDRF); Daria Taglioni, World Bank; Sébastien Miroudot, Organisation for Economic Co-operation and Development (OECD); Seamus Grimes, National University of Ireland; Chan-Yuan Wong, National Tsing Hua University; Xiaopeng Yin, University of International Business and Economics (UIBE); Joaquim J.M. Guilhoto, IMF; Jong Woo Kang, Asian Development Bank (ADB); Jules Hugot, ADB; Angella Faith Montfaucon, World Bank; Satoshi Inomata, IDE-JETRO and OECD; Ran Wang, UIBE; and Rainer Lanz, WTO.

The editors are grateful to Professor Zhongxiu Zhao, the President of UIBE, Prof. Robert Koopman of the American University, and Dr. Albert Park, the Chief Economist of ADB, for their support from the report's inception to its publication. Thanks go to William Shaw, who edited the report; Joseph Manglicmot, who typeset the report; and Mike Cortes, who created the cover.

Chapter 1's authors thank Elaine S. Tan, Joseph Ernest Zveglich Jr., Eric Suan, John Arvin C. Bernabe, Miro Frances Capili, and Paul Dent. Chapter 2's authors thank Jules Hugot, Angella Faith Montfaucon, and Satoshi Inomata. Chapter 3's authors thank William Shaw, Yue Lv, Hao Xiao and JSPS for the Research Grant (No. 20K01674 and No. 20KK0033), Japan, and the 111 Research Grant, B18014, China. Chapter 5's authors thank Zhi Wang, Hiromu Fukai, Tamaki Suzuki, Rumiko Nakamura, Fei Yan, Keying Wang and National Natural Science Foundation of China, No.72003023. Chapter 6's authors thank Lisa T. Ballance, Valentina De Marchi, Annelies Goger, Thiam Hee Ng, and Joseph Ernest Zveglich Jr., Chapter 7's authors thank Weidi Yuan and Marc Bacchetta.

Abbreviations

4IR	fourth industrial revolution
ADB	Asian Development Bank
ADBI	Asian Development Bank Institute
AE	advanced economies
AI	artificial intelligence
AIDCP	Agreement on the International Dolphin Conservation Program
AIRS	atmospheric infrared sounder
AMD	Advanced Micro Devices
AMNE	activities of multinational enterprises
APT	assembly, packaging and testing
ASEAN	Association of Southeast Asian Nations
ASMI	Advanced Semiconductor Materials International
ASML	Advanced Semiconductor Material Lithography
BCG	Boston Consulting Group
BDA	big data analytics
BPO	business process outsourcing
BRIC	Brazil, Russia, India and China
CBAM	carbon border adjustment mechanism
CBDR	common but differentiated responsibilities
CCL	Controlled Commodity List
CEIC	China Economic Information Center
CEO	chief executive officer
CER	central east region
CF	carbon footprint
CGE	computable general equilibrium
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
COP	conference of the parties
COVID-19	corona virus disease 2019
CPA	Center For Preventive Action
CPI	consumer price index
CPU	central processing unit
CSM	Chartered Semiconductor Manufacturing
CSO	civil society organization
CSR	corporate social responsibility
DAO	discrete, analog, and optoelectronics
DARPA	Defense Advanced Research Projects Agency

DDRs	due diligence requirements
DML	dolphin mortality limit
DOE	domestically owned enterprise
DRAM	dynamic random access memory
DS	dispute settlement
DSB	dispute settlement body
DSU	dispute settlement understanding
DVA	domestic value added
DVAR	domestic value-added ratio
EAR	Export Administration Regulations
ECRA	Export Control Reform Act
ECT	Energy Charter Treaty
EDA	electronic design automation
EEBT	emissions embodied in bilateral trade
EEC	European Economic Community
EIA	Energy Information Administration
EMDEs	emerging markets and developing economies
EoS	elasticity of substitution
EPR	extended producer responsibility
ERSO	Electronics Research and Service Organization
ESPRIT	European Strategic Programme for Research and Development in Information Technology
ETP	eastern tropical Pacific
ETRI	Electronics and Telecommunications Research Institute
ETS	carbon emissions trading system
EU	European Union
EU-ETS	European Union Emission Trading Scheme
EUV	extreme ultraviolet
EVs	electric vehicles
FDI	foreign direct investment
FIBA	factor income-based accounting
FIE	foreign affiliate
FSC	Forest Stewardship Council
FVA	foreign value added
G7	Group of Seven
GaAs	gallium arsenide
GATS	General Agreement on Trade in Services
GATT	General Agreement on Tariffs and Trade
GCF	Green Climate Fund
GDP	gross domestic product

GFC	global financial crisis
GHG	greenhouse gas
GISS	Goddard Institute for Space Studies
GISTEMP	GISS surface temperature analysis
GPS	global positioning system
GRS	global recycle standard
GSCM	green supply chain management
Gt	gigaton
GTAP	global trade analysis project
GVCs	global value chains
GW	gigawatt
HHI	Hirschmann-Herfindahl index
HR	human resources
HS	Harmonized System
IBM	International Business Machines Corporation
IC	integrated circuits
ICT	information and communications technology
IDE-JETRO	Institute of Developing Economies – Japan External Trade Organization
IDM	integrated device manufacturing
IEA	International Energy Agency
IFC	international finance centre
IFS	Intel Foundry Services
ILO	International Labour Organization
IMF	International Monetary Fund
IMO	International Maritime Organization
IO	input–output
IoT	internet of things
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
IPDC	Industrial Parks Development Corporation
IRP	International Review Panel
ISCO	International Standard Classification of Occupations
ISO	International Standards Organization
IT	information technology
ITC	investment tax credit
ITRI	Industrial Technology Research Institute
LCA	life cycle assessment
LCR	local content requirement
LEED	Leadership in Energy and Environmental Design

LNG	liquefied natural gas
LSI	large scale integration circuit
M&S	Marks & Spencer
MIMIC	microwave and millimeter wave integrated circuit
MMPA	Marine Mammal Protection Act
MNC	multinational corporation
MNEs	multinational enterprises
MRIO	multiregional input–output
MRIOTs	multiregional input-output tables
MSMEs	micro, small, and medium-sized enterprises
MTS	multilateral trading system
NAFTA	North American Free Trade Agreement
NASA	National Aeronautics and Space Administration
NBER	National Bureau of Economic Research
NDC	nationally determined contribution
NEUVLP	National Extreme Ultraviolet Lithography Program
NGOs	non-governmental organizations
nm	nanometer
NOAA	National Oceanic and Atmospheric Administration
NT	no-trade
NTMs	non-tariff measures
NTPs	non-trade provisions
OECD	Organisation for Economic Co-operation and Development
OEM	original equipment manufacturer
OPEC	Organization of the Petroleum Exporting Countries
PBA	production-based accounting
PC	personal computer
PDC	pure double counting
PEFC	Programme for the Endorsement of Forest Certification
PET	polyethylene terephthalate
PPI	producer price index
PRC	People's Republic of China
PTA	preferential trade agreement
PV	photovoltaic
PVH	Phillips-Van-Heusen
R&D	research and development
RBC	responsible business conduct
RBI	Reserve Bank of India
RCA	Radio Corporation of America
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals

REDII	Renewable Energy Development Directive
RFID	radio frequency identification technology
ROW	rest of the world
RRF	Recovery and Resilience Facility
RTA	regional trade agreement
RVCs	regional value chains
SAC	Sustainable Apparel Coalition
SCEnAT	supply chain environmental analysis tool
SDG	sustainable development goals
SEMATECH	semiconductor manufacturing technology
SGS	Société Générale de Surveillance
SIA	Semiconductor Industry Association
SME	semiconductor manufacturing equipment
SMEs	small and medium enterprises
SMIC	Semiconductor Manufacturing International Corporation
SPS	sanitary and phytosanitary
SVS	scientific visualization studio
TBTs	technical barriers to trade
TiFI	trade in factor income
TIVA	trade in value added
TREND	TRadeand ENvironment Database
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
TV	television
UIBE	University of International Business and Economics
UK	United Kingdom of Great Britain and Northern Ireland
UMC	United Microelectronics Company
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	United Nations Framework Conventionon Climate Change
UPS	United Parcel Service
US	United States
US DoJ	US Department of Justice
US FTC	US Federal Trade Commission
USA	United States of America
USD	United States dollar
USPTO	United States Patent and Trademark Office
VLSI	very large scale integration circuit
WBCSD	World Business Council for Sustainable Development
WBES	World Bank Enterprise Survey
WHO	World Health Organization

WMS	World Management Survey
WRAP	Worldwide Responsible Accredited Production
WRI	World Resources Institute
WTO	World Trade Organization

Editorial and Advisory Committee

The Editorial Committee

Chairperson

Yuqing Xing, professor, National Graduate Institute for Policy Studies and oversea academic dean, Research Institute for Global Value Chains, University of International Business and Economics

Members

David Dollar, senior fellow, John L. Thornton China Center at the Brookings Institution

Elisabetta Gentile, senior economist, Asian Development Bank and fellow, Global Labor Organization

Bo Meng, senior research fellow, Institute of Developing Economies – Japan External Trade Organization

Victor Stolzenburg, research economist, World Trade Organization

The Advisory Committee

Chairperson

Robert Koopman, Professor, American University

Members

Albert F. Park, chief economist, Asian Development Bank

Satoshi Inomata, chief senior researcher, Institute of Developing Economies – Japan External Trade Organization

Zhi Wang, consulting professor and founding director, Research Institute for Global Value Chains, University of International Business and Economics and research faculty and senior policy fellow, Schar School of Policy and Government, George Mason University

Etel Solingen, distinguished professor and Thomas T. and Elizabeth C. Tierney Chair in Peace and Conflict Studies, University of California Irvine

Key Messages and Findings

I. Benefits of GVCs

- GVCs foster positive outcomes for firms in developing economies by improving productivity and alleviating information and finance constraints; workers benefit from higher wages and better working conditions.

- When GVC integration fails to deliver expected benefits, it is often due to underlying market failures such as labour market frictions, market power by large firms, and structural disparities.

- Policies for inclusive development should focus on facilitating entry into GVCs and increasing spillovers to the domestic economy. Current efforts are too often limited to improving inclusiveness exclusively within GVCs.

II. Vulnerability

- The export value and share of potential bottleneck products had been increasing since 2000, contributing to the vulnerability of GVCs. Also, there was considerable concentration in sources of foreign value added.

- Trade in services was particularly affected by the pandemic and merchandise trade was negatively impacted by the rising trade tensions.

- The trade tensions and the COVID-19 pandemic highlighted the need to improve economies' resilience and mitigate dependence on a limited number of suppliers.

- Digitalization was a key tool for resilience and recovery during the pandemic and facilitated access to labor supply for certain industries, especially the services sector.

- GVC-related trade increased in 2021 and 2022, occurring alongside considerable growth in exports. A general shortening of GVCs is also observed during these years relative to the overlapping periods of PRC-US trade tensions and the COVID-19 pandemic.

III. Potential for deglobalization

- The PRC-U.S. trade tensions and the ongoing Russian war in Ukraine are having huge impacts on global energy supply chains, making geopolitical concerns the dominant factor in the policies governing energy trade.

- The escalating trade weaponization and trade sanctions will lead to segmented regional energy supply chains, such as the EU-US energy supply chain and the Eurasia energy supply chain.

- Renewable energies are expected to play a pivotal role in reshaping the energy global supply chains and even the political landscape.

- Semiconductor GVCs are highly complex and well integrated across the world with many locations involved, such that no single economy can fully control or monopolize them.

- The US remains the dominant player in most key segments of these semiconductor GVCs, in particular chip design through American "fabless" firms.

- Current trade-distorting industrial policies pursued by many governments attempting to "reshore" and/or "shore up" domestic semiconductor manufacturing are unlikely to be effective.

IV. Greening of GVCs

- Since 2001, developing economies' CO_2 emissions from purely domestic value chains have doubled. To reduce these emissions, they need more effective policy tools. Greening their domestic production can also green their exports in GVC.

- To a certain extent, GVCs are more carbon-intensive than domestic activities, as they require multiple stages of production and transportation across borders. It is important to introduce carbon pricing along GVCs to substantially raise the cost of emissions globally in the Paris Agreement era.

- Current emission reduction targets do not explicitly define the different roles and responsibilities of GVC actors. MNEs generally capture more value added of GVCs and should play more active roles to fight climate change.

- Institutional drivers such as national environmental regulations still play the leading role in GVC greening. Market and technological drivers tend to be driven by institutional drivers.

- If lead firms do not provide their suppliers with enough financial, managerial, and knowledge resources for implementing green strategies, smaller firms risk being left out of the chain.

- Accounting, monitoring, disclosing the environmental outcomes, and multilateral efforts to orchestrate and harmonize private and national initiatives are crucially important.

Executive Summary

The main theme of the *2023 Global Value Chain Development Report* is the resilience and sustainability of value chains in response to the diverse shocks of recent years. It provides an overview of the most recent trends in GVCs (chapter 1), in particular the effects of trade tensions and the COVID-19 pandemic (chapter 2), as well as geopolitical tensions on GVCs. It illustrates some of the effects by providing case studies on energy supply chains (chapter 3) and semiconductor value chains (chapter 4). The report then turns to challenges brought about by the climate crisis. It first shows results of different methods tracing CO_2 emissions through GVCs (chapter 5) and then offers a framework to help greening GVCs (chapter 6). The report concludes with emphasizing the immense potential of GVCs for supporting inclusive development (chapter 7).

Examining GVCs in Times of Global Shocks

Chapter 1 provides an overview of recent developments in GVCs from the perspective of recent major global shocks to international trade. Recent data showed some potential for recovery, with gross exports and GVC participation increasing from 2020—an oberservation that holds true in both nominal and real terms. However, the presence of ongoing global shocks – including the Russian war in Ukraine, lingering economic effects of the COVID-19 pandemic, and trade tensions between the United States and the People's Republic of China (PRC) – may threaten to derail this trajectory, thereby promoting the need to assess potential sources of the vulnerability that GVCs have towards shocks.

One such contributor is the trade in potential bottleneck products, which are characterized as having a limited number of suppliers, few substitutes, yet constituting a considerable share of international trade. A total of 1,075 (out of 5,384) analyzed products were identified as potential bottlenecks in 2021, which had an increasing share in total export value throughout the years. Another potential source of vulnerability is geographic concentration in value and frequency of trade. Considerable concentration in sources of foreign value added (FVA) in exports is seen even before the Global Financial Crisis (GFC) hit, though this persisted even beyond the shock and well into the post-pandemic onset world. From a frequency perspective, around 80 percent of all pass-throughs in supply chains were accounted for by only a handful of economies. Though this share decreased in 2020, which may be due to the restrictions imposed on trade and mobility, the change was only marginal and considerable concentration is still observed. The economies belonging atop the rankings in FVA sources were not necessarily the same ones that recorded the most pass-throughs, and vice versa.

The calls for GVC resilience were examined through an analysis of reshoring measures and other trajectories for GVC reconfiguration. Emphasis was placed on diversification of intermediate inputs as a potential risk mitigation strategy. There is still much room to diversify away from domestic sources of input, suggesting that there is already substantial home bias across economies, regions, and sectors. Looking at the case of the PRC, which recently enforced measures to encourage furthering the domestic content of its products, mixed results are seen across different types of exports, trade destinations, and sectors. Ambiguity surrounding the impact of such policies warrants further statistical analysis to unveil the facilitating factors as well as barriers for realizing the goal of localization. To complement this analysis, looking at MNEs' participation in GVCs through the lens of trade in factor income (TiFI) is suggested for future research. Several studies including Gao et al (2023) found that dissimilarities exist in the activities of domestic owned versus foreign owned firms along global supply chains. For example, regional characteristics of current GVCs were discovered to be mostly attributable to domestic owned firms in each economy and that these enterprises were mostly involved in the three regional centers of North America (centered on the US), Europe (centered on Germany), and East Asia (centered on PRC), serving as the driving force for the regionalization of current supply chains. On the other hand, the value-added creation of foreign-owned MNEs typically exhibited more global characteristics.

The calls for GVC resilience were also examined through an analysis of reshoring activities. Emphasis is placed on reshoring from the perspective of domestic agglomeration. Backward and forward agglomeration indices have been on the downtrend from 2019 to 2021 in many economies, providing little evidence of reshoring activities in this period. The United States, however, showed some signs of reshoring for some of its sectors that registered increases in their backward agglomeration indices.

Effect of Trade Tensions and the Pandemic on GVCs

Chapter 2 primarily focuses on the effects of trade tensions and the COVID-19 pandemic on GVCs, as well as the effects of digital technology on the recovery and trend toward reshoring. This chapter shows that both trade tensions and the pandemic have led to substantial changes in GVCs as they led to higher tariffs and non-tariff measures (NTMs). NTMs and tariffs can accumulate along GVCs as intermediate goods cross border several times, leading to higher costs for downstream producers. Global trade tensions have led to significantly higher trade costs since 2018 and pose a threat to the development of GVCs. Similarly, the shocks to GVCs caused by the COVID-19 pandemic has brought significant disruption to the global economy.

The trade tensions increased the tariff burden of global production, especially for downstream producers. The tariffs of some intermediate inputs imported by the PRC jumped 47%, due to the PRC's retaliatory measures and cumulative effect along GVCs. The US and the PRC incurred an additional indirect tariff burden of 10 and 6.5 billion dollars, respectively, while third-party countries incurred additional indirect tariff burden of 30%–70%. Interestingly, indirect tariffs in most sectors in the PRC increased by around 50%, while they increased by more than 150% in the US. Additional non-tariff burdens induced by the trade tensions and the COVID-19 pandemic mainly affected less-flexible firms.

While the trade tensions do not appear to have affected total global trade volumes, they led to significant changes in the geographical patterns of GVCs. The PRC shifted its export focus to East Asia and Pacific region and Europe and Central Asia region, while the US forged closer trade ties with Canada and Mexico. Both the PRC and the US reorganized their imports from the Europe & Central Asia region, the East Asia and the Pacific region, and Latin America & Caribbean region.

In contrast, the COVID-19 pandemic led to sharp decline in global trade volumes, but the process reversed quickly. Numerical modeling suggests that all economies should have fully recovered by 2025, albeit at different speeds. The data also shows that non-GVC trade and trade-related activities significantly contracted during the COVID-19 pandemic, leading to an increase in pure domestic consumption. Meanwhile, cross-border trade involving MNEs slightly increased as a result of stronger links between MNEs and domestic firms.

The effects of digitalization on the recovery were also analyzed and further evidence was obtained in support of the hypothesis that economies with superior digital infrastructure were less affected than other economies during the COVID-19 pandemic. Global demand for digital technology led to increased investment in high-tech industries, thereby boosting FDI-related activities.

Disruptions of World Energy GVCs

Chapter 3 takes up the issue of how these shifts in value chains affect the world energy transition and climate governance. One major possibility is that the EU countries may use the Russian war in Ukraine as an opportunity to speed up the development of renewable energy and realize energy transition earlier than expected. On the other hand, due to the energy crisis and the huge energy demand, some economies gave up their phasing-out-coal policy and began to increase the use of coal and to restart coal-fired power generations. These shifts led to a temporary increase of carbon emissions and may delay the UN's net-zero emission strategy and carbon neutrality timetables.

The long-lasting PRC-US trade tensions and the ongoing Russian war in Ukraine are fueling geopolitical tensions. These geopolitical tensions have made geopolitical concerns surpass economic interests and become the dominant factor affecting world energy trade and economic development. All these dynamic movements are giving huge impacts on global energy supply chains.

Our CGE scenario analyses demonstrate that the Russian war in Ukraine and various sanctions against Russia will reshape the patterns of the world energy trade and formulate some new regional energy supply chains: the EU-US energy supply chain, the Eurasia energy supply chain, and the diamond shaped energy supply chains of US-Japan-Australia-India.

The Semiconductor Supply Chain

In 2023, the global semiconductor industry has clearly reached a new critical juncture, where supply chain resilience, national security, and competition for technology leadership are challenging the highly popular and efficient "fabless" model through which chip design and semiconductor manufacturing (known as wafer fabrication in "fabs") can be separated organizationally and geographically. The recent COVID-19 pandemic, global chip shortages, and the US export restrictions on semiconductor technologies have accentuated worldwide attention to this important high-tech sector and its supply chain configurations. Many national governments in advanced economies have now placed far greater urgency on, and enacted specific industrial policies for, (re)building their domestic semiconductor manufacturing capacity. The rise of this new techno-nationalism is transforming the highly internationalized semiconductor industry into the age of "real nation-states should have fabs".

Chapter 4 provides substantial empirical evidence for several key observations on the global semiconductor supply chain. We find that vertical disintegration has driven the globalization of semiconductor production over time. The rise of fabless chip design firms and their manufacturing suppliers, known as foundry fabs, represents one such key driver. This "fabless revolution" starting in the US since the 1980s can be explained by high costs in chip design and production, financial market pressures for short-term profits, and the rise of efficient foundry fabs in East Asia. We show that government support was crucial in the initial development of East Asian memory chip producers (e.g. Samsung) and foundry fabs (e.g. TSMC) in the 1980s. Since 2010s, important market shifts in industrial applications towards computers/data storage and wireless communications have been crucial in explaining the rapid growth of leading fabless firms, foundry producers, and integrated manufacturing firms in microprocessors and memory chips.

Meanwhile, massive innovations in semiconductor technologies have resulted in extremely high costs of cutting-edge chip design and manufacturing since 2010. Only a few market leaders from the US, the EU, and East Asia now dominate in the different segments of semiconductor global value chains, from design software and intellectual properties to materials and equipment suppliers. By the turn of 2020s, the ever-more sophisticated processes of chip design and production and their concomitant ecosystems of highly specialized firms mean that no single economy can be self-sufficient in the entire semiconductor value chain. In this context, semiconductor GVCs in the post-pandemic era are in transition as more national economies want to have their own fabs for national security and risk mitigation reasons. Nevertheless, we note that this pursuit of "fabs everywhere" through technological sovereignty is unlikely to be realistic because of the complex organization of existing semiconductor GVCs and the extreme demand for technological capabilities and capital investment in cutting-edge chipmaking. It will likely result in a fragmented rather than integrated global semiconductor market, which would inevitably undermine the sector's economies of scale and trust relationships and, even worse, lead to excess capacity, underutilized fabs, and technological bifurcation worldwide.

GVCs and Climate Change

Chapter 5's point of departure is that GVCs have led to a surge in CO_2 emissions from international production sharing through both trade and investment (e.g., FDI) channels. The GVC phenomenon, which involves multiple cross-border flows of intermediate goods, may complicate the implementation of the Paris Agreement, which relies on a patchwork of national policies. A persistent challenge in international climate change negotiations is how to allocate responsibility for global warming among various participants in GVCs, such as producers, consumers, exporters, importers, investors, and investees.

This chapter presents a consistent GVC accounting framework (Meng et al, 2023) that allows us to trace the CO_2 emissions responsibility of different country-sector-bilateral combinations through various trading routes. Our results show that the emissions from production processes in developing countries, based on their own responsibility for CO_2 emissions, have accounted for a large share of global emissions growth since 2001 and reached a peak in 2019. This is worrisome because most developing countries have weaker environmental regulations and lower enforcement levels. Given the fact that GVCs are rooted in domestic sources, it is imperative to curb these emissions with more effective tools including environmental regulation, taxation, and the introduction of carbon trading schemes (ETS) domestically. Taking the PRC as an example (see Tang et al. 2020), if more balanced regulations coverage and more equal access to the financial system for heterogeneous firms (no matter they are large-scaled or SMEs, state-owned, foreign-invested, or private firms) could be introduced, the PRC's 2030 commitment to reduce carbon emissions could be achieved more efficiently with less GDP loss (its

green investment would be 64% lower, and its energy efficiency would be 71% higher than in the business-as-usual scenario). Once the PRC can get "greener" in its domestic production, its exports via GVCs will also be greener.

Although the carbon intensity of GVCs, as measured by emissions per unit of value-added, has decreased in both developed and developing countries between 1995 and 2021, generating GDP through international trade is still a more carbon-intensive process than generating GDP through purely domestic value chains. In this regard, introducing a Carbon Border Adjustment Mechanism (CBAM) in the context of a trade-investment-environment nexus, should be an option to promote the formation of green GVCs in the Paris Agreement era. However, a well designed CBAM at the global level is crucial for getting consensus to increase carbon cost and reduce carbon leakage. For example, applying a GVC-based CGE simulation analysis to the EU's CBAM, (Qian et al. 2023) show that GDP would rise in several EU countries, while CO_2 emissions outside the EU would be reduced. However, the EU's CBAM would also trigger a slight increase in total CO_2 emissions within EU due to the "rebound effects" and carbon leakage across EU countries; most countries, especially the non-EU countries, would suffer a larger decline in consumers' welfare. Therefore, our suggestion is that carbon border adjustment should be designed along GVCs at the country-sector-bilateral level, based on each country's share of responsibility for CO_2 emissions, rather than a simple one-way imposition like a trade tariff.

In addition to looking at responsibility at the country level, we also examine the roles of MNEs, who are the main actors in GVCs. Based on MNEs' complex production arrangements, global CO_2 emissions are transferred not only between investing countries (home countries) and producing countries (host countries), but also among other consuming countries (third countries) in the GVC network, which adds to the complexity of global carbon transfer. From a global perspective, about 30%-40% of MNEs' carbon emissions are embodied in their exports to third countries, but these shares vary across different economies due to different FDI motivations and GVC production arrangements of MNEs. Of all these third-country induced emissions, nearly 80% of them are related to GVC activities, but this share is only 60% in India and over 90% in Australia, and the GVC position of host countries is an important factor for this difference. In the textile sector, for example, nearly 1/3 of MNEs' emissions are generated in the PRC, and 50% of them are induced by third countries, while this share is only 14% in the US and more than 90% in Viet Nam. In the motor vehicle sector, the largest emissions of MNEs are generated in South Africa, followed by the PRC and Mexico; however, in South Africa, over 50% of MNEs' emissions are induced by third countries, while in the PRC, this share is merely 20%, and in Mexico, nearly half of MNEs' emissions are induced by their home countries.

The transnational investment of MNEs also affects the distribution of emission responsibility and economic benefits across countries. Overall, during 2005-2016, the factor income-based accounting (FIBA) value-added and CO_2 emissions of advanced

economies are underestimated by 415.37 billion USD to 489.63 billion USD and 287.23Mt to 766.50Mt, respectively, while those of emerging markets and developing economies are overestimated. The latter bears some of the emission responsibility of the former, which partly supports the pollution haven hypothesis. From the national perspective, major FDI-outflowing economies receive more factor income and incur less environmental cost, while major FDI-inflowing economies receive less factor income and incur more environmental cost. As of 2016, the cumulative net carbon transfers from advanced economies to emerging markets and developing economies through MNEs' investment amounted to 1800.80 Mt. If this environmental cost is converted into incentive funding, it would provide an additional 26.61 billion USD to supplement the Green Climate Fund (GCF). Our research provides a useful reference point for future negotiations of carbon responsibility sharing across countries and offers a feasible way for financing the GCF, which will facilitate the achievement of the net-zero emission target consistent with the Paris Agreement.

Although there is a general agreement on the principle of "common but differentiated responsibilities" (CBDR) among the international community, many challenges remain in implementing it effectively. Given the increasing difficulty of limiting global warming to 1.5°C and the fact that most developing countries have no absolute emissions reduction targets and relatively weak environmental regulations, it is crucial to help these countries set appropriate and ambitious targets for reducing carbon emissions and/or achieving carbon neutrality, which could help curb the current rapid rise in global CO_2 emissions. The Paris Agreement allows countries to start from different points and pursue different ambitions toward their own carbon neutrality goal, and uses production-based accounting to measure their emissions (e.g., the original idea of carbon neutrality at the individual country level means taking full responsibility for all direct and indirect emissions), without explicitly considering the responsibility sharing of carbon leakage caused directly and indirectly by international trade and investment. This implies that a net carbon exporting country and a net FDI inflow country might bear more responsibility in achieving its own carbon neutrality goal, while a net carbon importing country and a net FDI outflow country might bear less responsibility than needed. In this sense, negotiating about responsibility sharing for carbon leakage across countries is inevitable if we want to achieve the global goal of net-zero emissions.

GVC Greening: A Conceptual Framework for Policy Action

The environmental impact of GVCs can be decomposed into three different mechanisms. First, a *scale effect*, whereby an increased level of production leads to increased transport volumes and travels, waste production, and overexploitation of scarce resources, with detrimental effects on the environment. The second mechanism is the *composition effect*, whereby GVCs break up the production process into tasks that can be shifted from one location to another. This leads to environmental benefits

when production tasks are relocated where it is the most efficient, or environmental costs when carbon-intensive tasks are relocated to jurisdictions with lax regulations. The third and last mechanism is the *technique effect*, whereby knowledge flows among firms along a value chain facilitate the development, adoption, and adaptation of environment-friendly production techniques. The phenomenon of net environmental gains from the introduction of environmental innovation into GVCs is commonly referred to as 'GVC greening.'

Chapter 6 presents a conceptual framework to investigate: (i.) why GVC greening occurs; (ii.) the types of environmental innovation undertaken in GVCs; (iii.) the actors involved; (iv.) how the greening occurs in GVCs and their different stages; and (v.) the outcomes of GVC greening. The framework lays the foundation for a discussion of policy actions aimed at maximizing net environmental gains through the technique effect (GVC greening) and establishing strong accountability mechanisms to discourage pollution outsourcing.

The chapter reaches three key conclusions. First, while GVC greening has institutional, market, and technological drivers, institutional drivers still play the leading role. New policies and legislation related to domestic or global sustainability transformation agendas are central to GVC greening. Market and technological drivers are also important, but tend, ultimately, to be driven by institutional issues.

Promoting such drivers requires a shared effort among institutional actors at national and global levels. However, as advanced economies are increasingly competing to gain competitive advantage in new green technologies, domestic policies play a greater role than global concerns.

Governments turning sharply away from multilateral cooperation may pose a major challenge to promoting environmentally friendly GVCs. A way forward to safeguard multilateralism and global institutional drivers sustaining GVC greening is to invest in initiatives developed among smaller groups of like-minded economies. One example is the Breakthrough Agenda, involving 45 economies and the private sector to accelerate the shift to green technology in different industries. Coordination at the global level, e.g., a single international carbon tax rate, might also help promote the transition towards the net-zero emission goal.

The second key message is that several actors, not only lead firms but also suppliers, national and local governments, and often a combination of them, contribute to GVC greening. In some cases, suppliers anticipate future environmental requirements to leverage their environmental upgrading initiatives as a competitive factor to access new buyers and markets.

However, the greening opportunities may not be equal among suppliers. Several studies show that lead firms do not always provide enough financial, managerial and knowledge resources for their suppliers to implement green strategies, leaving them out of the chain if they are unable to meet such requirements. This risk is particularly high for small firms in developing economies but also in developed ones.

Uneven distribution of costs, benefits, and rewards for greening value chains poses a challenge for policymakers to address this supplier-squeeze. Actors external to the GVC, such as national or local governments, NGOs, and independent certification bodies, can provide technical and financial support to suppliers in GVCs to implement environmental innovations. National or sub-national public actors can provide the basic infrastructure that contributes to GVC greening.

Finally, there is very limited evidence on the biophysical outcomes of GVC greening. There are important tradeoffs between environmental and socioeconomic outcomes, and the final assessment of whether GVC greening happens or not generally remains a research gap in most of the existing studies. Therefore, accounting, monitoring, and disclosing the environmental outcomes and the possible tradeoffs with socioeconomic outcomes are challenging but essential dimensions to investigate along the entire value chain. However, once again the transboundary nature of GVCs poses a challenge that requires multilateral efforts to orchestrate and harmonize private and national initiatives to monitor environmental outcomes.

Towards Inclusive GVCs

Chapter 7 explores the role of GVCs in driving inclusive development within developing economies. Inclusiveness is a key aspect of resilient and sustainable GVCs. As the backlash against globalization in advanced economies has shown, rising inequality can lower political support for trade and increase barriers to GVC integration. Moreover, since the impacts of shocks tend to be unevenly distributed within economies, it is important that all parts of society are able to recover quickly for the economy as a whole to be resilient. GVCs can also accelerate (green) technology diffusion from technological leaders to the less innovative. Therefore, by prioritizing inclusiveness, GVCs can play a pivotal role in building sustainable and resilient economies for the benefit of all stakeholders.

The topic of this chapter holds more significance than ever for two reasons. First, the negative shocks prompted by the COVID-19 pandemic, geopolitical tensions, and the environmental crisis have been shown to disproportionately hurt certain groups within developing economies, such as low-skilled workers, female employees and MSMEs. Second, consumers are increasingly aware of the spillover effects of their choices on workers in developing economies. This has triggered renewed efforts by policymakers and investors

to address inclusiveness in supply chains. Ensuring that the resulting policy responses are grounded in solid evidence is important for them to achieve lasting improvements.

The chapter has two key messages: First, GVC integration leads, on average, to better outcomes for firms and workers in developing economies. The evidence consistently shows that local suppliers to MNCs and firms exporting intermediates outperform other firms in developing economies. In particular, GVCs provide MSMEs with chances for quality upgrading, knowledge spillovers, technology transfers, and innovation through their affiliations with lead firms. The chapter shows in this regard that firms in developing economies with higher GVC integration tend to have substantially better management practices. Furthermore, becoming part of GVCs can assist in alleviating credit constraints, a substantial challenge encountered by MSMEs.

The performance premium spills over to workers as well. Being employed at MNCs or their suppliers generally results in higher wages and better working conditions, including a higher likelihood of formal employment. For instance, in Cambodia, a surge in garment exports to the EU induced a 16-22 percent increase in employment at formal establishments. Women often benefit from these developments in particular. However, several non-trade related constraints, like access to education, limit their upgrading opportunities. In this regard, the chapter shows that GVC integration lowers gender wage gaps in low-skill occupations but has essentially no effect on inequality at high-skill occupations such as managerial positions.

The second key message is that where GVC integration fails to deliver or underdelivers on benefits, it tends to be caused by underlying market failures and policy barriers rather than GVC integration itself. An important example is market power. Both monopolistic/oligopolistic and monopsonistic/oligopsonistic behaviour of firms on product and labour markets can severely skew the distribution of profits in value chains and put undue pressure on local suppliers to cut costs with negative implications for workers. The chapter highlights a study showing that the income of Ecuadorian farmers in agricultural GVCs would be 77% higher if intermediaries behaved competitively. Other key factors are limited adaptive capacity due to incomplete financial or labour markets in developing economies.

These two findings have important policy implications. Since GVC integration tends to benefit firms and workers, the focus should be on facilitating entry into GVCs and spillovers to the domestic economy to ensure that GVCs are truly inclusive. To maximize the potential of GVCs for inclusive development, it is crucial to address the underlying market failures and barriers that lead to an uneven distribution of the gains from GVCs.

The current policy focus is on non-trade provisions (NTPs) in regional trade agreements, import bans and restrictions, and due diligence requirements (DDRs). However, these policies often aim at improving working conditions exclusively within GVCs even though the evidence suggests that workers and firms within GVCs already enjoy better outcomes. As a result, they might aggravate existing differences between those inside and those outside GVCs. Moreover, many of these policies have been shown to produce adverse effects. The inclusion of NTPs in trade agreements can potentially hinder country-level inclusion in GVCs by raising costs and uncertainty. DDRs appear to assume that firms willingly underpay workers or refuse to improve working conditions, but this is not in line with the evidence. To make sure that these policies work in favour of inclusive development, they should be accompanied by more cooperation and take into account the lessons from the academic literature.

David Dollar
Senior Fellow
John L. Thornton China Center
at the Brookings Institution

1

Examining Global Value Chains in Times of International Shocks

Mahinthan Joseph Mariasingham, Angelo Jose Lumba, Christian Regie Jabagat

1.1 Introduction

Even before the beginning of the coronavirus disease (COVID-19) pandemic in early 2020, the pace of globalization had already slowed. What once was an era of booming cross-border transactions, pushing the frontiers of international trade at the turn of the century, became—quite abruptly—a period of stagnating export and import activity. This dramatic shift from "hyperglobalization" (Subramanian and Kessler 2013) to "slowbalization" (The Economist 2019) occurred as the world dealt with the vestiges of the 2008 global financial crisis (GFC). The crisis ushered in skepticism towards globalization, along with renewed motivation to reconfigure the emerging architecture of international trade known as global value chains (GVCs). Global trade would then be disrupted further by trade tensions between the People's Republic of China (PRC) and the United States (US), with these two economic powerhouses and major players in GVCs imposing tariffs against each other to reshore manufacturing jobs. By 2019, these tensions had escalated and threatened to stifle export activities at a global scale.

A global pandemic was officially declared by the World Health Organization (WHO) on 11 March 2020, as COVID-19 spread rapidly worldwide. Along with it came unprecedented, and at times radical, modifications to economic and social activities, each geared towards the unified goal of controlling the speed and extent of COVID-19 transmission. Mobility restrictions such as lockdowns, quarantine and isolation, curfews, and travel controls were instituted in certain parts of the world, severely impacting key service sectors such as entertainment, leisure, and tourism. Some businesses that were deemed "nonessential" were even ordered to close, while a few others were allowed to operate at only limited capacity.

Note: Chapter contributed by the Asian Development Bank (ADB). The views expressed are those of the authors and do not necessarily reflect the views and policies of ADB or its Board of Governors or the governments they represent.

Industries that did not face such stringent constraints did, however, also face their own issues. For instance, the purchasing managers' index of supplier delivery times in the manufacturing sector showed a decline from 49.4 in January 2020 to 37.7 in April 2020, indicating longer lead times and capacity constraints, e.g., intermediates and labor supply shortages and transportation delays (CEIC 2022; Attinassi et al. 2021). In addition, the shipping and distribution industry—one of the main components of international logistics and playing a fundamental role in the functioning of supply chains—had to curtail its capacity at the start of the pandemic to adjust for an observed drop in demand. Then, however, came a surge in logistics demand attributed to national stimulus policies and an increase in purchases of household goods and electronics, causing an imbalance and leading to notable port congestion and record container freight rates soon after (UNCTAD 2022).

Concerns about the risks and uncertainties surrounding GVCs were reinvigorated because of pandemic policies and events. While such risks have always been present, even in the absence of shocks, multiple crises since the turn of the millennium have made them more salient over time. Chapter 1 of the GVC Development Report 2021 left readers wondering whether the same trend of stagnation in supply chains would persist, or even worsen, during the pandemic. This was especially concerning since the expansion of GVCs relies heavily on large-scale investments, which are fundamentally built on confidence derived from a good, stable, and predictable business environment.

Fortunately, signs of recovery in GVCs have already been reported due to concerted efforts to fend off the spread of COVID-19, worldwide adoption of digital technologies, and a return to past conceptions of "normalcy" that ultimately saw suspended economic and social activities resume. This renewed stability, however, is once again threatened by the Russian war in Ukraine, which has triggered an increase in commodity prices since the beginning of 2022.

This first chapter of the *Global Value Chain Development Report 2023* is based on the premise of successive shocks. The structure of gross exports and trends in GVC participation are first examined in the context of major recent disruptions to the global economy. During the initial years of the Global Financial Crisis (GFC), PRC–US trade tensions, and the COVID-19 pandemic, significant declines in exports were observed alongside decreasing shares of GVC-related trade to gross exports. A general shortening of GVCs also occurred from 2007–2009 (GFC) while a lengthening transpired from 2018–2020 (combined PRC–US trade tensions and COVID-19 pandemic). As considerable price changes were commonly experienced during these periods, a comparison of GVC-related metrics in nominal and real terms is also conducted to determine if any noticeable deviations occurred in instances of "abnormal" trade activity.

The chapter also investigates the evolving discourse on risks surrounding international trade and GVCs. Three characteristics that can give way to vulnerabilities are explored: trading of risky products, concentration in sources of value-added, and concentration in

frequency of engagement in supply chains. The annual aggregate export value and share of potential bottleneck products—based on market concentration, market relevance, and market substitutability—had been increasing since 2000. On the other hand, there has always been considerable concentration in sources of foreign value added and pass-through frequency in supply chains—an observation that holds true before, during, and after periods of global shocks. Lastly, the chapter discusses reconfiguration strategies that governments and enterprises can explore to help mitigate negative impacts associated with shocks to GVCs, namely replication, diversification, regionalization, and reshoring. It is shown that while export diversification across economies worldwide remained quite high over time, agglomeration indices—in general—provided little evidence of reshoring activities.

1.2 Global Value Chains During Periods of Shocks

Already this century, there have been four major global shocks to international trade.

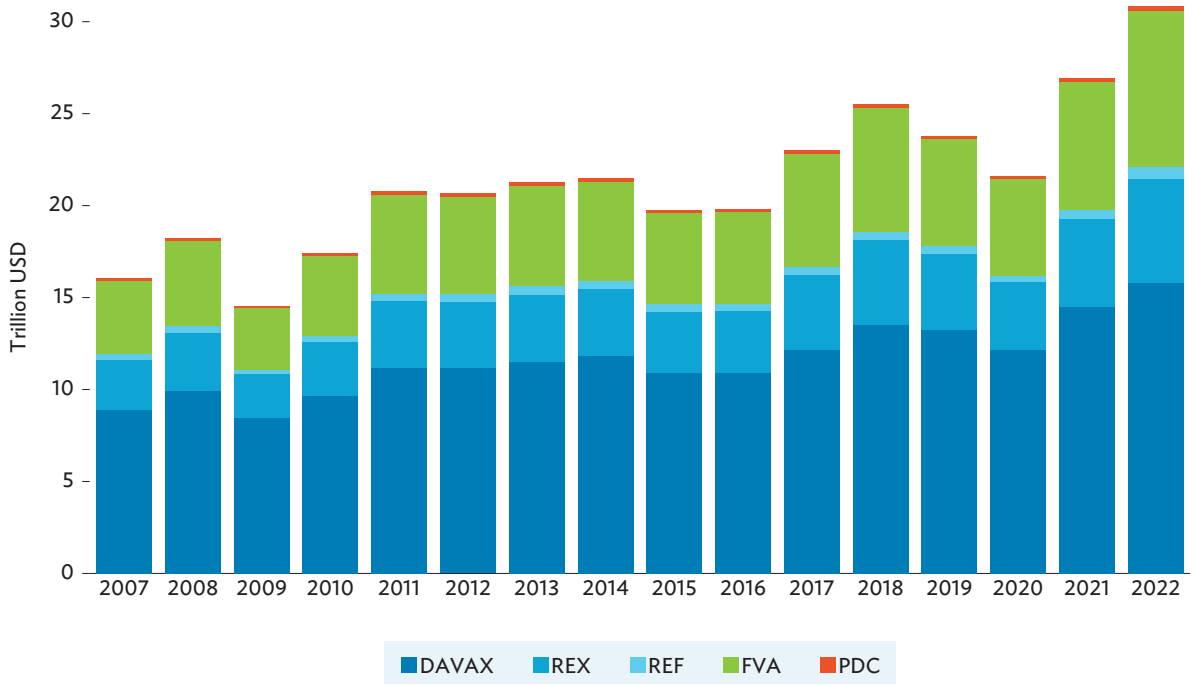
The first major shock was the GFC, which is widely considered to have reached its peak in 2008. Its origins can be traced back to the mid-2000s, when the housing bubble—driven by a combination of improved access to credit and low-interest rates on mortgages—took place in the US. As financial institutions witnessed the ensuing increase in mortgages, they began offering subprime mortgages, even to borrowers with poor credit histories (Loo 2020). These instruments, called "mortgage-backed securities", were sold globally to investors as more complex securities, making them difficult to assess in terms of value and risk. Eventually, homeowners, who had no true means to keep up with their mortgages in the first place, started defaulting on their mortgages. This caused significant drops in the value of mortgage-backed securities and, subsequently, enormous losses for the global financial system, which had become highly interconnected.

The subsequent freeze in lending and loss of confidence in the financial sector developed into a worldwide recession, characterized by depressed demand for highly tradable goods, plummeting business revenues, and widespread job losses. In fact, the fallout from the GFC led to global gross domestic product (GDP) contracting by 5.2%, as well as a decline of around 10.4% in global trade of goods and services in 2009. This drop in world trade was even more abrupt than the decline during the start of the Great Depression in 1929 (Eichengree and O'Rourke 2009). The immediate, simultaneous impacts on incomes worldwide can be attributed to the increasing synchronization of economic activity, with national GDP being correlated globally (Baldwin 2009; World Bank 2020).[1]

[1] This is in line with studies that investigated the pattern of higher business cycle correlations among economies with deeper integration in GVCs (Burstein, Kurz, and Tesar 2008).

A closer look into the structure of exports provides valuable insight into how GVCs fared during and after the GFC. Applying the decomposition framework of Borin and Mancini (2019), it can be seen in Figure 1.1 that gross exports increased from around $16 trillion to $18 trillion from 2007 to 2008. At the time, domestic value-added that is directly absorbed by the importer (DAVAX) held the lion's share, comprising more than 50% of the value of gross exports, while foreign value-added (FVA) took up around 25%. By 2009, however, exports had contracted by around 20%, with the share of DAVAX increasing by 3.805 percentage points and that of FVA, domestic value-added sent to the importer then reexported and eventually absorbed abroad (REX), and domestic value-added sent to the importer then reexported and eventually absorbed back by the exporter (REF) decreasing by 2.338, 1.155, and 0.114 percentage points, respectively. World trade showed signs of improvement in the years that followed, and even surpassed pre-crisis levels (in nominal terms) as early as 2011. In addition, shares of all value-added components became more stable and predictable.

Figure 1.1: Decomposition of World Exports, 2007–2022

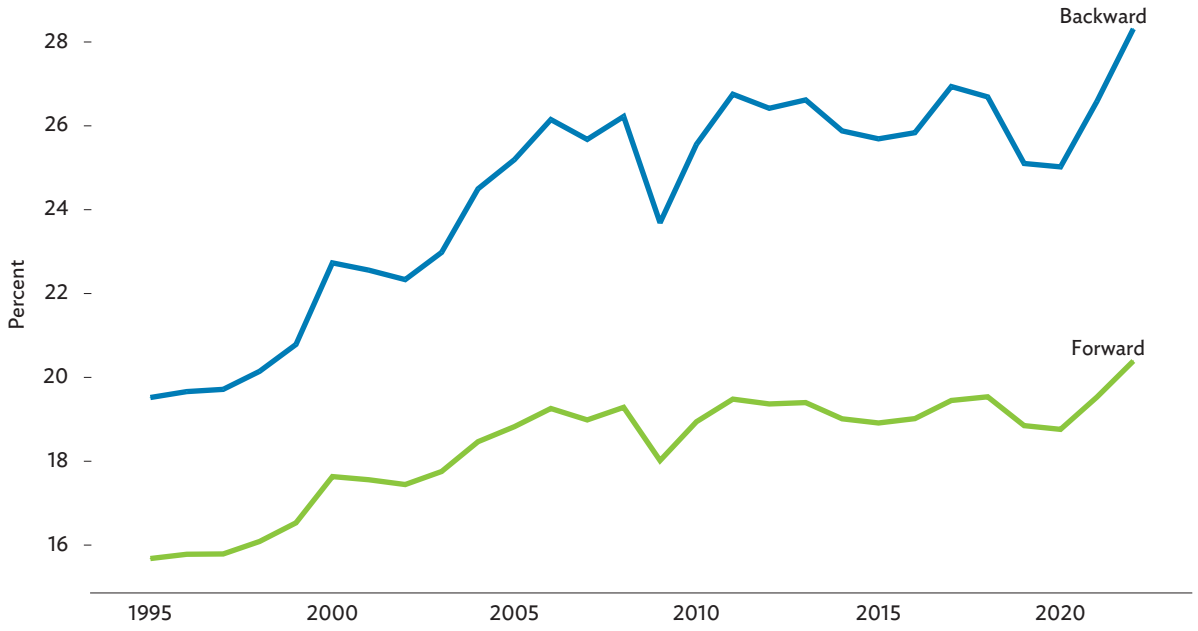


$ = United States dollars, DAVAX = domestic value-added directly absorbed by the importer, FVA = foreign value-added, PDC = pure double counting, REF = domestic value-added sent to the importer then reexported and eventually absorbed back by the exporter, REX = domestic value-added sent to the importer then reexported and eventually absorbed abroad.
Note: Gross exports decomposition follows the framework of Borin and Mancini 2019.
Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

Also following the framework of Borin and Mancini (2019), Figure 1.2 depicts the world's trade–based GVC participation rates from the perspective of backward and forward linkages. Forward GVC participation refers to the share of REX and REF in total exports: it is indicative of how an economy exports domestically produced

inputs to its trading partners for further processing in downstream production stages (WTO n.d.). Backward GVC participation takes the share of FVA and the pure double counting[2] (PDC) term in total exports: it is an indicator of the extent of an economy's use of foreign-sourced intermediates in the production of goods and services for export.

Figure 1.2: Backward and Forward Global Value Chain Participation Rates, World, 1995–2022



Notes: Global value chain (GVC) participation rates are calculated following the framework of Borin and Mancini 2019. Backward GVC participation is the ratio of the sum of foreign value-added (FVA) and pure double counting (PDC) to exports. Forward GVC participation is the ratio of the sum of domestic value-added sent to the importer then reexported and eventually absorbed abroad (REX) and domestic value-added sent to the importer then reexported and eventually absorbed back by the exporter (REF) to exports.

Sources: For 1995–2006: World Input-Output Database, 2013 Release. For 2007–2022: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

Figure 1.2 shows that, from 1995 until the peak of the GFC in 2008, the phenomenon of hyperglobalization was quite apparent, with forward GVC participation increasing from 15.68% to 19.28% and backward GVC participation growing from 19.52% to 26.22% over the 13-year period. In 2009, as the world attempted to deal with the aftermath of the GFC, both participation rates decreased and seemed to have stagnated in the years that followed. As mentioned above, the subprime mortgage crisis led to a sharp contraction of consumer durable goods, such as automobiles and machineries, especially in developed economies (Eaton et al. 2016). This reduction in demand for final goods also drove trade trends via intermediate parts and components required to manufacture those goods (Ferrantino and Larsen 2009), which was reflected by the drop in both GVC participation

[2] These are value-added items that are recorded more than once in a gross trade flow resulting from the back-and-forth transactions involved in cross-border production processes (Koopman, Wang, and Wei 2014)

rates. In terms of overall GVC participation[3] almost all economies' rates fell compared to 2007 as seen in Figure 1.3. However, GVC-related trade seemed to have recovered quite speedily as these rates rebounded in 2010, with a few exceptions including Cambodia, Fiji, Kazakhstan, Lao PDR, Maldives, Philippines, and Thailand.

For each economy-sector pairing, the average GVC production length was also calculated using the methodology of Wang et al. (2017). This gives the average number of stages that separate domestic value-added creation in intermediate products to its final consumption (ADB 2023a). World level measures were derived as weighted averages, with each economy's share in global total value added used as shares.

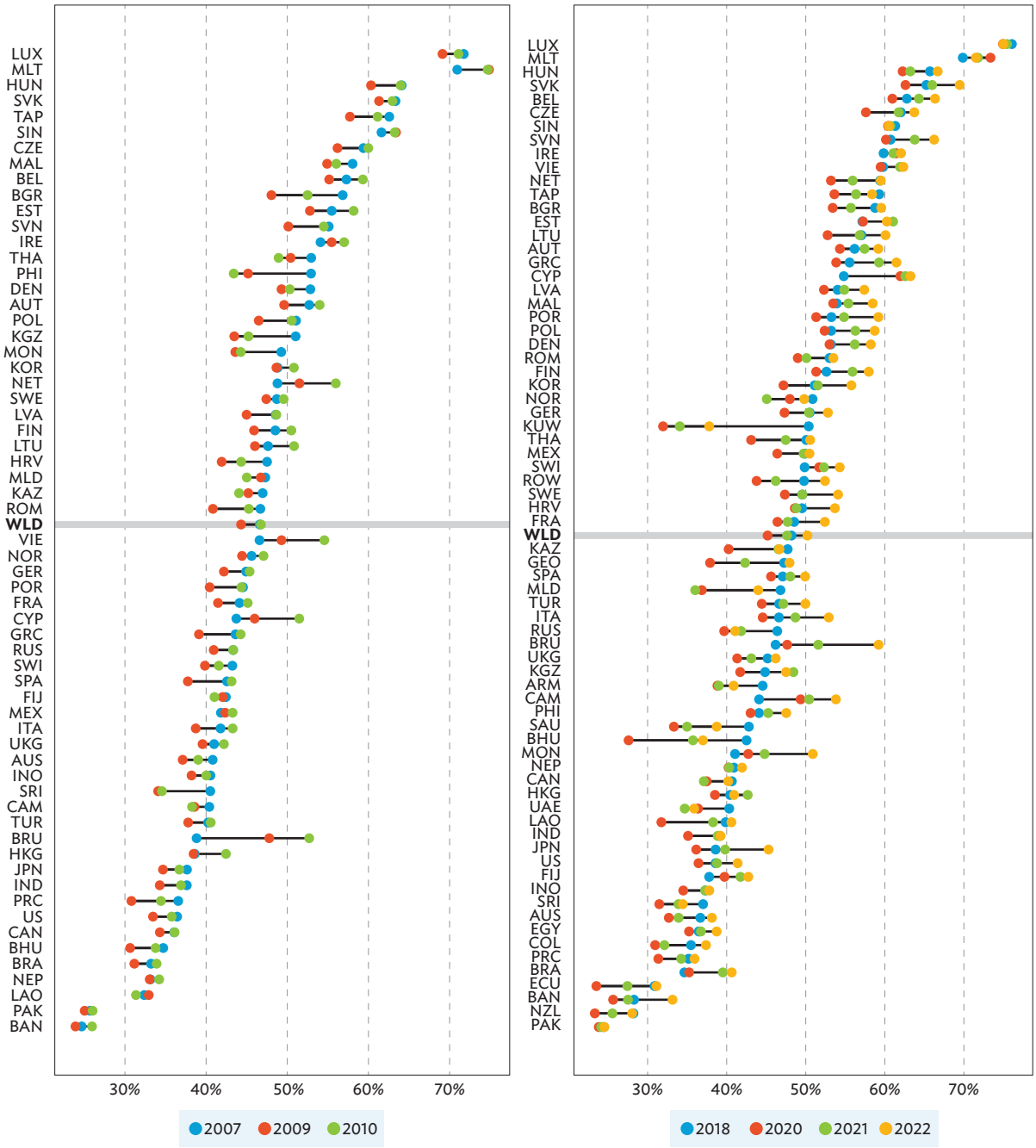
From 2007 to 2009, average GVC production lengths of sixteen sectors, comprised mostly of services and low-technology manufacturing sectors, shortened (Figure 1.4). As an aggregate, a shortening is also observed with the GVC production length going down from 8.75 in 2007 to 8.73 in 2009. This could have resulted from the decline in GVC participation, possibly characterized by increased reliance on domestic sources of value-added or even a temporary concentration of production processes towards a few economies. On the other hand, a lengthening of GVC production lengths was recorded for all sectors classified as medium- to high-technology. By 2010, a general lengthening of GVCs occurred with a large majority of sectors recording higher production lengths compared to 2009.

The second major global trade shock was caused by trade tensions between the PRC and the US, which began in 2018 before intensifying in 2019. The US administration's concern with the longstanding trade deficit it had with the PRC—alongside a gamut of other apprehensions related to intellectual property, national security, and quality of trade policies—gradually escalated into US imposition of tariffs and trade barriers on a few products from the PRC, which then retaliated with its own tariffs on US goods and services. This initial exchange was eventually extended with tariffs from both economies on a wider range of products, negatively impacting industrial sectors and significantly hurting trade between the two. With the PRC's role as a supply-and-demand hub in simple GVC networks, and the US being an important hub in complex GVC networks (Li, Meng, and Wang 2019), supply chains and markets worldwide were disrupted soon after.

The impacts of PRC–US trade tensions on GVCs are demonstrated back in Figure 1.1, which shows world exports falling by around 6.8% ($25.52 trillion to $23.78 trillion) from 2018 to 2019. In 2017, the share of DAVAX went down by 2.417 percentage points, but then increased as the PRC–US trade tensions commenced (by 0.336 percentage points in 2018 and by 2.757 percentage points in 2019). FVA, on the other hand, registered an increase of 1.643 percentage points in 2017, before consecutive dips of 0.245 and 1.747 percentage points in 2018 and 2019, respectively. Declines in REF and REX can also be seen in 2018 and 2019, respectively.

[3] This is simply derived by adding the backward GVC participation rate and forward GVC participation rate of an economy

Figure 1.3: Global Value Chain Participation of Economies, 2007–2010 and 2018–2022

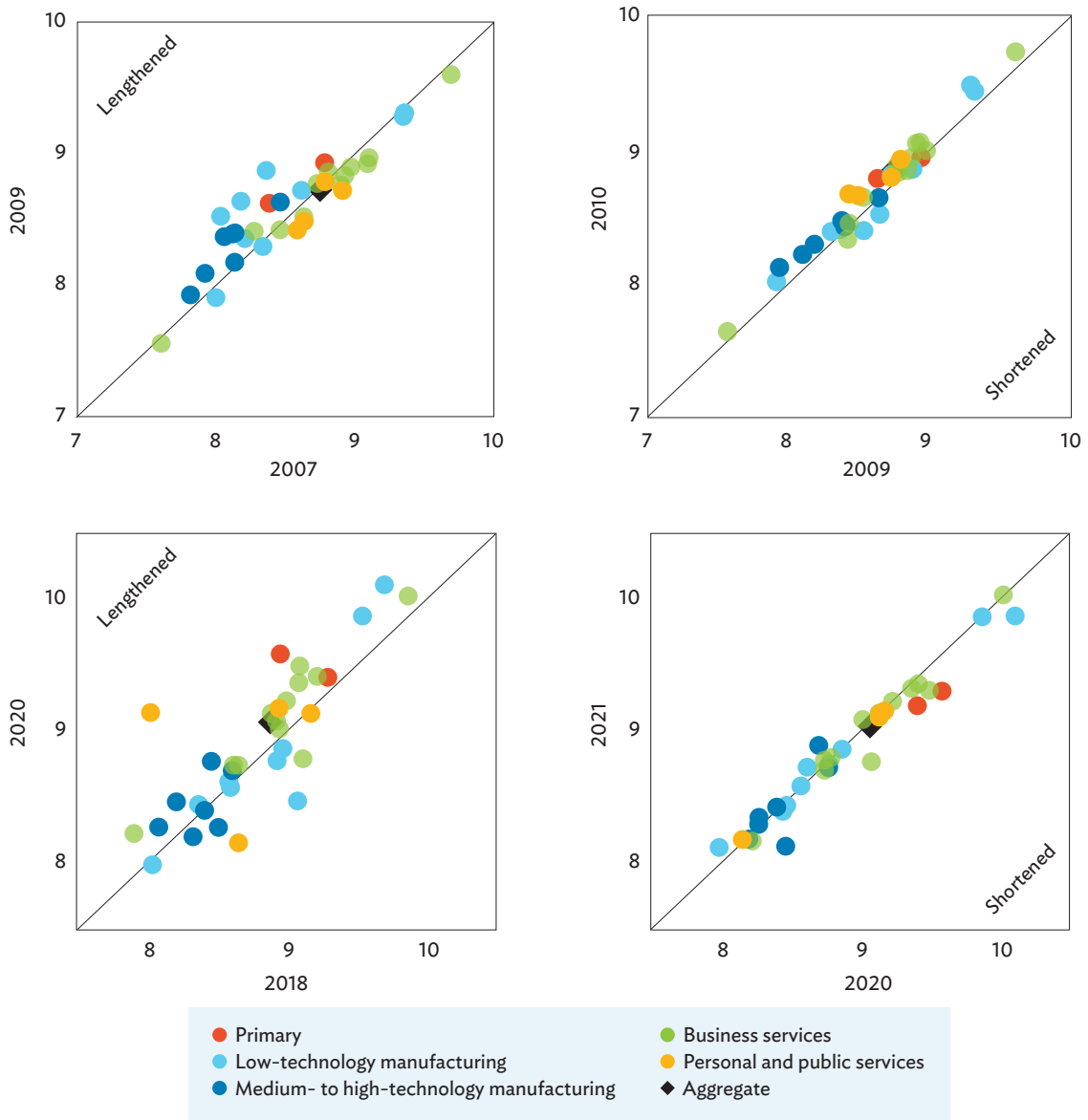


ARM = Armenia; AUS = Australia; AUT = Austria; BAN = Bangladesh; BEL = Belgium; BGR = Bulgaria; BHU = Bhutan; BRA = Brazil; BRU = Brunei Darussalam; CAM = Cambodia; CAN = Canada; COL = Colombia; CYP = Cyprus; CZE = Czech Republic; DEN = Denmark; ECU = Ecuador; EGY = Egypt; EST = Estonia; FIJ = Fiji; FIN = Finland; FRA = France; GEO = Georgia; GER = Germany; GRC = Greece; HKG = Hong Kong, China; HRV = Croatia; HUN = Hungary; IND = India; INO = Indonesia; IRE = Ireland; ITA = Italy; JPN = Japan; KAZ = Kazakhstan; KGZ = Kyrgyz Republic; KOR = Republic of Korea; KUW = Kuwait; LAO = Lao People's Democratic Republic; LTU = Lithuania; LUX = Luxembourg; LVA = Latvia; MAL = Malaysia; MEX = Mexico; MLD = Maldives; MLT = Malta; MON = Mongolia; NEP = Nepal; NET = Netherlands; NOR = Norway; NZL = New Zealand; PAK = Pakistan; PHI = Philippines; POL = Poland; POR = Portugal; PRC = People's Republic of China; ROM = Romania; RUS = Russia; RoW = Rest of the World; SAU = Saudi Arabia; SIN = Singapore; SPA = Spain; SRI = Sri Lanka; SVK = Slovak Republic; SVN = Slovenia; SWE = Sweden; SWI = Switzerland; TAP = Taipei,China; THA = Thailand; TUR = Türkiye; UAE = United Arab Emirates; UKG = United Kingdom; US = United States; VIE = Viet Nam, WLD = World average.

Notes: Global value chain (GVC) participation rates are calculated following the framework of Borin and Mancini 2019. It is the ratio of GVC-related trade—i.e., sum of domestic value-added sent to the importer then reexported and eventually absorbed abroad (REX), domestic value-added sent to the importer then reexported and eventually absorbed back by the exporter (REF), foreign value-added (FVA), and pure double counting (PDC)—to exports.

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

Figure 1.4: Global Value Chain Production Lengths by Sector, World, 2007–2010 and 2018–2022



Notes: Global value chain production lengths are the sum of backward and forward lengths. These are computed following the methodology of Z. Wang, S. Wei, X. Yu, and K. Zhu. 2017. Characterizing Global Value Chains: Production Length and Upstreamness. *NBER Working Paper*. No. 23261. Cambridge, MA: National Bureau of Economic Research.

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

When it comes to GVC participation, as shown in Figure 1.2, backward rates went down by a total of 1.835 percentage points from 2017 to 2019, while forward rates decreased marginally from 19.45% to 18.85%. The impacts of the PRC–US trade tensions—at least from the perspective of GVCs—appear to be less than those caused by the GFC. This may be due to a variety of factors, including trade redirection and the extent of digitalization.

The third major shock to international trade was the COVID-19 pandemic, which emerged while PRC–US trade tensions were still present. The shock began as a negative supply crisis, with infection containment measures disrupting the normal functioning of businesses, logistics, and supply chains, while also limiting the availability of labor. It eventually spread to demand channels (Brinca, Duarte, and Faria-e-Castro 2020; Del Rio-Chanona et al. 2020) as consumer spending and investment declined. In contrast with the GFC, which saw depressed demand in durable and investment goods, the decline in services trade was more severe during the pandemic (World Bank 2021; WTO 2021). However, with emphasis on public health and safety requiring the sudden confinement of social activities to people's homes, the demand for consumer electronics and home appliances, along with medical supplies, surged (Ossa and Le Moigne 2021). Computers and laptops, for instance, recorded the largest growth in exports from 2019 to 2020, reaching roughly $28 billion (ADB 2022).

The increased global adoption of digital technology is also widely regarded as a key development during the COVID-19 pandemic. Digitalization enabled enterprises to maintain operations and even accelerate commercial trends in consumer electronics, thereby mitigating trade shocks from both the supply and demand sides (OECD 2020; WTO 2021). Even though not all e-commerce sales entail cross-border trade, the expansion in retail trade via mail orders or the internet resulted in remarkable development in the e-commerce sector throughout 2020 (WTO 2021). Companies such as United Parcel Service (UPS) and PayPal reported substantial growth in cross–border shipment volumes (Fitzpatrick et al. 2020).

Another prominent trend observed during the pandemic was the considerable level of government response, with stimulus packages and labor market support, e.g., employment retention programs, helping to prevent worst-case scenarios from eventuating. Accumulated fiscal and monetary stimulus in 2020 and early 2021 reached a historic level of more than 15% of global GDP (IMF 2021). In fact, in advanced economies, the value of fiscal and monetary support was equivalent to about 25% of their GDP. In low-income economies, the equivalent figure was below 3% of GDP, suggesting a degree of heterogeneity according to the economies' development status. By contrast, during the GFC, the financial sector disruptions made it more difficult to obtain the trade finance necessary to jumpstart recovery of international business activities (Ahn, Amiti, and Weinstein 2011; Chor and Manova 2012; WTO 2021).

As a side note, due to the overlapping timelines between the PRC–US trade tensions and the COVID-19 pandemic, it is challenging to attribute observations for 2020 onwards to one or the other of these crises—at least from a measurement perspective. It is reasonable to treat observations on economic trends and patterns as the compounded effects of both crises, especially in the absence of a carefully crafted way of disentangling their impacts.

With this in mind, world exports declined by only 9.12% in 2020, which is around 11 percentage points lower (in absolute value) compared to 2009 (Figure 1.1). The share of DAVAX also increased marginally (0.398 percentage points) in the same year, while those of FVA, REX, and REF all decreased. In 2021, exports suddenly grew by around 24.57%, with the total value reaching a peak (in nominal terms) of approximately $26.92 trillion. The trends in the shares of DAVAX and other value-added components of gross exports were also reversed for the year. Meanwhile, GVC participation rates continued to decline from 2019 to 2020, albeit quite marginally at 0.1 of a percentage point (Figure 1.2). This may be due to the considerable slumps in GVC participation in 2019, which left little room for further contraction. Recovery in 2021 was quite instantaneous as both backward and forward rates came very close to reaching their values from 2018 and before.

It is also worth noting that, except for a few (e.g., Bangladesh, Kazakhstan, Maldives, Nepal, Sri Lanka, Taipei,China, and United Kingdom) economies with large business service sectors, almost all registered higher overall GVC participation rates in 2021 relative to 2019 as seen in Figure 1.3. This signifies that the service sector lagged in terms of recovery relative to its manufacturing counterparts, thereby having a prolonged impact on service-oriented economies.

In contrast to the GFC, a general lengthening of GVCs took place from 2018 to 2020 (Figure 1.4). Twenty-three sectors across all aggregate categories (i.e., primary, low-technology manufacturing, medium- to high-technology manufacturing, business services, and personal and public services) had higher GVC production lengths, which indicates that the combined impact of the PRC–US trade tensions and COVID-19 pandemic were felt across the board. Such a lengthening could be attributed to the trade redirection resulting from the imposition of tariffs as well as the issues of port congestion and border closures that occurred during this period. This would have added additional layers/stages to a production process as it looked for alternative options in response to a deviation from established procedures. By 2021, GVC production lengths shortened vis-à-vis a return to previous patterns of GVC participation.

The last and most recent shock to the global economy was the Russian war in Ukraine. While the beginnings of this crisis can be traced back to the 1990s, tensions are generally recognized to have intensified in early 2014 amid political turmoil that saw then Ukrainian President Viktor Yanukovych flee the country. This was followed by Russian troops taking over Crimea to “protect the rights of Russian citizens and speakers” in the region (CPA 2023 para. 2), with armed conflict breaking out soon after. In the years that followed, initiatives to resolve the situation were put forward but were mostly ineffective. Deployment of battalions in other Eastern European areas, as well as sanctions on Russian individuals and companies linked to the conflict, were also made (CPA 2023). In February 2022, President Vladimir Putin started the Russian war in Ukraine, and with it came a host of economic sanctions on Russia by the US, Canada,

and the European Union (EU). Sanctions against several economies were also imposed by Russia. This impacted the world economy through higher commodity prices, supply chain disruptions, and further reduction of business confidence (Kammer et al. 2022).

It remains difficult to quantify the immediate impacts of the Russian war in Ukraine on the value-added structure of exports and GVC participation since multi-economy input-output tables for 2023 were not available at the time of writing this report. Reflecting patterns observed for the other three major shocks, significant trade impacts were not seen during the first year of the Russian war in Ukraine: world exports grew by 14% in 2022, leading to a new record high value of $30.83 trillion. DAVAX continued to fall (–2.591 percentage points) while FVA, REX, and REF all increased. GVC participation indices also peaked in 2022, with the backward rate increasing by 1.73 percentage points and the forward rate growing by 0.86 percentage points. Lastly, overall GVC participation rates of almost all economies were higher in 2022 compared to their pre-crises levels in 2018 (Figure 1.3). It will be interesting to see if these surges were sustained for 2023, which would be in contrast to what was observed during past crises.

In summary, an interesting pattern is seen during periods with significant fluctuation in exports, as was the case in the years following the four major global shocks:

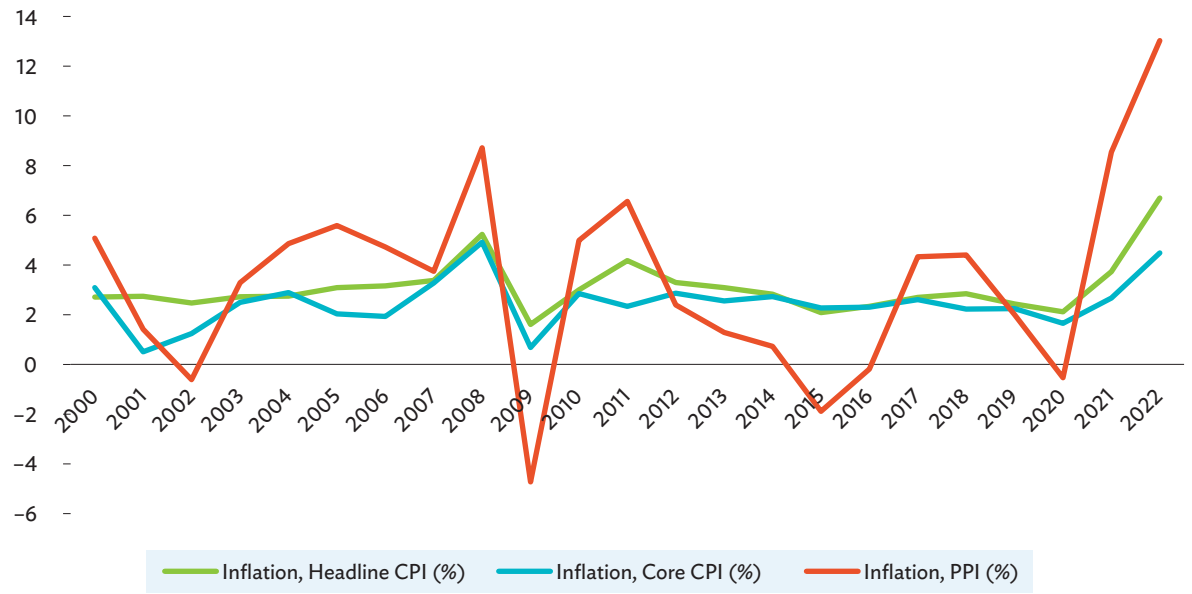
- During years of notable export growth, the relative share of DAVAX decreased vis-à-vis an increase in FVA, REF, and REX.
- As a corollary, periods with substantial declines in exports were characterized by increasing DAVAX and decreasing shares of FVA, REF, and REX.

This pattern suggests that GVC-related trade (which undergoes multiple border crossings and is constituted by FVA, PDC, REF, and REX) is cyclical with major changes in exports: such trade increases with significant growth in exports and declines with significant contraction in exports. It follows that traditional trade (which undergoes only one border crossing) is elevated in periods when export activities become more challenging, and vice versa. Such an observation may simply be coincidental and due to circumstances (e.g., port congestion and border closures in 2020) that make it more difficult for enterprises to successfully trade intermediates worldwide. On the other hand, this may reflect certain characteristics of the structure of international trade and GVCs that make them vulnerable (or at least sensitive) to shocks. Lastly, the pattern observed may be indicative of adjustment mechanisms being implemented by governments and firms worldwide in response to higher perceived risks in GVCs and suboptimal conditions related to participation (these aspects are explored in detail in subsequent sections of this chapter).

1.3 Dollar Prices and Global Value Chains

There seems to be an inextricable link between price levels and the occurrence of economic shocks. During the GFC, what began as a surge in housing prices in 2008 turned into deflationary pressures that were experienced worldwide due to reduced consumer spending, a slowdown in business investment, and an overall reduction in demand. In Figure 1.5, these trends can be clearly seen across different measures of inflation.

Figure 1.5: Global Inflation Rates, 2000–2022
(%)



CPI = consumer price index, PPI = producer price index.
Note: Gross domestic product-weighted global headline and core CPI (%) and PPI year-on-year growth rate (%).
Source: J. Ha, M. Kose, and F. Ohnsorge. 2021. One-Stop Source: A Global Database of Inflation. *Policy Research Working Paper, No. 9737.* Washington, DC: World Bank.

Meanwhile, Naisbitt and White (2020) noted that the increases in tariffs that were commonplace during the PRC–US trade tensions acted as a negative supply shock, which raised the prices of intermediates as well as final output. Since 2020, as economies worldwide have learned how to navigate their paths to normalcy following the peak of the COVID-19 pandemic, a surge in inflation has also been observed. This was made worse by the compounding effect of the Russian war in Ukraine on global commodity prices. Global headline consumer price index (CPI) inflation, which includes food and energy prices, increased in 2021 and reached up to 6.7% in 2022. Even if food and energy prices are unaccounted for (core CPI), inflation was still at its highest in 2022, at least for all years considered. The producer price index (PPI), which captures price changes received by manufacturers and producers, spiked in the years following the onset of the COVID-19 pandemic, reaching 13% in 2022.

Understanding the impact of global economic shocks on price levels, a main point of inquiry is whether trends and patterns captured in GVC statistics are dictated by price changes and not by structure. This means it could be possible that dependence on foreign-sourced inputs and the provision of intermediates along global supply chains have remained relatively stable over time (in terms of volume and number of transactions) and that price changes may have framed a different scenario from what actually happened. To account for this, the Asian Development Bank (ADB) developed multiregional input-output tables (MRIOTs) in nominal and real terms for 2000–2022. These tables can be used for deriving separate sets of GVC indicators. Thus, trends in GVC indicators in nominal terms reflect changes in production technology, prices, and exchange rates over time, while those in real terms only indicate technological and structural changes. Any differences between these metrics can therefore be ascribed to dollar price changes, which capture the combined effects of movements in price and exchange rate, since all MRIOTs are expressed in US dollars (ADB 2023).

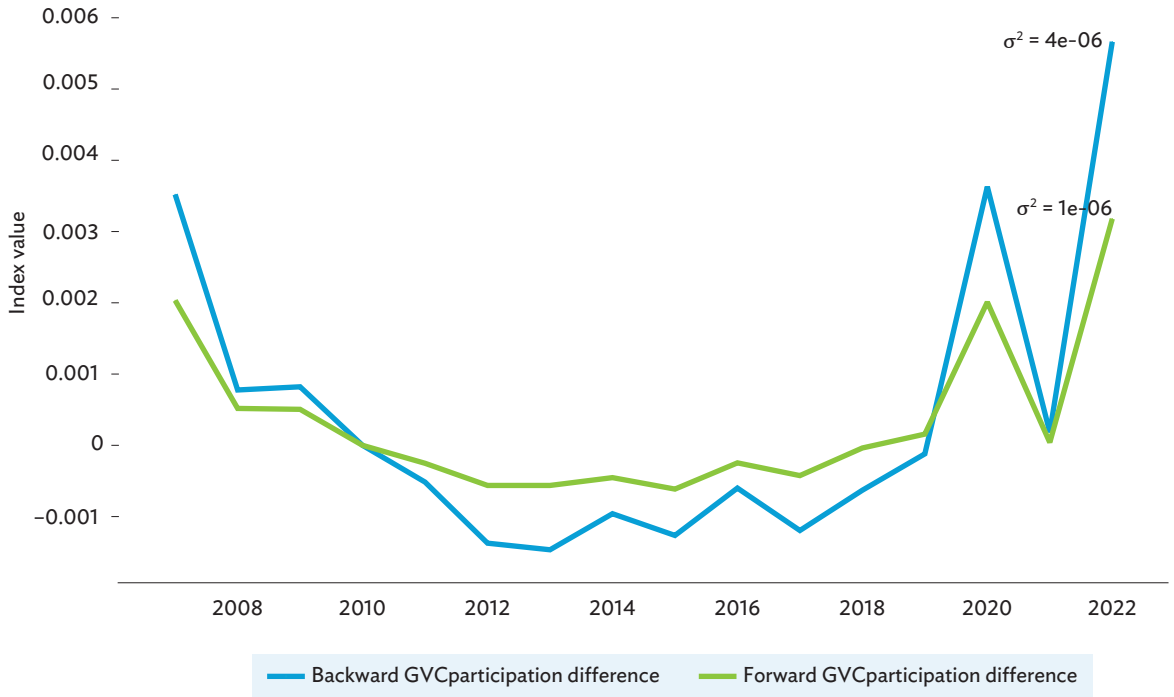
ADB (2023b) showed that there is stability in the breakdown of gross exports into traditional trade and GVC-related trade and this holds true whether or not dollar price changes are accounted for. However, during the 2021–2022 surge in inflation, the gap between gross exports in nominal and real terms increased to as high as 8% in 2021 and 7% in 2022. This may ultimately impact analysis of global trade. At the global level, GVC participation rates in nominal and real terms were also shown to be consistent with each other over the 15 years from 2007 to 2022. Figure 1.6 displays the differences between these estimates for both forward and backward GVC participation, which were simply calculated by subtracting the estimate in real terms from that in nominal terms. Though the range in differences was quite small, and the variances were both close to zero, it is interesting to see a considerable increase from 2021 to 2022, which meant that nominal rates were possibly overestimating actual participation during the recent inflation surge.

At a national level, such consistency is not preserved across all economies: some, such as Singapore and Türkiye, registered notable discrepancies between real and nominal estimates; while Kazakhstan and the US had relatively uniform trends.

To further examine the interplay of real and nominal GVC participation, a few additional indicators have been considered in this report: namely, the level of discrepancy, the variability of discrepancy, and occurrences of divergence (Box 2.1). Based on the first two indicators, a grouping of economies was established relative to their median values as seen in Figure 1.7.

Quadrant 1 of Figure 1.7 represents the group with low discrepancy and high variability. Hong Kong, China; the Lao People's Democratic Republic; and Singapore are among the economies that fell into this quadrant, signifying trends in current and constant prices that are not too far apart in levels but possess a considerable degree of variability in terms of their differences.

Figure 1.6: Differences in Backward and Forward Global Value Chain Participation Rates, Nominal vs Real, 2007–2022



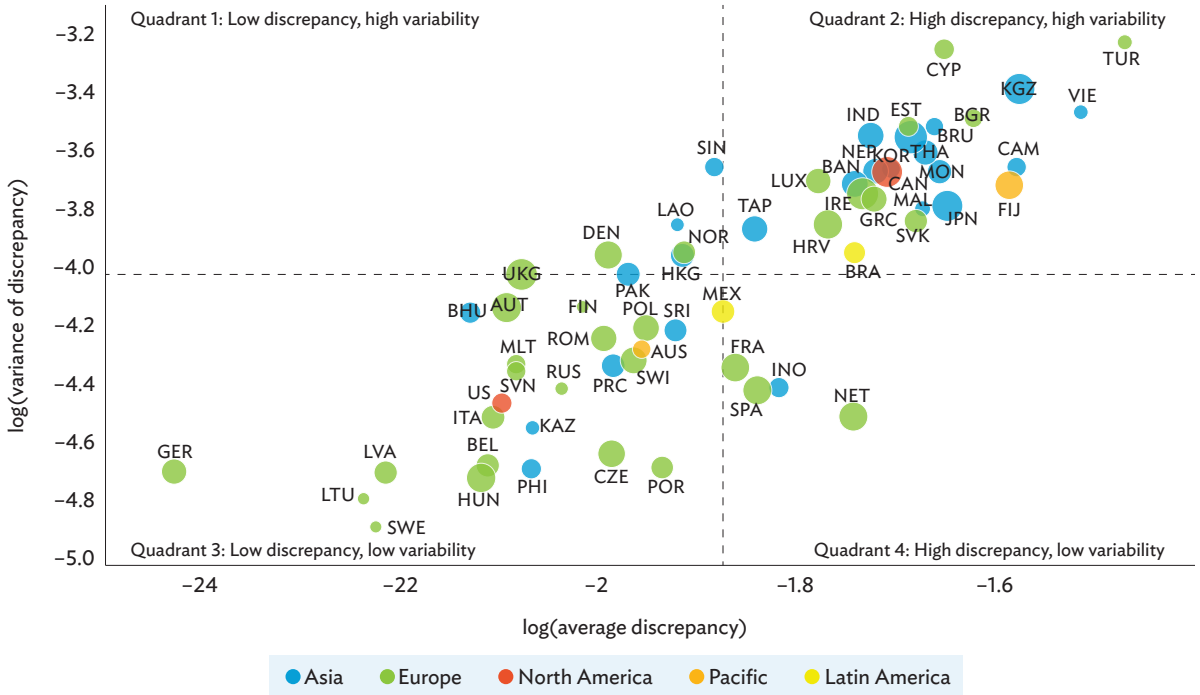
σ^2 = variance, GVC = global value chain.
Note: The difference is calculated by subtracting the estimate in real terms from the estimate in nominal terms.
Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

Quadrant 2 of Figure 1.7 corresponds to those economies with differences in GVC participation rates that are higher (on average) and more variable than the median. Thus, not only do they have considerable differences between current and constant price estimates, they are also more volatile than the central value (i.e., median). Türkiye, Viet Nam, and the Kyrgyz Republic are notable examples as they are the farthest away from the median values. Some of these economies also had several instances of diverging trends (as indicated by the size of the bubble), with notable examples being Maldives (5 diverging trends), Japan (4), and the Kyrgyz Republic (4).

Quadrant 3, on the other hand, corresponds to the group of economies with differences in GVC participation rates that are lower (on average) and less variable than the median. In essence, these economies are more "stable" in the sense that their current and constant price estimates are closely aligned and are relatively more predictable. The PRC and the US, two powerhouse economies in international trade and GVCs, belong to this group, with the latter exhibiting more consistency than the former. Among all economies in this group, the PRC and Sri Lanka recorded the highest number of instances of diverging trends at 3 each.

Meanwhile, Quadrant 4 contains the group with high discrepancy and low variability. Only four economies fell into this quadrant, namely France, Indonesia, the Netherlands, and Spain. This means that these economies had relatively high but consistent levels of discrepancy between their current and constant price estimates of GVC participation.

Figure 1.7: Discrepancy, Variability, and Divergence of Real and Nominal Global Value Chain Participation



AUS = Australia; AUT = Austria; BAN = Bangladesh; BEL = Belgium; BGR = Bulgaria; BHU = Bhutan; BRA = Brazil; BRU = Brunei Darussalam; CAM = Cambodia; CAN = Canada; CYP = Cyprus; CZE = Czech Republic; DEN = Denmark; Developing Asia = DevAsia; EST = Estonia; Europe = Europe; FIJ = Fiji; FIN = Finland; FRA = France; GER = Germany; GRC = Greece; HKG = Hong Kong, China; HRV = Croatia; HUN = Hungary; IND = India; INO = Indonesia; IRE = Ireland; ITA = Italy; JPN = Japan; KAZ = Kazakhstan; KGZ = Kyrgyz Republic; KOR = Republic of Korea; LAO = Lao People's Democratic Republic; LTU = Lithuania; LUX = Luxembourg; LVA = Latvia; MAL = Malaysia; MEX = Mexico; MLD = Maldives; MLT = Malta; MON = Mongolia; NEP = Nepal; NET = Netherlands; NOR = Norway; PAK = Pakistan; PHI = Philippines; POL = Poland; POR = Portugal; PRC = People's Republic of China; ROM = Romania; RUS = Russia; SIN = Singapore; SPA = Spain; SRI = Sri Lanka; SVK = Slovak Republic; SVN = Slovenia; SWE = Sweden; SWI = Switzerland; TAP = Taipei,China; THA = Thailand; TUR = Türkiye; UKG = United Kingdom; US = United States; VIE = Viet Nam

Notes: Average discrepancy refers to the mean of the absolute values of differences between current and constant price estimates across time. Variance of discrepancy refers to the variance of the absolute values of differences between current and constant price estimates across time. Log base 10 of average discrepancy and variance of discrepancy are presented for visualization purposes. The vertical dashed line represents the median log base 10 average discrepancy, while the horizontal dashed line signifies the median log base 10 variance of discrepancy. Bubble sizes correspond to the number of instances when current price trends diverge from constant price trends (i.e., if one increases and the other decreases, vice versa).

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

The size and variability of differences in real and nominal measures of GVC participation can vary considerably, depending on whether backward or forward GVC participation is measured.[4] The extent to which an economy provides intermediate inputs to production processes across the globe may be consistent when measured across real and nominal rates, which indicates that GVC participation from the forward perspective is relatively unaffected by dollar price changes. At the same time, the economy may depend on foreign intermediates that face significant variation in dollar prices, which could lead to considerable differences in real and nominal GVC backward participation rates. On the other hand, an economy's provision of intermediates across supply chains may be subject to more irregularities in terms of dollar prices relative to its dependence on intermediates, which would lead to better consistency in terms of backward rates compared to forward rates.

[4] In a similar presentation to Figure 1.7, this would be reflected in economies being in different quadrants when backward participation is measured compared to when forward participation is measured.

Overall, 20 of 62 economies showed a change in grouping. Four economies (Hong Kong, China; the Lao People's Democratic Republic, Pakistan, and the Philippines) shifted from a forward participation rate in Quadrant 2 (high discrepancy, high variability) to a backward participation rate in Quadrant 3 (low discrepancy, low variability). This indicates a considerable level and variability of the gap between current and constant price estimates from a forward perspective, accompanied by relative steadiness and proximity from a backward perspective.

Box 1.1: Characterizing Economies Based on Differences in Current and Constant Price Estimates

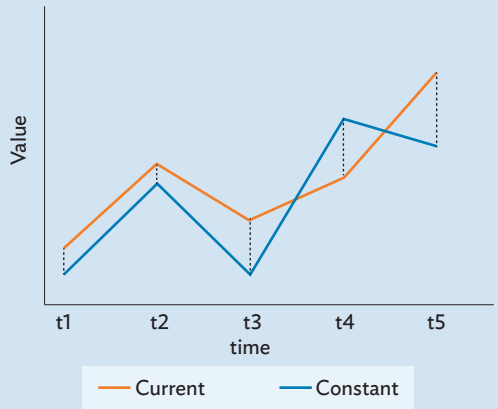
To group economies based on the trends in their respective current and constant price estimates of global value chain (GVC) participation, the following dimensions were considered: (i) level of discrepancy, (ii) variability of discrepancy, and (iii) occurrences of divergence. To explain how both price estimates are measured, an illustrative example is provided below. At each point in time (i.e., t1, t2, t3, t4, t5), the difference between current and constant price estimates (represented by the dashed lines) can be derived by subtracting one from the other. For the purposes of this analysis, the sign and/or direction of this difference was not a point of interest, thus absolute values of the discrepancies were taken. These are then averaged across time to get the average discrepancy, which is provided in the equation below:

$$\mathrm{avgDisc_i} = \frac{\sum_{t=1}^{T} \left|\mathrm{CurrentGVCParticipation_{i,t}} - \mathrm{ConstantGVCParticipation_{i,t}}\right|}{T}$$

where $avgDisc_i$ refers to the average discrepancy of economy i's GVC participation rates, t is period, and |x| refers to the absolute value of any number x. Intuitively, this measures how far apart (on average) the estimates in current and constant prices are from each other across time. The variability of discrepancy is simply the variance of absolute values of differences, which is represented in the equation below:

$$\mathrm{VarDisc_i} = \sum_{t=1}^{T} \left(\left|\mathrm{CurrentGVCParticipation_{i,t}} - \mathrm{ConstantGVCParticipation_{i,t}}\right| - \mathrm{avgDiscrepancy_i}\right)^2$$

where $VarDisc_i$ refers to the variance of discrepancies of economy i's GVC participation rates. Intuitively, this measures how variable the differences of estimates in current and constant prices are over time.



Source: Conceived by the authors of the Asian Development Bank's *Global Value Chain Development Report 2023.*

At period t5 in the illustration above, the current price trend increases while the constant price trend decreases. This indicates that, if prices and exchange rates are included in the analysis, growth is recorded from t4 to t5. However, if prices and exchange rates are controlled for or removed, a reduction in the measure is observed. This divergence has a potential impact on decision-making processes as the conceptualization of potential policy interventions may rest on the movement of a set of indicators across time. For this reason, the third dimension for grouping economies is measured by counting the number of instances of these divergences that occurred over the study period.

Conversely, four economies (Bangladesh, Canada, Greece, and Nepal) shifted from a forward participation rate in Quadrant 3 to a backward participation rate in Quadrant 2. As for other changes in grouping when shifting from a forward to a backward perspective, three economies (the Netherlands, Poland, and the PRC) moved from Quadrant 2 to either Quadrant 1 or Quadrant 4; two economies (Belgium and Sri Lanka) moved from Quadrant 1 to either Quadrant 3 or Quadrant 4; three economies (Croatia, Finland, and the UK) moved from Quadrant 3 to either Quadrant 1 or Quadrant 4; and four economies (Australia, Kazakhstan, Thailand, and Viet Nam) moved from Quadrant 4 to either Quadrant 2 or Quadrant 3.

GVCs are associated with the fragmentation of production and relocation of processes to areas where tasks are optimally delivered. With development of GVCs comes the expansion of production networks that inch ever closer to involving every economy in the world. Naturally, such modifications in the architecture of production also introduce new and evolving interdependencies among players participating in international trade, which become more salient during periods of crisis as disruptions in supply are felt across the board. The next two sections of this chapter explore risks surrounding international trade and GVCs by examining three characteristics that possibly contribute to the vulnerability of value chains to shocks: (i) trade of potential bottleneck products, (ii) concentration in sources of value-added, and (iii) concentration in pass-through frequency in supply chains.

1.4 Potential Bottleneck Products in International Trade

The impact of crises can be amplified if production is limited to a few locations. Trade tends to protect individual economies from volatility and shocks by enabling the diversification of sources of supply and demand (WTO 2023a). However, when trade in certain critical products is concentrated at a global scale, this diversification channel is muted and trade can instead exacerbate crises. Different studies have proposed ways to identify such potential bottlenecks in global trade. Majune and Stolzenburg (2022) defined these products as having a limited number of suppliers and few substitutes, yet constituting a relevant share of global trade.

One case in point is medical equipment such as face masks, for which Germany, the PRC, and the US accounted for almost half of global supply in 2019 (Hayakawa and Imai 2022). As demand for face masks skyrocketed in 2020, the reliance on these three economies increased exponentially. However, as the economies confronted challenges in production and logistics during the COVID-19 pandemic, their capacity to meet global demand became limited. The Russian war in Ukraine also highlighted the inherent risks associated with the world's reliance on a few economies to produce goods, as price hikes of oil and agricultural commodities led to the worsening of food and energy insecurity, even though the trading system adjusted swiftly to restrict negative impacts (WTO 2023b).

The literature on potential bottlenecks in trade has been growing. Korniyenko, Pinat, and Dew (2017) assessed the fragility of all globally traded goods and identified "100 risky import products" based on three dimensions: (i) presence of central players, (ii) tendency to cluster, and (iii) international substitutability. From here, the authors also discovered that virtually all economies import potential bottlenecks but at varying degrees. Building on this study, Reiter and Stehrer (2021) constructed a product riskiness index that uses five components: (i) outdegree centrality[5], (ii) the tendency to cluster, (iii) international substitutability, (iv) the Hirschmann-Herfindahl index (HHI), and (v) nontariff measures. This approach resulted in 435 of 4,706 products being identified as risky, representing around 26% of world import values.

Attempts to identify potential bottleneck products have also been conducted at the regional and economy levels. In 2021, for example, the European Commission classified 137 of 5,000 products as being risky for the EU based on concentration, importance of extra EU imports in total EU imports, and substitutability of extra EU imports with EU production (European Commission 2021). Jiang (2021) constructed a measure of dependency from four indicators covering import diversification, import substitutability (internal and external), and end-use category. The methodology was applied to Canada's 2019 import data and resulted in 500 of 5,331 products being classified as vulnerable. Bonneau and Nakaa (2020), on the other hand, assessed France's vulnerability to products from non-European economies, which was measured by the degree of concentration of non-EU-27 supplier economies in imports and the number of suppliers of the product. Of the 5,000 products that were analyzed, 121 were identified as vulnerable.

A new framework proposed by Majune and Stolzenburg (2022) to identify potential bottleneck products across the world will now be discussed in detail. This will help demonstrate the general idea behind analyses that belong to this body of literature and highlight that concentration is a relevant concern in global trade. Doing so helps form a better appreciation of these approaches in widening the understanding of risks and vulnerabilities present within international trade and GVCs. Potential bottlenecks, together with their respective operationalization, have been identified based on the criteria shown in Table 1.1.

To classify a product category as a potential bottleneck, the following rules are made under each criterion in Table 1.1:

(i) The HHI is at least 0.25. This follows the US Department of Justice and the Federal Trade Commission's definition for concentrated industries (US DoJ and US FTC 2010).

5 In network analysis, outdegree centrality refers to the number of outgoing connections a node has in a directed network. This number is often normalized by dividing it by the total number of possible outgoing connections this node can have.

(ii) The annual export value exceeded $30 million in 2000, inflated by annual global trade growth for the following years. This is based on export values of a selected list of products where concentration has led to disruptions in the past.

(iii) The elasticity of substitution (EoS) score is greater[6] than the average EoS for a given year indicating limited substitutability.

Table 1.1: Criteria for Classifying Product Categories as Potential Bottlenecks

Criterion	Definition	Metric/s
Market concentration	Refers to the number of suppliers of and their respective shares in total exports of a given product category.	Hirschmann-Herfindahl index (HHI)
Market relevance	Refers to the importance of a product category in global trade based on export value and the number of importers.	Annual export value
Market substitutability	Refers to the degree of substituting a product category for another	Product-level elasticity of substitution (EoS) scores from Fontagné, Guimbard, and Orefice (2022a; 2022b)

Source: S. Majune and V. Stolzenburg. 2022. Mapping Potential Bottleneck Products in the World. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

As significant estimates of EoS scores are not available for all products, results that include and exclude the third criterion are provided, which exhibit consistency. Therefore, the following section focuses only on the results that exclude the EoS.

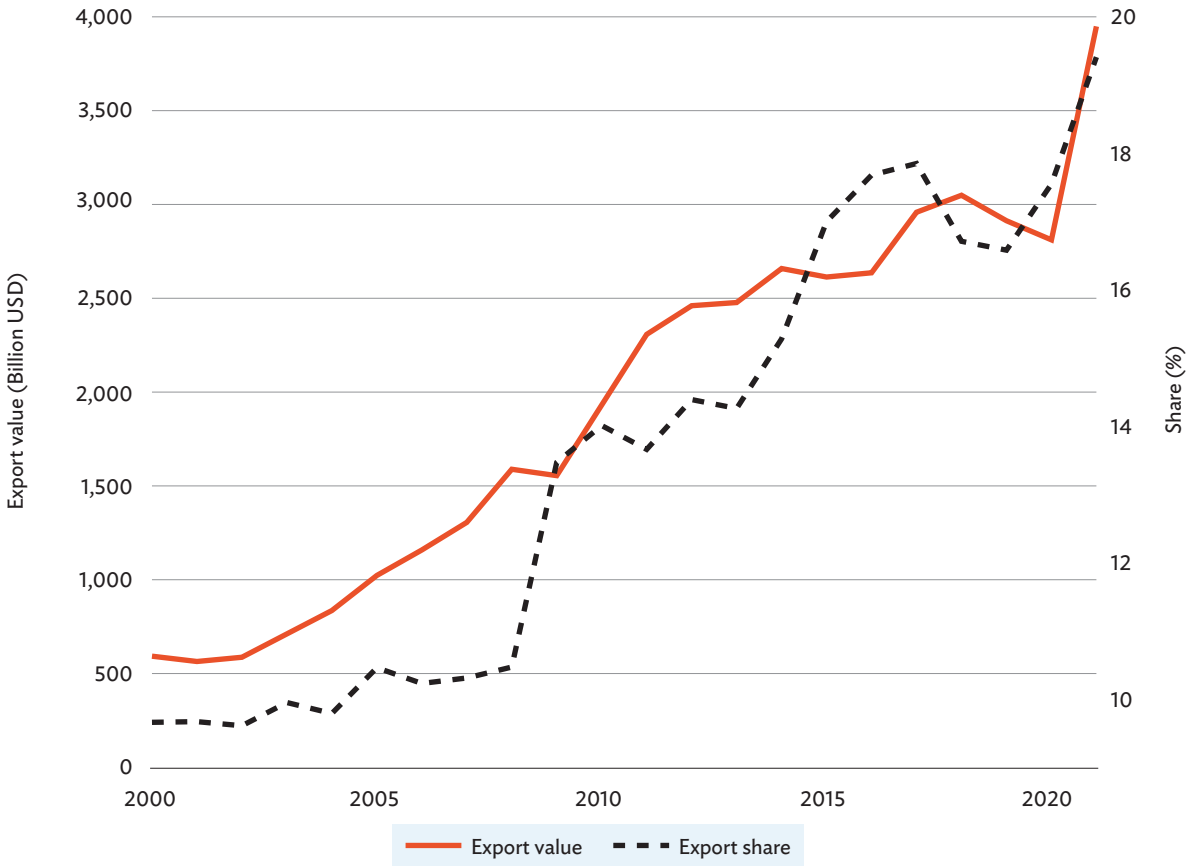
Applying their methodology to annual economy-product-destination data from the United Nations Comtrade Database[7] for the period 2000–2021, Majune and Stolzenburg (2022) describe potential bottlenecks in terms of trade flows, dynamics, and usage. A total of 1,075 (about 20%) of the 5,384 analyzed products were identified as potential bottlenecks in 2021, up from 778 in 2000. Their annual aggregate export value increased over the same period from just below $600 billion to about $4 trillion. This means that the share of global trade covered by potential bottlenecks more than doubled from 9.66% in 2000 to 19.41% in 2021 (Figure 1.8). While the share was relatively steady at around 9%–10% before the GFC, concentration has increased steadily since, with only a short disruption before the COVID-19 crisis.

Assessing individual geographic regions, potential bottleneck products are found mostly to be exported by East Asia and the Pacific, with their combined share of the global export value in these products increasing from just over 33% in 2000 to almost 66% in 2021. This is followed by Europe and Central Asia, North America, and Latin America and the Caribbean. Among these top regions, the role of Europe and Central Asia and of North America has steadily decreased to the benefit of East Asia and the Pacific.

6 EoS values are negative.

7 Products are at the 6-digit level classification of the Harmonized System (HS) and concorded to the 2017 HS revision.

Figure 1.8: Export Value and Share of Potential Bottlenecks in the World, 2000–2021



Sources: United Nations Comtrade data, 2000–2021; and World Trade Organization estimates.

Table 1.2 lists the top 10 economies exporting potential bottleneck products for 2000, 2005, 2010, 2015, and 2021. The PRC and the US were clearly the main players in the supply of these commodities across 2000–2021, although the US share gradually diminished (seemingly to the advantage of the PRC). The PRC averaged close to 33% of the global export value of these products for the study period, thereby reinforcing the dominance of that economy in supplying the risky products established in related literature. European economies (i.e., France, Germany, Italy, the Netherlands, and the UK) as well as Canada also played considerable roles. The Republic of Korea emerged as one of the main suppliers of these potential bottleneck products, with consistently rising shares leading to it ranking third among all economies in 2021. Australia's contribution increased along similar lines. Around 70% of the global export value of these commodities was generated by the top 10 suppliers over the 21-year period.

In terms of industries, electrical equipment accounted for by far the highest proportion of the export value of potential bottlenecks: the sector's share more than doubled from 20% in 2000 to 47% in 2021. This was driven mostly by demand for mobile phones and semiconductors. The second-most dominant sector was fuels, which accounted for 10% of export value in 2021. When looking at industry shares by the number of products,

Table 1.2: Top Exporters of Potential Bottleneck Products, 2000–2021
(%)

2000		2005		2010		2015		2021	
Economy	Share	Economy	Share	Economy	Share	Economy	Share	Economy	Share
PRC	19.1	PRC	32.2	PRC	35.7	PRC	39.5	PRC	36.3
US	18.4	US	10.0	US	8.5	US	8.3	US	6.4
Japan	9.4	Japan	7.2	Germany	4.4	Germany	4.3	Rep. of Korea	5.0
France	6.2	Germany	5.2	Japan	4.3	Rep. of Korea	4.0	Australia	4.2
Canada	5.2	France	4.9	France	3.6	France	3.2	Viet Nam	4.2
Germany	5.1	Netherlands	3.0	Brazil	3.6	Australia	3.2	Germany	3.4
Italy	3.4	Malaysia	2.8	Australia	3.0	Japan	3.0	Brazil	3.3
UK	3.3	Italy	2.6	Rep. of Korea	2.7	Viet Nam	2.8	Japan	2.7
Netherlands	2.2	Ireland	2.4	Netherlands	2.2	Brazil	2.2	Indonesia	2.4
Malaysia	1.6	UK	2.3	Malaysia	1.9	Netherlands	2.0	France	2.2
Total	74.0		72.5		69.8		72.5		70.2

PRC = People's Republic of China, Rep. = Republic, UK = United Kingdom, US = United States.
Sources: United Nations Comtrade data, 2000–2021; and World Trade Organization estimates.

rather than by trade value, particular sectors feature prominently. These include textiles, chemicals (particularly lithium and nickel), and vegetables (particularly cereals). This corresponds to discussions surrounding the Russian war in Ukraine and the ongoing transition to a green economy globally.

To determine the usage rates of potential bottleneck products by industry, Majune and Stolzenburg (2022) concord the 2017 version of the Harmonized System (HS) classification to the 2012 input-output table from the US Bureau of Economic Analysis, allowing industries that are most dependent on inputs classified as potential bottlenecks to be identified. The results show that most heavily exposed industries are in the food and beverage sector. Hence, efforts to deconcentrate trade flows involving risky products could have significant contributions to achieving food security, as also highlighted by impacts of the Russian war in Ukraine.

1.5 Geographic Concentration in Value and Frequency of Trade

In the context of GVCs, a supply chain faces a considerable amount of risk if a significant volume of value-added in the goods and services it produces comes from or passes through only a few areas, with no clear viable alternatives.

Concentration in Foreign Value-Added Sources

As shown earlier in this chapter, gross exports can be decomposed into a set of value-added terms. One of these components, foreign value-added (FVA), measures the

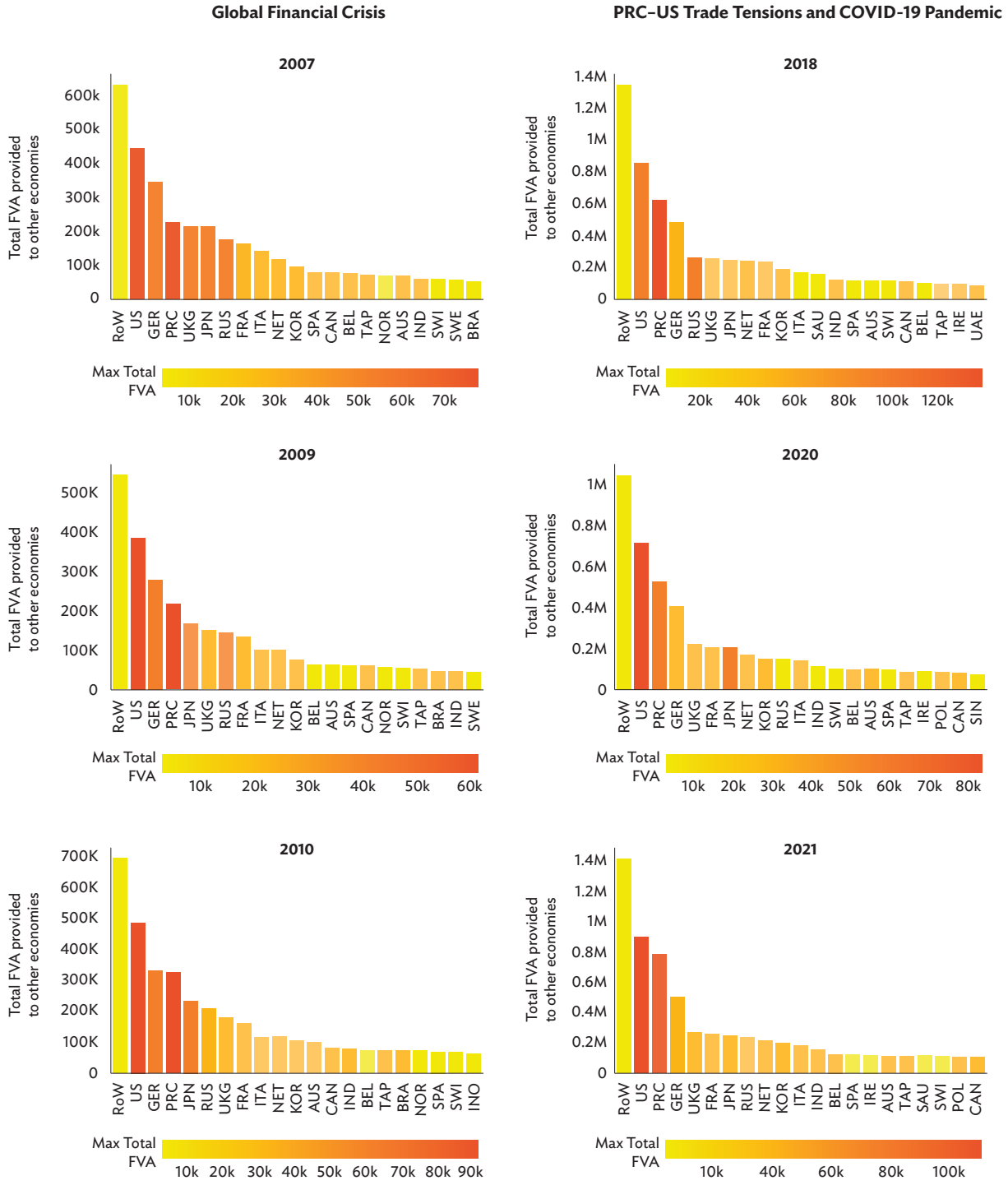
amount of value-added embodied in an economy's (or an economy-sector's) exports that comes from its trading partners. For example, if economy A exports 100 monetary units to the world and 25% is comprised of FVA, then 25 monetary units worth of value-added do not originate domestically and therefore come from other economies. Using Borin and Mancini's (2019) framework, it is possible to disaggregate FVA into the source economies such that, following the example above, the 25 monetary units of FVA can be traced to the economies where they originated: say, 15 from economy B, 7 from economy C, and 3 from economy D. It then follows that a similar activity can be undertaken for economies B, C, and D, and that total FVA sourced from each can be derived.

Using this algorithm and ADB's multiregional input-output tables (MRIOTs) as the data source, FVA of an economy (say i) is first decomposed into its sources at the economy-sector level. The resulting matrix is then summed across all economies $j \neq i$ to get the total amount of FVA sourced from each of them in the production of economy i's exports. This is iterated for each economy in the MRIOTs, which totaled 63 for 2000–2017 and 73 for 2017–2022. The resulting aggregated matrices are joined and are further summed across all economies to derive the total amount of FVA that each economy provides to its global exports. This metric provides a good indication of backward dependence on an economy in GVC trade. If all players in international trade are playing equal roles as suppliers of value-added, some uniformity across economies should be observed. If not, and there is a skew toward a few economies, then there is evidence of concentration.

Figure 1.9 shows the results of the algorithm for two periods: (i) 2007–2010, i.e., the onset of the GFC (2007) and the two years (2009 and 2010) that immediately followed the peak of trade disruptions in 2008; and (ii) 2018–2021, i.e., the beginning of PRC–US trade tensions (2018), the overlap with the COVID-19 pandemic (2020), and the year immediately following the climax of disturbances in trade (2021). In the figure, the color scale indicates the highest value of FVA provided by one economy to another, with warmer colors corresponding to higher figures. For example, in 2007, the highest value-added supplied by the US to another economy was almost $78.5 billion.

In 2007, the top 20 sources of FVA contributed 81% of total world FVA, which means there was considerable concentration in backward dependence before the GFC hit. The US and Germany were the top providers of FVA for this year, with FVA from the US equaling almost 75% of that from all economies outside the top 20. Similarly, FVA from Germany was more than 50% of the value from the Rest of the World. In the following years, about the same level of concentration was still present, with the top 20 providers accounting for 80.87% of total world FVA in 2009 and 81.26% in 2010.

Figure 1.9: Backward Dependence on Value-Added, Top 20 Economies and Rest of the World
($ million)



$ = United States dollars; AUS = Australia; BEL = Belgium; BRA = Brazil; CAN = Canada; FRA = France; FVA = foreign value-added; GER = Germany; IND = India; INO = Indonesia; IRE = Ireland; ITA = Italy; JPN = Japan; k = 1,000; KOR = Republic of Korea; M = million; NET = Netherlands; NOR = Norway; POL = Poland; PRC = People's Republic of China; RoW = All other economies outside the top 20; RUS = Russia; SAU = Saudi Arabia; SIN = Singapore; SPA = Spain; SWE = Sweden; SWI = Switzerland; TAP = Taipei,China; UKG = United Kingdom; US = United States.

Notes: The vertical axis corresponds to the total FVA ($ million) provided by an economy in the production of all other economies' gross exports. Bar colors represent the maximum amount of FVA that an economy provides to a single economy to produce its exports.

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

By 2018, the PRC had overtaken Germany in the rankings, becoming the economy that supplied the second-most FVA to the world. With this change, not only did the two economies that had engaged in extensive trade restrictions now hold the two most significant positions in enabling GVC trade, but there was also a concentrated dependence on them by all others. It is therefore not surprising that GVCs were negatively affected by the disturbances resulting from these trade tensions.

The concentration of FVA was still apparent during the onset of the COVID-19 pandemic in 2020 and in 2021, when a considerable recovery in the value of gross exports was observed. During this period, the top 20 sources of FVA comprised around 78% of total world FVA.

It is worth noting that the list of economies appearing atop the rankings during both 2007–2010 and 2018–2021 remained relatively static. Overall, these findings indicate that the underlying structure of backward dependence in GVCs, characterized by concentration towards a few economies, was preserved despite the disruptions caused by the GFC, the PRC–US trade tensions, and the COVID-19 pandemic.

Concentration in Frequency of Engagement

The analysis of backward dependence has so far delved only into the volume dimension of concentration. There is also, however, a dimension of risk that stems from the frequency of engagement of one economy with another (Inomata and Hanaka 2023). To illustrate the concept, if an individual infected with COVID-19 interacts with a second person several times during a day, even for only short intervals, the second person may be as exposed to the risk of infection as anyone who interacts with the infected individual for longer periods. In global supply chains, even if a certain economy is not a major supplier of inputs to other economies in the production of their respective exports, it may still be possible for the supplier economy to be frequently engaged with production processes. This may include being a major entrepôt in certain trade routes and/or providing incremental inputs to different stages of a production process. These engagements, particularly when concentrated, increase the probability of being involved in unforeseen circumstances, such as natural, economic, or political shocks, and must therefore be considered in the holistic assessment of trade risk.

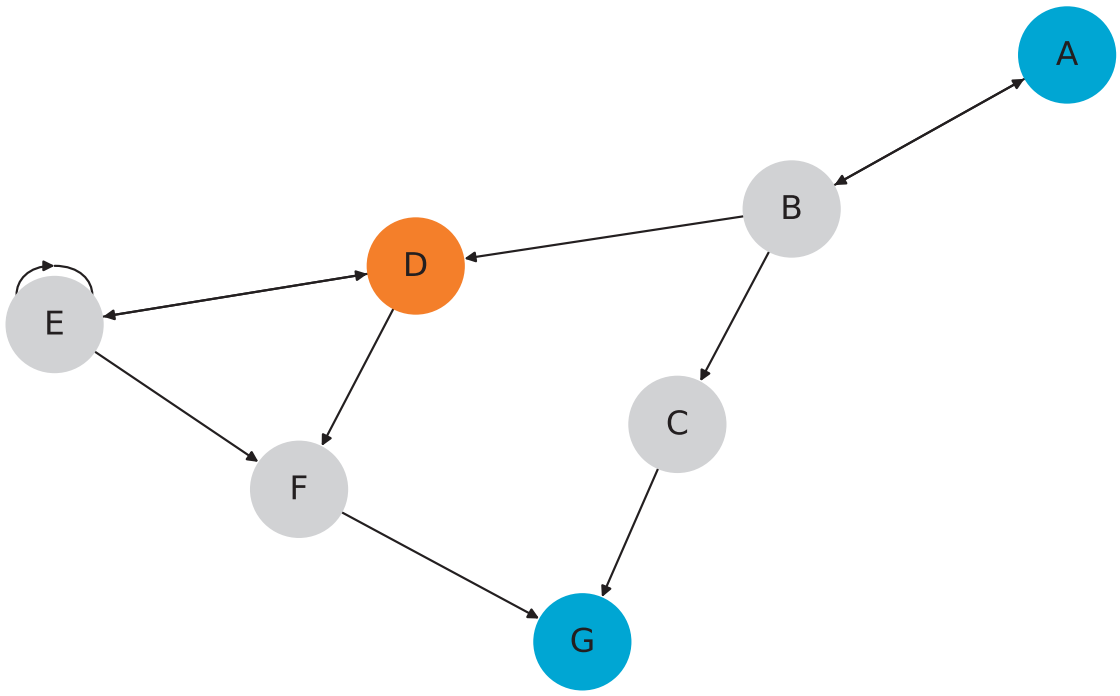
To further demonstrate the idea of frequency, consider the schematic example in Figure 1.10. Here, a supply chain can connect economy A with economy G via five different production paths that pass through economy D (which happens to be the risk economy in this example). Supply can also travel both ways through economy E. The five relevant production paths are therefore:

(i) A → B → D → E → E → F → G
(ii) A → B → D → E → F → G

(iii) A → B → D → E → D → F → G
(iv) A → B → D → E → E → D → F → G
(v) A → B → D → F → G

Note that economy A and economy G can alternatively be connected via economy B and economy C.

Figure 1.10: Trade in a Directed and Unweighted Network



Source: Conceived by the authors of the Asian Development Bank's Global Value Chain Development Report 2023.

Paths (iii) and (iv) pass through economy D twice, while the rest only do so once. If a crisis occurs in economy D, which may render trade that passes through it unsuccessful within a given probability, then it may be less risky to go through paths (i), (ii), and/or (v).

Real–world supply chains are, however, significantly more detailed and complex than the network shown in Figure 1.10, and it is virtually impossible to repeat the same simple exercise using actual trade patterns and relationships. Thus, a manageable way to measure more complex relationships—one that takes into consideration the direction and weights of trade links—is needed.

Liang, Qu, and Xu (2016) used the concept of "betweenness" in conjunction with key sector analysis to measure the importance of intermediate sectors (referred to as transmission sectors) in mitigating the environmental pressure brought about by supply chains. In network theory, any given network is comprised of nodes (vertices) that are connected by links (edges). Expanding on the earlier example, take the

monitoring of coronavirus case transmission, which became especially prominent during the COVID-19 pandemic. Under this example, the nodes would be represented by individuals: those with confirmed infections; the people they interacted with; the family, friends, and work colleagues of those direct contacts; and so on. These relationships or interactions are then represented by the edges, establishing the links between the individuals that form the network.

In network analysis, the betweenness (or betweenness centrality) of a node refers to the extent to which it lies on the shortest path between other nodes, thereby indicating how it brokers or controls the flow of transactions among other nodes in the network (McCulloh, Armstrong, and Johnson 2013). In an unweighted and undirected network, the betweenness of any given node is derived by obtaining the ratio of the number of binary shortest paths between two nodes that pass-through the nominated node to the number of binary shortest paths between two nodes. The shortest path in this context refers to the path that has the least number of steps from one node to another. In Figure 1.10, for example, the shortest path between economy A and economy G is A → B → C → G.

Once directionality is introduced into a network, a slight modification to betweenness must be made since a node that lies on the shortest path from Node A to Node B does not necessarily mean that it lies on the shortest path going the other way from Node B to Node A. Thus, the normalization process is altered to account for the distinction between paths from one node to another, and vice versa.[8] When weights are introduced to a network, shortest path-based measures of centrality (e.g., betweenness and closeness) become more challenging to interpret, since the edges may indicate strength of a connection that could facilitate transmission of information and make transactions more efficient (Opsahl, Agneessens, and Skvoretz 2010). Therefore, these measures are adjusted to account for edge weights by using algorithms. For instance, the algorithms of Djikstra (1959) treat weights as costs of transmission, those of Newman (2001) and Brandes (2001) take the inverse of tie weights, and those of Opsahl integrate the number of intermediary nodes and inverse tie weights.

In an economy comprised of multiple sectors that interact with each other to produce their respective goods and services, network analysis offers promising applications. Liang, Qu, and Xu (2016) took advantage of this idea, but they had to consider self-flows, directionality, and weights. Given this, the authors resorted to structural path analysis to devise a structural path betweenness metric that measures a given sector's role and/or impact in transmitting environmental pressures within a supply chain. With a slight modification to the formula, this betweenness-based metric can be transformed into an indicator that tracks how many times a given supply chain passes through a sector of concern or, in the context of MRIOTs, an economy-sector of interest (Box 1.2).

---

8 In undirected and unweighted networks, a link from Node A to Node B is equivalent to the link from Node B to Node A. The link simply indicates that there's a connection between the two nodes, disregarding origin and extent of the interaction. The adjacency matrix for this type of network is thus binary and symmetric.

Box 1.2: Deriving the Number of Times a Supply Chain Passes Through a Sector

Liang, Qu, and Xu begin their 2016 study with a presentation of the backward propagation of a final demand impact that starts from sector s, passes through r sectors $(k_1, k_2, \dots, k_r)$, and ends at sector t. This is given by:

$$a_{sk_1} a_{k_1k_2} a_{k_2k_3} \dots a_{k_rt} y_t$$

Here, sector t faces a final demand of y_t, thus requiring inputs from other sectors along the production chain, all of which may or may not rely on other sectors themselves. $a_{sk_1} a_{k_1k_2} a_{k_2k_3} \dots a_{k_rt}$ are technical coefficients from **A**. Following Inomata and Hanaka (2023), the notation can be configured by (i) setting sector q as the target and assuming that it is one of the intermediate sectors along the production path above, and (ii) denoting upstream sectors relative to t as $u_1, u_2, \dots, u_m$ and downstream sectors relative to t as $d_1, d_2, \dots, d_n$, giving:

$$a_{u_1u_2} a_{u_2u_3} \dots a_{u_{l-1}u_l} a_{u_lt} a_{td_1} a_{d_1d_2} \dots a_{d_{m-1}d_m} y_{d_m}$$

The right half of this term (in blue) is the impact propagation from sector d_m to sector t, which may have different configurations, depending on the choice of $d_1, d_2, \dots, d_{m-1}$. Thus, the total impact of all such paths is given by:

$$\sum\nolimits_{d_1,\dots,d_{m-1}} a_{td_1} a_{d_1d_2} \dots a_{d_{m-1}d_m} y_{d_m}$$

Further, the left half of the term (in orange) is the higher–order backward propagation from sector t to sector u_1. Similarly, it may also have different combinations of sectors involved. Thus, the total impact for all such paths is derived by summing the term for all choices of $u_2, \dots, u_l$. Therefore, the total impact delivered along all the paths that run through the production sequence from sector d_m to sector u_1 via sector t is given by:

$$\left(\sum\nolimits_{u_2,\dots,u_l} a_{u_1u_2} a_{u_2u_3} \dots a_{u_{l-1}u_l} a_{u_lt}\right)\left(\sum\nolimits_{d_1,\dots,d_{m-1}} a_{td_1} a_{d_1d_2} \dots a_{d_{m-1}d_m} y_{d_m}\right)$$

This can be expressed in matrix notation as:

$$[\boldsymbol{A}^l]_{u_1t}\, [\boldsymbol{A}^m]_{td_m} y_{d_m}$$

where $[\boldsymbol{A}^h]_{ij}$ refers to the i–jth element of the hth power of the matrix **A**, indicating the total amount of impacts from sector j to i across all paths with a length of h. As upstream and downstream paths may take on any length, getting the entire set of impact propagations for all paths that cross sector t must consider every possible combination of these lengths. This is given by:

$$\sum\nolimits_{l=1}^{\infty} \sum\nolimits_{m=1}^{\infty} (\boldsymbol{A}^l \boldsymbol{J}_{(t)} \boldsymbol{A}^m \hat{\boldsymbol{y}}) = \boldsymbol{T} \boldsymbol{J}_{(t)} \boldsymbol{T} \hat{\boldsymbol{y}}$$

where $\boldsymbol{T} = \boldsymbol{LA}$, L is the Leontief inverse matrix, $\boldsymbol{J}_{(t)}$ is an n x n matrix containing 1 for the t-tth element and 0 elsewhere, and $\hat{\boldsymbol{y}}$ is a diagonalized version of the final demand vector. With some slight modifications, the term above can be reconfigured to represent the number of times a particular supply chain passes through and/or engages a target sector in the production of goods and services.

References

S. Liang, S. Qu, and M. Xu. 2016. Betweenness-Based Method to Identify Critical Transmission Sectors for Supply Chain Environmental Pressure Mitigation. *Environmental Science & Technology*. 50. pp. 1330–1337.

S. Inomata and T. Hanaka. 2023. Measuring Exposure to Network Concentration Risk in Global Supply Chains: Volume versus Frequency. *Structural Change and Economic Dynamics*. Elsevier.

The methodology is applied to the MRIOTs by setting each economy-sector as the target. In a given run, a matrix containing the pass-through indices of each economy-sector towards a selected area of concern is generated. This is then aggregated to an economy-level matrix by (i) adding all pass-through matrices generated for an economy[9], and (ii) reducing the dimension to economy-by-economy. Thus, the resulting

[9] There are 35 matrices for a given economy, corresponding to the number of sectors in the MRIOTs.

matrix now has elements that represent the number of times economies engage with each other in the production of final goods and services. Engagements of an economy with itself are zeroed out for this analysis, since it is outside the scope of interest. Figure 1.11 displays the results of these runs for the same periods as covered in Figure 1.9.

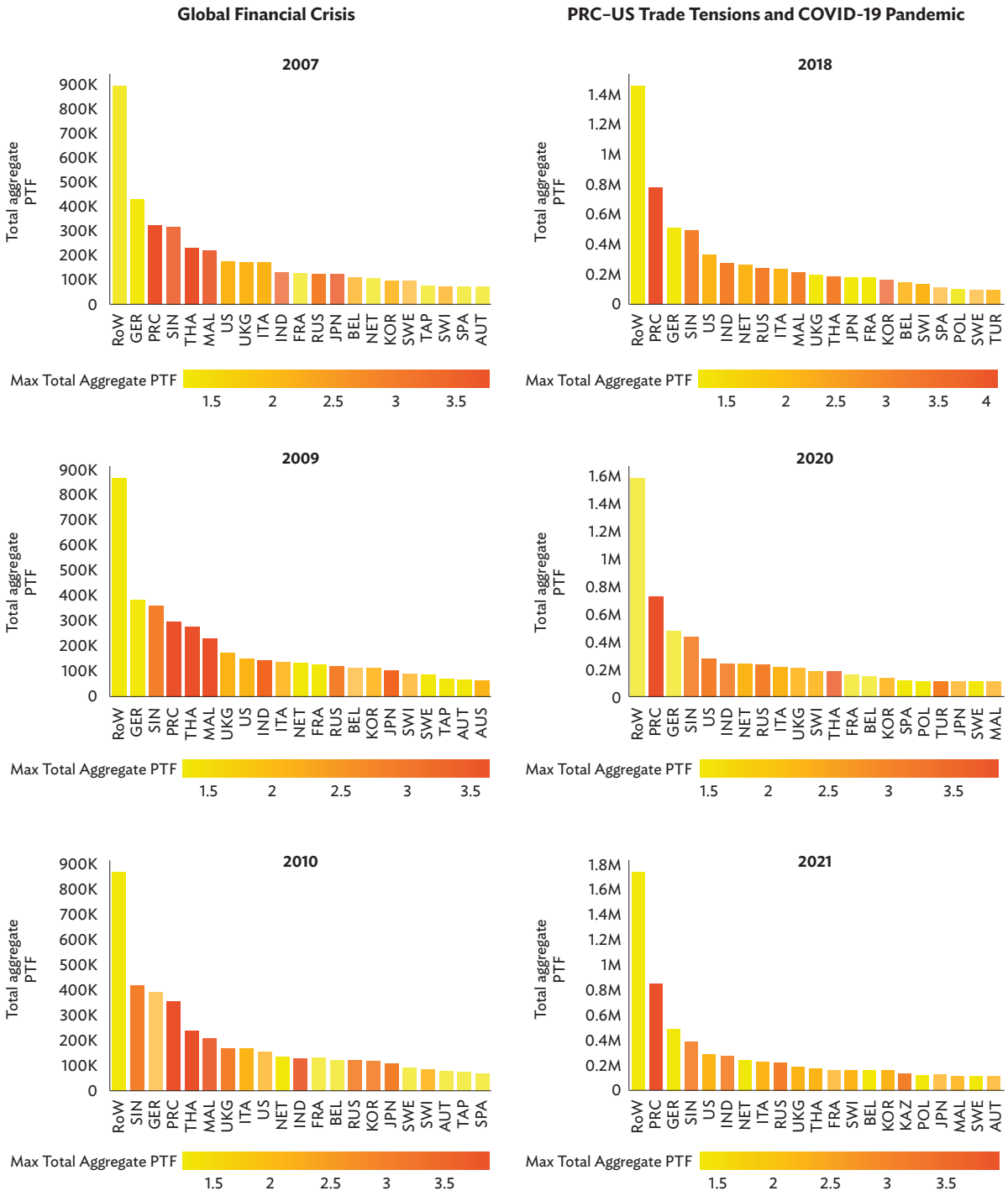
In 2007, the top three economies in terms of pass-through frequencies were Germany, the PRC, and Singapore. Although Singapore held a less prominent role in the provision of FVA to the world, its free trade zones are known to facilitate entrepôt trade as well as transhipment activities, which connect various parts of the world trade-wise. Due to the high volume of goods being re-exported in its ports, little value-added is added to trade despite the high instances of pass-throughs. In fact, Singapore eventually reached the very top of the rankings for pass-through frequencies in 2010. By contrast, the US did not rank as high as it did in terms of backward dependence, which may be due to the fact that the economy outsources some of its production processes to elsewhere in the world. Thus, a significant proportion of the US's value-added contributions to other economies' exports may not even pass through it at all. The top 20 economies accounted for 78.35% of the total pass-throughs worldwide, signalling concentration in the frequency of engagement even before the GFC reached its peak. These shares increased further to 78.94% and 79.46% in 2009 and 2010, respectively.

Before the peak of the PRC–US trade tensions, the PRC overtook Singapore and Germany to assume the world's top ranking in terms of pass-through frequency. It maintained this position even during the onset of the COVID-19 pandemic in 2020 and the initial period of recovery in 2021. Although concentration was still evident for 2018–2021, the shares of the top 20 economies were less than during the GFC and even decreased marginally each year. In 2018, 77.07% of total pass-throughs occurred in the top 20 economies. This concentration had decreased by around 3 percentage points by 2020, and it fell by another 0.83 percentage points in 2021. These falls may very well have been due to restrictions in trade and the pressures faced by the logistics sector at the height of the pandemic.

1.6 Adjusting to Shocks

As demonstrated earlier in this chapter, years of notable export decline—which typically occur shortly after the onset of a global economic crisis—are associated with an increase in the share of traditional trade and a decline in GVC trade. Concentration in value-added dependency and frequency of engagements may play an important role in this as they limit the number of viable alternatives in the short run. With a more evenly distributed set of roles in a supply chain, instances of bottlenecks occurring in an economy (or a group of economies) may be mitigated by passing on—at least in the interim—the responsibility of provisioning production inputs to other players in the network. However, when only a few players perform key roles, such as supplying value-

Figure 1.11: Pass-Through Indices, Top 20 Economies and Rest of the World



$ = United States dollars; AUS = Australia; AUT = Austria; BEL = Belgium; FRA = France; GER = Germany; IND = India; ITA = Italy; JPN = Japan; KAZ = Kazakhstan; k = 1,000; KOR = Republic of Korea; M = million; MAL = Malaysia; NET = Netherlands; POL = Poland; PRC = People's Republic of China; PTF = pass-through frequencies; RoW = All other economies outside the top 20; RUS = Russia; SIN = Singapore; SPA = Spain; SWE = Sweden; SWI = Switzerland; TAP = Taipei,China; THA = Thailand; TUR = Türkiye; UKG = United Kingdom; US = United States.

Notes: The vertical axis corresponds to the number of times economies pass through a particular economy, excluding itself. For a particular economy, the color of the bar represents the maximum number of times another economy passes through it.

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

added to exports, the system becomes prone to short-circuiting[10] that could result in drops in GVC participation during periods of crisis.

The observed decline in GVC trade that took place during the GFC, the PRC–US trade tensions, and the COVID-19 pandemic may also be indicative of ensuing reconfiguration strategies implemented by governments and/or firms to lessen the reliance on cross–border trade of intermediates. Such initiatives or dialogues gather momentum during periods of extensive shocks, as GVCs—with their overly complex networks of production that both transmit and mitigate risk—come under greater scrutiny. It is important to note that, after the three crises mentioned above, recovery in terms of the value of gross exports and the return to usual structures of trade occurred quite quickly relative to the onset of the crises. Reconfiguration strategies could have very well played a large part in this.

Prospects for Global Value Chain Reconfiguration

International production is expected to undergo dramatic transformation in the near future. It will be enabled by technological change, driven by the evolving economics that those technologies will imply, and shaped by the interaction between policy and sustainability trends. These developments are expected to trigger a reconfiguration of the prevailing structure of GVCs. While transformation could take many directions, four likely trajectories arise in the academic literature: replication, diversification, regionalization, and reshoring (UNCTAD 2020). Overall, the direction taken by individual industries will depend on the starting point of their archetypical international production configurations.

Replication is characterized by centrally coordinated "distributed manufacturing", with production steps bundled together and replicated in many locations, thereby implying shorter value chains. Automation makes it possible to reproduce the same production processes in many locations, with minimal labor absorption and marginal costs, while digitalization is enabled by efficient central coordination of the network. Distributed manufacturing is generally associated with the application of additive manufacturing or 3D printing, a technology that combines automation and digitalization.

It should be noted that the replication trajectory is not applicable across all industries. UNCTAD (2020) observed that, among the four trajectories of international production, replication is least likely to lend itself to broad application across industries. In addition to constraints to applications of 3D printing in relation to raw materials, this trajectory

10 Several circumstances may lead to this. In one of these, assume that there are nodes in the supply network that play a limited role in the provisioning of inputs and that dependence on a few nodes is present. If, for some reason, the minor nodes are unable to perform this task, the responsibility to provide their inputs may have no other alternative except for the nodes for which dependence is concentrated. If this happens, overloading may occur in these dominant nodes, which may negatively affect their efficiency. Furthermore, if the dominant nodes are the ones that lose their ability to supply inputs, then it is unrealistic to pass their responsibilities to those nodes that are used to playing only limited roles, thereby impeding the functioning of the network.

demands very specific business conditions. Overall, replication is expected to result in lower foreign direct investment; lower GVC trade; and increased trade in services, intangibles, data flows, and payments of royalties and licensing fees.

Diversification leverages GVCs (rather than dismantling them) to build resilience. This trajectory represents the main alternative to reshoring. Given that the concentration of production and supply chain dependence are central issues to the discussion on resilience, companies and economies may find diversifying internationally more effective than reshoring. This might imply giving up some economies of scale by involving more locations and suppliers in the value chain.

Resilience to shocks may be gained by diversifying inputs across economies and by making inputs from different economies more substitutable. Diversification substantially reduces global GDP losses in response to shocks in key upstream suppliers. It also reduces GDP volatility following productivity shocks to multiple economies that are interrelated. Thus, it is important to find avenues to expand trade opportunities, which can boost resilience in the world economy in the face of a variety of shocks. To further build resilience in GVCs, economies could diversify their suppliers of intermediate inputs internationally, sourcing them in more equal amounts across economies. Diversification could enhance resilience by reducing reliance on a single economy or by establishing relationships that can be tapped during a crisis (IMF 2021).

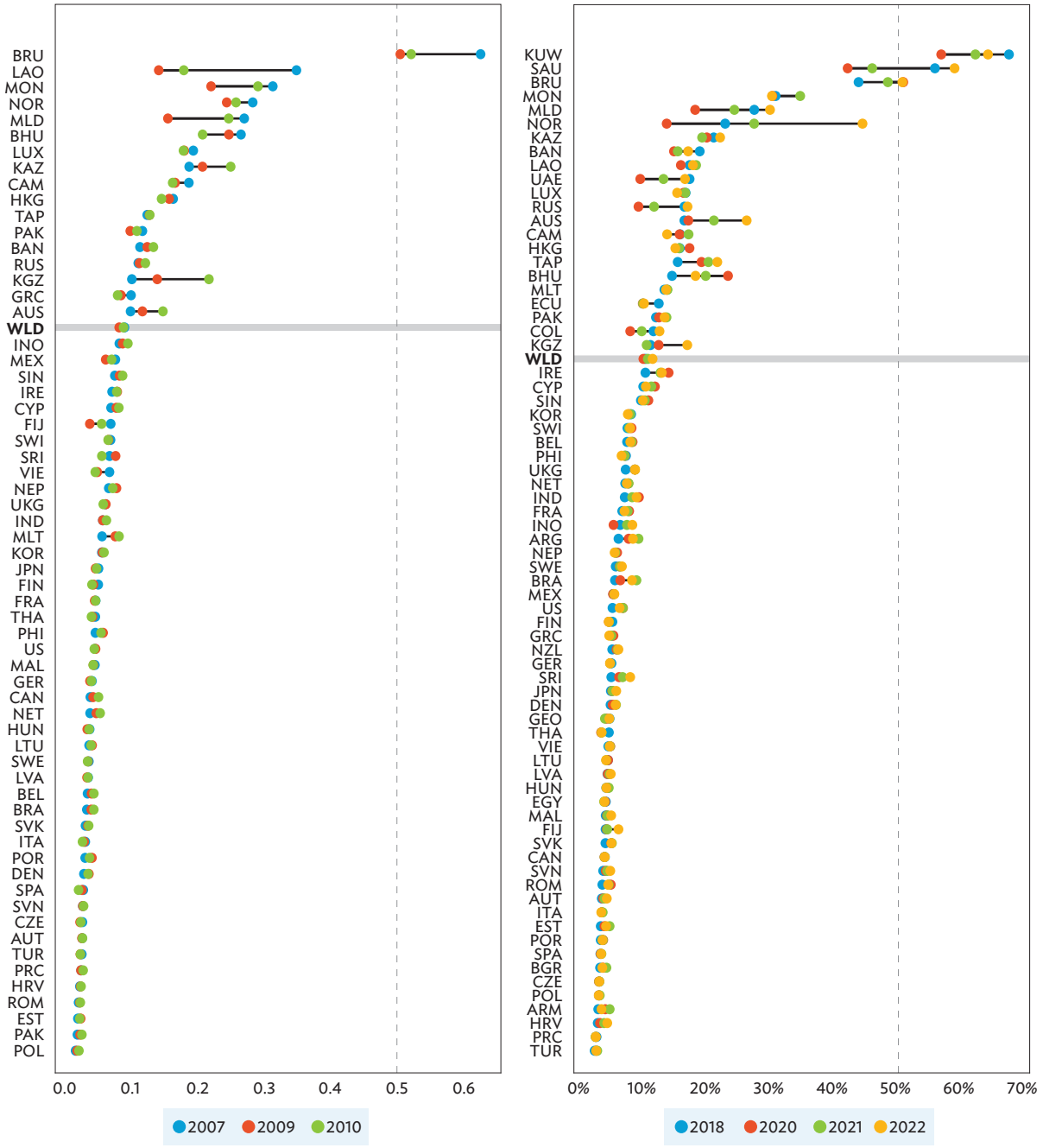
To examine the extent of diversification worldwide, Herfindhal-Hirschman Indexes (HHIs) were derived for each economy using this formula:

$$HHI = \sum_{n=1}^{E} \frac{(S_i^r)^2 - 1/N}{1 - 1/N}$$

where S_i^r is the share of value-added exports of economy r, sector i, and N is the total number of sectors in economy r. HHI is a measure of concentration of a given economy, as higher values correspond to an economy relying heavily on a few sectors for value-added exports. On the other hand, lower values of HHI indicate reliance on more sectors for value-added exports. In line with this, economies are considered more diversified if their HHIs are low, vice versa.

Apart from Brunei Darussalam, all economies had low (i.e., less than 0.5) HHIs at the start of the GFC in 2007. By 2009, world averages showed less concentration compared to 2007 before marginally increasing in 2010. This provides evidence that suggests diversification being practiced by economies worldwide prior to, during, and after the GFC. Looking at 2018, almost all economies still exhibited export diversification, with Brunei Darussalam's concerted efforts to achieve diversification appearing to have paid off. Interestingly, world averages show increasing HHI a year into the COVID-19 pandemic while economy-level measures reveal a trend towards lower diversification in 2022.

Figure 1.12: Herfindahl-Hirschman Indexes of Economies, 2007–2010 and 2018–2022



HHI = Herfindahl-Hirschman Index

Notes: HHI is a measure of an economy's export concentration. Thus, higher values of HHI correspond to lower levels of diversification. The HHI indices shown in the figure are computed using value-added exports, which allows contributions of other sectors in exports that may not be captured by traditional measures to be included.

Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

Regionalization implies a geographic reconfiguration of GVCs to shorten the value chains present in the macro-regions, thus giving birth to regional value chains or RVCs (Elia et al. 2021). RVCs apply the standard model of fragmented and vertically specialized value chains at the regional or local level. This can be the result of either a

retreat from GVCs, with multinational enterprises (MNEs) replicating value chains at the regional level, or the growth of international production on a regional basis, with MNEs structuring their operations nearshore. The shift from global to regional value chains brings the extremes of these chains geographically closer. At the same time, the geographical distribution of value-added would tend to increase (UNCTAD 2020).

In principle, GVC-intensive industries can also replicate their models at the regional level. This is already happening to some extent, e.g., in the automotive industry. The growth of a market for inexpensive consumer products (such as electronics or textiles) in developing economies will also push RVCs in these sectors. Barriers to the development of RVCs in GVC-intensive industries include the persistence of economies of scale and high capital costs of machinery as well as labor-cost differentials and the need for specialized labor or suppliers. Moreover, RVCs are not easy to establish. For a region to attract or develop an entire value chain is more difficult than for an economy to attract investment in a production task or industry segment where it has a competitive advantage. RVCs require regional coordination and conducive business systems and conditions. While the political momentum for a shift to regionalism is growing, implementation is not expected to be immediate.

Reshoring implies the relocation of production activities back to the home economy (Fratocchi et al. 2014). In this trajectory, the most defining elements of modern GVCs—the fragmentation of tasks (unbundling) and geographic dispersion (offshoring)—are challenged. The direction is towards a simplification of the production process and the use of onshore or nearshore operations. Lower fragmentation and geographic dispersion, as well as more capital-intensive operations, will generally favor a return to more direct control by MNEs of their remaining overseas operations (insourcing). This model thus reverts the historical trends of international production; from unbundling to rebundling, offshoring to reshoring, and outsourcing to insourcing.

Advanced robotics-driven automation plays a key role in reshoring. By reducing the relevance of labor cost arbitrage opportunities, it disarms the most powerful driver of task fragmentation and offshoring to low-cost locations. Automation makes reshoring a sustainable option for many MNEs. In the manufacturing sector, this trajectory is primarily relevant for higher-technology, GVC-intensive industries, including the machinery and equipment, electronics, and automotive sectors (UNCTAD 2020). Reshoring is generally expected to result in lower foreign direct investment, reduced divestment and relocation, and lower GVC trade overall. Furthermore, Elia et al. (2021) note that relocation policies need to be supported by, and combined with, industrial policies that enforce the competitiveness of the production system of the home economy or macro-region. Such policies should aim to boost innovations aimed at improving product value and/or reducing production costs.

One way to examine possible evidence of reshoring[11] is by adopting the concept of agglomeration to global trade. The agglomeration indices developed by Baris et al. (2022) estimate a backward agglomeration index that captures the extent to which different sectors in the economy source value-added from domestic sectors for domestic consumption, along with a forward agglomeration index that measures the extent to which domestic sectors absorb value-added (Box 1.3). Examining trends in the backward agglomeration index reveals insights on reshoring activities as high values imply that more economy-sectors source a larger portion of intermediate inputs domestically.

In 2008, only one instance of a shift to a "reshoring economy" classification was observed (Italy—from a low agglomeration category). In fact, only two economies out of the 60 with data were classified under this category. Also during this year, Brunei Darussalam became a "low agglomeration" economy after being a "reshoring" economy in 2007. By 2009, only Kazakhstan remained in the latter category before being joined by the Russian Federation a year after. Interestingly, these economies are all known for their reliance on the natural resources and mining super-sector (i.e., mining, quarrying, oil and gas extraction) for their exports.

In 2018, only four out of seventy-two economies were part of the "reshoring" category. No instances of shifting categories occurred between 2018 and 2019. By 2020, Ecuador and Türkiye also became "reshoring" economies, joining Australia, Kazakhstan, Russian Federation, and Saudi Arabia. However, both economies no longer belonged in this category in the years that followed. Overall, there is little evidence of reshoring as most economies fell under "low agglomeration" (175 out of 248 possible instances from 2007–2010, 263 out of 360 possible instances from 2018–2022) and "high agglomeration" (47 out of 248 possible instances from 2007–2010, 65 out of 360 possible instances from 2018–2022) in the years studied.

Conducting an assessment of consecutive years from 2019 to 2021, the overlapping period when the combined impacts of PRC–US trade tensions and the COVID-19 pandemic were being felt worldwide, backward and forward agglomeration indices took a downward trend in many economies, providing little evidence of reshoring activities over these 3 years (Figure 1.14).

The decline in both agglomeration indices from 2020 to 2021 is consistent with the increase in GVC participation over the same period, as an overall decrease in the influx of activities to domestic economies generally implies that economies tend to rely more on global production processes. Furthermore, Baris et al. (2022) found that a negative correlation exists between backward and forward agglomeration and GVC participation.[12]

---

[11] Conventional approaches include the use of the Kearney Reshoring Index, which is derived by calculating the year-on-year change in the manufacturing import ratio of the US.

[12] However, Baris et al. (2022) noted that a positive correlation exists between trade-based GVC participation and agglomeration for economies with high backward or forward agglomeration. This suggests that the relationship between agglomeration and GVCs is more complex than initially thought.

Box 1.3: Calculating the Value-Added Agglomeration Index

Agglomeration indices look at how much value-added is sourced from and/or absorbed in domestic economy-sectors, given the production of final goods in other sectors (Baris et al. 2022). Because the approach is based on value-added, it differs from more common approaches based on firm location. To construct, let $\mathbf{v}$ be the vector of value-added coefficients and $\mathbf{y}^d$ be the vector of domestic final goods sales. Moreover, let $\mathbf{A}^d$ be the matrix of domestic technical coefficients and $\mathbf{B}^d \equiv (\mathbf{I} - \mathbf{A}^d)^{-1}$. Then

$$V^D = \hat{\mathbf{v}}\mathbf{B}^d\mathbf{y}^d$$

captures the value-added generated in each economy-sector that ends up as final goods absorbed domestically, while

$$Y^D = \mathbf{v}\mathbf{B}^d\hat{\mathbf{y}}^d$$

measures the final goods of each economy-sector that are absorbed domestically and whose value-added also originated domestically. A hat on top of a vector, as in $\hat{\mathbf{x}}$, denotes its diagonalized version. Let $\mathbf{va}$ be the vector of value-added generated by each economy-sector and $\Phi_{(j,r,t)} = V^D_{(j,r,t)}/Va_{(j,r,t)}$. The forward agglomeration index for economy-sector (j,r) is given by:

$$AGG^F_{(j,r,t)} = \frac{\Phi_{(j,r,t)}}{\sum_{\tau=t-1}^{t}\sum_{r=1}^{G} 0.5\gamma_{(j,r,\tau)}\Phi_{(j,r,\tau)}}.$$

The numerator is the share of value-added generated in (j,r) to the total value-added generated that ends up as final goods absorbed domestically. The denominator is the 2-year moving average of the same share for all economies in the world, weighted by share of economy r to the total global output of sector j, $\gamma_{(j,r,\tau)} \in (0,1)$. Thus, the AGG^F index compares the value-added that is absorbed in domestic production relative to the world average.

Likewise, let $\mathbf{y}$ be the vector of final goods sales by each economy-sector and let $\Theta_{(j,r,t)} = Y^D_{(j,r,t)}/Y_{(j,r,t)}$. The backward agglomeration index for economy-sector (j,r) is given by:

$$AGG^B_{(j,r,t)} = \frac{\Theta_{(j,r,t)}}{\sum_{\tau=t-1}^{t}\sum_{r=1}^{G} 0.5\gamma_{(j,r,\tau)}\Theta_{(j,r,\tau)}}.$$

The numerator is the share of final goods consumed domestically in (j,r) whose value-added comes from the domestic sectors in the total final demand for (j,r). As with the previous index, the denominator is a 2-year moving average of the same share for all economies. Thus AGG^B measures how much value-added for sector originates from domestic sectors relative to the rest of the world. Being ratios, agglomeration in either perspective is said to be high if the index is greater than 1 and the converse is true if it is less than 1. An economy-sector may be profiled by whether it has high or low forward and backward agglomeration. The four possible types are presented in the "agglomeration map" below.

Reshoring economies $AGG^F < 1, AGG^B > 1$	High agglomeration $AGG^F > 1, AGG^B > 1$
Low agglomeration $AGG^F < 1, AGG^B < 1$	DVA-generating economies $AGG^F > 1, AGG^B < 1$

DVA = domestic value-added

A high backward agglomeration signals that domestic value-added embodied in final goods and services consumed domestically is high. Intuitively, this implies that domestic production for domestic consumption is higher than the world average. Meanwhile, a high forward agglomeration indicates that domestic sectors absorb a significant portion of value-added generated by an economy-sector. This means that value-added that goes to domestic production is higher than the world average. The classification presented in the agglomeration map combines these two effects to determine the form of domestic linkages taking place in an economy sector.

Reference

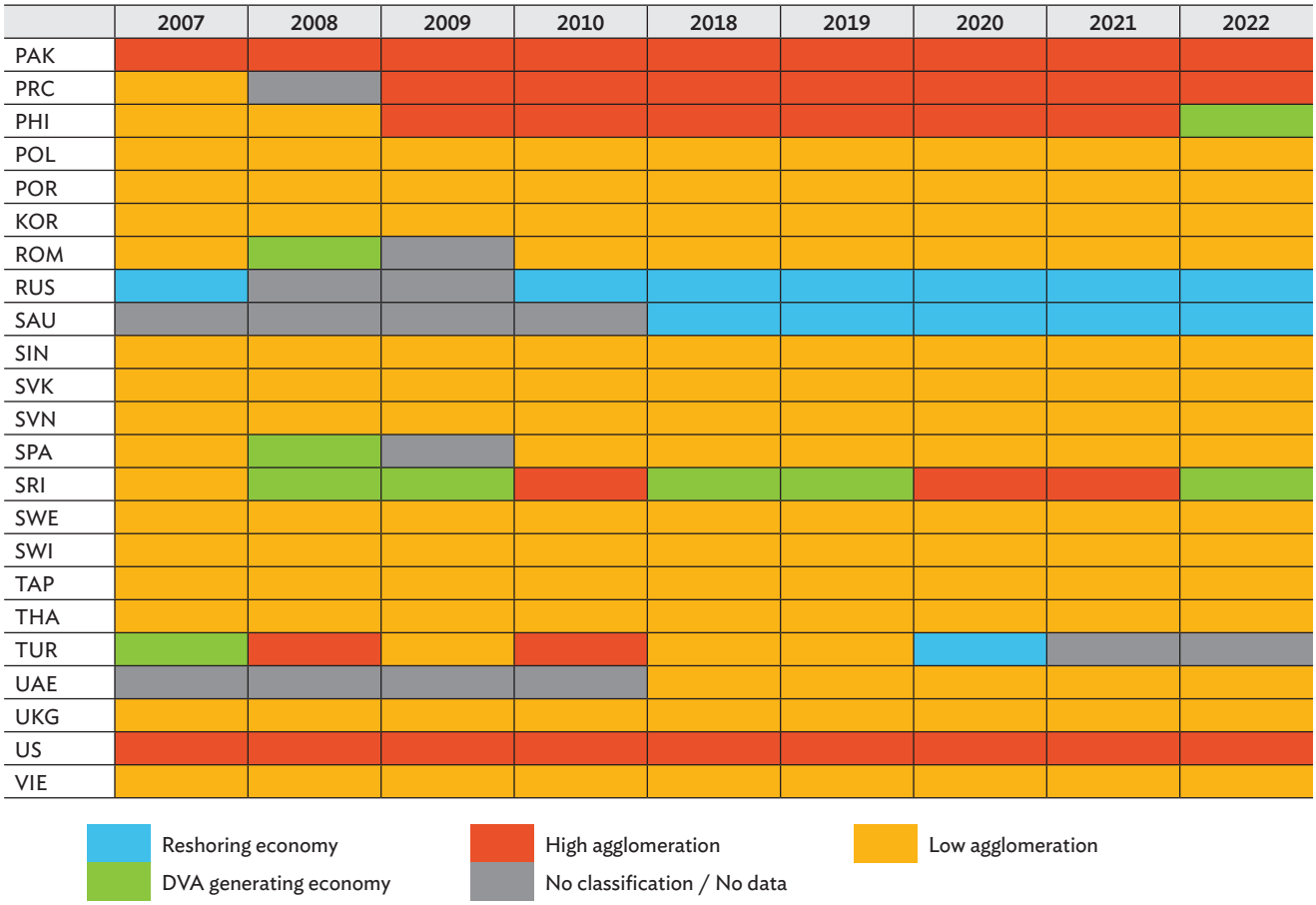
K. Baris, M. C. Crisostomo, K. Garay, C. Jabagat, M. Mariasingham, and E. Mores. 2022. Measuring Localization in the Age of Economic Globalization. *ADB Economics Working Paper Series.* No. 647. Manila: Asian Development Bank.

Figure 1.13: Agglomeration Classes of Economies, 2007–2010 and 2018–2022

	2007	2008	2009	2010	2018	2019	2020	2021	2022
ARG									
ARM									
AUS									
AUT									
BAN									
BEL									
BHU									
BRA									
BRU									
BGR									
CAM									
CAN									
COL									
HRV									
CYP									
CZE									
DEN									
ECU									
EGY									
EST									
FIJ									
FIN									
FRA									
GEO									
GER									
GRC									
HKG									
HUN									
IND									
INO									
IRE									
ITA									
JPN									
KAZ									
KUW									
KGZ									
LAO									
LVA									
LTU									
LUX									
MAL									
MLD									
MLT									
MEX									
MON									
NEP									
NET									
NZL									
NOR									

continued on next page

Figure 1.13: continued

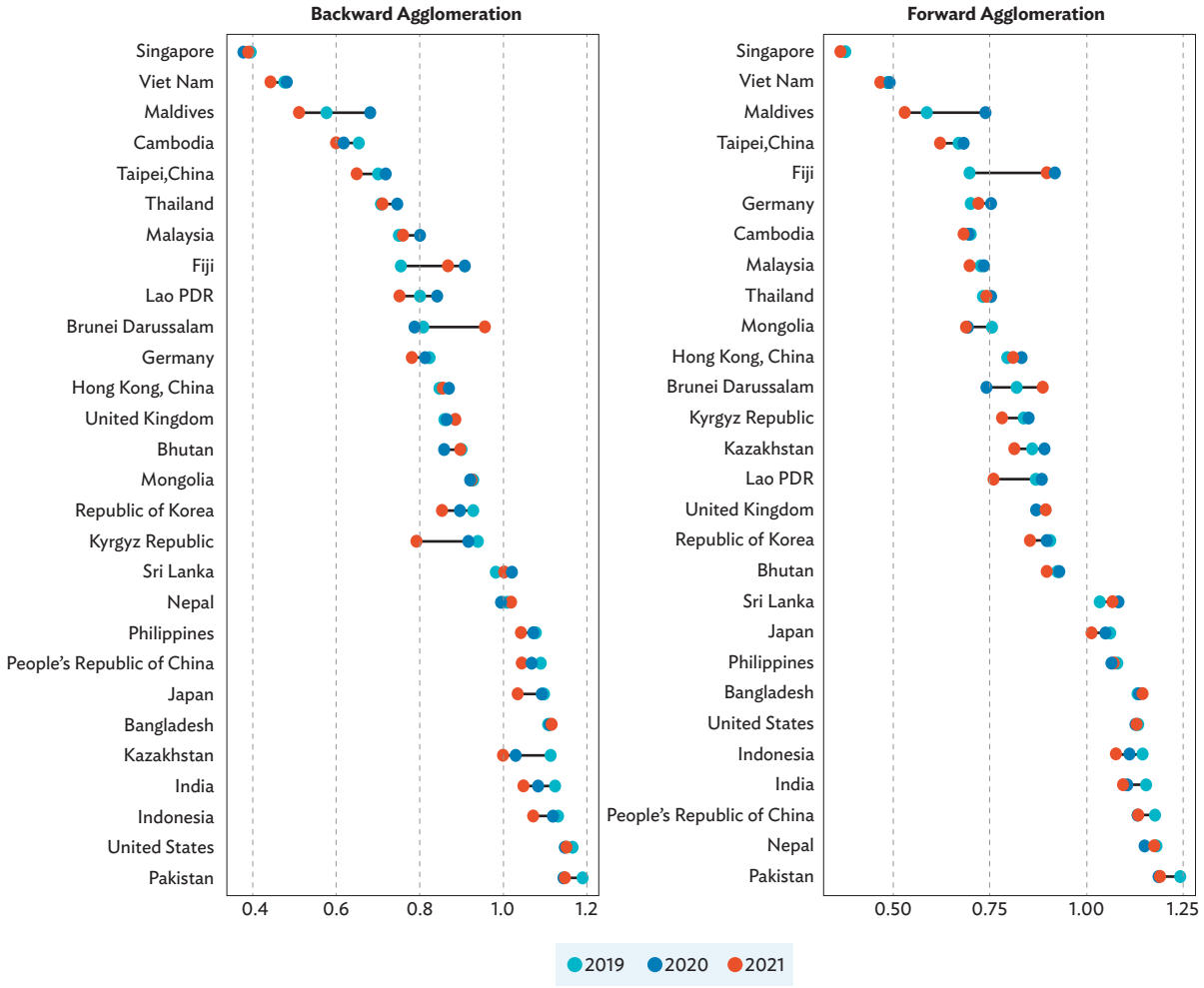


Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

The US is an interesting case in terms of agglomeration from 2007 to 2021, with its backward agglomeration index values increasing over this period while forward agglomeration decreased for almost all sectors. This suggests evidence of reshoring for some US sectors. The sectors with the highest backward agglomeration over the 14-year period were metal, paper, leather, water transport, transport, and electrical and optical equipment.

Overall, while the values of backward agglomeration suggest reshoring activities have taken place in several sectors of selected economies since 2007, aggregate trends on backward domestic linkages are inconclusive as to the existence of a wave of reshoring across many economies. Due to the significant costs of relocation, reshoring takes time, planning, and coordination. Furthermore, because of the interconnectedness of value chains, economies that are considered offshoring destinations for higher-income economies can simultaneously offshore to, or reshore from, other less-developed economies (Krenz and Strulik 2020). This makes it difficult to conclude patterns of reshoring behavior at the macro level.

Figure 1.14: Backward and Forward Agglomeration of Selected Economies, 2019, 2020, 2021



Sources: Asian Development Bank Multiregional Input-Output Database; and Asian Development Bank estimates.

It is also difficult to quantify trends toward reshoring without readily available firm-level datasets that capture the relocation intentions of MNEs. Existing micro- and firm-level studies on the restructuring of GVCs reveal two divergent patterns of behavior. The first is that MNEs are restructuring their production processes less than initially expected: the length of GVCs has not been reduced, future investment plans have not changed much, and there is no sign of a wave of reshoring (Di Stefano et al. 2021). Furthermore, while MNEs are considering organizational changes to improve their resilience to global shocks, these changes often do not imply a halt in international production and investment. The second pattern shows that several governments have enacted policies to encourage reshoring, nearshoring, or regionalization of production, whether through fiscal incentives, lower tariffs, relocation subsidies, support for innovation and human capital, or a combination of all these (Elia et al. 2021).

Localization Policies in the People's Republic of China

The fragmentation of production that materialized with the rise of GVCs allowed developing economies to insert themselves into complex production processes that facilitated the transfer of knowledge and technology from MNEs to local firms, helping set the blueprint for industrialization. The PRC took extensive advantage of these developments to become one of the largest economies and major players in international trade, consistently placing atop the rankings for GDP and gross export value worldwide. Recently, however, the outlook for the international economic environment of the PRC has started to become less favorable. The trade tensions between the PRC and the US led to the imposition of strict export controls toward the former, aiming to cut off supply of high-tech components to its high–technology manufacturing firms such as Huawei (Cai and Wang 2022). In addition, movements toward "ally shoring"—wherein Western firms are being convinced to reduce their economic dependence on the PRC by partnering with firms within member economies of a network (e.g., the Economic Prosperity Network)—are now being made.

In response to this, the Government of the PRC unveiled its dual circulation economic strategy, which puts the onus on domestic consumption to be the major vehicle for economic development. Under this strategy, it is envisioned that dependence on foreign economies for key technology and products is eliminated and that domestic firms will augment their capacity for innovation to become frontrunners in advanced technologies (Cai and Wang 2022). It could be argued that this decoupling strategy originated before the beginning of the trade tensions, as the PRC was pursuing its own form of "Made in China" as early as 2012. In any case, the current goal of the government is centered on technological independence from the West, and several measures have already been put in place to realize this goal.

In their 2022 paper, Cai and Wang listed new local content requirement (LCR) policies in the PRC. Such policies refer to measures encouraging the use of local inputs in production as a prerequisite for obtaining financial incentives or gaining market access, thereby creating incentives for firms to select suppliers based on their nationality instead of quality and cost factors. Prior to the PRC's accession to the World Trade Organization, these policies were explicit as trade preferences, while tax incentives were granted based on the usage rates of local inputs. In addition, under the rules and regulations of the Government of the PRC, foreign firms were mandated to follow technology transfer requirements. Though these were gradually lifted by 2002, a host of implicit LCR policies soon emerged, which masked localization strategies and/or objectives under the guise of equal treatment of enterprises regardless of nationality. Due to their covert nature, these LCRs may be difficult to identify (Cai and Wang 2022).

To assess the effectiveness of LCR policies on furthering the localization goals of the Government of the PRC, looking into the domestic content in production may be a sensible first step. Finding evidence that suggests considerable increases DVA, particularly in the economy's own products, may warrant further statistical analysis.

DVA embodied in the PRC's output is estimated by Cai and Wang (2022) in two ways. First, in a standard input-output model (Part A of Box 1.4), the decomposition of each industry's DVA is given by:

$$DVA = GDP = \boldsymbol{A}_v(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\boldsymbol{Y}^f + \boldsymbol{A}_v(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\boldsymbol{Y}^{ef} + \boldsymbol{A}_v(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\boldsymbol{Y}^{ei}$$

In the equation above, the first term refers to value-added that is domestically produced and consumed, the second is DVA embodied in traditional exports, and the third is DVA embodied in GVC-related trade. Detailed trade data from the General Customs Administration of PRC distinguishes between processing exports and ordinary exports. Processing exports differ from ordinary exports as they are mainly produced with imported intermediates. If such a distinction is of analytical importance, an extended input-output model is used (Part B of Box 1.4), which results in an adjusted decomposition of an industry's DVA given by:

$$\begin{aligned} DVA = GDP = {} & \boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\boldsymbol{Y}^f + \boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\left(\boldsymbol{Y}^{ef} - \boldsymbol{E}^{Pf}\right) + \boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\left(\boldsymbol{Y}^{ei} - \boldsymbol{E}^{Pi}\right) \\ & + (\boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}\boldsymbol{A}^{DP} + \boldsymbol{A}_v^P)\boldsymbol{E}^P \end{aligned}$$

The first three terms have the same interpretations as in the standard input-output model, while the additional fourth term refers to direct $(\boldsymbol{A}_v^P\boldsymbol{E}^P)$ and indirect $(\boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}\boldsymbol{A}^{DP}\boldsymbol{E}^P)$ domestic value-added embodied in processing exports.

Using the PRC's 2007, 2012, and 2017 benchmark input-output tables—published by the National Bureau of Statistics and detailed trade data for 2007–2017 from the General Customs Administration— Cai and Wang (2022) estimated that the share of DVA in the PRC's gross exports was 64.6% in 2007, 65.3% in 2012, and 69.9% in 2017 (Table 1.3). This indicates that, even before the start of the PRC–US trade tensions, the domestic content in the PRC's exports was already on an upward trend.

From 2007 to 2017, the shares of DVA in the PRC's processing and normal exports moved in opposite directions. DVA fell from 37.4% to 28.4% of the value of processing exports, while the DVA share in normal exports increased by 2.2 percentage (85.2% to 87.4%) points over the period. Since the overall objective of localization policies introduced by the Government of the PRC is to decrease reliance on foreign economies for production of goods and services, one indication of their effectiveness is increased DVA generation in the economy's exports. This is clearly seen as early as 2012—when the economy implemented its decoupling strategy—in the form of marginal increases in DVA shares in normal and gross exports. However, the new information gathered from data that split processing exports from normal exports at the aggregate level suggest otherwise, at least for the period studied (Cai and Wang 2022). Though these exports are, by definition, mainly produced with imported intermediates, the fact that the shares of DVA have not only been inconsistent but are also decreasing may be worth noting in assessing the success of PRC's localization policies.

Box 1.4: Standard and Extended Input-Output Models

Part A: Standard Input-Output Model

The standard or "noncompetitive" input-output model is given by:

$$\boldsymbol{A}^D\boldsymbol{X} + \boldsymbol{Y}^D = \boldsymbol{X}$$
$$\boldsymbol{A}^M\boldsymbol{X} + \boldsymbol{Y}^M = \boldsymbol{M}$$

where $\boldsymbol{A}^D$ corresponds to the technical coefficients matrix for domestic products while $\boldsymbol{A}^M$ is a matrix of direct input coefficients of imported products. $\boldsymbol{Y}^D$ and $\boldsymbol{Y}^M$ are n x 1 vectors of final demands for domestically produced and imported products, respectively. **X** is a n x 1 vector of gross outputs while M is a n x 1 vector of imports. Rewriting the first equation gives:

$$\boldsymbol{X} = \left(\boldsymbol{I} - \boldsymbol{A}^{\boldsymbol{D}}\right)^{-1}\boldsymbol{Y}^D$$

where $\left(\boldsymbol{I} - \boldsymbol{A}^{\boldsymbol{D}}\right)^{-1}$ is the Leontief inverse giving the total domestic requirements for meeting final demands faced by sectors. Letting $\boldsymbol{A}_v$ be a 1 x n vector of each sector's ratio of total value-added to gross output, i.e., v_i/X_i where v_i pertains to the value-added of sector I, domestic value-added (DVA) or gross domestic product (GDP) by industry can be calculated as:

$$DVA = GDP = \boldsymbol{A}_v(\boldsymbol{I} - \boldsymbol{A}^D)^{-1}\boldsymbol{Y}^D$$

Expressing $\boldsymbol{Y}^D$ as the sum of vectors of domestic final demand, exports of final products, and exports of intermediate products leads to decomposition equation of DVA in a standard input-output model.

Part B: Extended Input-Output Model

These models are used when processing exports are of analytical importance. The extended input-output table accounting for processing exports is represented in the figure below:

			Intermediate use			
			Production for domestic use and normal exports	Production of processing exports	Final use (C+I+G+E)	Gross Output or Imports
		DIM	1,2,..., N	1,2,..., N	1	1
	Production for domestic use and normal exports (D)	1 . . . N	Z^{DD}	Z^{DP}	$Y^D - E^P$	$X - E^P$
Domestic Intermediate Inputs	Processing Exports (P)	1 . . . N	0	0	E^P	E^P
Intermediate Inputs from Imports		1 . . . N	Z^{MD}	Z^{MP}	Y^M	M
Value-added		1	V^D	V^P		
Gross output		1	$X - E^P$	E^P		

Source: K. Cai and Z. Wang. 2022. Local Content Requirement Policies in China and Their Impacts on Domestic Value-Added in Exports. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

Using this information, the input-output model is now given by:

$$\begin{bmatrix} \boldsymbol{I} - \boldsymbol{A}^{DD} & -\boldsymbol{A}^{DP} \\ \boldsymbol{0} & \boldsymbol{I} \end{bmatrix} \begin{bmatrix} \boldsymbol{X} - \boldsymbol{E}^P \\ \boldsymbol{E}^P \end{bmatrix} = \begin{bmatrix} \boldsymbol{Y}^D - \boldsymbol{E}^P \\ \boldsymbol{E}^P \end{bmatrix}$$
$$\boldsymbol{A}^{MD}(\boldsymbol{X} - \boldsymbol{E}^P) + \boldsymbol{A}^{MP}\boldsymbol{E}^P + \boldsymbol{Y}^M = \boldsymbol{M}$$

continued on next page

Box 1.4: continued

The solution of this model is

$$\boldsymbol{X} - \boldsymbol{E}^P = (\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}(\boldsymbol{Y}^D - \boldsymbol{E}^P) + (\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}\boldsymbol{A}^{DP}\boldsymbol{E}^P$$

where $\boldsymbol{A}^{DD}$ and $\boldsymbol{A}^{DP}$ are the technical coefficients matrices for domestic products and normal exports as well as for the production of processing exports, respectively. Letting $\boldsymbol{A}_v^D$ and $\boldsymbol{A}_v^P$ be direct value-added coefficient vectors for domestic sales and normal exports as well as processing exports, respectively, DVA or GDP by industry can be calculated as:

$$DVA = GDP = \boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}(\boldsymbol{Y}^D - \boldsymbol{E}^P) + \boldsymbol{A}_v^D(\boldsymbol{I} - \boldsymbol{A}^{DD})^{-1}\boldsymbol{A}^{DP}\boldsymbol{E}^P + \boldsymbol{A}_v^P\boldsymbol{E}^P$$

Once again, expressing $\boldsymbol{Y}^D$ as the sum of vectors of domestic final demand, exports of final products, and exports of intermediate products leads to decomposition equation of DVA in an extended input-output model.

Reference

K. Cai and Z. Wang. 2022. Local Content Requirement Policies in China and Their Impacts on Domestic Value-Added in Exports. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

Table 1.3: Domestic Value-Added in Processing Exports v Normal Exports, People's Republic of China; 2007, 2012, 2017
(%)

	Normal Exports			Processing Exports			Weighted Sum		
	2007	2012	2017	2007	2012	2017	2007	2012	2017
Total Exports									
Total FVA	14.8	14.5	12.7	62.6	69.8	71.7	35.4	34.7	30.2
Direct FVA	4.5	4.5	4.8	57.9	66.3	69.2	27.5	27.0	23.9
Total DVA	85.2	85.5	87.4	37.4	30.2	28.4	64.6	65.3	69.9
Direct DVA	28.5	30.4	30.4	10.9	8.9	9.3	21.0	22.5	24.1
All Merchandise									
Total FVA	16.0	16.8	14.9	62.7	70.0	71.8	39.4	40.8	35.8
Direct FVA	5.0	5.4	5.9	58.0	66.5	69.4	31.6	33.0	29.2
Total DVA	84.0	83.2	85.1	37.3	30.0	28.2	60.6	59.2	64.2
Direct DVA	23.4	22.0	22.3	10.9	8.8	9.2	17.1	16.1	17.5
Manufacturing Goods (food-processing sectors excluded)									
Total FVA	16.4	17.2	15.3	63.0	70.2	72.0	40.3	41.8	36.7
Direct FVA	5.2	5.6	6.1	58.3	66.7	69.6	32.4	33.9	30.0
Total DVA	83.6	82.8	84.7	37.0	29.8	28.0	59.7	58.2	63.3
Direct DVA	22.4	21.3	21.6	10.9	8.9	9.2	16.5	15.6	16.9

DVA = domestic value-added, FVA = foreign value-added.
Sources: Data from the National Bureau of Statistics and General Customs Administration; and estimates in K. Cai and Z. Wang. 2022. Local Content Requirement Policies in China and Their Impacts on Domestic Value-added in Exports. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

Conclusion

This report provides an overview of recent developments in GVCs from the perspective of prevailing trends and patterns in international trade, while also considering emerging methodologies and approaches related to the evolution of value chains. Recent data show some signs of recovery for GVC participation, particularly from 2020 to 2021. However, the presence of ongoing global shocks—including the lingering economic effects of PRC–US trade tensions and the COVID-19 pandemic as well as the impacts of the Russian war in Ukraine—may threaten to derail this positive trajectory.

The tendency to form clusters or production hubs contributes to the negative impacts global shocks have on GVCs. Acknowledging that the first step in addressing risk is to understand and measure it, new methods that identify potential bottlenecks or "choke points" and measure the extent of concentration (e.g., in the supply of value-added and frequency of engagements) in international trade have started to emerge. The hope is that these techniques will help guide researchers and policymakers alike to arrive at sensible recommendations towards participation in GVCs.

The report has also examined the calls for GVC resilience through an analysis of trajectories for GVC reconfiguration. Particular focus is given to reshoring, a phenomenon that is aptly captured by the agglomeration indices of Baris et al. (2022). Looking at the case of the PRC, which recently enforced measures to encourage furthering the domestic content of its products, mixed results are seen across different types of exports, trade destinations, and sectors. Ambiguity surrounding the impact of such policies warrants further statistical analysis to reveal the facilitating factors as well as barriers for realizing the goal of localization.

To complement this analysis, it is suggested that future research looks at MNEs' participation in GVCs through the lens of trade in factor-income (TiFI). Several studies, including Gao et al. (2023), found that dissimilarities exist in the activities of domestically owned versus foreign-owned firms along global supply chains. For example, regional characteristics of current GVCs were discovered to be mostly attributable to domestically owned firms in each economy, and that these enterprises were mostly involved in the three regional centers of North America (centered on the US), Europe (centered on Germany), and East Asia (centered on the PRC). This can serve as the driving force for the regionalization of current supply chains. On the other hand, the value-added creation of foreign-owned MNEs typically exhibited more global characteristics. As updates on databases that distinguish the activities of MNEs from the rest become available at the intercountry level, it will be interesting to see if the findings of previous papers and reports that utilized the TiFI approach still hold true, even after facing wide-ranging shocks. For instance, updates to the Organisation for Economic Co-operation and Development's Analytical Activities of MNEs Inter-Country Input-Output Tables may reflect on the findings around TiFI in the GVC Development Report 2021, Suder et al. (2015), Suder et al. (2022), and other academic texts.

The COVID-19 pandemic remains unresolved due to the unknown potential of new subvariants, and this is coupled with ongoing economic uncertainty stemming from geopolitical tensions between the PRC and the US as well as from the Russian war in Ukraine. It remains to be seen whether these headwinds will trigger a long-term reconfiguration of GVCs. At the very least, governments worldwide must arm themselves with the capacity to understand the existing issues around GVCs. They must use a vast array of approaches and determine which issues are most applicable in certain situations, so they can minimize negative economic and social impacts in the event of future crises.

References

Ahn, J., M. Amiti, and D. E. Weinstein. 2011. Trade Finance and the Great Trade Collapse. *American Economic Review*. 101 (3). pp. 298–302.

Asian Development Bank (ADB). 2022. *Asian Economic Integration Report: Advancing Digital Services Trade in Asia and the Pacific*. Manila.

ADB. 2023a. *Transforming Bangladesh's Participation in Trade and Global Value Chains*. Manila.

ADB. 2023b. *Key Indicators for Asia and the Pacific 2023*. Manila.

Attinassi, M., M. Balatti, M. Mancini, and L. Metelli. 2021. Supply Chain Disruptions and the Effects on the Global Economy. *ECB Economic Bulletin*. Issue 8/2021. Frankfurt am Main, Germany: European Central Bank.

Baldwin, R. 2009. The Great Trade Collapse: What Caused It and What Does It Mean? *Centre for Economic Policy Research for VoXEU.org*. 1–14. Geneva: CEPR, The Graduate Institute.

Baris, K., M. C. Crisostomo, K. Garay, C. Jabagat, M. Mariasingham, and E. Mores. 2022. Measuring Localization in the Age of Economic Globalization. *ADB Economics Working Paper Series*. No. 647. Manila: ADB.

Bonneau, C. and M. Nakaa. 2020. Vulnerability of French and European Imports. No. 274. Tresor Economics.

Borin, A. and M. Mancini. 2019. Measuring What Matters in Global Value Chains and Value-Added Trade. *Policy Research Working Paper No. 8804*. Washington, DC: World Bank.

Brandes, U. 2001. A Faster Algorithm for Betweenness Centrality. *Journal of Mathematical Sociology*. 25. pp. 163–177.

Brinca, P., J. Duarte, and M. Faria e Castro. 2020. Measuring Labor Supply and Demand Shocks During COVID-19. *Federal Reserve Bank of St. Louis Working Paper*. No. 2020-011. St. Louis: Federal Reserve Bank.

Burstein, A., C. Kurz, and L. Tesar. 2008. Trade, Production Sharing, and the International Transmission of Business Cycles. *Journal of Monetary Economic*. 55 (4). pp. 775–95.

Cai, K. and Z. Wang. 2022. Local Content Requirement Policies in China and Their Impacts on Domestic Value-Added in Exports. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

CEIC. 2022. Capacity Utilization and Purchasing Managers Index Suppliers Delivery Times Data [Online]. Available: CEIC database.

Center for Preventive Action (CPA). 2023. War in Ukraine. *Global Conflict Tracker*.

Chor, D. and K. Manova. 2012. Off the Cliff and Back? Credit Conditions and International Trade During the Global Financial Crisis. *Journal of International Economics*. 87 (1). pp. 117–133.

Del Rio-Chanona, R. M., P. Mealy, A. Pichler, F. Lafond, and D. Farmer. 2020. Supply and Demand Shocks in the COVID-19 Pandemic: An Industry and Occupation Perspective. *INET Oxford Working Paper*. No. 2020-05. Oxford: Institute for New Economic Thinking.

Di Stefano, E. 2021. COVID-19 and Global Value Chains: The Ongoing Debate. *Occasional Papers, Bank of Italy and the Eurosystem*. Rome.

Djikstra, E. W. 1959. A Note on Two Problems in Connexion with Graphs. *Numerische Mathematik*. 1. pp. 269–271.

Eaton, J., S. Kortum, B. Neiman, and J. C. Romalis. 2016. Trade and the Global Recession. *American Economic Review*. 106 (11). pp. 3401–3438.

Eichengreen, B. and K. H. O'Rourke. 2009. A Tale of Two Depressions. VoxEU Columns.

Elia, S., L. Fratocchi, P. Barbieri, A. Boffellid, and M. Kalchschmidt. 2021. Post-Pandemic Reconfiguration from Global to Domestic and Regional Value Chains: The Role of Industrial Policies. *Transnational Corporations*. 28 (2). pp. 67–96.

European Commission. 2021. Updating the 2020 New Industrial Strategy: Building a Stronger Single Market for Europe's recovery. *Commission Staff Working Document*.

Ferrantino, M. and A. Larsen. 2009. Transmission of the Global Recession through US Trade. VoxEU Columns.

Fitzpatrick, M., I. Gill, A. Libarikian, K. Smaje, and R. Zemmel. 2020. The Digital-led Recovery from COVID-19: Five Questions for CEOs. *McKinsey Digital*. New York: McKinsey & Company.

Fratocchi, L., A. Ancarani, P. Barbieri, C. Mauro, G. Nassimbeni, M. Sartor, M. Vignoli, and A. Zanoni. 2016. Motivations of Manufacturing Reshoring: An Interpretative Framework. *International Journal of Physical Distribution and Logistics Management*. 46 (2). pp. 98–127.

Gao, Y., B. Meng, G. Suder, and J. Ye. 2021. Who Dominates Global Value Chains? Multinationals vs Domestic Firms. *IDE Discussion Paper 825*.

Gao, Y., B. Meng, G. Suder, J. Ye, and Y. Sun. 2023. Making Global Value Chains Visible: Transnational Corporations versus Domestically Owned Firms. *Transnational Corporations Journal*. Vol. 30. No. 1.

Ha, J., M. Kose, and F. Ohnsorge. 2021. One-Stop Source: A Global Database of Inflation. *Policy Research Working Paper*. No. 9737. Washington, DC: World Bank.

Hayakawa, K. and K. Imai. 2022. Who Sends Me Face Masks? Evidence for the Impacts of COVID-19 on International Trade in Medical Goods. *The World Economy*. 45 (2). pp. 365–385.

Inomata, S. and T. Hanaka. 2023. Measuring Exposure to Network Concentration Risk in Global Supply Chains: Volume versus Frequency. *Structural Change and Economic Dynamics*. Elsevier.

International Monetary Fund (IMF). 2021. *World Economic Outlook: Global Trade and Value Chains During the Pandemic*. Washington, DC.

Jiang, K. 2021. Identification of Vulnerable Canadian Imports. Government of Canada.

Kammer, A., J. Azour, A. A. Selassie, I. Goldfajn, and C. Y. Rhee. 2022. How War in Ukraine is Reverberating Across the World's Regions. *IMF Blog*.

Koopman, R., Z. Wang, and S. Wei. 2014. Tracing Value-Added and Double Counting in Gross Exports. *American Economic Review*. 104(2). pp. 459–94.

Korniyenko, M., M. Pinat, and B. Dew. 2017. Assessing the Fragility of Global Trade: The Impact of Localized Supply Shocks Using Network Analysis. *International Monetary Fund WP/17/30*.

Krenz, A. and H. Strulik. 2020. Quantifying Reshoring at the Macro-Level Measurement and Applications. *Growth and Change*. 52. pp. 1200–1229.

Li, X., B. Meng, and Z. Wang. 2019. Recent Patterns of Global Production and GVC Participation. *Global Value Chain Development Report 2019: Technological Innovation, Supply Chain Trade, and Workers in a Globalized World*. Washington, DC: World Bank Group.

Liang, S., S. Qu, and M. Xu. 2016. Betweenness-Based Method to Identify Critical Transmission Sectors for Supply Chain Environmental Pressure Mitigation. *Environmental Science & Technology*. 50. pp. 1330–1337.

Loo, A. 2020. 2008–2009 Global Financial Crisis The Great Recession. Corporate Finance Institute. Vancouver, British Columbia.

Majune, S. and V. Stolzenburg. 2022. Mapping Potential Bottleneck Products in the World. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

McCulloh, I., H. Armstrong, and A. Johnson. 2013. *Social Network Analysis with Applications (1st Edition)*. Wiley.

Naisbitt, B. and K. Whyte. 2020. The Effects of the Trade War on Inflation. *National Institute Economic Review*. No. 251.

Newman, M. E. J. 2001. Scientific Collaboration Networks. II. Shortest Paths, Weighted Networks, and Centrality. *Physical Review*. 64 (016132).

Opsahl, T., F. Agneessens, and J. Skvoretz. 2010. Node Centrality in Weighted Networks: Generalizing Degree and Shortest Paths. *Social Networks*. 32 (3). pp. 245–251.

Organisation for Economic Co-operation and Development (OECD). 2020. *OECD Digital Economy Outlook 2020*. Paris.

Ossa, R. and M. Le Moigne. 2021. Crumbling Economy, Booming Trade: The Surprising Resilience of World Trade in 2020. *Kuhne Impact Series Working Paper*. No. 01-21. Zurich: University of Zurich.

Reiter, O. and R. Stehrer. 2021. Learning from Tumultuous Times: An Analysis of Vulnerable Sectors in International Trade in the Context of the Corona Health Crisis. Report No. 454. Vienna: The Vienna Institute for International Economics Studies.

Subramanian, A. and M. Kessler. 2013. The Hyperglobalization of Trade and Its Future. *Working Paper Series*. No. 13-6. Washington, DC: Peterson Institute for International Economics.

Suder, G., P. W. Liesch, S. Inomata, I. Mihailova, and B. Meng. 2015. The Evolving Geography of Production Hubs and Regional Value Chains Across East Asia: Trade In Value-Added. *Journal of World Business*. 50 (3). pp. 404–416.

Suder, G., B. Meng, Y. Gao, J. Ye, and W. Cheng. 2022. Making Multinational Enterprises: Gain of Factor-Income Visible in Global Value Chains. Paper prepared for the *Global Value Chain Development Report 2023* workshop. Geneva. 7–11 November.

The Economist. 2019. Globalisation Has Faltered. 24 January.
United Nations Conference on Trade and Development (UNCTAD). 2020. *World Development Report 2020*. Geneva.
UNCTAD. 2022. *Building Capacity to Manage Risks and Enhance Resilience: A Guidebook for Ports*. Geneva.
United States Department of Justice and the Federal Trade Commission. 2010. *Horizontal Merger Guidelines*. Washington, DC: US Department of Justice.
Wang, Z., S. Wei, X. Yu, and K. Zhu. 2017. Characterizing Global Value Chains: Production Length and Upstreamness. *NBER Working Paper*. No. 23261. Cambridge, MA: National Bureau of Economic Research.
World Bank. 2020. *World Development Report*. Washington, DC.
World Trade Organization (WTO). no date. Trade in Value Added and Global Value Chains. *Country Profiles and Explanatory Notes*. Geneva.
WTO. 2021. *COVID and Rising Shipping Rates: Facts*. Geneva.
WTO. 2023a. *World Trade Report 2023: Reglobalization for a Secure, Inclusive and Sustainable Future*. Geneva.
WTO. 2023b. *One Year of War in Ukraine: Assessing the Impact on Global Trade and Development*. Geneva.

2

Impacts of Trade Tensions and COVID-19 on Global Value Chains

Yuning Gao, Enxhi Tresa, Tao Zhang, Meichen Zhang and D'Maris Coffman

2.1 Introduction

The organization of trade in global value chains (GVCs) has facilitated the circulation of goods and services between sectors and countries, but at the same time has increased their interdependence (Baldwin, 2017; Feenstra, 1998). Recent shocks have led to an increased awareness of mutual interdependence among countries and highlighted the susceptibility of trade flows to trade barriers. Changes in a country's trade policy or exogenous shocks, such as COVID-19, reverberate down the supply chain leading to disruptions. That said, such events also come as opportunities to better understand the interplay between existent policies and the organization of GVCs, to improve resilience to future shocks.

This chapter discusses the propagation of shocks in global value chains and their interaction with trade policies illustrated by the trade tensions between the US and its main trade partners, and the COVID-19 pandemic. In recent years, trade conflicts and COVID-19 have caused GVCs to re-adjust. Trade-restrictive policies often lead to retaliation by affected countries that in turn raise import tariffs or place other restrictions on their trade partners. For instance, in 2018 and the following years, tariffs were raised on bilateral trade between the United States and several of its trade partners, especially the People's Republic of China (PRC), with significant impacts on global trade and investment (Bown & Kolb, 2023). This chapter aims to better understand how economies react to shocks depending on their interlinkages in GVCs, paving the way towards better preparedness strategies for future shocks.

Another important major shock to GVCs was the COVID-19 pandemic. The world's most significant public health crisis since the 1918 influenza pandemic hit both

supply and demand side, resulting in the worst recession since the Great Depression. Disruptions in global supply chains caused by several lockdowns led to a significant contraction in demand (Freeman & Baldwin, 2020). The global economy decelerated, countries' GDP, imports and exports fell, and the prices of goods rose. The disruptions to GVCs prompted stakeholders to modify their strategies, both at the macro and micro level. At the macro level, governments had to undertake several measures to cushion the negative impacts on producers and consumers. At the micro level, firms adapted by reorganizing their supply chains, considering diversification of their suppliers, an increase in inventories or revisiting their supply chains' length.

After all, as mentioned above, disruptions in supply chains might also come as opportunities to better prepare for future shocks. Since COVID-19 has resulted in an unprecedented shock to the global economy, digital technologies have been regarded as a key tool for resilience and recovery during the pandemic era. Digitalization can indeed facilitate access to labor supply for certain industries, especially through the services sector. This paper also discusses its interaction with GVCs in the context of resilience and reducing risks of future shocks.

The rest of the chapter is organized as follows. Section 1 first discusses propagations of shocks and spillover effects in GVCs by illustrating how changes in trade policy along the value chain affect trade partners. Section 2 discusses trade tensions and how they may intensify regionalism. Section 3 focuses on the impact of COVID-19 on GVCs. Section 4 explores digitalization, resilience, and recovery, and section 5 concludes.

2.2 Sources of shocks and their propagation in Global Value Chains

Events such as trade conflicts or a global pandemic create disruptions that propagate through the value chain. For instance, US–PRC trade tensions have significantly increased bilateral tariffs and non-tariff measures for the concerned countries and their main trading partners. In addition, these shocks have sparked new debates regarding the benefits and risks related to GVCs. There is growing consideration about whether shifting towards more localized production would offer better protection against disruptions, which often result in supply shortages and uncertainty for consumers and businesses.

This section discusses the possible sources and risks related to the propagation of shocks in GVCs, providing an overview at the macro and micro levels. It also illustrates how trade policies amplify the propagation of shocks and discusses the role of tariffs and non-tariff measures.

Sources of Shocks and Mechanisms of Propagation

Shocks to GVCs are varied, including extreme weather events, trade tensions, geopolitical tensions, and pandemic (Solingen et al., 2021). Such shocks can be interlinked with each other and interact in specific contexts. For instance, trade tensions between the US and the PRC overlapped with the pandemic reinforcing each other's effects on increased uncertainty in trade policy as revealed by the trade policy uncertainty index (Ahir et al., 2022).

Supply chain connections play a crucial role in how shocks are transmitted between countries. This has far-reaching implications for the interplay between demand, trade, and production. Traditional models typically assume that a country's imports rely on domestic demand. However, in the current world characterized by intricate international supply chains, changes in demand in other countries have also become influential determinants. According to OECD TIVA statistics, more than 20% of global imports are utilized as inputs in domestic production processes and then integrated into goods that are subsequently re-exported. Demand shocks in a particular country can propagate upstream through the global production network to input suppliers. Similarly, supply disruptions can be transmitted downstream, affecting other parts of the supply chain.

The outbreak of COVID-19 has revealed the interdependence of countries in terms of the supply of inputs and final goods. The demand for some manufactured goods and services, such as airlines, tourism, restaurants, sports, and other face-to-face communication-dependent services dropped significantly, leading to a decrease in demand for all parts of the production chain linked to these goods and services.Cigna et al. (2022) show that GVC spillovers could magnify the decline in world trade, adding some 25% to the effects that could occur on the back of bilateral linkages. In contrast, the demand for other goods increased, such as medical equipment, electronics, and vaccines, with GVCs central to the effective supply of these items worldwide (WTO, 2023).

Large firms also play an essential role in the propagation of shocks through GVCs. Fluctuations at the firm level can be connected to overall economic fluctuations (Gabaix, 2011; Herskovic et al., 2020). Trade linkages at the firm level are significantly associated with increased comovement of international business cycles (di Giovanni et al., 2018). The extent of shock transmission also relies on the type of transaction between firms, whether through arm's length trade (i.e., trade between independent parties) or intra-group trade (i.e., trade between vertically linked firms). During the trade collapse in the 2008-09 global financial crisis, intra-group trade in intermediates experienced a more rapid decline followed by a faster recovery than arm's length trade (Altomonte et al., 2012).

Trade policies certainly play an important role in helping to cope with shocks or hinder their adverse effects. For instance, trade flows subject to lower trade costs declined by less than average during the 2020 COVID-19 pandemic, as higher-cost and less established suppliers were squeezed out of international markets (Nicita & Tresa, 2023). However, trade policies in the global value chain are also an instrument of shock propagation as countries are interlinked. This is what the following sub-section focuses on.

Propagation of Shocks through Tariff Measures in GVCs

The rise of GVCs has partly resulted from the liberalization of intermediate goods trade. Access to foreign intermediate inputs can increase the amount and quality of exports by exposing firms to new inputs and technologies (Cal`ı et al., 2022; Goldberg et al., 2010). Though tariffs are relatively low due to several liberalization initiatives, minor tariff variations might significantly affect the global production chain. In fact, economic shocks and their potential propagation effects induce countries to reconsider their policies in the international trading system and reconsider linkages through global value chains(Blanchard et al., 2016).

GVCs can amplify the impact of tariff changes on imported intermediate goods. The multi-stage production model implies that trade costs play a larger role for two reasons. First, products cross borders multiple times, so tariffs are repeatedly imposed on some parts. Second, even if the value added by a country represents only a tiny percentage of the value of an exported good, its trading partners will still levy tariffs on the total value. These two effects are sometimes called accumulation and magnification effects (Dollar et al., 2017; Yi, 2003; Yi, 2010).

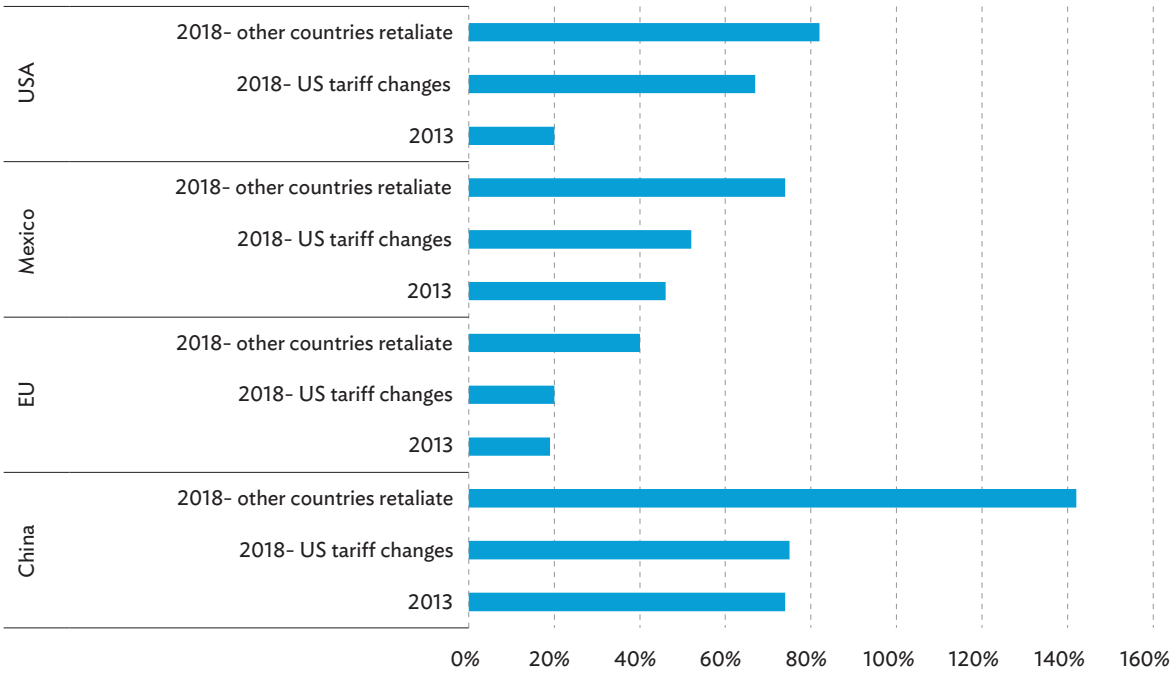
As a result, when production is fragmented, trade policy can have particularly strong impacts on indirect users located further downstream in the chain. Yi (2003) was the first to highlight that relaxing trade barriers in sequential production could result in spillover effects on the performance of indirect users. This idea has been supported by several theoretical contributions demonstrating the significant impact of indirect trade costs on downstream producers (Costinot et al., 2012; Johnson & Noguera, 2012; Noguera, 2012). Recent studies utilize quantification exercises to examine the role of trade protection in GVCs (Bellora & Fontagné, 2019; Erbahar & Zi, 2017). They underline the importance of considering vertical linkages and reveal the adverse consequences of trade protection for trade partners operating within the same production chain.

Rouzet and Miroudot (2013) compute cumulative tariffs and show that tariffs increase significantly when finished goods reach customers. Tresa (2022) does a similar exercise but distinguishes tariffs on inputs and final goods by computing cumulative input tariffs. His analysis shows how the effects of the trade tension between the US and the PRC have also been felt by their main trade partners. The cumulative input tariff is the trade weighted sum of all tariffs directly and indirectly embodied in all stages of GVCs, which can be captured by the Leontief inverse matrix.

Figure 2.1 shows the variations in cumulative input tariffs from 2013 to 2018 along the entire production chain under a fixed GVC structure (Tresa, 2022). The second bar for each country/economic bloc shows the cumulative input tariffs following changes in tariffs imposed by the US in 2018. As expected, cumulative input tariffs increased for the US. Interestingly, other countries' cumulative input tariff exposure also increased, especially for Mexico. This reflects that Mexico sources many inputs from the US, and the cumulative input tariffs increase in the US propagated to Mexican products that use components from the US.

The final bar for each country/economic bloc shows the cumulative input tariffs following not only US tariff changes but also those by countries that retaliated. As can be seen, the increase was significant, with the PRC's cumulative input tariffs almost doubling. This amplification was the result not only of the increase in tariffs by the PRC, but also of the increases by countries that are part of the Chinese value chain, such as the US. Importantly, the cumulative input tariffs of the US also increase in the final bar, even if US tariffs did not change. As in the case of the Mexican example above, this resulted from using foreign components that became more expensive following retaliation. The example illustrates that value chains should be a key consideration when determining trade policy.

Figure 2.1: The Change of the Average Cumulative Input Tariffs



Notes: This figure shows cumulative input tariffs with simple mean on sectors concerned by increases in tariffs: Agriculture, Hunting, Forestry and Fishing; Basic Metals and Fabricated Metal; Chemicals and Chemical Products; Coke, Refined Petroleum and Nuclear Fuel; Electrical and Optical Equipment; Electricity, Gas and Water Supply; Food, Beverages and Tobacco; Leather, Leather and Footwear; Machinery, Nec; Manufacturing, Nec, Recycling; Other Non-Metallic Mineral; Pulp, Paper, Paper, Printing and Publishing; Renting of M&Eq and Other Business Activities; Rubber and Plastics; Textiles and Textile Products; Transport Equipment; Wood and Products of Wood and Cork. The second bar for each economic block shows cumulative input tariffs following the US tariff changes in 2018. The final (upper) bar shows cumulative input tariffs following all other countries' tariff changes in 2018.

In terms of costs, US–PRC trade tensions have resulted in a total extra 23 billion US dollars (the currency throughout the paper)indirect tariff burden (0.11% to the total global imports), of which 67% is attributed to the US's unilateral additional tariffs on Chinese goods. Moreover, the US and the PRC have had to bear additional indirect tariff burdens of approximately 10 and 6.5 billion US dollars (about an extra 0.31% and 0.09% to the total global imports), respectively. The European Union (EU), Canada, and Mexico have also incurred additional indirect tariff costs between 700 million and 1.7 billion US dollars (Mao & Görg, 2020; Wu et al., 2021). Focusing on individual sectors concerning indirect tariffs, all sectors in the PRC except for wood products were subject to indirect tariff increases of less than 50%, while all sectors in the US except for textiles and petroleum incurred additional indirect tariffs of more than 150%.

This illustration clearly shows that due to the pervasive presence of GVCs, trade tensions come at a cost to the overall economy that is much larger than direct impacts might suggest.

Propagation of Shocks through Non-Tariff Measures in GVCs

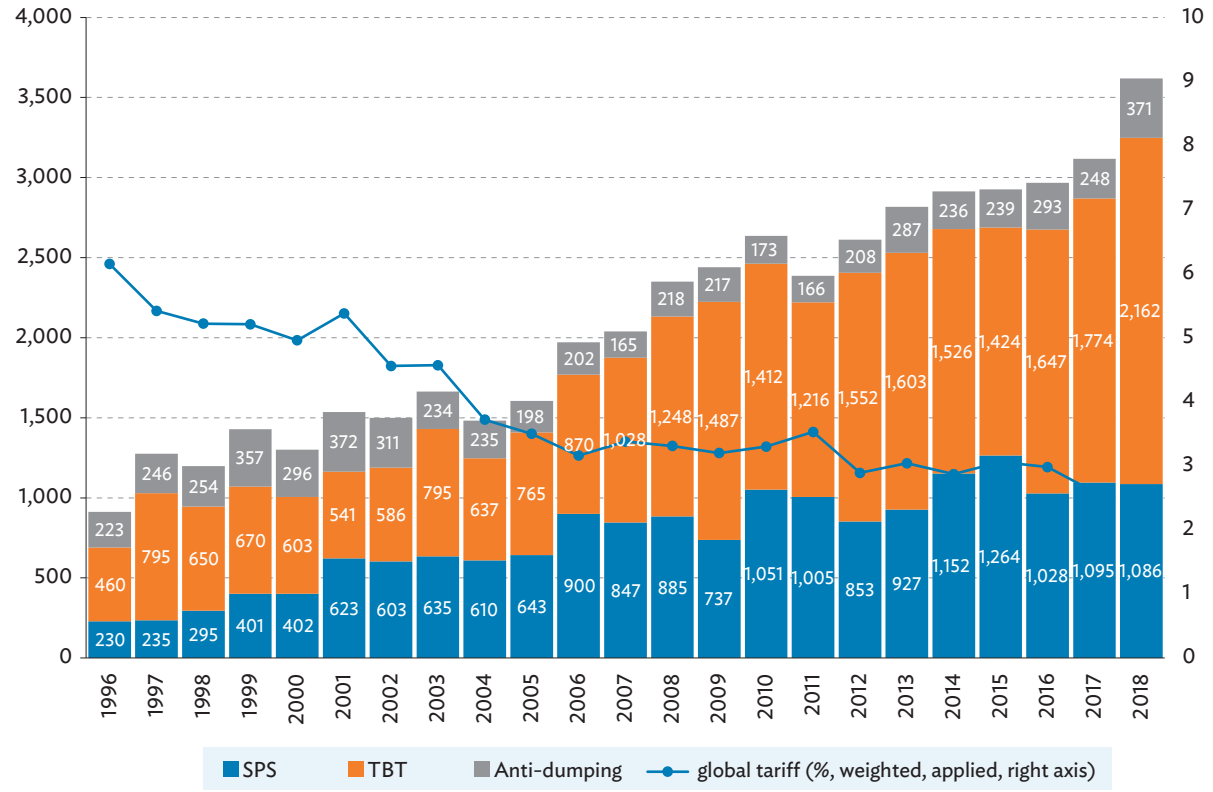
Few studies have quantitatively analyzed the impact of NTMs on GVCs, especially in comparison with tariffs. Ghodsi and Stehrer (2022) examined the effects of two types of NTMs, sanitary and phytosanitary (SPS) measures and technical barriers to trade (TBTs), on GVCs and found that the cumulative effect of tariffs was greater than that of NTMs. However, the cumulative cost of compliance with TBTs over previous stages of production had a significant negative impact on value-added and gross exports. This indicates that the cumulative effect of NTMs is relevant in the context of production fragmentation.

Average global tariffs have declined from more than 12% in the 1990s to less than 9% today, but there has been a rapid increase in NTMs to about four times the level in the 1990s, and they continue to rise (see Figure 2.2). As a result, the impact of behind-the-border NTMs on international trade is growing, especially vis-à-vis tariffs (OECD, 2019).

During the initial period of the COVID-19 pandemic until August 2020, various countries collectively implemented 384 trade-related measures, of which 283 were NTMs (see Figure 2.3). During this period, almost all tariffs aimed to reduce import costs, while 179 NTMs aimed to restrict trade (Lee & Prabhakar, 2021). These NTMs were mainly aimed at securing the domestic supply of goods and preventing the importation of the COVID-19 virus.

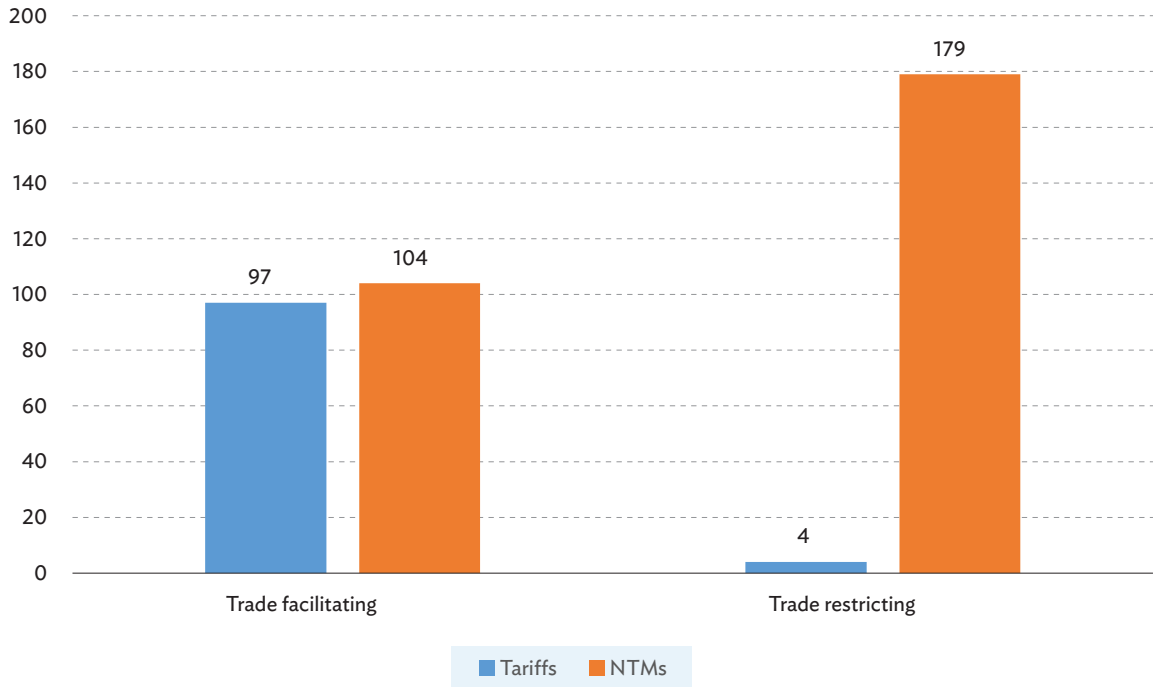
Recent research highlights that NTMs can have substantial adverse effects on GVCs. Ghose and Montfaucon (2022) show that firms that were part of a GVC were more resilient in the long run during the pandemic, but that NTMs, such as port-of-entry restrictions, severely aggravated the harmful effects of COVID-19. Cal`ı et al. (2022) corroborate these findings by showing that negative competitiveness shocks cause exports of firms subject to NTMs on their inputs to decline much stronger than exports of other firms. Notably, the magnitude of the effect depends on the type of NTM, which suggests that policymakers may achieve policy objectives without unduly restricting trade by using the appropriate NTMs.

Figure 2.2: The Trend of Global Tariff and NTMs



Sources: Cho et al. (2020)

Figure 2.3: Trade Facilitating and Restricting NTMs during COVID-19



Sources: Lee and Prabhakar (2021)

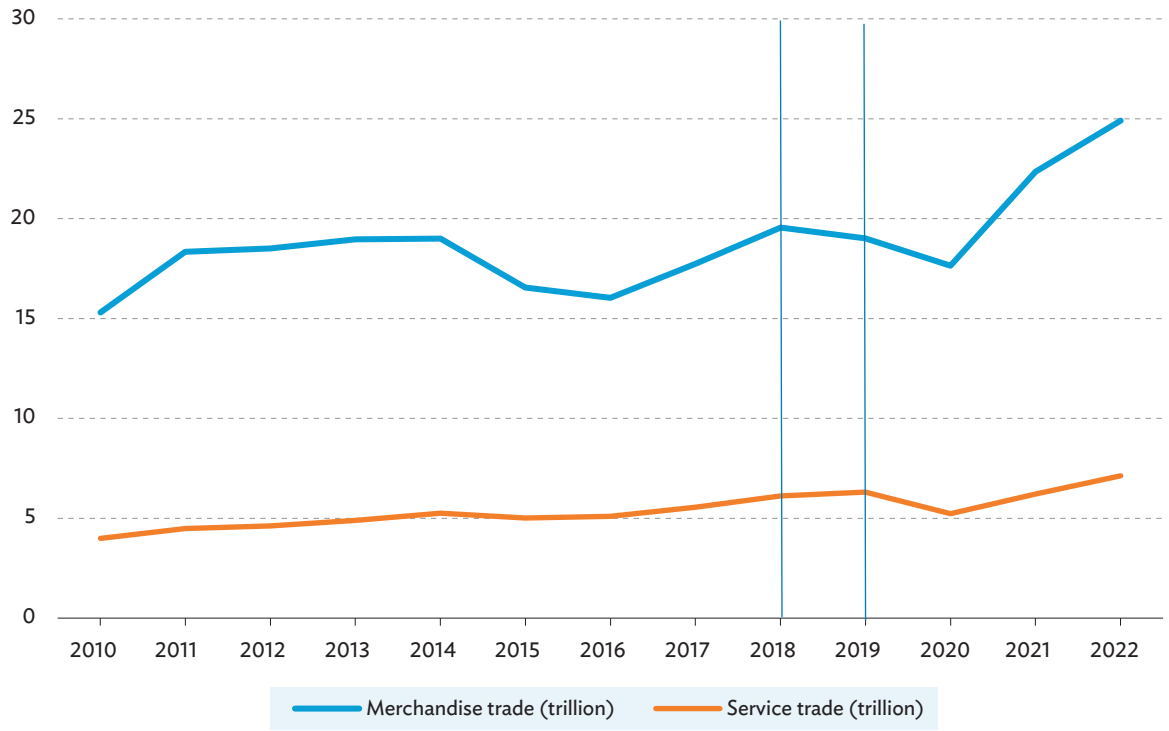
2.3 Patterns of Restructuring and Regionalization of Global Trade

Global Trade Picture

Globally, merchandise trade increased in 2018 and 2019 despite rising trade tensions leading to higher tariffs. Trade in services increased initially but then decreased. The outbreak of the COVID-19 pandemic hurt global trade, which fell sharply, especially trade in services. However, trade is resilient and recovered quickly after the pandemic, reaching new heights in 2021 and 2022 (see Figure 2.4).

The PRC, the US, and the EU continue to be the largest contributors to the global economy and GVCs, playing by far the greatest roles in the global supply of goods and services in 2021 (see Figure 2.5). Taking the intermediate market as an example, these three regions exported 10.2%, 10.3% and 29.9% of global total intermediate goods and services, respectively. The intermediate import shares of these three regions are 14.7%, 9.9% and 28.2%, respectively.

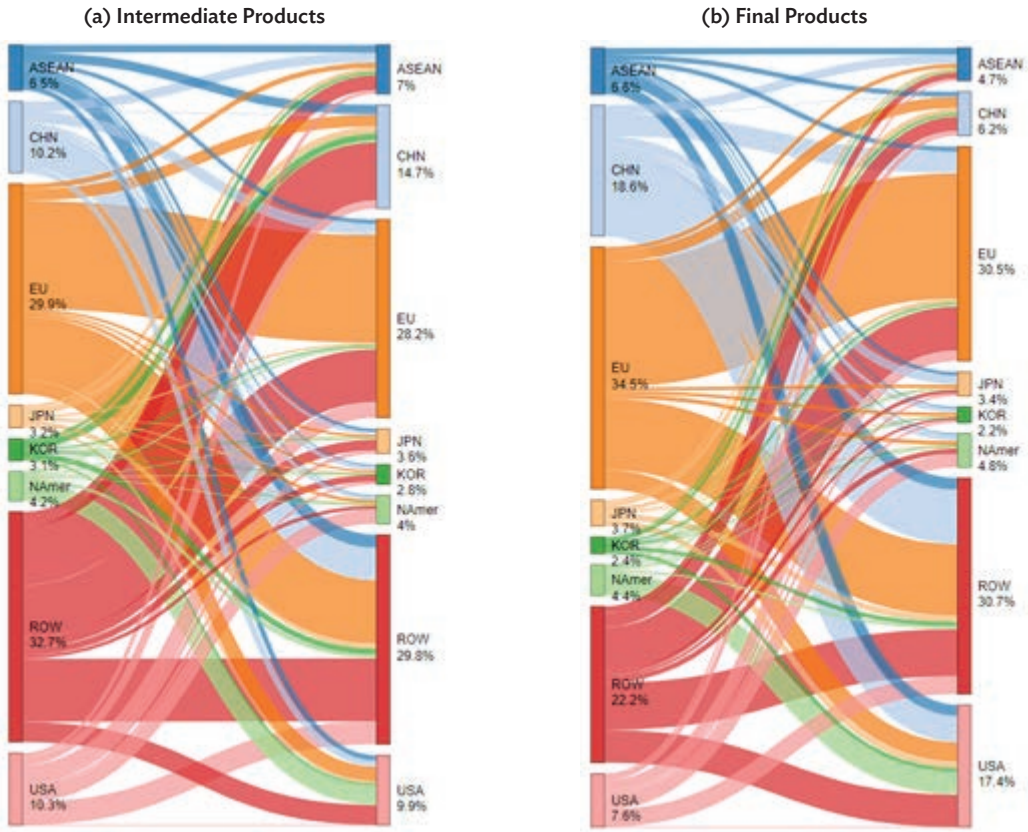
Figure 2.4: Global Export of Merchandise and Service



Source: World Trade Organization (WTO) statistics.

As to the bilateral trade flows, shown as the links between the exporters and importers, the PRC supplied 24% of Europe's imports of final goods and services from outside the continent but only 13%[1] of its imports of intermediate goods. The EU imported more intermediate products from the US (17%), and 20% of the US's imports were from the EU. In contrast, for final consumption, the US and the EU were more reliant on supplies from the PRC. The PRC provided 25% of the rest of the world's imports of final products, while the PRC and the US each supplied 14% of the rest of the world's intermediate product imports.

Figure 2.5: Global Trade of Intermediate and Final Products in 2021



Note: Domestic trade of each country was omitted in the initial input–output table and then aggregated to 8 regions. Regions in the left part of each panel are the exporters, and the corresponding numbers are the export shares of each country. Similarly, regions on the right part of each panel are importers and the numbers are import share. The links between exporters and importers are bilateral exports.

Sources: Asian Development Bank (ADB) Multi-regional Input–Output (MRIO) Database database 2021

Trade Diversion

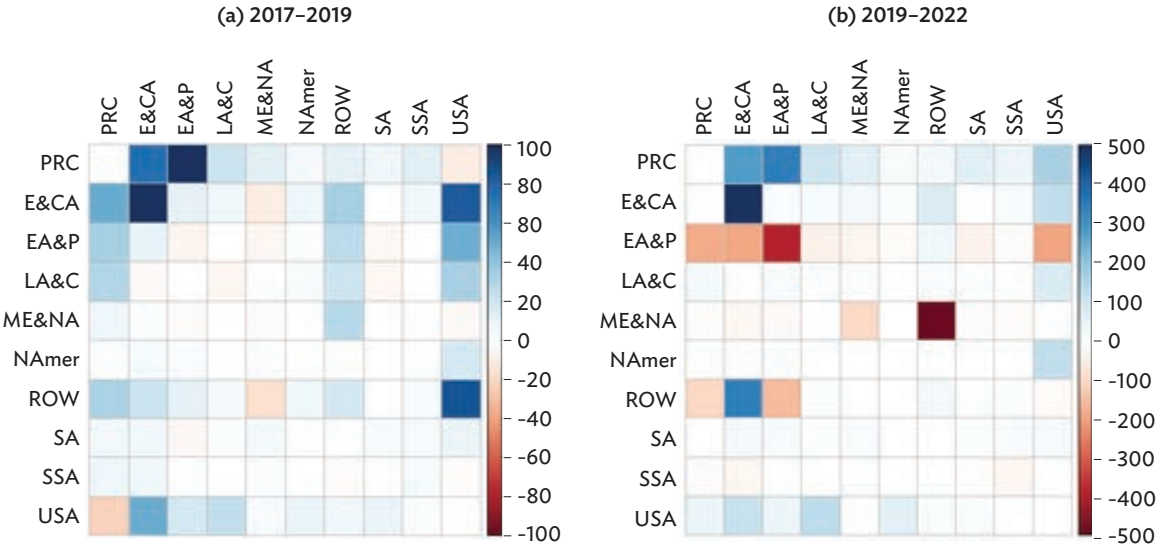
While aggregate trade held up despite trade tensions and was resilient during the pandemic, there have been significant changes in the geography of trade during the period 2017–2022 (see Figure 2.6). In response to the tariff increases by the US, the PRC shifted

[1] According to the ADB MRIO 2021, the EU's total import of intermediate goods and services in 2021 (excluding the intra-regional trade) was 2053.4 billion dollars, the imports from the PRC were 269.1 billion dollars, so the share was about 13%.

its export focus to East Asia and Pacific and Europe and Central Asia, with exports to those regions increasing by 11.7% and 16.1%, respectively, or about 100 billion US dollars and 75 billion US dollars, respectively. Exports of goods from the PRC to Viet Nam, Indonesia, and Malaysia increased by 36.7%, 31.3%, and 25.0%, respectively. The US increased its exports to Europe and Central Asia by 14.9%, of which the exports to the UK increased by 22.8% (12.9 billion US dollars). Meanwhile, exports of goods from the US to Mexico and Canada increased by 5.3% (12.9 billion US dollars) and 3.5% (9.9 billion US dollars), respectively. These are the top three absolute changes in exports to individual countries. As for imports, the PRC and the US shifted their sourcing to the Europe & Central Asia region, the East Asia & Pacific region, and the Latin America & Caribbean region.

Gross trade data suggests that the PRC strengthened its ties with East Asia during the period 2017–2019, while the US forged closer trade ties with Canada and Mexico, while both the PRC and the US reorganized their imports from the Europe & Central Asia region, the East Asia and the Pacific region, and Latin America & Caribbean region.

Figure 2.6: Change in Gross Exports in 2017–2019 and 2019–2022



Notes:
1. The changes in gross export between regions are shown in the picture. Actually, the intra-export from E&CA to E&CA in the left picture increased by 331 billion dollars, and that in the right picture increased by 993 billion. But both were truncated for better visualization.
2. The classification of region is based on World Bank. E&CA=Europe & Central Asia, EA&P = East Asia & Pacific, LA&C = Latin America & Caribbean, ME&NA = Middle East & North Africa, NAmer = North America, SA = South Asia, SSA= Sub-Saharan Africa, ROW = Rest of the world.

Source: World Integrated Trade Solution (WITS) trade data, gross exports.

Global trade has changed dramatically in the post-COVID era (2019–2022), compared with the pre-COVID period (2017–2019). Intra-trade (gross export) in the Europe & Central Asia region has increased by $331 billion US dollars prior to the COVID-19 pandemic, and has increased by $993 billion US dollars in the post-pandemic period. Europe and Central Asia region has also strengthened their ties with the PRC and Africa (included in the rest of

the world), while reducing trade with the Americas. The East Asia and Pacific region and Middle East and North Africa region experienced significant supply shortages during the pandemic and have become more reliant on Chinese imports to meet their consumption and production requirements. Looking at the PRC and the US, although bilateral trade declined during the trade tensions, they strengthened their ties in the face of the COVID-19 pandemic and were responsible for the largest change in each other's imports.

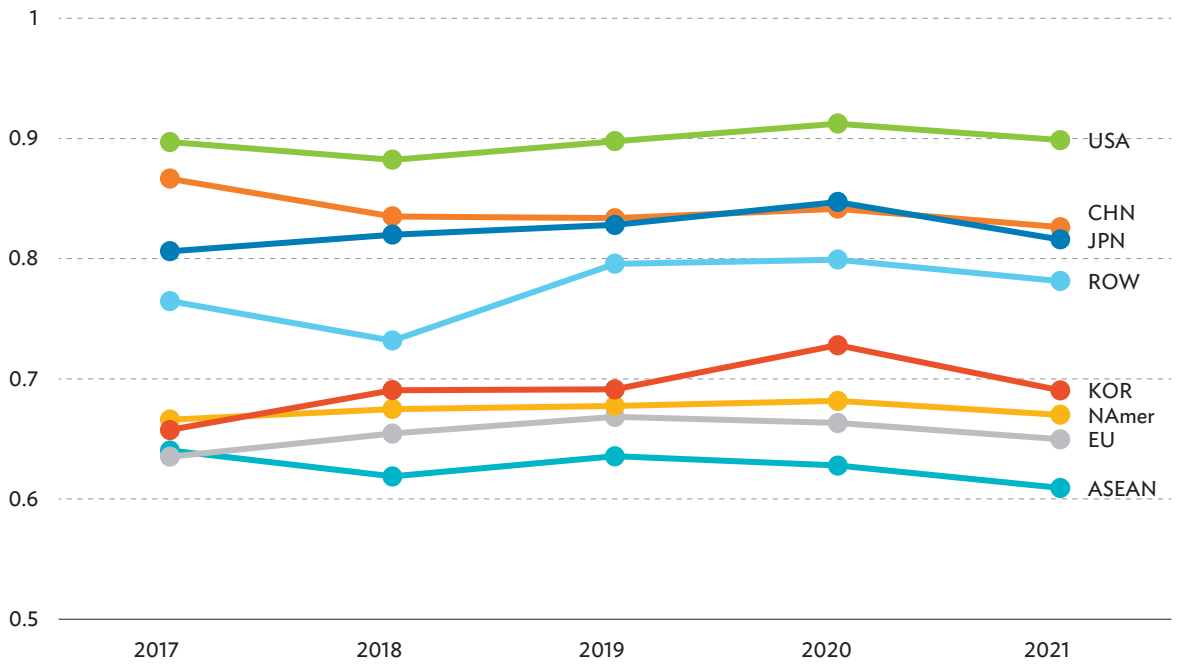
Focusing on Asia, imports of inputs by developing Asian economies from non-Asia regions declined, but there was an increase in intra-regional trade (see Figure 2.8). Thus, the resilience of regional supply chains mitigated the decline in imports from non-regional suppliers. The resilience of the PRC's exports enabled upstream industries in developing Asian economies to remain solvent, and regional sales of intermediate goods to the PRC also increased. The PRC's resilient demand for final goods helped developing Asian economies' exporters of inputs to weather the COVID-19 pandemic.

Reshoring and Regionalization

Through GVCs, developing countries have taken over most of the low-skilled production due to their abundant labor resources to supply the world (Baldwin & Ito, 2021). However, the frequent occurrence of internal or external shocks, such as trade tensions, pandemics and geopolitical conflicts, have raised concerns about the stability and security of GVCs. To minimize the risk of disruptions, some countries have enacted supply chain security strategies to ensure the stability of their supply chains. Such strategies might entail efforts to re-shore or regionalize production. This is less of an option for developing regions, which are relatively technologically backward who are dependent on importing high-tech inputs to increase their competitiveness in the global market. This sub-section briefly analyzes patterns of trade with several indicators that could help identify patterns of reshoring or regionalization, such as the domestic value-added share in exports (DVAR), value-added trade in intermediates, and production length.

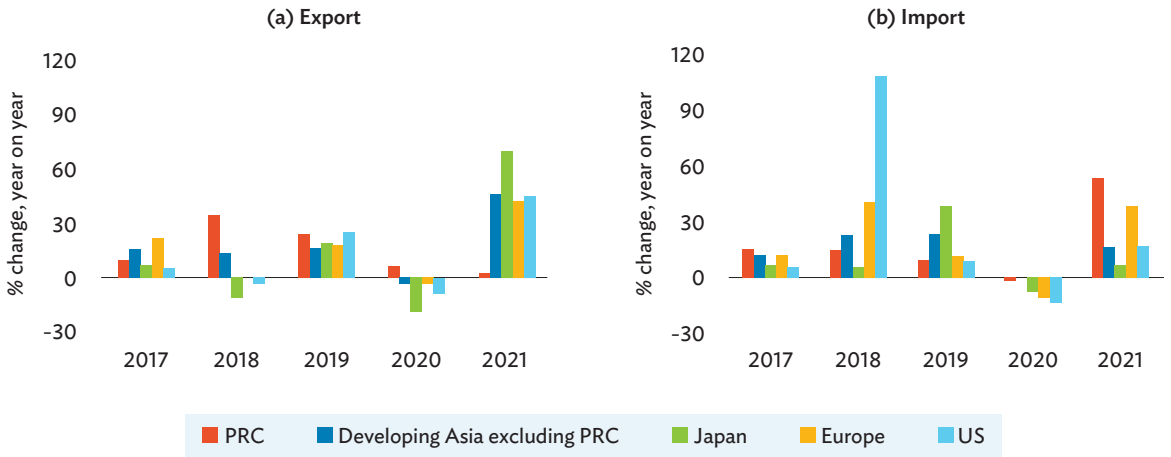
From 2017 to 2021, DVA shares were mostly steady in most regions (see Figure 2.7). While there has been a slight decline in the shares of the PRC and ASEAN, these variations are minor. However, developing Asia's intermediate goods trade data indicates the first signs of regionalization. Developing Asia's value-added trade in intermediate goods remained stable in the pre-tension period 2013–2016 in terms of both intra- and extra-regional trade. In contrast, by 2019, value-added trade in intermediate goods within developing Asian economies had risen by 63% compared with 2016 (see Figure 2.8), which was primarily driven by regional exports of intermediates to the PRC. These patterns reflect the increased level of regionalization as US–PRC tensions mounted (Hugot & Platitas, 2022), with the PRC shifting its imports of intermediate goods away from the US toward developing Asian economies. According to Hugot and Platitas (2022), regional exports of intermediate goods from developing Asia economies to the rest of the world declined significantly in 2019, which made the PRC an even more critical market for producers of intermediate inputs throughout Asia.

Figure 2.7: The Domestic Value-Added Share in the Total Export



Notes: North America (the US, Canada and Mexico), EU refers to the European Union excluding the United Kingdom, ASEAN includes Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Myanmar, and Viet Nam.
Source: University of International Business and Economics (UIBE) global value chain index database, EXin5VA, ADBMRIO2022 version

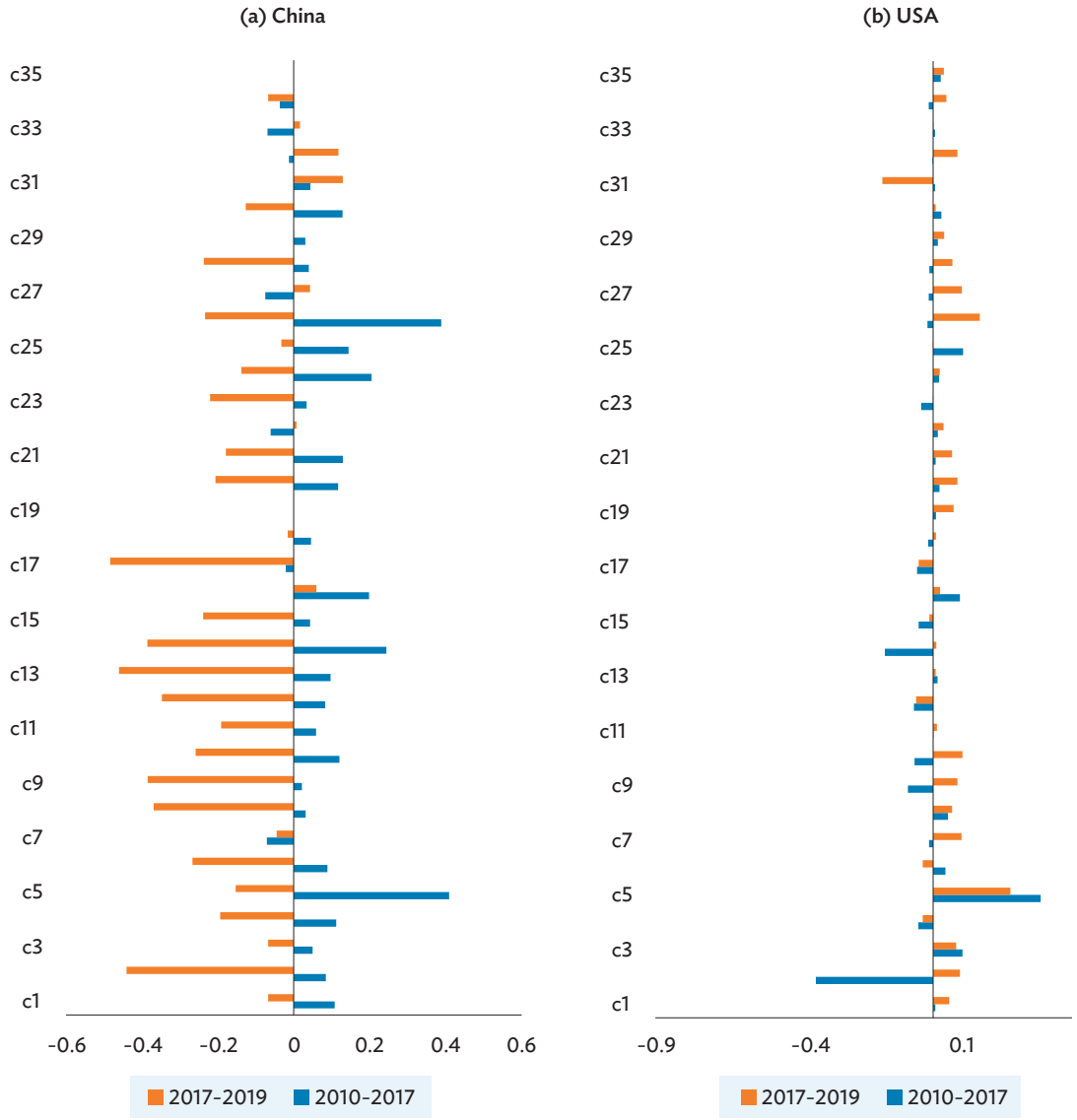
Figure 2.8: Changes in Developing Asian Economies' Value-Added Trade in Intermediate Goods



Notes: Europe = the European Union, Norway, Russia, Switzerland, Türkiye, and the United Kingdom; PRC = People's Republic of China; US = United States, Developing Asia = Bangladesh; Bhutan; Brunei Darussalam; Cambodia; Fiji; Hong Kong, China; India; Indonesia; Kazakhstan; Kyrgyz Republic; Lao People's Democratic Republic; Malaysia; Maldives; Mongolia; Nepal; Pakistan; People's Republic of China; Philippines; Republic of Korea; Singapore; Sri Lanka; Chinese Taipei; Thailand; and Viet Nam.
Trade in intermediate goods was excluded for the following industries: mining, mineral fuels, food and beverages, metals, and other minerals.
Sources: Asian Development Bank Multi-regional Input Output Database 2022. Hugot, J., & Platitas, R. (2022).

In addition, changes in the production length also imply a trend towards more local intermediate goods markets, at least for the PRC. Before 2018, the length of the production chain in most industries in the PRC increased, implying a deeper integration into the global production system, especially in the manufacturing sector, while the length of US manufacturing value chains remained relatively stable. However, from 2017-19 the length of the production chain in the vast majority of Chinese industries (30 out of 35) declined, while that in most US industries (29 out of 35) increased, albeit to a much smaller degree (see Figure 2.9).

Figure 2.9: Changes in Sectoral Production Length of the PRC and the USA



Source: UIBE global value chain index database, Length_ADBMRIO2022

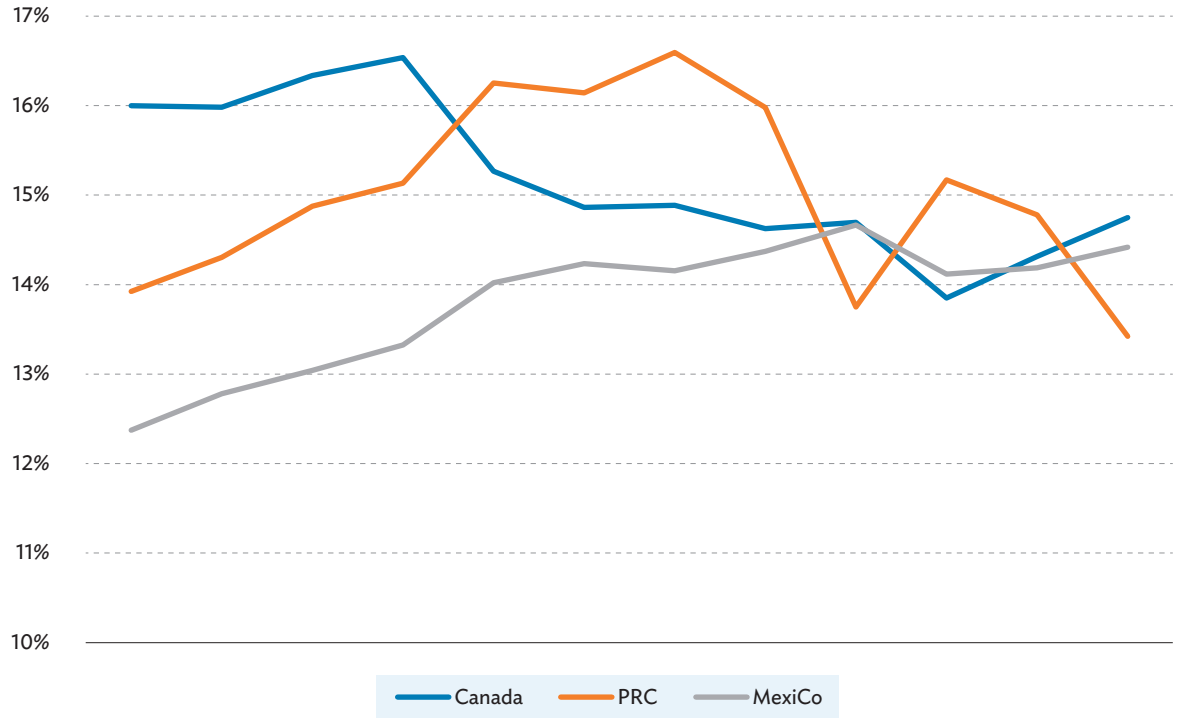
2.4 Trade Tensions and Global Value Chains

Trade Among the Major Economies

Since the onset of the US–PRC trade tensions and the COVID-19 pandemic, the trade patterns of the world's major economies have changed (see Appendix 3). The EU has increased its trade with the PRC and the US driven in particular by changes in German trade. Germany has increased its trade with the PRC, the US, and Poland while reducing its trade with France, which has fallen from first to fourth in terms of Germany's largest trading partners. The US continues to be PRC's largest trading partner, even though trade between the two countries in relative terms has fallen since the commencement of the trade tensions. The PRC's trade with high-tech Asian economies initially declined, but trade with Southeast Asian countries such as Viet Nam has increased. Malaysia has the highest share of trade within the ASEAN region, and the PRC has long been its largest trading partner beyond the region, followed by the US; Hong Kong, China; and Japan.

Before the trade tensions, the PRC was the largest source of imports and the third-largest export destination for the US, while the US was the third-largest source of imports and the largest export destination for the PRC. Since then, the US slipped from being the PRC's largest trading partner to its third-largest partner behind ASEAN and the EU, while the PRC fell from being the US's largest trading partner to its third-largest partner behind Canada and Mexico (see Figure 2.10).

Figure 2.10: Top Three Trade Partners in Merchandise of the US

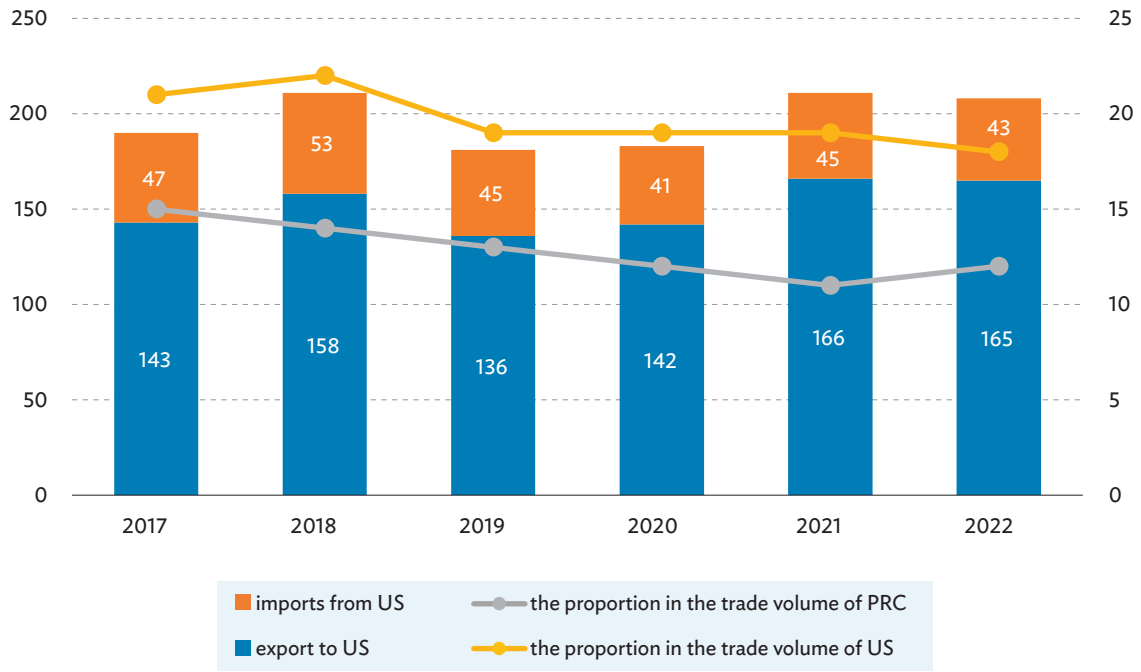


Sources: United Nations (UN) Comtrade database

Between 2017 and 2019, total imports by the US from the PRC decreased by 11.1%, with imports of products subject to increased tariffs decreasing by 18.4%, while imports of other products increased by 3.5%. Specifically, the US reduced its imports of industrial supplies and consumer goods from the PRC and increased its imports of automobiles and food products. As for the PRC, total imports from the US decreased by 19.8%, with imports of products subject to increased tariffs decreasing by 27.0% and imports of other products decreasing by 0.8%. During COVID-19 (2019–2022), bilateral trade between the US and the PRC increased dramatically. Total US imports from the PRC increased by 19.5%, with imports of products subject to tariff increases rising by 5.6% and imports of other products rising by 41.4%. Meanwhile, the PRC's imports from the US increased by 15.9%, with imports of products subject to tariff increases falling by 0.1% and imports of other products rising by 58.4%. Thus, in terms of overall trade volume, PRC–US bilateral trade has demonstrated resilience.

Although the total trade volume between the PRC and the US has maintained an upward trend in recent years, trade in products subject to tariffs, especially high-tech products, has shown a gradual downward trend (Bown, 2023; WTO, 2023). The US has introduced numerous trade acts and policies in an effort to limit the trade of certain security-related high-tech products with the PRC. In line with this and as shown in Figure 2.11, the PRC's trade volume of high-tech products with the US declined. Imports fell from $46.5 billion in 2017 to $43 billion in 2022. The fall has been even more pronounced in relative terms. The proportion of the PRC's total trade in high-tech products that was accounted for by trade with the US fell from 14.5% in 2017 to 11.8% in 2022, while the proportion of the US's total trade in high-tech products that was accounted for by trade with the PRC fell from 21.1% to 18.0% over the same period.

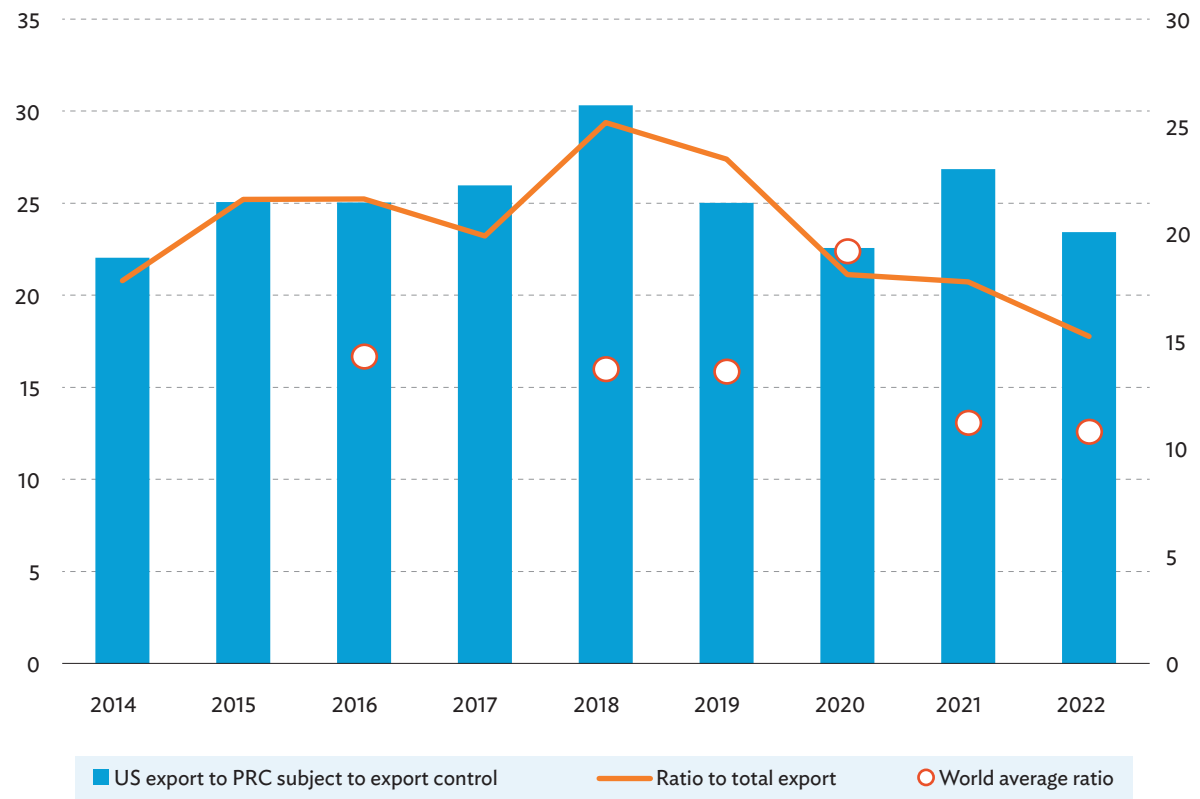
Figure 2.11: PRC-US Trade in High-Tech Products



Source: WITS database.

The decline in US exports of high-tech products to the PRC is likely to have been affected by US export controls. The US has increased exports of some products in specific areas to the PRC over the past few years. However, the Bureau of Industry and Security of the US Department of Commerce has reported that the overall trend of exports to the PRC of products belonging to export-controlled categories is declining (see Figure 2.12). The PRC increased its imports of these goods before the US export controls came into effect, resulting in exports of US export-controlled goods increasing significantly in 2018 before declining. Despite some volatility in subsequent years, the share of total exports to the PRC represented by these goods declined from 25% in 2018 to 15% in 2022.

Figure 2.12: US Export to PRC Subject to US's Government Export Control



Notes: Controlled exports include exported products subject to a BIS license requirement and exports under No License Required (NLR) reporting an Export Control Classification Number
Source: US Bureau of Industry and Security (BIS) report, US Trade with China, 2014–2022

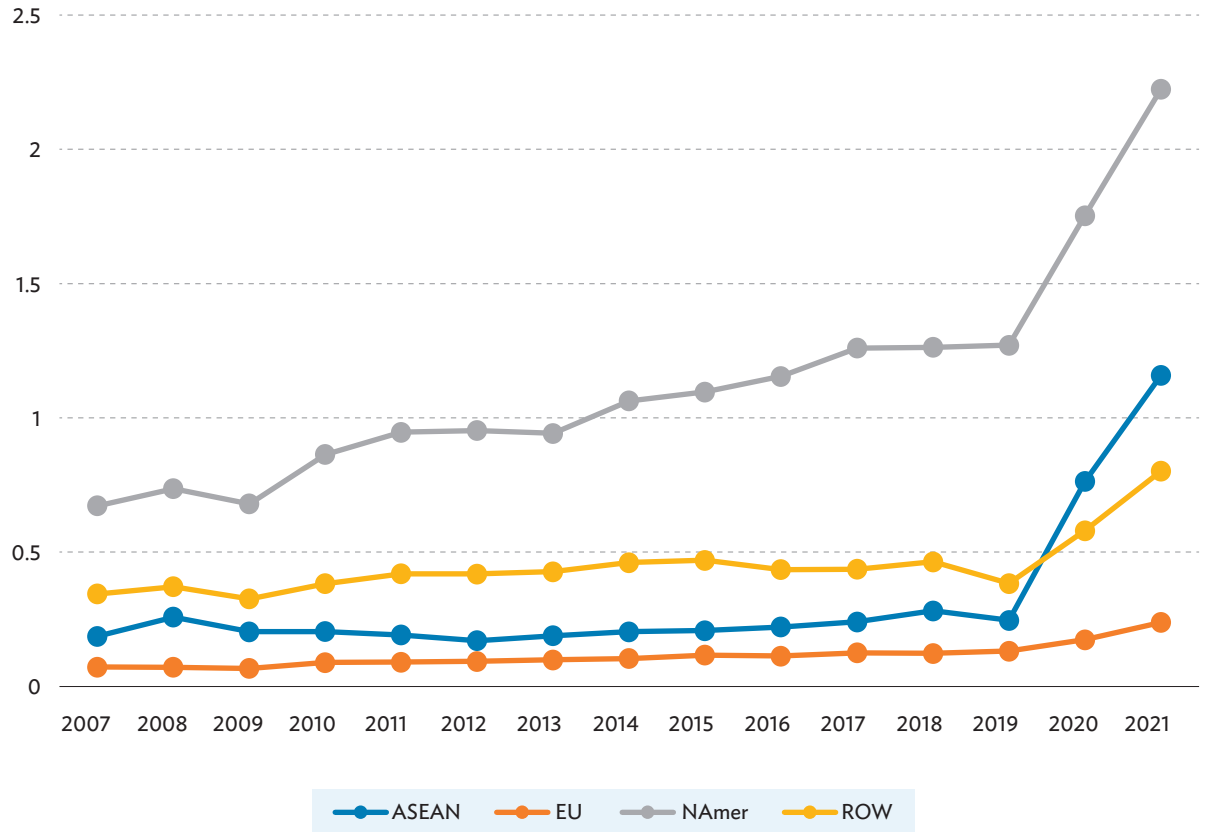
Triangular Trade between the PRC, the US and Third Countries

The rise of GVCs implies that countries are increasingly connected indirectly through trade. As the foreign content of exports increases, importers depend to a larger degree on the suppliers of their suppliers. This means that looking at simple bilateral gross trade statistics when assessing the interdependence between two countries might be

misleading. For instance, in response to an increase in bilateral trade costs, companies look for alternative paths in an effort to avoid tariffs and the associated uncertainty. A prominent example of this is the response of firms from the PRC and the Republic of Korea, which avoided US antidumping duties by relocating production to countries not targeted by those duties (Flaaen et al., 2020). This section presents initial statistics on indirect imports by the US from the PRC through third parties.

Using multi-regional input–output tables published by the Asia Development Bank, we calculate indirect exports from the PRC to the US through third regions by multiplying the ratio of intermediate imports of a given third country from the PRC to the total intermediate input of that country with the ratio of its exports of final products to the US to its total exports at the sectoral level and then aggregating to the regional level using simple averages. Although direct exports from the PRC to the US have gradually decreased since 2018, Figure 2.13 shows that indirect exports have increased in recent years, primarily via ASEAN, Mexico, and Canada since 2020. At the industry level, fabrics and textile products, leather and footwear, equipment manufacturing, electrical and optical equipment, and transportation equipment (see Box 2.1) are the key US industries that indirectly import intermediate goods from the PRC.

Figure 2.13: Indirect Import of Intermediate Inputs from the PRC to the US through Third Regions

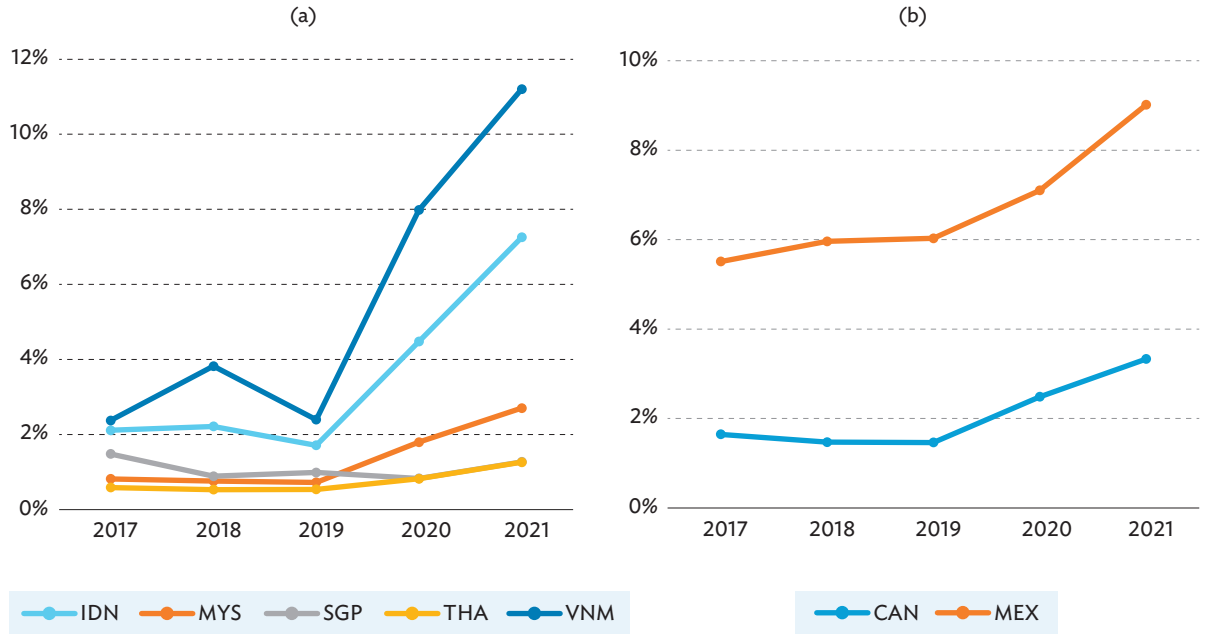


Notes: The indirect import was calculated by multiplying the ratio of intermediate imports of the third country from the PRC to the total intermediate input of the third country with the ratio of export of final products from the third country to the US to the total export of third country at the sectoral level. The lines represent simple averages across sectors.

Sources: Asian Development Bank Multi-regional Input–Output Database 2022

Southeast Asian countries, which are geographically close to the PRC and have relatively low labor costs, have become important intermediaries for trade between the PRC and the US. In particular, Malaysia, Singapore, and Viet Nam have experienced a significant increase in exports to the US as a share of total exports. Meanwhile, imports of intermediate goods from the PRC by ASEAN countries such as Indonesia, Malaysia, Thailand, and Viet Nam have rapidly increased, especially in 2020 and 2021. Figure 2.14a shows that the proportion of US imports from the PRC through Viet Nam and Mexico has risen significantly over the past five years. Goods imported through Viet Nam went from as low as 2% in 2019 to 10.4% in 2021. The indirect intermediate import from the PRC through Mexico to the US rose to 8% at that year, up from 5% in 2017 (see Figure 2.14b).

Figure 2.14: The Ratio of Indirect Intermediate Import of the US from the PRC through ASEAN and USMCA Countries.



Notes: We compute here the share of sector-specific exports of final goods from the PRC to the US as a percentage of the total sectoral exports of final goods, and the share of sector-specific intermediate goods exported to the US from the PRC as a percentage of the total sectoral imports of intermediate goods by the US. These two figures were then multiplied and aggregated using simple averages at the country level to represent the indirect imports by the US of intermediate goods from the PRC through ASEAN countries.

Sources: ADB MRIO database

This evidence on triangular trade is in line with several recent studies. Fajgelbaum et al. (2021) highlight that some third countries, especially Viet Nam, Thailand, the Republic of Korea, and Mexico, benefitted significantly from the tensions as they increased their exports to the US and the rest of the world. Alfaro and Chor (2023) suggest that this combination of increased sourcing of inputs from the PRC and increased exports to the US of these economies is likely inefficient and presents early evidence of associated price increases in US imports from Viet Nam and Mexico.

Box 2.1: Changes in Global Trade Patterns – The Rise of Electric Vehicles and the Auto Industry

The International Organization of Motor Vehicle Manufacturers (OICA) has reported that the PRC has become the world's leading auto manufacturing and consuming country, accounting for approximately 31.8% of global production and 32.9% of global sales in 2022 thanks in part to electric vehicles (O, 2023). In recent years, the Chinese government has provided support to new-energy vehicle (NEV) producers in an effort to promote domestic auto production. During 2012–2017, the DVA share of auto exports rose slightly. Meanwhile, the DVA shares in processing exports and foreign-invested firms' exports declined during this period, indicating that the PRC's domestic auto industry was positioned deeper in GVCs as an intermediate importer (Cai & Wang, 2022).

In the meantime, the tariffs imposed by the US on Chinese-made auto parts significantly impacted US imports from the PRC, resulting in declines of 22.8% and 26.7% in 2019 and 2020, respectively (Gaydarska et al., 2022). Mexico was one of the beneficiaries of the trade tensions because the decline in imports by the US of auto parts from the PRC was accompanied by a corresponding increase in imports from Mexico.

2.5. COVID-19, GVCs and Digitalization

The Impact of COVID-19 on Reshaping Global Value Chains

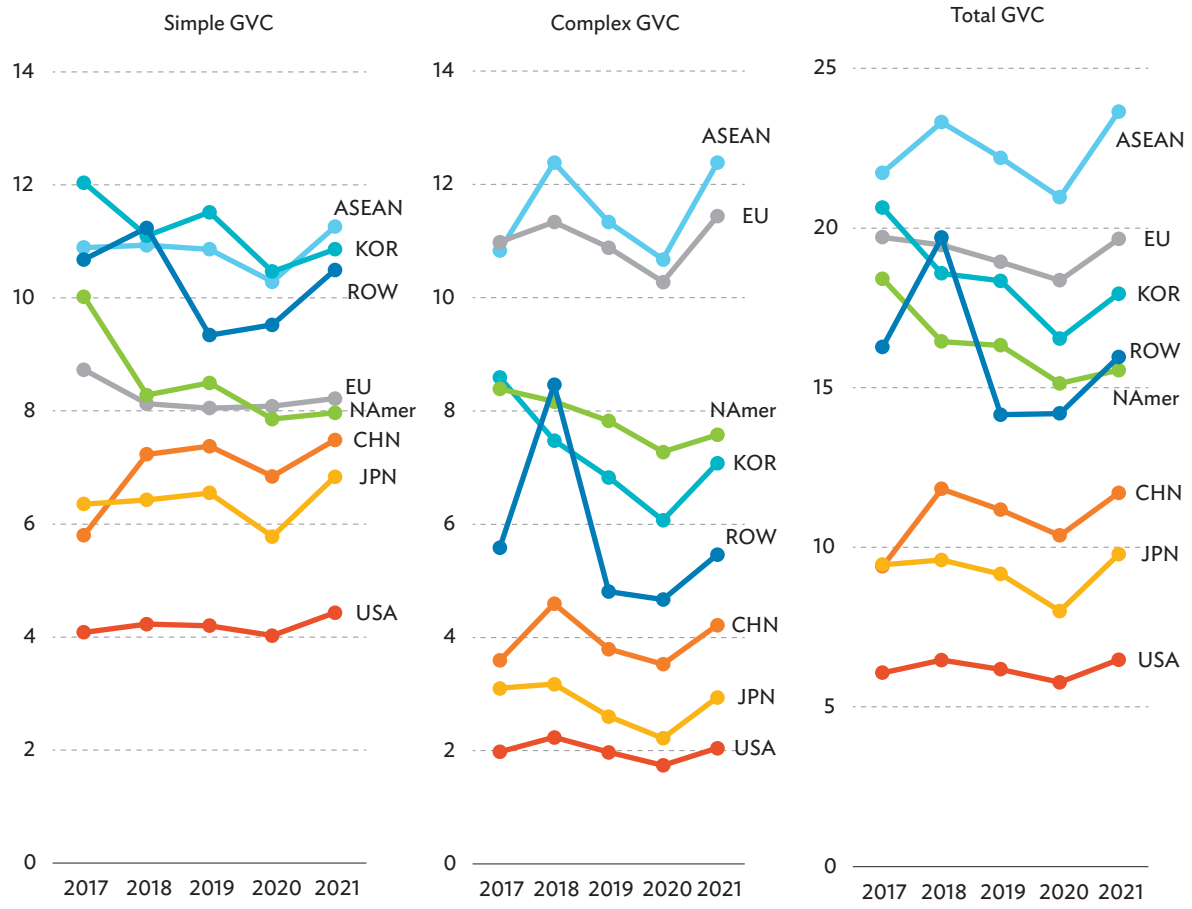
The COVID-19 pandemic and related disruptions to the movement of products and people have exacerbated challenges to globalization. The collapse of supply chains during the pandemic has led to concerns about the ongoing availability of key commodities, and policymakers have considered various responses to increase resilience, including regionalization and reshoring (Barbieri et al., 2020). Moreover, the pandemic came during a period at which GVC expansion was already slowing down. Previous studies have identified several factors behind this trend (Bacchetta et al., 2021; Enderwick & Buckley, 2020). These factors include rising trade costs and trade policy uncertainty. As discussed above, rising trade tensions have led to tariff increases between major trading economies. Another factor is eroding wage differences between developed and developing economies that decrease the returns to offshoring. A third factor is technological progress in areas like automation and artificial intelligence.

Recent trade data provide some clues regarding the reconfiguration of the value chains to see whether the pandemic accelerated the slowdown of GVCs through regionalization. We analyze the reconfiguration of GVCs using aggregate interregional trade data and value chain indicators (see Figure 2.15). The pandemic led to a severe contraction of GVCs in 2020, but GVC activity rebounded rapidly in 2021.

Counterfactual Analysis of the Impact of the COVID-19 Pandemic on GVCs

To assess whether the rebound in GVC activity is likely to continue, we use a counterfactual analytical framework in the form of an extended computable general equilibrium (CGE) model to explore the impact of this external shock on GVCs (see Appendix 4). This analysis considers four sources of shock: labor, consumption preferences, trade costs, and tourism. The key setting is that while various countries are

Figure 2.15: The Share of Total, Simple and Complex GVC Activities



Notes: For simplicity, the GVC indicators are aggregated from UIBE GVC indexes, which originally are country-specific indices. The country-level backward decomposed items are firstly aggregated and then calculated the share of GVCs, which may induce bias.
Sources: UIBE global value chain database, FGin5VA, ADBMRIO 2022 version.

set to recover at different rates depending on their performance during the pandemic, almost all the shocks are expected to return to the baseline by 2025. For example, the labor supply decreased sharply in 2020 due to COVID-19, but would gradually bounce back to the original level prior to the pandemic.

Next, we assess the impact of the COVID-19 shock on different components of exports based on a decomposition that allows to more clearly separate between GVC trade and traditional trade (see Box 2.2 for details). In addition, we distinguish between domestic and foreign firms as the COVID-19 pandemic has significantly impacted global investment patterns.

The effects discussed in this section are counterfactual estimates representing the difference between the business-as-usual and policy scenarios so that the results can be positive or negative. For example, the World Economic Outlook data published by the International

Monetary Fund in October 2019 suggested that the PRC's GDP growth was expected to be 5.8% in 2020 under the business-as-usual scenario. However, due to the COVID-19 pandemic, GDP growth was only 2.2%. Thus, the counterfactual result is negative 3.6%, which can be regarded as the effect of the COVID-19 pandemic on the PRC's GDP.

Box 2.2: GVC activities with FDI heterogeneity

Extended CGE modeling incorporating MNEs was used to quantify the impact of the COVID-19 pandemic on GVCs. A GVC decomposition method that distinguishes between domestic and foreign investment (Wang et al., 2021) was used to map the impacts of the COVID-19 pandemic. This framework distinguished five indexes: VD, VRT, VGT, VGI, and VGTI.

(1) **VD:** Value added created by domestic firms in their final production to satisfy domestic final demand, which is pure domestic activity.
(2) **VRT:** Value added created by domestic firms but embedded in final goods exports to satisfy final demand abroad, representing traditional trade production activities.
(3) **VGT:** Value added embodied in intermediate exports that are produced by domestic firms in the exporting country, but used by domestic firms in the direct importing country to produce final products either for domestic consumption or for export to third-party countries, which is regarded as trade-related GVC activities.
(4) **VGI:** Value added embodied in the activities of foreign firms in a host country. All of the production activities and linkages between foreign firms and domestic/foreign firms are located in the host country and aim to meet the final demand in either domestic or foreign markets, which represents FDI-related GVC activities (VGI).
(5) **VGTI:** Value added embodied in activities involving both cross-border investment by foreign firms and cross-border trade. The value added created by domestic (foreign) firms is embedded in the intermediate exports that are used by foreign (domestic) firms to produce final products that are either consumed domestically (in the direct importing country) or exported to other countries, which represents trade- and FDI-related GVC activities.

The COVID-19 pandemic significantly impacted traditional global trade (VRT), with trade of final products falling by 13.3% in 2020 before rebounding by 20.4% in 2021. Regarding trade-related activities (VGT), this was mainly the result of the contraction of trade in intermediate goods due to lockdowns or export restrictions at the global level.

However, FDI activities (VGI and VGTI) were not significantly affected by the COVID-19 pandemic. First, capital is more mobile than physical goods, and multinational companies were able to adjust their global allocations in response to the pandemic. Second, due to national lockdowns, overall demand tended to favor domestic supply, thereby increasing linkages between domestic producers, among which the strong links between local and foreign firms support the FDI activities. Although all items experienced a negative impact in 2020, the structure shows that the proportion of pure domestic production activities increased while that of all other items decreased. Following the breakdown of international supply chains as a result of increased trade costs, coupled with government restrictions on exports, especially of essential goods, there was an increase in domestic production and supply.

At the economy level, PRC, Mexico, and ASEAN differed from other economies (see Figure 2.16). The PRC experienced a sharp increase in pure domestic activities, which offset the decline in international demand. In addition, the PRC's FDI-related activities increased, which is more likely to have been driven by foreign firms within the PRC

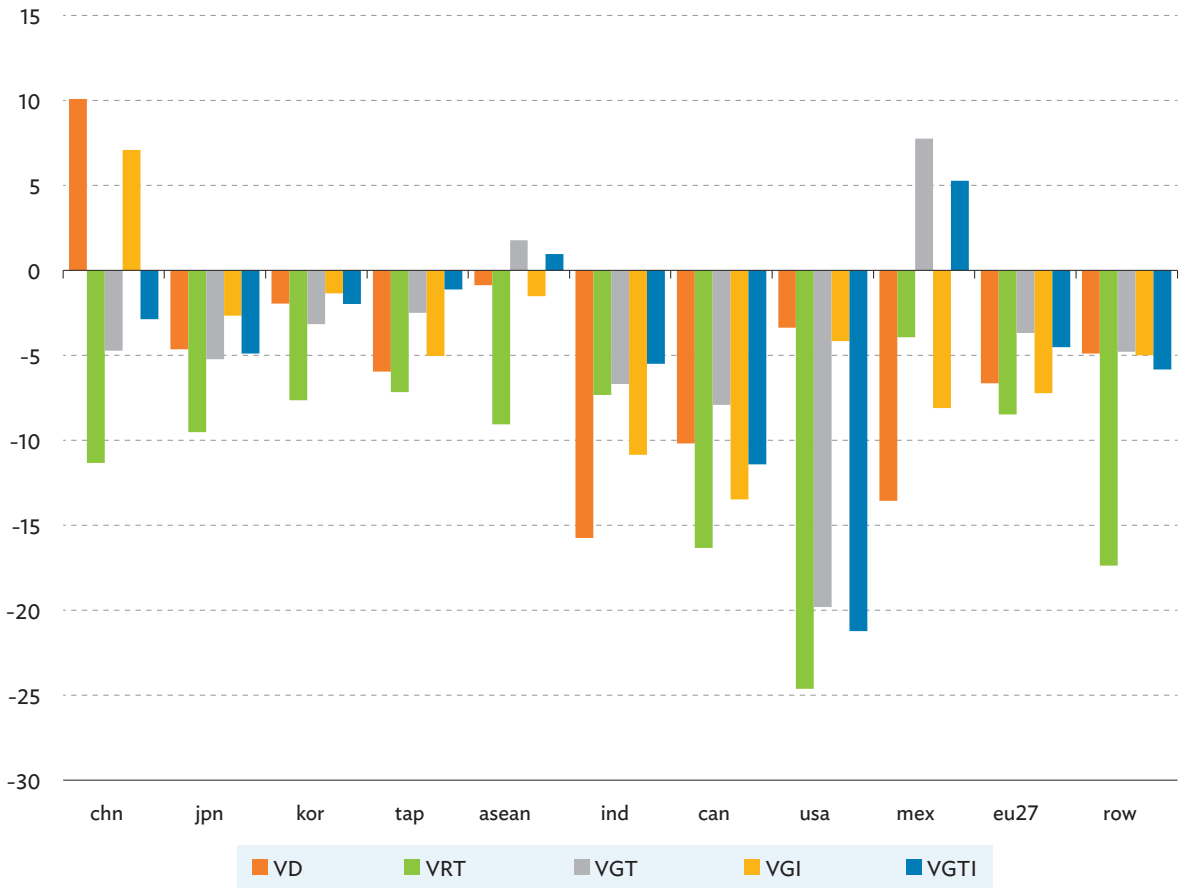
than by cross-border trade activities of foreign firms. First, as mentioned earlier, the resilience of the PRC's production during the pandemic enabled the PRC to continue to supply significant amounts of products to the rest of the world, particularly ASEAN countries. Second, the increase in domestic demand, coupled with border closures, increased demand from the PRC's domestic suppliers, including foreign-owned firms within the PRC. This is also consistent with the internal financing hypothesis whereby local foreign-owned firms tend to retain profits to enable increased investment in regions offering higher returns (Moosa & Merza, 2022). UNCTAD data revealed that the PRC's FDI inflows increased during the pandemic in both 2020 and 2021[2].

In contrast, Mexico and ASEAN received more orders from abroad, so the trade-related activities (VGT) and trade- and FDI-related activities (VGTI) in these countries increased during the pandemic. The former describes cross-border production activities of domestic firms in different regions, while the latter describes cross-border production activities between domestic and foreign firms. The increase in both suggests that Mexico and ASEAN imported intermediate products to enable them to produce final products during the pandemic. As can be seen from the detailed GVC decomposition framework, several channels require further empirical analysis. Firstly, domestic firms strengthened their linkages with local firms in other countries. Secondly, foreign firms in other countries used their global advantages to outsource to domestic or foreign firms in Mexico and ASEAN. Third, foreign-owned firms in Mexico and ASEAN purchased intermediate goods from domestic firms in other countries.

The COVID-19 pandemic not only affected the structure of global trade but also restructured the value chains. We chose four countries, the PRC, the US, Mexico, and India, to discuss the typical changes in GVCs (see Figure 2.17). After the PRC returned to normal following the pandemic, pure domestic production and FDI-related activities were higher than the baseline. Mexico's traditional trade was crowded out by the economic recovery in other regions and has continued to decline since then. In addition, although trade-related activities and trade- and FDI-related activities increased during the 2020 pandemic, they might decline in the future once these activities in other countries start to recover. Mexico's performance was essentially the result of a reorganization of the GVCs. At the beginning of the pandemic, Mexico imported more intermediate goods to produce final goods, attracting a large amount of FDI. During the recovery, the PRC's strong supply capacity for final products and productivity recovery in other countries reduced the demand for Mexican products. Thus, Mexico's traditional trade has gradually declined. Global capital has also tended to gravitate toward the PRC, the US, and Europe, thereby reducing investment into Mexico and shifting the impact of COVID-19 on Mexico's FDI-related activity from positive to negative in the long run.

2 UNCTAD, Global foreign direct investment flows over the last 30 years, https://unctad.org/data-visualization/global-foreign-direct-investment-flows-over-last-30-years, accessed by July, 2023

Figure 2.16: Changes in Value-Added Activities in 2020 (%)

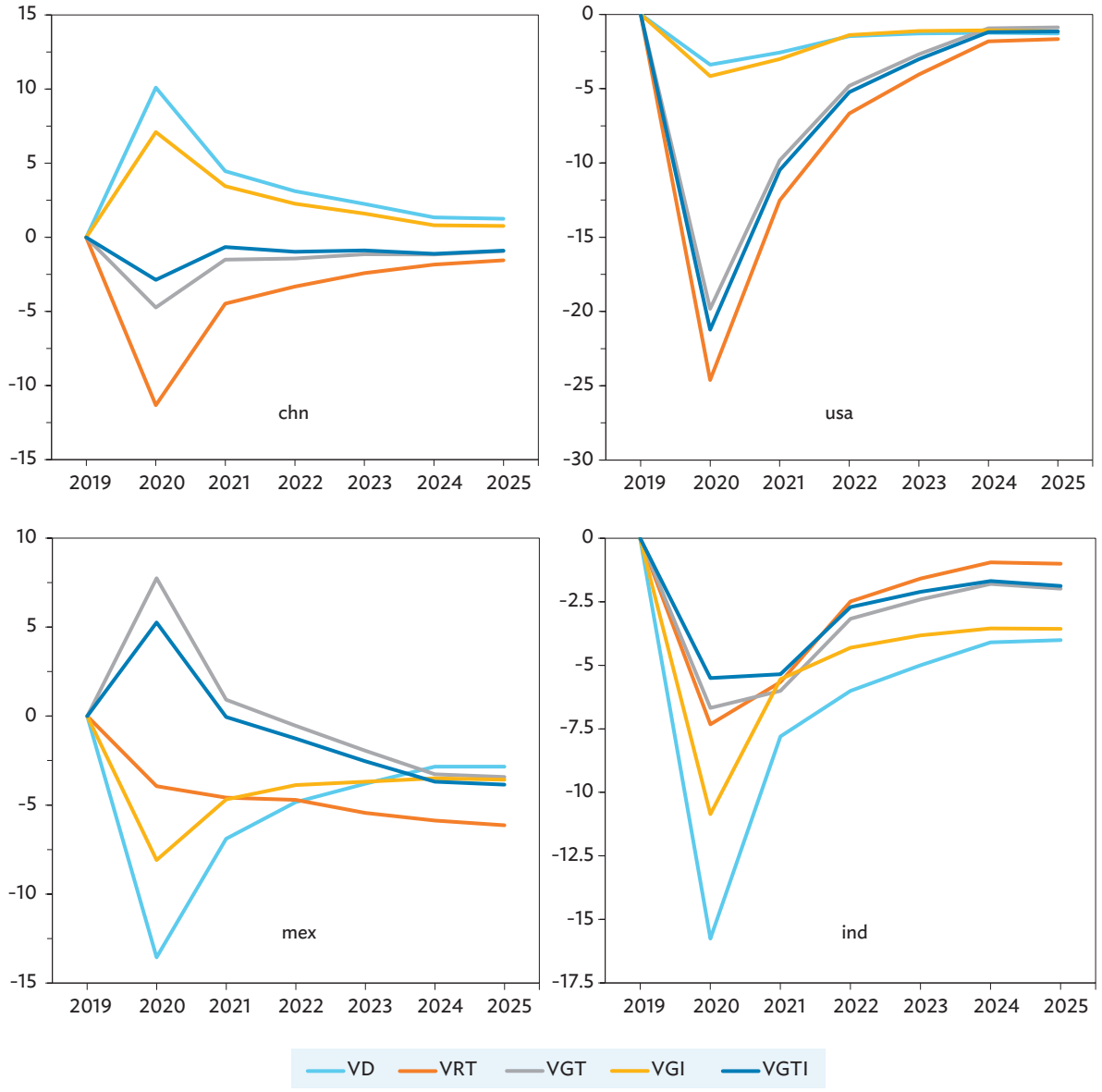


Note: VD = pure domestic production activities, VRT = traditional trade production activities, VGT = trade-related GVC activities, VGI = FDI-related GVC activities, and VGTI = trade- and FDI-related GVC activities, following Wang, Wei, Yu & Zhu (2021).

The long-term trends in the US and India are similar, with the GVC indicators gradually returning to the baseline following the shock. However, the impact of the pandemic was more significant in India, which experienced an outbreak of COVID-19 in the first half of 2021 and thus was slower to recover than the US. In addition, the US, which offers greater returns on investment, received more FDI, enabling a faster recovery.

As shown in Figure 2.17, due to the higher growth rates of pure domestic and FDI-related activities relative to other components, the proportions of these two activities in the PRC would increase. Similarly, as for India, all items except pure domestic activities increased indicating that India would participate more in GVC activities. At the same time, Mexico's trade-related and trade-FDI-related activities are also important to the global value chains. In summary, trade disruptions as a result of the COVID-19 pandemic caused a sharp decline in trade. However, trade rebounded even stronger in 2021, reversing previous trends.

Figure 2.17: Growth rates of GVC items in the PRC, the US, Mexico, and India.



Note: VD = pure domestic production activities, VRT = traditional trade production activities, VGT = trade-related GVC activities, VGI = FDI-related GVC activities, and VGTI = trade- and FDI-related GVC activities, following Wang, Wei, Yu & Zhu (2021).

Digitalization, Resilience and Recovery

In an increasingly interconnected and rapidly changing world, GVCs face numerous challenges that can disrupt operations and impact global economies. Digital infrastructure and technologies offer a promising means of enhancing the resilience of supply chains, promoting rapid adaptability and thereby enabling businesses to thrive in volatile environments.

Firstly, the development of the digital economy itself can enhance economic resilience by increasing the size of the economy (OECD, 2018). The rise of digital industries, such as the platform economy and the Internet economy, has increased the number of industrial forms in numerous countries, expanded employment options (Bai et al., 2021), and spread regional systemic risk, all of which can help countries to combat external shocks (Pisu et al., 2021).

Secondly, digitalization improves transparency and the allocation of resources (OECD, 2018). Digital technologies can help reduce information asymmetries, lowering search costs for producers and dramatically increasing the circulation of resources. Information sharing can strengthen the connection between suppliers and buyers, and facilitate collaboration among stakeholders, thereby reducing friction along the value chain. Digital platforms enable seamless communication, information sharing, and coordination among suppliers, manufacturers, distributors, and customers (Santos et al., 2023). Technologies like the Internet of Things, cloud computing, and big data analytics enable businesses to streamline processes, monitor operations in real-time, and make data-driven decisions.

Thirdly, digitalization can help manage the risks and improve the security of global supply chains (Eling & Lehmann, 2018). Increased visibility enables early detection of potential disruptors and the appropriate adjustments to mitigate risks swiftly and effectively. By creating an interconnected ecosystem, businesses can quickly identify bottlenecks, resolve issues, and make informed decisions, thereby fostering resilience and adaptability (Bürgel et al., 2023; Forliano et al., 2023).

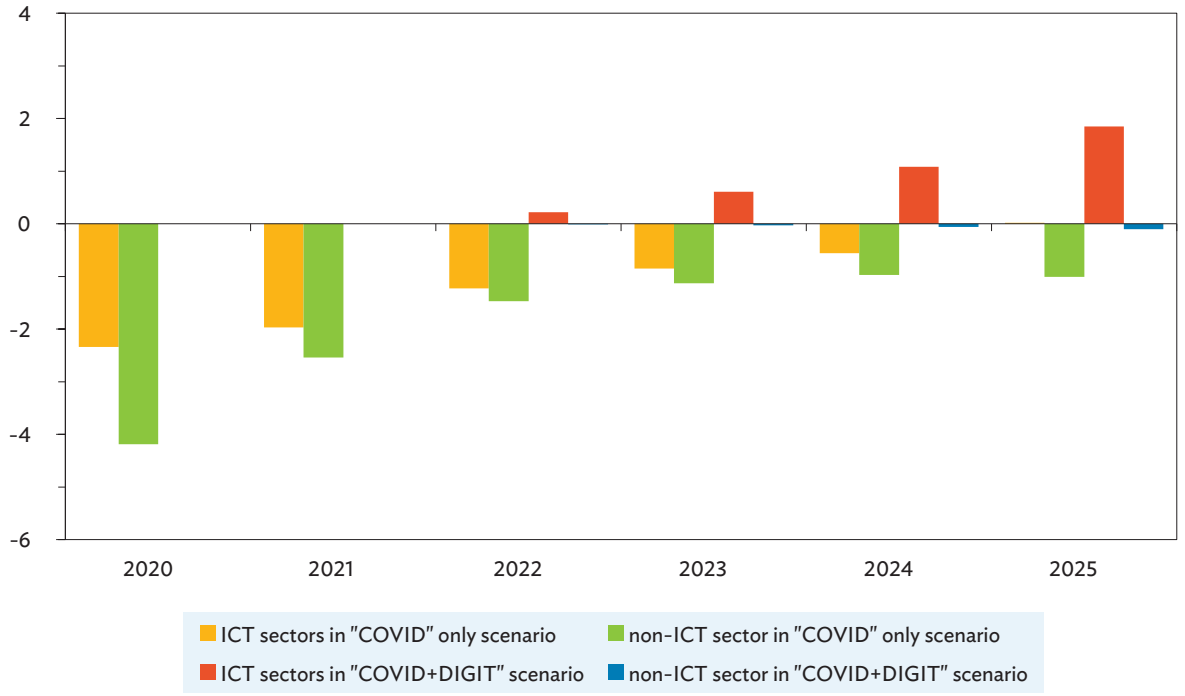
In particular, blockchain technology can provide an immutable and transparent transaction record, thereby enhancing stakeholders' trust and security (Ganne, 2018). Radio Frequency Identification technology enables tracking products, materials, and components, enabling greater control of the production process and reducing the likelihood of disruptions. With improved visibility, businesses can proactively manage supply chain complexities, respond to evolving customer demands, and minimize the impact of unexpected events. Integrating automation and robotics technologies into industrial processes reduces dependence on manual labor and enhances efficiency.

During the COVID-19 pandemic, digital technology enhanced the resilience of the production and supply chain systems in various countries, thereby reducing the impact of the pandemic on their economies (Gaspar et al., 2022; Jaumotte et al., 2023; Kim & Kim, 2023; Kim et al., 2022). The flexibility provided by the ability to work remotely increased the labor supply in some industries, while technologies such as artificial intelligence and robots maintained stable productivity in the manufacturing industry (Abidi et al., 2022; Copestake et al., 2022). Digital technologies enable productivity gains and economic growth by improving users' access to information and reducing trade and transaction costs (Khalil et al., 2022). In particular, establishing a healthy digital economic ecosystem in low- and middle-income countries can help them recover and build resilience in response to shocks similar to the COVID-19 pandemic. However, the digital divide can potentially exacerbate economic inequality, and technological catch-up requires considerable organizational and institutional change (Tinhinan, 2020).

Evidence from quantitative modeling that estimates the effects of digital technology policies on GVCs during COVID-19 reveals several facts (Gao et al., 2022). As shown in Figure 2.18, the decline in output of the information and communications technology (ICT) industry was less than that of non-ICT industries as a result of the increased demand for remote communication by individuals, businesses, and governments.[3] The results showed that the ICT industry experiences significant growth, while non-ICT industries barely change. The reasons for the difference between these two sectors are twofold. First, producers may shift resources to ICT inputs without affecting average costs (cost-neutral preference). Thus, total costs are unchanged but demand for ICT products rises. Second, we also assumed that the efficiency of ICT intermediate input would improve in the future, which can reduce the demand for ICT products, but this effect was insufficient to offset the effect of preference shift on the ICT demand. Thus, the overall effect of these two settings on the output of ICT sector was positive.

A natural question is whether the impact of the COVID-19 pandemic on GDP was relatively small in regions with relatively well-developed ICT infrastructure. Figure 2.19 shows scatter plots of several digital indicators against potential GDP changes.[4] All the scatter

Figure 2.18: Counterfactual Outputs of ICT and non-ICT Industries During the COVID-19



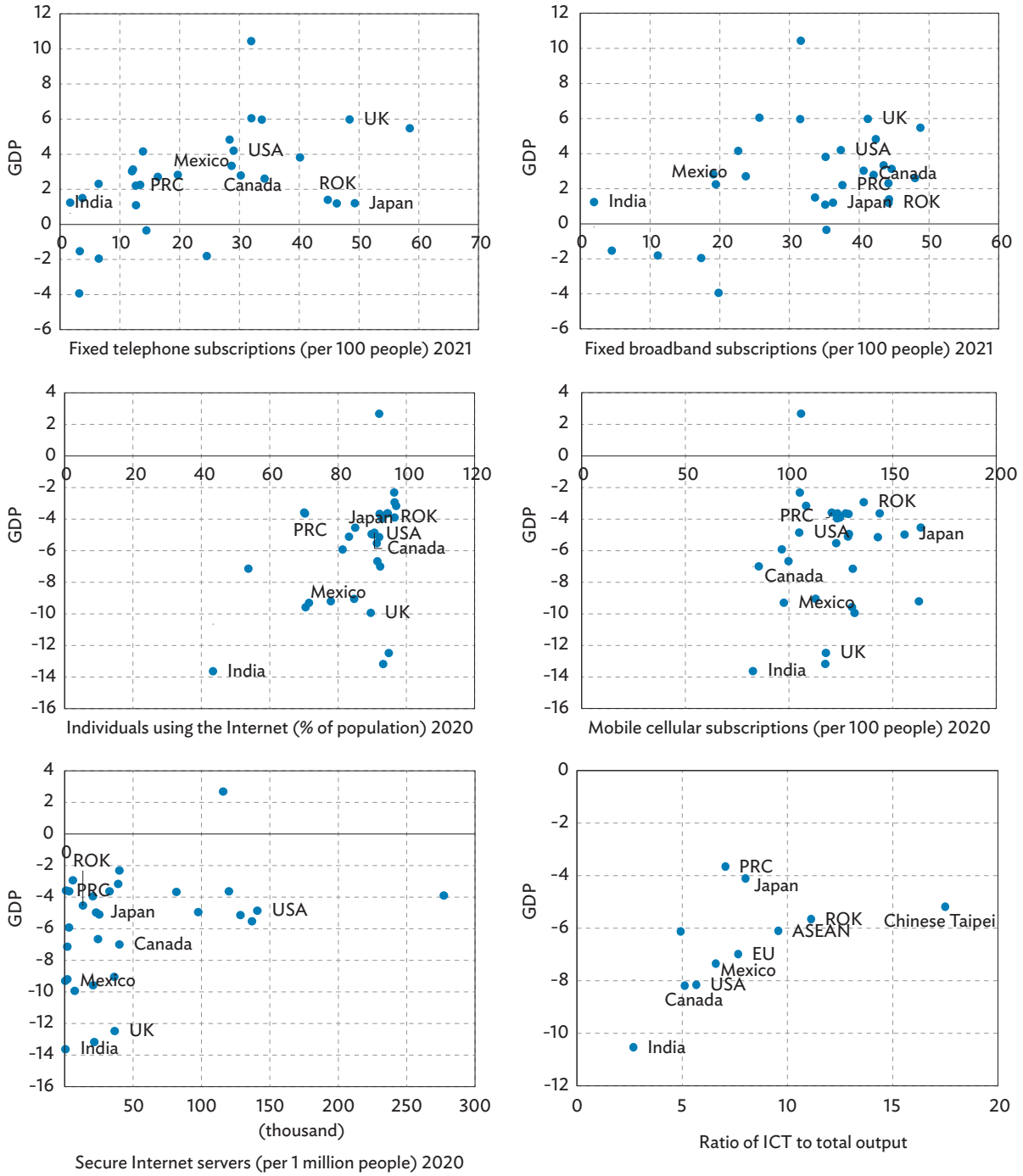
Notes: In the 'COVID' scenario, we only considered shocks to the labor supply, consumption preferences, trade costs, and tourism. In the 'COVID+DIGIT' scenario, we considered the shocks in the COVID scenario, but also included extra shocks, that is the producers would prefer more digital technology input and the efficiency of the technology usage will rise.

3 Here it is assumed that demand for intermediate ICT inputs by industries rose, as well as the efficiency of ICT inputs.

4 These indicators were obtained from the World Bank, and included fixed broadband subscriptions, fixed telephone subscriptions, mobile cell phone subscriptions, numbers of individuals using the Internet, and numbers of secure Internet servers per unit of population.

plots indicate that economies with more developed digital infrastructure experienced smaller declines in GDP (c-e), or recovered more quickly than other regions (a-b). Such findings illustrate the role of digitalization in dealing with shocks such as the COVID-19 pandemic and in shielding productivity and preserving employment.

Figure 2.19: Potential GDP Changes (%) and Digital Infrastructure



Note: The potential GDP changes in the first five scatterplots, panel (a)-(e), are the difference between actual and projected GDP published in the IMF's World Economic Outlook in October 2019. Panel (f) shows the counterfactual GDP result obtained from the CGE model.

Sources: World Development Indicators, International Monetary Fund World Economic Outlook, October 2019,

Conclusion

This chapter illustrated the propagation of shocks in GVCs and the correspondingly changing patterns in trade through events such as the US–PRC trade tensions and the COVID-19 pandemic. It discussed such effects based on the existing literature as well as indicators constructed by the authors. It also provided a general overview of trade patterns after such events and discussed the role of digital technology in the recovery and some trends toward reshoring.

Trade tensions between the PRC and the US reshaped global trade. Even though the aggregate trade flows did not decrease significantly, effects were felt at the sectoral level. Numbers show that during 2017–2022, global trade was reconfigured, and trade diversion effects followed. For instance, in response to the tariff increases by the US, the PRC shifted its export focus to East Asia and Pacific region and Europe and Central Asia region, with exports to those regions increasing by 11.7% and 16.1%, respectively.

The trade tensions increased the costs of global production, especially for downstream producers. Trade costs such as tariffs and non-tariff measures can accumulate along GVCs as goods and services cross borders several times, leading to higher costs of intermediate goods for downstream producers. The PRC's cumulative input tariffs, which consist of the retaliatory tariffs imposed by the PRC on the US and indirect tariffs along GVCs, jumped by an average of 47%. The US and the PRC incurred an additional indirect tariff burden of 10 and 6.5 billion US dollars, respectively, while third-party countries incurred additional costs of 30%–70%. The elasticity of DVA in response to the cumulative input tariffs was about 34%. Additional non-tariff burdens induced by the trade tensions and the COVID-19 pandemic mainly affected firms that were less able to diversify their production inputs or use additional inventories. While the trade tensions also induced increased regionalization and reduced the length of the global production chains, they did not trigger de-globalization.

The disruption of GVCs caused by the COVID-19 pandemic led to significant changes in the global economy. The COVID-19 pandemic first led to a sharp decline in trade, but the process subsequently reversed. Almost all traditional trade and trade-related activities significantly contracted during the COVID-19 pandemic, leading to an increase in consumption of output produced domestically (without intermediate inputs from abroad). Meanwhile, cross-border trade involving MNEs increased slightly as a result of stronger links between MNEs and domestic firms. The PRC played a far greater role in Asian production during the COVID-19 pandemic, with developing Asian economies' imports of inputs from the PRC declining by just 1%, while those from other regions (e.g. Europe, the US) fell by over 10%.

The effects of digitalization on economic recovery were also analyzed, and further evidence was obtained supporting the hypothesis that countries with superior digital infrastructure were less affected than others during the COVID-19 pandemic. Global

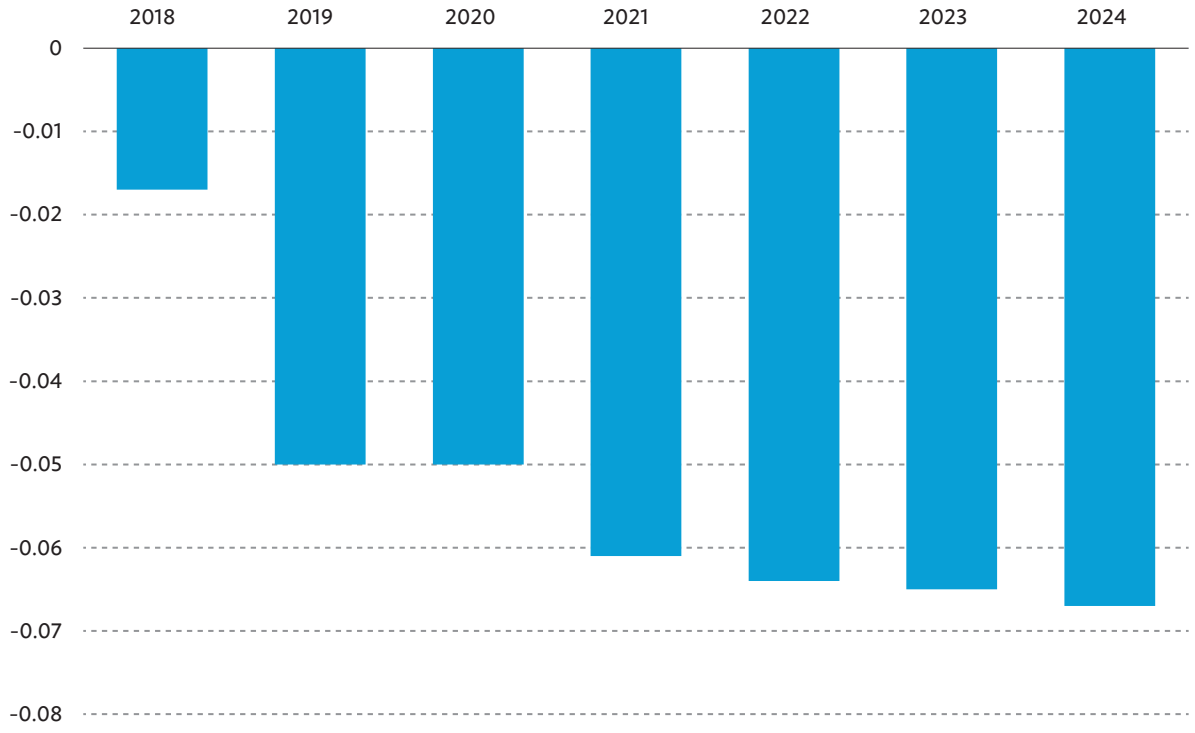
demand for digital technology led to increased investment in high-tech industries, thereby boosting FDI-related activities. The findings should help public policymaking in the post-COVID era about the resilience of GVCs, which could be strengthened by increasing the digitalization of economies, to better cope with uncertainties caused by trade conflicts and other external shocks.

Appendix

Appendix 1: Changes in the Average Global Value Chain Production Length as a Result of the US–PRC Trade Tension

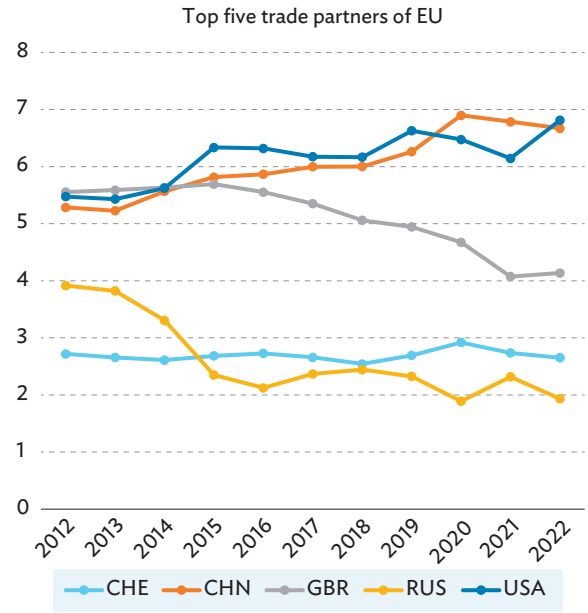
Disruptions arising from the US–PRC trade tension were expected to lead to an increase in reshoring (Meng et al., 2022). Although the average GVC production length is projected to decrease in the near future based on CGE modeling, this does not necessarily mean that the US–PRC trade tension triggered a process of de-globalization, if it is defined as the shortening of global value chain production length. Indeed, only two Asian economies, Hong Kong, China and Malaysia, de-globalized, although many less-developed Asian economies increased their self-reliance through increased domestic consumption while reducing their exports. In contrast, self-reliance declined in most advanced regional economies in terms of consumption, but increased in terms of exports, with machinery exports including more domestic content (Hugot & Platitas, 2022). Moreover, this CGE study has only considered the additional tariffs imposed by the US and the PRC on each other. We have not included other policies to minimize the adverse effects of these two countries or even any policies of other countries.

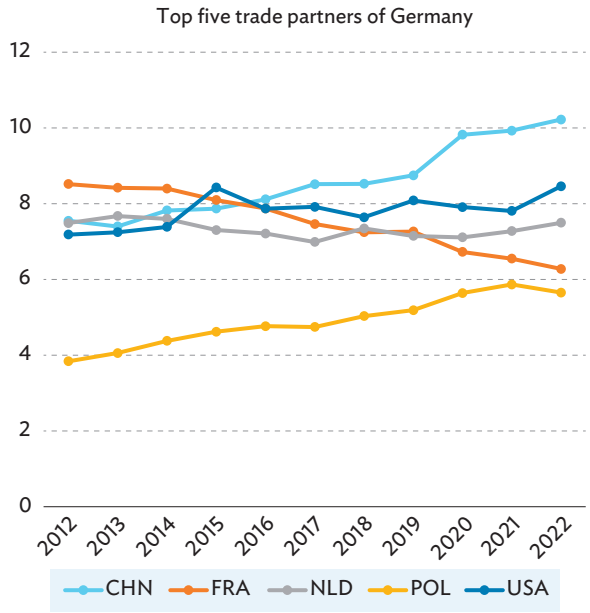
Figure 2.20: Changes in the Average Global Value Chain Production Length as a Result of the US–PRC Trade Tension (%)

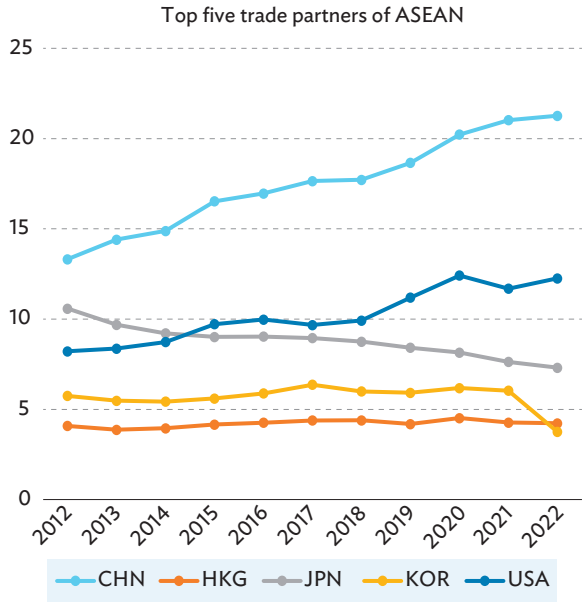


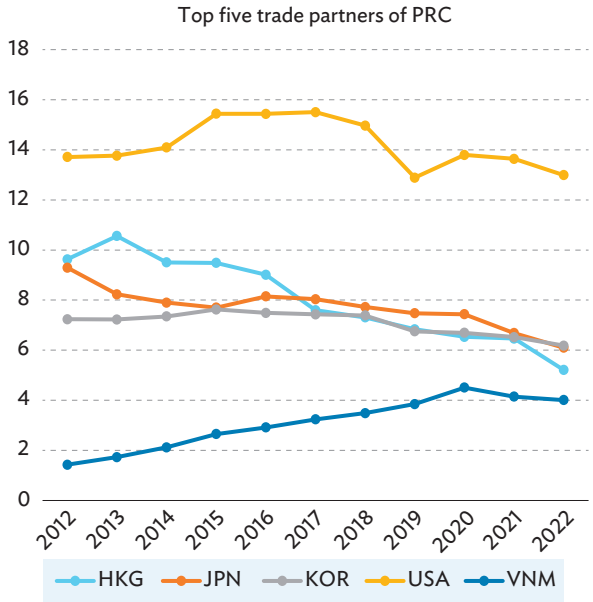
Source: (Meng et al., 2022)

Appendix 2: Top Five Trading Partners of the World's Main Economies





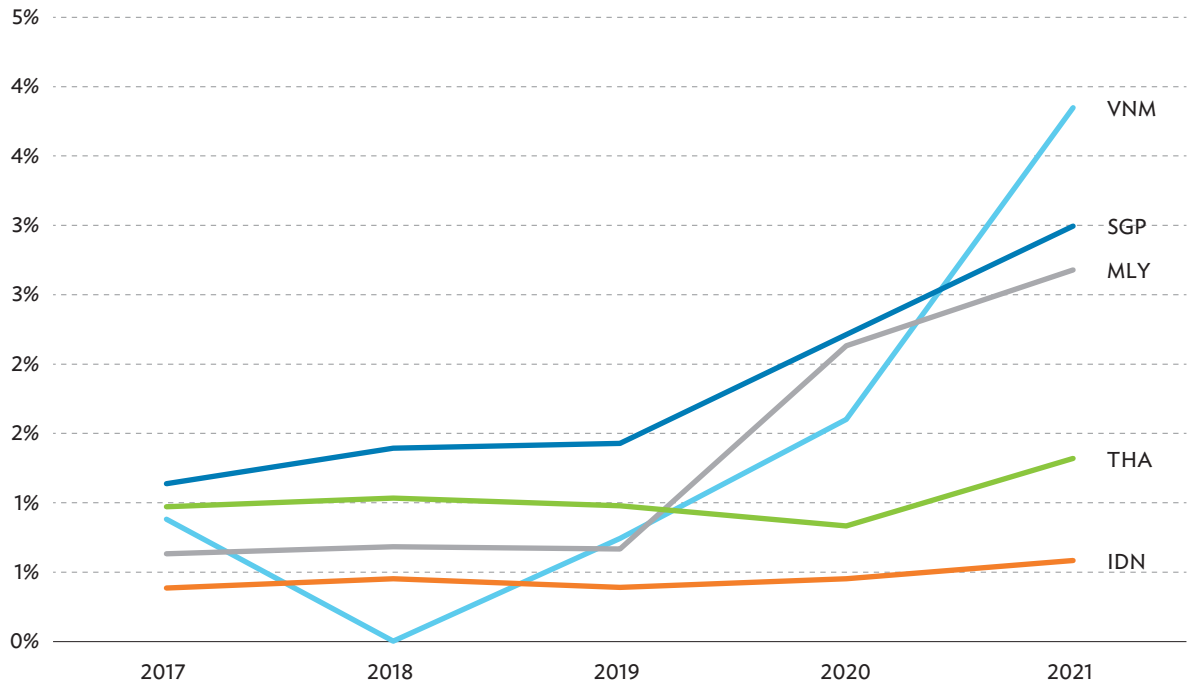




Source: UN COMTRAD

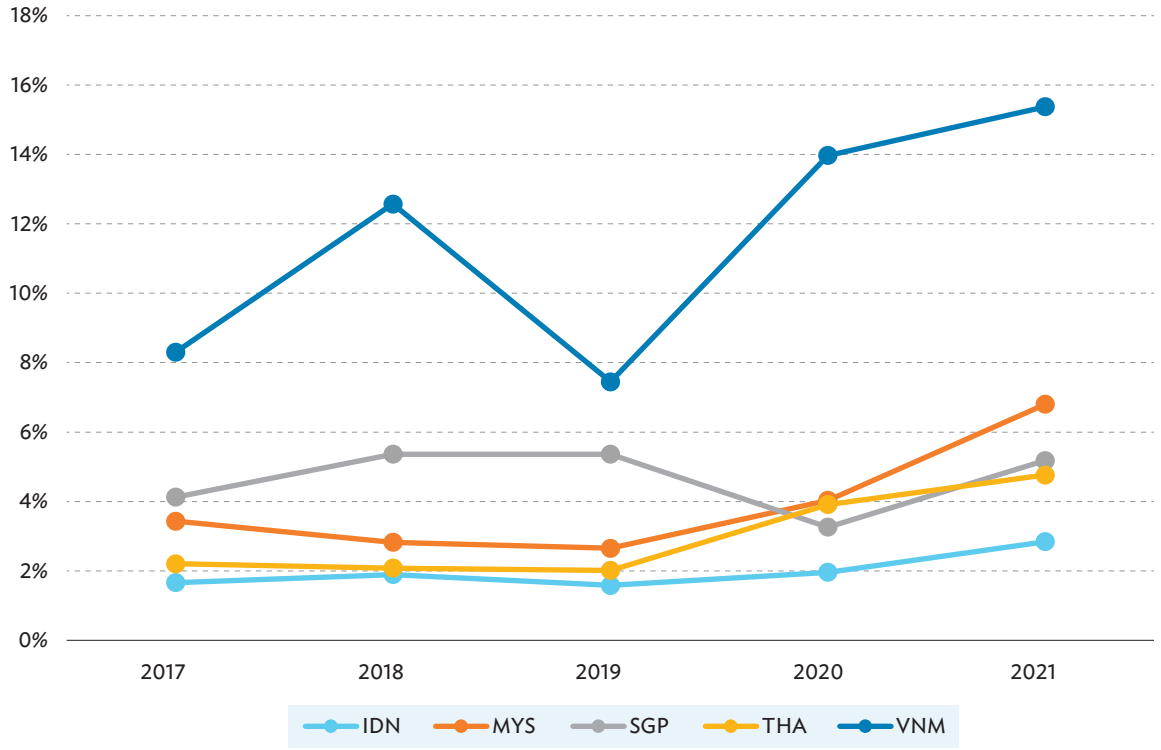
Appendix 3: Gross Trade between the US and ASEAN Countries

Figure 2.21: ASEAN Exports to the US as a Share of Total Exports (2017–2021)



Source: ADB MRIO database

Figure 2.22: Intermediate Imports from the PRC as a Proportion of ASEAN Total Intermediate Imports by Country (2017–2021)



Source: ADB MRIO database

Appendix 4: CGE Model Construction and Scenario Setting

Clear insights into the role and activities of MNEs are critical to understanding GVCs, whose strong growth has significantly challenged existing economic insights and policy implications associated with globalization. This study combines the OECD AMNE database and the GTAP-MRIO tables to develop a CGE model that incorporates MNEs, as well as the GVC decomposition module (Wang et al., 2021). The AMNE database is a global input–output database covering 34 industries and 60 regions that provides detailed data on the activities of foreign affiliates in specific countries (inward and outward activities of MNEs). The GTAP-MRIO database is a global set of input–output tables covering 141 regions and 65 industries that does not consider firm heterogeneity.

The basic premise of the model is to use the AMNE database to calculate the shares of intermediate use, final use, value added, and gross output of domestic and foreign firms, and then to divide the GTAP-MRIO database into domestic and foreign firms before rebalancing the database. For the extension involving the global computable general equilibrium model, comprehensive reference is made to other investment settings (Mai, 2005; Xiao & Ciuriak, 2014) in an effort to improve the production and consumption behavior of firms, but monopolistic behavior is not considered currently. In addition, for the dynamic mechanism setting, we refer to the MONASH investment function (Dixon et al., 2013). Specifically, first, the accumulation of capital uses recursive dynamic rules. Second, it basically presents an inverse logistic function relationship between investment and the return on capital.

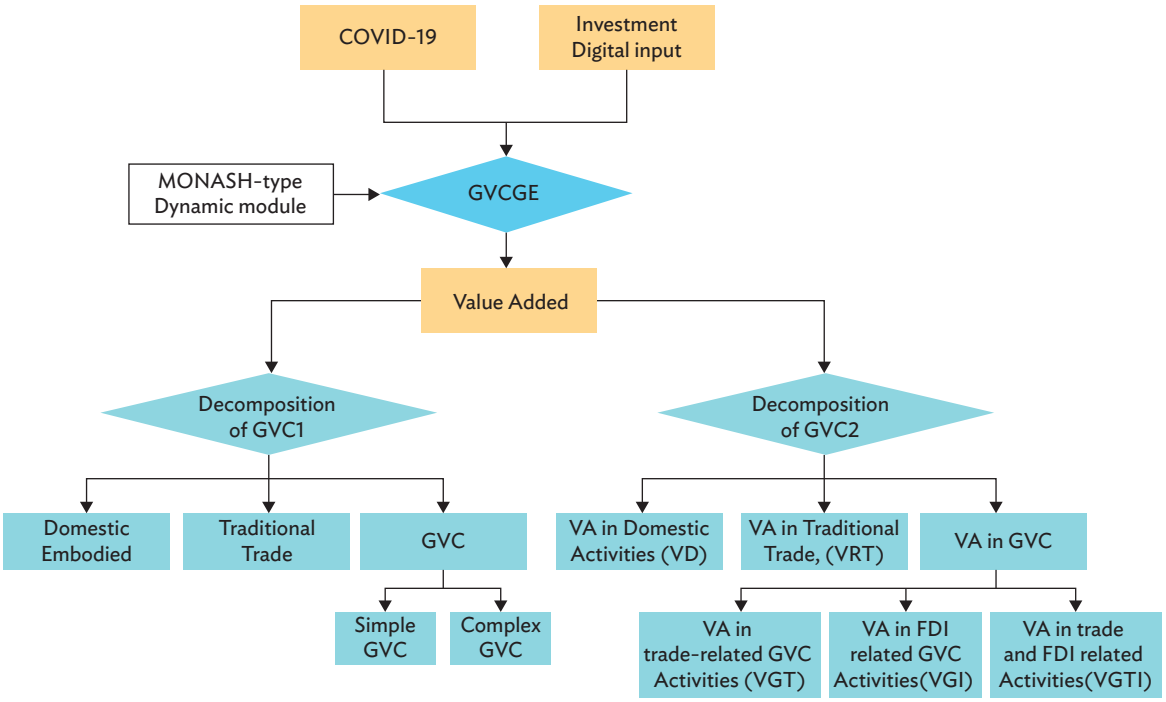
Three policy scenarios are examined in this study: the US–PRC trade tension, the COVID-19 pandemic, and digitalization (see Appendix Table 1).

Appendix Table 1: Scenarios in the CGE Modeling

Scenarios	Contents
BASELINE	growth rate of GDP, skilled labor force, unskilled labor force, and population
TRADE	US-PRC trade conflicts: additional tariffs in 2018 and 2019, Phase One Agreement in 2020. Export control of high-tech products from the US to the PRC
COVID	Decline in labor supply, shift in consumption preference, increase in trade costs, decline in tourism.
DIGITAL	Producers input more ICT intermediate goods or services, more efficient use of ICT intermediate input

- In the trade scenario, the conflict commenced in 2018 and ended in 2020 with a Phase One Agreement. Direct tariffs increased in the first two years and then decreased in 2020. Specifically, shocks on the agricultural import of the PRC from US are included in 2020 and 2021. Controls on the export of high-tech products from the US to PRC were also considered.
- The COVID-19 pandemic affected the global economic system through four major paths: a decline in the labor supply, a shift in consumption preferences towards telecommunication, health, public administration service etc., increased trade costs, and a decline in tourism demand. The economies of each country are recovering at different rates, but all are expected to return to their baseline by 2025.
- An important factor affecting resilience and recovery is digital technology. ICT was used as a proxy in the evaluation of the impact of the digital gap on the recovery of various countries. We assumed that producers preferred increasing their use of ICT intermediate input during the COVID-19 pandemic. Meanwhile, the efficiency of intermediate input of ICT products is also expected to be improved. These two shocks would have opposite effects on the ICT's output.

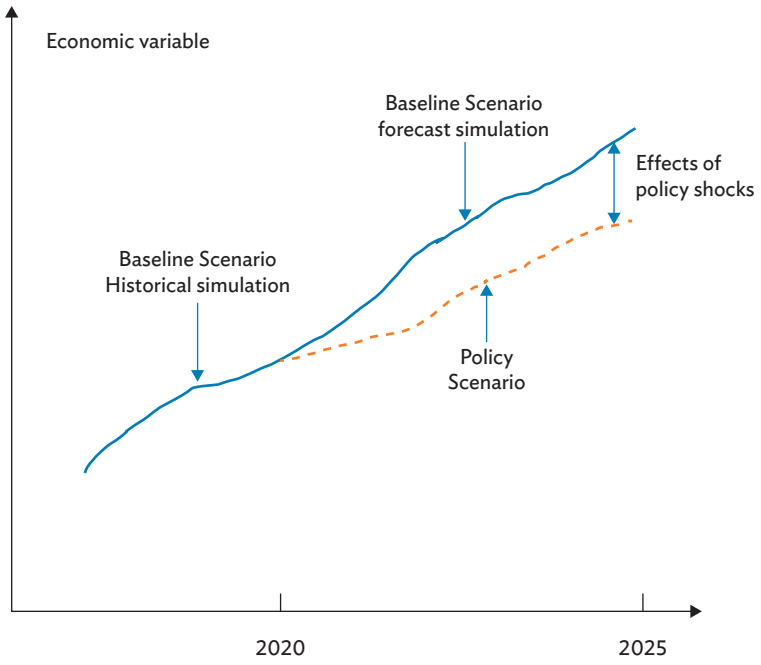
Figure 2.23: The GVCGE Framework



Note: The GVCGE model follows Aguiar et al., (2020), Corong et al., (2017), Hertel, (1997), the MONASH type dynamic module follows Dixon et al., (2013), and the GVC decomposition follows Wang et al., (2017, 2021).

Figure 2.24 can help readers to understand the results of the counterfactual analysis. The effects of policy shocks (e.g., trade tension, COVID-19 and digitalization in Appendix Table 1) on the economic variables (e.g., global value chain indicators) are represented by the differences of variables in the baseline and policy scenarios. For example, the latest reference year of the GTAP v10 database is 2014, but the COVID-19 outbreak in 2020, so that the historical simulation would start in 2014 and end in 2020. Then the forecast simulation moves the figure of the global economy to the future without considering COVID-19. The historical and forecast simulations consist of the baseline scenario. In the policy scenario, the COVID-19 shocks were introduced to the model, which would impose negative (or positive) effects on some economic variables, such as the GDP growth rate. In this chapter, we only focus on the effects of policy shocks mentioned in Appendix Table 1.

Figure 2.24: The Effects of Policy Shocks on Economic Variables



Source: Mai et al. (2010)

Appendix 5: The Impact of Digital Policy on Global Value Chains

The impacts of digital input and technological improvements on GVC trade were also analyzed (see Appendix Table 2). Pure domestic, FDI-related and trade-related activities are all predicted to increase in both the PRC and ASEAN, with a greater increase in pure domestic activities in ASEAN. Trade-related activities will also increase in Chinese Taipei, while the US, Canada, and India will benefit from increased traditional global trade. The PRC will experience a slight increase in all areas except trade-related activities because if the PRC attracts more investment in digital infrastructure, domestic consumption and all FDI-related activities will increase.

Appendix Table 2: Projected Impacts of Digital Input and Technological Improvements on GVC Activities in 2025

	VD	VRT	VGT	VGI	VGTI
PRC	0.20	0.01	-0.32	0.12	0.14
Japan	0.13	-0.14	-0.91	-0.20	-1.27
Republic of Korea	0.57	-0.47	-0.10	0.18	-0.19
Chinese Taipei	0.57	-0.37	0.30	0.19	0.00
ASEAN	0.63	-0.23	-0.71	0.46	0.10
India	-0.16	0.20	-0.54	-0.28	-0.58
Canada	-0.03	0.21	-0.48	-0.09	-0.51
USA	-0.07	0.21	-0.40	-0.18	-0.45
Mexico	0.26	-0.61	-0.95	-0.01	-0.88
EU27	0.26	-0.12	-0.74	0.10	-0.74
ROW	-0.09	0.30	-0.49	-0.17	-0.63

Note: VD = pure domestic production activities, VRT = traditional trade production activities, VGT = trade-related GVC activities, VGI = FDI-related GVC activities, and VGTI = trade- and FDI-related GVC activities, following Wang, Wei, Yu & Zhu (2021).

References

Abidi, N., El Herradi, M., & Sakha, S. (2022). Digitalization and Resilience: Firm-level Evidence During the COVID-19 Pandemic. *IMF Working Papers*, *2022*(034), A001. https://doi.org/10.5089/9798400201073.001.A001

Aguiar, A., Corong, E., & van der Mensbrugghe, D. (2020). *The GTAP Recursive Dynamic (GTAP-RD) Model: Version 1.0* https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=6135

Ahir, H., Bloom, N., & Furceri, D. (2022). The World Uncertainty Index. *National Bureau of Economic Research Working Paper Series*, *No. 29763*. https://doi.org/10.3386/w29763

Alfaro, L., & Chor, D. (2023). Global Supply Chains: The Looming "Great Reallocation". *Paper prepared for the Jackson Hole Symposium, 24-26 Aug 2023, organized by the Federal Reserve Bank of Kansas City.*

Altomonte, C., Di Mauro, F., Ottaviano, G. I., Rungi, A., & Vicard, V. (2012). Global value chains during the great trade collapse: a bullwhip effect?

Bacchetta, M., Bekkers, E., Piermartini, R., Rubinova, S., Stolzenburg, V., & Xu, A. (2021). *COVID-19 and global value chains: A discussion of arguments on value chain organization and the role of the WTO*.

Bai, J. J., Brynjolfsson, E., Jin, W., Steffen, S., & Wan, C. (2021). *Digital resilience: How work-from-home feasibility affects firm performance*.

Baldwin, R. (2017). *The great convergence: Information technology and the new globalization*. Harvard University Press.

Baldwin, R., & Ito, T. (2021). The smile curve: Evolving sources of value added in manufacturing. *Canadian Journal of Economics/Revue canadienne d'économique*, *54*(4), 1842-1880.

Barbieri, P., Boffelli, A., Elia, S., Fratocchi, L., Kalchschmidt, M., & Samson, D. (2020). What can we learn about reshoring after Covid-19? *Operations Management Research, 13, 131-136*.

Bellora, C., & Fontagné, L. (2019). *Shooting oneself in the foot? Trade war and global value chains* [Presented at the 22nd Annual Conference on Global Economic Analysis, Warsaw, Poland]. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5733

Blanchard, E. J., Bown, C. P., & Johnson, R. C. (2016). Global Supply Chains and Trade Policy. *National Bureau of Economic Research Working Paper Series, No. 21883*. https://doi.org/10.3386/w21883

Bown, C. P. (2023). *US imports from China are both decoupling and reaching new highs Here's how* https://www.piie.com/research/piie-charts/us-imports-china-are-both-decoupling-and-reaching-new-highs-heres-how

Bown, C. P., & Kolb, M. (2023). *Trump's Trade War Timeline: An Up-to-Date Guide*. Retrieved March 24 from https://www.piie.com/blogs/trade-and-investment-policy-watch/trumps-trade-war-timeline-date-guide

Bürgel, T. R., Hiebl, M. R. W., & Pielsticker, D. I. (2023). Digitalization and entrepreneurial firms' resilience to pandemic crises: Evidence from COVID-19 and the German Mittelstand. *Technological Forecasting and Social Change*, *186*, 122135. https://doi.org/https://doi.org/10.1016/j.techfore.2022.122135

Cai, K., & Wang, Z. (2022). Local Content Requirement Policies in China and Their Impacts on Domestic Value-added in exports. *WTO GVC report background paper*.

Cal`ı, M., Ghose, D., Montfaucon, A. F., & Ruta, M. (2022). Trade Policy and Exporters' Resilience: Evidence from Indonesia. *WTO GVC report background paper*.

Cheng, L., Mi, Z., Coffman, D.M., Meng, J. and Chang, D., 2021. Destruction and deflection: Evidence from American antidumping actions against China. Structural Change and Economic Dynamics, 57, pp.203-213.

Cho, J., Hong, E. K., Yoo, J., & Cheong, I. (2020). The Impact of Global Protectionism on Port Logistics Demand. *Sustainability*, *12*(4), 1444. https://www.mdpi.com/2071-1050/12/4/1444

Cigna, S., Gunnella, V., & Quaglietti, L. (2022). Global value chains: measurement, trends and drivers. *ECB Occasional Paper*(2022/289).

Copestake, A., Estefania-Flores, J., & Furceri, D. (2022). Digitalization and Resilience. *IMF Working Papers*, *2022*(210), A001. https://doi.org/10.5089/9798400225697.001.A001

Corong, E. L., Hertel, T. W., McDougall, R., Tsigas, M. E., & Van Der Mensbrugghe, D. (2017). The standard GTAP model, version 7. *Journal of Global Economic Analysis*, *2*(1), 1-119.

Costinot, A., Donaldson, D., & Komunjer, I. (2012). What goods do countries trade? A quantitative exploration of Ricardo's ideas. *The Review of Economic Studies*, *79*(2), 581-608.

di Giovanni, J., Levchenko, A. A., & Mejean, I. (2018). The Micro Origins of International Business-Cycle Comovement. *American Economic Review*, *108*(1), 82-108. https://doi.org/10.1257/aer.20160091

Dixon, P. B., Koopman, R. B., & Rimmer, M. T. (2013). The MONASH style of computable general equilibrium modeling: a framework for practical policy analysis. In *Handbook of computable general equilibrium modeling* (Vol. 1, pp. 23-103). Elsevier.

Dollar, D. R., Inomata, S., Degain, C., Meng, B., Wang, Z., Ahmad, N., Primi, A., Escaith, H., Engel, J., & Taglioni, D. (2017). Global value chain development report 2017: measuring and analyzing the impact of GVCs on economic development.

Eling, M., & Lehmann, M. (2018). The Impact of Digitalization on the Insurance Value Chain and the Insurability of Risks. *The Geneva Papers on Risk and Insurance - Issues and Practice*, *43*(3), 359-396. https://doi.org/10.1057/s41288-017-0073-0

Enderwick, P., & Buckley, P. J. (2020). Rising regionalization: will the post-COVID-19 world see a retreat from globalization? *Transnational Corporations Journal*, *27*(2).

Erbahar, A., & Zi, Y. (2017). Cascading trade protection: Evidence from the US. *Journal of International Economics*, *108*, 274-299.

Fajgelbaum, P., Goldberg, P. K., Kennedy, P. J., Khandelwal, A., & Taglioni, D. (2021). *The US-China trade war and global reallocations*.

Feenstra, R. C. (1998). Integration of trade and disintegration of production in the global economy. *Journal of Economic Perspectives*, *12*(4), 31-50.

Flaaen, A., Hortaçsu, A., & Tintelnot, F. (2020). The production relocation and price effects of US trade policy: the case of washing machines. *American Economic Review*, *110*(7), 2103-2127.

Forliano, C., Bullini Orlandi, L., Zardini, A., & Rossignoli, C. (2023). Technological orientation and organizational resilience to Covid-19: The mediating role of strategy's digital maturity. *Technological Forecasting and Social Change*, *188*, 122288. https://doi.org/https://doi.org/10.1016/j.techfore.2022.122288

Freeman, R., & Baldwin, R. (2020). *Supply chain contagion waves: Thinking ahead on manufacturing 'contagion and reinfection' from the COVID concussion*. VOX EU. https://cepr.org/voxeu/columns/supply-chain-contagion-waves-thinking-ahead-manufacturing-contagion-and-reinfection

Gabaix, X. (2011). The Granular Origins of Aggregate Fluctuations. *Econometrica*, *79*(3), 733-772. https://doi.org/https://doi.org/10.3982/ECTA8769

Ganne, E. (2018). *Can Blockchain revolutionize international trade?* World Trade Organization Geneva.

Gao, Y., Zhang, T., Ye, J., & Meng, B. (2022). The Impact of COVID-19 Pandemic on Global Value Chains: Considering Firm Ownership and Digital Gap. *WTO GVC report background paper*.

Gaspar, J.-M., Wang, S., & Xu, L. (2022). Size and Resilience of the Digital Economy. *Available at SSRN 4057864*.

Gaydarska, H., Akahira, H., & Xing, Y. (2022). The impact of the US-China trade war on the imports of the American automobile industry from China. *WTO GVC report background paper*.

Ghodsi, M., & Stehrer, R. (2022). Trade policy and global value chains: tariffs versus non-tariff measures. . *Review of World Economics, 158(3), 887-916.*

Ghose, D., & Montfaucon, A. F. (2022). Firms in Global Value Chains during Covid-19: Evidence from Indonesia. *WTO GVC report background paper*.

Goldberg, P. K., Khandelwal, A. K., Pavcnik, N., & Topalova, P. (2010). Imported Intermediate Inputs and Domestic Product Growth: Evidence from India*. *The Quarterly Journal of Economics*, *125*(4), 1727-1767. https://doi.org/10.1162/qjec.2010.125.4.1727

Guan, D., Wang, D., Hallegatte, S., Davis, S.J., Huo, J., Li, S., Bai, Y., Lei, T., Xue, Q., Coffman, D.M. and Cheng, D., 2020. Global supply-chain effects of COVID-19 control measures. Nature human behaviour, 4(6), pp.577-587.

Herskovic, B., Kelly, B., Lustig, H., & Nieuwerburgh, S. V. (2020). Firm Volatility in Granular Networks. *Journal of Political Economy*, *128*(11), 4097-4162. https://doi.org/10.1086/710345

Hertel, T. W. (1997). *Global trade analysis: modeling and applications*. Cambridge university press.

Hugot, J., & Platitas, R. (2022). Cross-border value chains in developing Asia survive trade tensions and the global pandemic. *WTO GVC report background paper*.

Jaumotte, F., Li, L., Medici, A., Oikonomou, M., Pizzinelli, C., Shibata, I., Soh, J., & Tavares, M. M. (2023). Digitalization During the COVID-19 Crisis: Implications for Productivity and Labor Markets in Advanced Economies. *Staff Discussion Notes, 2023*(003).

Johnson, R. C., & Noguera, G. (2012). Proximity and Production Fragmentation. *American Economic Review*, *102*(3), 407-411. https://doi.org/10.1257/aer.102.3.407

Khalil, A., Abdelli, M. E. A., & Mogaji, E. (2022). Do Digital Technologies Influence the Relationship between the COVID-19 Crisis and SMEs' Resilience in Developing Countries? *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(2), 100. https://doi.org/https://doi.org/10.3390/joitmc8020100

Kim, B., & Kim, B.-G. (2023). An Explorative Study of Resilience Influence on Business Performance of Korean Manufacturing Venture Enterprise. *Sustainability*, *15*(9), 7218. https://www.mdpi.com/2071-1050/15/9/7218

Kim, J., Estrada, G., Jinjarak, Y., Park, D., & Tian, S. (2022). ICT and Economic Resilience during COVID-19: Cross-Country Analysis. *Sustainability*, *14*(22), 15109. https://www.mdpi.com/2071-1050/14/22/15109

Lee, S., & Prabhakar, D. (2021). *COVID-19 non-tariff measures: The good and the bad, through a sustainable development lens*. UN Geneva, Switzerland.

Mai, Y. (2005). *The MONASH-Multi-Country (MMC) model and the investment liberalisation in China's Oil Industry*. Centre of Policy Studies (CoPS).

Mai, Y., Dixon, P., & Rimmer, M. T. (2010). *CHINAGEM: A Monash-styled dynamic CGE model of China*. Centre of Policy Studies (CoPS).

Mao, H., & Görg, H. (2020). Friends like this: The impact of the US–China trade war on global value chains. *The world economy*, *43*(7), 1776-1791. https://doi.org/10.1111/twec.12967

Meng, B., Gao, Y., Zhang, T., & Ye, J. (2022). *The US-China relations and the impact of the US-China trade war: global value chains analyses*. IDE-JETRO.

Moosa, I. A., & Merza, E. (2022). The effect of COVID-19 on foreign direct investment inflows: stylised facts and some explanations. *Future Business Journal*, *8*(1), 20. https://doi.org/10.1186/s43093-022-00129-5

Nicita, A., & Tresa, E. (2023). The heterogeneous effects of trade policy on trade resilience during the 2020 trade downturn. *The world economy*.

Noguera, G. (2012). Trade costs and gravity for gross and value added trade. *Job Market Paper, Columbia University*, *4*.

O, M. (2023). *Introducing China's Auto Industry (Part 1)*. Investor Insights Asia. Retrieved April from https://www.investorinsights.asia/post/introducing-china-s-auto-industry-part-1

OECD. (2018). *Tax Challenges Arising from Digitalisation – Interim Report 2018*. https://doi.org/doi:https://doi.org/10.1787/9789264293083-en

OECD. (2019). *Non-Tariff Measures. OECD Trade Policy Briefs*. https://www.oecd.org/trade/topics/non-tariff-measures/

Pisu, M., Rüden, C. v., Hwang, H., & Nicoletti, G. (2021). Spurring growth and closing gaps through digitalisation in a post-COVID world: Policies to LIFT all boats. https://doi.org/doi:https://doi.org/10.1787/b9622a7a-en

Rouzet, D., & Miroudot, S. (2013). The cumulative impact of trade barriers along the value chain: An empirical assessment using the OECD inter-country input-output model.

Santos, S. C., Liguori, E. W., & Garvey, E. (2023). How digitalization reinvented entrepreneurial resilience during COVID-19. *Technological Forecasting and Social Change*, *189*, 122398. https://doi.org/https://doi.org/10.1016/j.techfore.2023.122398

Solingen, E., Bo, M., & Ankai, X. (2021). *Rising Risks to Global Value Chains*. World Trade Organization.

Tinhinan, E. K. (2020). *Uneven Disruption: Covid-19 and the digital divide in the Euro-Mediterranean Region*. I. M. Yearbook.

Tresa, E. (2022). OECD Spillover Effect of Tariff in Global Value Chains. *WTO GVC report background paper*.

Wang, D., Hubacek, K., Liang, X., Coffman, D.M., Hallegatte, S. and Guan, D., 2021. Reply to: Observed impacts of the COVID-19 pandemic on global trade. Nature Human Behaviour, 5(3), pp.308-309.

Wang, Z., Wei, S.-J., Yu, X., & Zhu, K. (2017). *Measures of participation in global value chains and global business cycles*

Wang, Z., Wei, S.-J., Yu, X., & Zhu, K. (2021). Tracing Value Added in the Presence of Foreign Direct Investment. *National Bureau of Economic Research Working Paper Series*, *No. 29335*. https://doi.org/10.3386/w29335

WTO. (2023). *World Trade Report 2023: Reglobalization for a secure, inclusive and sustainable future*.

Wu, J., Wood, J., Oh, K., & Jang, H. (2021). Evaluating the cumulative impact of the US–China trade war along global value chains. *The world economy*, *44*(12), 3516-3533.

Xiao, J., & Ciuriak, D. (2014). Modelling the Trade in Services Agreement: Preliminary Estimates of Mode 1 and Mode 3 Liberalization. *Available at SSRN 3474745*.

Yi, K.-M. (2003). Can vertical specialization explain the growth of world trade? *Journal of Political Economy*, *111*(1), 52-102.

Yi, K.-M. (2010). Can Multistage Production Explain the Home Bias in Trade? *The American Economic Review*, *100*(1), 364-393. http://www.jstor.org/stable/27804932

3

Toward a Secure and Resilient Energy Supply Chain

Jinjun Xue, Yves Renouf, Youyi Deng, Xunpeng Shi, Kejuan Sun, Qian Sun

Global value chains (GVCs) are facing the greatest challenges from significant geopolitical changes. Combined with the COVID-19 pandemic shock, the energy transition and the increasing uncertainties, global value chains are at risk and need to be rebuilt to strengthen resilience. Chapter 3 examines the new geopolitical evolution due to the People's Republic of China (PRC)-US trade tensions, the ongoing Russian war in Ukraine and other regional tensions and their impacts on the rules underpinning the multilateral trading system, discuses the dynamics and the new patterns of energy supply chains, analyses the future of renewable energy supply chains, and explores the rebuilding of green, secure, and resilient GVCs that support the achievement of carbon neutrality targets.

The long-lasting PRC-US trade tensions and the ongoing Russian war in Ukraine are fueling geopolitical tensions and having huge impacts on global value chains, including global energy supply chains. These events have made geopolitical concerns rather than economic interests the dominant factor in shaping the policies governing energy trade. The data indicate that the PRC-US trade tensions are gradually leading to a decoupling between the two countries in some high-tech industries. Simulation analysis indicates that the Russian war in Ukraine and the various sanctions against Russia will reshape the patterns of world energy trade to form five segmented regional energy supply chains, including the EU-US energy supply chain, the Eurasia energy supply chain, the diamond shaped energy supply chain of US-Japan-Australia-India, the new Russia-Mongolia-PRC energy supply chain and the existing OPEC energy supply chain. These groupings will change the routes and patterns of world energy trade, and in turn could lead to further geopolitical conflicts.

All these dynamic movements are likely to affect the world energy transition and climate governance. One optimistic assumption is that the EU countries will use these crises as opportunities to speed up the development of renewable energy and formulate a

new green energy supply chain to accelerate its energy transition. However, under the pressure of the energy crisis and huge demand for energy in the post COVID-19 economic recovery, some economies postponed the phasing-out of coal and indeed increased the use of coal by restarting coalfired power generation plants. These one-step forward but two-steps backward policies could lead to temporary increases of carbon emissions and delay the UN's zero-emissions strategy and carbon neutrality timetables.

The remainder of this chapter is organized as follows. Section 1 evaluates the rising geopolitical tensions and their impacts on the rules underpinning the multilateral trading system to provide a legal background for the subsequent analyses. Section 2 discusses the dynamics of energy supply chains and analyses the impact of the Russian war in Ukraine on the world energy market in terms of price and the direction of changes in energy trading. Supported by CGE model simulations, Section 3 analyzes the new patterns of energy supply chains and describes a possible future for the energy geopolitical landscape. Section 4 presents new developments in renewable energy and examines the green and low-carbon energy supply chains under construction. Section 5 predicts the potential for achieving carbon neutrality in the context of environment regulation and climate mitigation targets, and section 6 summarizes the major arguments.

3.1 The Impact of Rising Geopolitical Tensions on the Rules Underpinning the Multilateral Trading System

This section sets the legal framework for the subsequent economic study of the impact of recent geopolitical crises, such as the Russian war in Ukraine, on GVCs and, more particularly, the global energy supply chains. It analyses the legal impact of the geoeconomic measures adopted in the context of these shocks and proposes some responses to preserve the legal system on which supply chains depend in a geopolitically more volatile world.

Why are GVCs, Including Energy Value Chains, Vulnerable to an Erosion of WTO Norms through Geoeconomics?

For over 70 years, trade experts have sought to keep geopolitics and trade separate. It is only recently, due to a shift in governments' priorities towards protecting their economies against a combination of external threats ("risk-based policies") that the term "geoeconomics" as a conceptual category of trade policies has appeared in international trade studies (Roberts, Choer Moraes et Ferguson, 2019). "Geoeconomics" are defined as trade and investment measures used for geopolitical reasons, or trade and investment policies considered as geopolitical objectives (Ciuriak, 2022).[1]

[1] According to Klaus Dodds, "geopolitics involves three qualities. First, it is concerned with questions of influence and power over space and territory. Second, it uses geographical frames to make sense of world affairs. Third, geopolitics is future-oriented. It offers insights into the likely behavior of states because their interests are fundamentally unchanging" (Dodds, 2019).

Geopolitical "risk-based" or "geoeconomic" trade policies currently promoted around the world are fundamentally at odds with the legal principles underpinning the multilateral trading system (MTS) and the functioning of GVCs (Bacchus, 2022). Geoeconomic policies are not designed to seize the benefits of trade opportunities in a win-win manner. Rather, they use trade to protect a country's interests from real or perceived geopolitical threats. Geoeconomics may be intended to ensure economic security, but mainly in terms of economic or technological superiority or independence from geopolitical rivals. For instance, geoeconomics seeks to achieve economic security not through cost-based trade diversification, but by reshoring production or trading with "friends" or "like-minded" countries (WTO, 2023).

In contrast, the development of GVCs is highly dependent on low trade costs. Trade liberalization has contributed to lower trade costs since the inception of the GATT in 1947 through a significant, negotiated reduction in tariff and non-tariff barriers and the liberalization of trade in services within the framework of legally binding commitments. The growth of GVCs was, thus, largely made possible thanks to the legal system put in place by the GATT and the World Trade Organization.

The role of international economic law is essentially to provide stability and predictability to trade and investment, but the legal system set up by the GATT introduced two additional features favorable to the development of GVCs. One was multilateralism, which allowed economies to make use of their comparative advantage more fully. The second was non-discrimination between similar imported goods and between imported goods and similar domestic goods. The implementation of those principles under the GATT and the subsequent WTO Agreements has ensured a progressive liberalization of international trade, eventually facilitating the development of value chains (WTO, 2023).

However, whether WTO rules should apply to trade in natural resources needed to produce energy or to direct trade in energy (e.g., cross-border sale of electricity) has been subject to discussions. During the Uruguay Round, very little was achieved both in terms of reducing barriers to trade in energy goods and with respect to market access in energy-related services. It has been argued that current WTO rules do not deal properly with trade in energy, notably due to the presence of natural monopolies and large -- often state-owned – enterprises (Cottier et al., 2010). Nevertheless, a number of WTO rules appear relevant, and energy-specific norms are often negotiated in the context of the WTO accession of energy-producing Members (Marceau, 2010).

The debate surrounding the suitability of existing multilateral trade rules to energy goods and services has not, however, prevented regional attempts to structure oil and gas markets along the principles of open trade and competition, such as the Energy Charter Treaty (ECT). The ECT originated in an initiative of the European Economic Community (the predecessor of the European Union) to organize the European and Central Asian oil and gas markets along the principles of the multilateral trading system after the fall of

the Soviet Union and its dismemberment into several independent oil and gas producing states. The ECT is a multilateral trade and investment agreement providing a legally binding framework for energy cooperation and designed to promote energy security through more open and competitive energy markets (Energy Charter Secretariat, 2023). The ECT provisions on trade apply the WTO principles of "most favored nation" and "national treatment" to foreign goods and investors. Contracting parties to the ECT must also eliminate quantitative restrictions on the import or export of energy products and related equipment. Moreover, under the ECT, energy trade disputes between countries that belong to both the WTO and the ECT have to be resolved under the WTO Dispute Settlement Understanding (DSU) (European Parliament, 2017).

However, the history of the Energy Charter is also revealing of the degree of exposure and vulnerability of trade in energy goods and services, as well as energy value chains, to the current erosion of multilateralism. The ECT entered into force in 1998. However, Russia ended its provisional application of the Treaty in 2009. Russia's withdrawal from the multilateral investment and trade framework of the ECT was probably founded not only on geopolitical reasons -- such as its suspicion of Western initiatives – but also on geoeconomics, with implications on energy value chains. Indeed, Russia was apparently concerned that "the ECT would force it to open its pipelines to transit of natural gas from Central Asia [to Europe] or that it would be forced to accept the construction of new transit pipelines across its territory (Romanova, 2014) (European Parliament, 2017). Without Russia, the ECT could no longer fulfil its original objectives and had to redefine its role in the multilateral organization of energy value chains.

How Geopolitical Crises are Eroding the Legal Fabric of the MTS and of Global Value Chains: The Effects of the Russian War in Ukraine on Energy Supply Chains

Geopolitically-motivated trade policies, such as trade sanctions, can significantly disrupt value chains. A number of WTO Members had already adopted trade sanctions against Russia after its annexation of Crimea in 2014. However, after the current Russian war in Ukraine started in February 2022, several western countries impose trade sanctions against Russian economic interests on a scale never seen before. Even though those sanctions targeted only Russian interests, they led to a reorganization of the supply chains between the PRC and Europe. With the Russian Railways placed under western sanctions in 2022, sectors such as electronics and car manufacturers sought alternative routes to avoid the transit of components or finished products through Russia (Pomfret, 2023). Russia reacted to western sanctions in the WTO by raising a "special trade concern" before the Committee on Market access (WTO, Unilateral Sanctions against Russia (ID77) 2022) but did not initiate any dispute settlement procedure.

Russia's own trade restrictions against Ukrainian exports to some CIS countries transiting through its territory, imposed from 2014 onward, had already been subject to a WTO dispute settlement procedure in which, for the first time, a panel had

interpreted Article XXI GATT (Security Exceptions). Essentially, the panel had found that the geopolitical situation between Ukraine and Russia at the time amounted to "war or other emergency in international relations" (Article XXI(b)(iii)) and that Russia had legally invoked Article XXI as a justification for its trade restrictive measures against Ukraine (*Russia - Traffic in Transit,* 2019).

The disruption to global value chains caused by the trade sanctions against Russia was aggravated when Russia responded by gradually cutting its supply of oil and gas to European countries, among others.

Natural resources are often subject to export restrictions (OECD, 2010). Such practices are legally acceptable as long as they are justified under one of the non-application clauses or exceptions provided for in the WTO Agreement (domestic shortage, environmental protection, price or production regulation, etc.). Nevertheless, the imposition of export restrictions by a country that is the main supplier of certain raw materials could seriously disrupt the functioning of global value chains. The vulnerability of supply chains from excessive reliance on a single supplier who could also use such dependence for geoeconomic purposes was pointed out by some authors (see Gavin, 2013) when the PRC restricted its exports of rare earths and other raw materials used in electronics. These policies were challenged (*China - Rare Earths,* 2014) and subsequently withdrawn.

"Trade Weaponization" and Trade Sanctions are Escalating

The adoption by western countries of unprecedented trade sanctions on Russia and the subsequent progressive reduction in Russia's exports of oil and gas to Europe probably represent the most significant example of "trade weaponization" in recent history.

"Trade weaponization" is not a trade law concept. It refers to the use of trade for non-trade purposes in a geopolitical context (Reinsch, 2021). The idea is to disrupt or threaten to disrupt trade with another country so as to inflict or threaten to inflict economic losses, in order to force it to change its policy. The use of the term "weapon" underlines the unamicable nature of the action.

To be effective, trade weaponization normally requires the existence of trade between the country intending to weaponize this trade and the targeted country(ies) and that the former be the exclusive or at least a predominant supplier/client of the product(s) concerned. The products concerned should preferably be "essential" or "strategic". Most importantly, it must be difficult for the targeted country(ies) to quickly find a substitute for the product, the supplier or the client, hence its potentially significant impact on supply chains. In the case of the Russian war in Ukraine, oil and gas exports were perfect "trade weapons" given the high degree of dependence of many European countries on Russian energy supply at the time and the expected damage to European economies before they could switch to other suppliers or sources of energy.

It is unlikely that any challenge before the WTO of either the sweeping trade sanctions imposed against Russia or the ban on exports of oil and gas imposed by the latter would be successful. In light of the findings of the panel on *Russia – Traffic in Transit*, the context in which those sanctions were adopted would most probably be deemed consistent with Article XXI(b)(iii) GATT (see above).[2] Thus, the current trade sanctions could remain in place for as long as the Russian war in Ukraine is not fully resolved.

While Article XXI(c) GATT 1994 and its GATS and TRIPS equivalents acknowledge the possibility for WTO Members to adopt trade sanctions in application of their "obligations under the United Nations Charter for the maintenance of international peace and security," UN-sponsored trade sanctions are only a part of the trade sanctions WTO Members impose on each other (Yotov and al. 2020). An increasing share of trade sanctions is unilaterally adopted by individual Members (Mulder, 2022).

The appeal of trade sanctions partly comes from their flexibility. They offer a wide range of variations, from temporary sectoral restrictions (*Japan--Measures Related to the Exportation of Products and Technology to Korea*, WTO, 2023) to waging war without formally being at war (WTO, 2022). In a world increasingly subject to geopolitical volatility, their use can only increase.

Trade sanctions add to the complexity and cost of trade and are a major source of legal uncertainty, in contradiction with the WTO principles of stability and predictability. Indeed, not only each economy has its own sanction regime but, when the scope of sanctions expands, regimes are modified to address loopholes and secondary sanctions are added to primary sanctions. The lists of targeted entities can sometimes be several hundreds of pages long (Reinsch, 2021).

This complexity can lead to "overcompliance". Out of caution, manufacturers will refuse to sell certain goods to certain clients, or shipping companies will not ship specific cargos to certain destinations, insurance companies will not ensure shipments or banks will refuse to finance trade with certain countries lest they become subject to criminal proceedings and fines for breaching national sanction regimes.

Possible Legal Responses to Protect the MTS and Global Value Chains Against Geoeconomics

As mentioned above, GVCs depend on open trade. The objective of the WTO reform outlined at the 12th Ministerial Conference (June 2022) remains to make the MTS work for all, particularly by restoring its capacity to solve disputes (WTO, 2022).

---

2 Trade sanctions are increasingly targeted against an individual or entity, rather than the state (Reinsch, 2021). While individuals targeted by western sanctions have sometimes successfully contested them before national courts or the European Court of Justice, these judgements were mostly based on technicalities and apply only to the business of the complaint.

However, many experts seem to have embraced a "realist" or "structuralist" approach to international relations and accepted the return of geopolitics in trade as some "fact of life" (Howse, 2022) that their predecessors, overly focused on the rule of law, naively refused to acknowledge (Nishimara, 2023). For them, the MTS was designed in the 1990s for a unipolar world sharing the same economic values – the "Washington Consensus." It is no-longer adapted to the inevitable resurgence of power-based diplomacy and it may survive only at the cost of loosening-up the rule-based system and giving governments more "policy space" to use trade for non-trade purposes (Howse, 2022). Even pro-MTS experts recognize that certain governments' economic "preferences" may no longer be reconciled (IMF, 2023), and that the only way to prevent an excessive impact of geopolitics on international trade is to introduce some minimum guidelines for unilateral policies ("guardrails") when differences in points of view are such that no agreement can be reached (Hoekman et.al., 2022).

Until the Second World War, international trade was essentially organized around discrimination or privileges (Spanish "Asiento", British "Imperial Preference"). By contrast, the GATT 1947 negotiators opted for a legal construction based on non-discrimination and transparency. They also made the choice to found the MTS on binding norms legally enforceable by any individual Contracting Party, irrespective of its economic or military power, as illustrated by the early case between The Netherlands and the United States (*United States - Restrictions on Dairy Products,* 1952) (WTO, 2023). Trade negotiations aimed at achieving a "balance of rights and obligations", as well as the principles of the most-favored nation and "special and differential treatment" for developing and least-developed economies also ensured that all contracting parties would benefit from the MTS. Any shift away from a system based on mutually negotiated rights and obligations towards a less legal and more political organization and functioning of the MTS, and from binding rules and disciplines towards "soft law" or "guardrails" would largely amount to a return to power-based diplomacy and spell the end of 70 years of "win-win" trade cooperation.

More consistent with the existing legal structure of the MTS would be to adapt the WTO rulebook to emerging challenges (Hoekman et.al., 2022), including political ones. It may indeed be preferable to allow certain policies as exceptions -- subject to multilaterally supervised conditions -- than having to declare them illegal, as in recent cases where Articles XXI GATT or 73 TRIPS were invoked, and run the risk that such rulings be disregarded. This would eventually compromise the rule-based trading system as a whole. WTO general and security exceptions could thus be adjusted to the new policy needs of Members, either through negotiation or interpretation under Article IX:2 WTO. Not everything needs fixing, however. Many of the derogations necessitated by the new health or environmental challenges are already covered by Articles XX GATT and XIV GATS. It may also not be judicious to seek to renegotiate the text of the WTO exceptions in the present geopolitical environment. However, a carefully drafted interpretation of WTO security exceptions to include contemporaneous security issues that the GATT 1947 negotiators could not have

contemplated, such as state-sponsored cyber-criminality or hybrid warfare, may be considered.

Some negotiated settlement on the question of the reviewability of security exceptions under the DSU would also contribute to restore the faith in and support for the MTS among those Members that do not have the means to engage in power diplomacy. A broader trust in the capacities of the rule-based system would contribute to stabilize trade relations and reduce the occasions to invoke security exceptions.

The mandatory and binding WTO dispute settlement mechanism was one of the core features of the rule-based MTS until the appellate mechanism ceased to function in 2019. A largely non-operational dispute settlement system both limits Members' legal capacities to respond to geoeconomic policies through peaceful means and serves the interests of countries that want to selectively comply with their WTO obligations (Van den Bosche and Akpofure, 2020). A restoration of the WTO dispute settlement system is, thus, essential to preserve a non-discriminatory and transparent MTS.

However, restoring the WTO dispute settlement system faces two particular obstacles to which only adjustments towards more consideration of the broader political context, as panels used to do under GATT 1947, could bring a solution at this stage.[3]

One is the risk of a member not complying with Dispute Settlement Body (DSB) recommendations and rulings against a measure for which it invoked a security exception. Even a return to a fully operational DSU will not prevent some Members from not implementing rulings of the DSB, even if they are subject to "sanctions" in return. Normally, Members have an obligation to comply with DSB rulings, but some have nonetheless occasionally preferred in the past, mainly for domestic political reasons, to maintain controversial measures and face a suspension of concessions or other obligations by the other party(ies) to the dispute. Given the intimate link between security and sovereignty, this risk is likely to be even higher with measures adopted for geopolitical reasons. The current mechanism of suspension of concessions and other obligations in case of non-compliance is not particularly well suited to the invocation of security exceptions because such "countermeasures" may only be adopted at the outcome of a DS procedure, sometimes years after its initiation, risking to create a period of impunity during which a Member may continue to apply unjustified protectionist or trade coercion measures with potentially lasting economic consequences for its trading partners.

A proposed solution could be to allow Members aggrieved by a security-based measure to immediately respond to such measure through the suspension of substantially equivalent concessions (Lester and Zhu, 2019). Another option would be to limit

3 After all, GATT contracting parties, from communist Poland to western European social democracies to liberal Chile, used to follow more diverse economic models than WTO Members probably do today.

disputes on security justifications to non-violation cases4 (Benton-Heath, 2020). Aggrieved Members could eventually seek compensation or take countermeasures, but negative political reactions in the responding Member to the WTO "condemnation" of a measure adopted for the protection of "essential national security interests" could be minimized.

The question of the "self-judging" nature of security exception clauses first argued in the *Russia – Traffic in Transit* case (2019) by Russia and the United States - and systematically raised by the latter in subsequent similar cases – also must be resolved. Options include the unequivocal acceptance of the judicial review of cases where such clauses are invoked under the terms defined by the panel in *Russia – Traffic in Transit*[5] or in some other form, if only to prevent protectionist abuses or coercion. A radically different approach would consist of excluding the review of security clauses from the scope of the DSU (Lester and Manak, 2022). However, in the latter case, the systemic consequences of this choice should be carefully assessed.

Indeed, a total absence of "judicial" or third-party review of the invocation of security exceptions could impact the predictability of a rule-based MTS, particularly in a period of geopolitical instability. Therefore, if security justifications are removed from the scope of the DSU, some substitute mechanism, e.g. in the form of a deliberative process, (Manak, 2023) should be put in place to review them in order to limit their spillover and avoid that they be used for protectionist purposes. This process could be purely diplomatic or evidence-based and led by experts to facilitate the identification of alternative solutions and compliance options. A specialized WTO security committee could be created for that purpose (Lester and Manak, 2022).

---

4 Under the DSU, complainants must demonstrate that a benefit accruing directly or indirectly to them under the WTO Agreement has been "nullified or impaired" through the application of a measure by another Member. Nullification or impairment can occur in three situations: (a) in presence of a violation by another Member of its WTO obligations ("violation" complaint), (b) due to the application of a measure by another Member, whether or not it conflicts with the WTO Agreement ("non-violation" complaint) or (c) as a result of the existence of any other situation. When nullification or impairment occurs in the absence of a violation, there is no obligation to withdraw the measure at issue, but a mutually satisfactory adjustment must be reached (Article 26.1(b) DSU).

5 In the *Russia – Traffic in Transit* (DS512) dispute, the Panel concluded that Article XXI(b) was not "self-judging" but vested in panels the power to review whether the requirements of the subparagraphs of this provision were met. The Panel considered that an "emergency in international relations" referred generally to a situation of armed conflict, or of latent armed conflict, or of heightened tension or crisis, or of general instability engulfing and surrounding a state. Both the existence of an "emergency in international relations" and whether the action was "taken in time of" such emergency, within the meaning of subparagraph (iii) of Art. XXI(b), were subject to objective determination. As to whether the action was necessary for the protection of the invoking Member's essential security interests, the Panel said that, in general, while it is for every Member to define for itself what it considers to be its essential security interests, such essential security interests must be sufficiently articulated to demonstrate their veracity. Moreover, the obligation of good faith also required that the measures at issue meet a minimum requirement of plausibility in relation to the proffered essential security interests, i.e. that they are not implausible as measures protective of those interests. (https://www.wto.org/english/tratop_e/dispu_e/cases_e/1pagesum_e/ds512sum_e.pdf)

3.2 New Dynamics of Global Energy Supply Chains

As the world shifts towards cleaner and more sustainable energy sources, various factors can influence the dynamics of energy supply chains and trade in energy, especially renewable energies. Here are some key issues and channels through which the energy transition and climate change mitigation will affect global energy supply chains and renewable energy trade.

The COVID-19 Shock to Energy Supply Chains

Since 2020, the COVID-19 pandemic has created a significant shock to global value chains which led to major temporal and geographical disruptions in the energy supply chain through lockdowns, border closures, logistical interruptions of population and labor mobility (even stopovers in air travel), layoffs of workers and temporary shutdown of production lines, demand distortions, and a diversion of government funding from energy projects to pandemic relief efforts.[6]

The COVID-19 damage revealed the weakness and risks of energy supply chains

The COVID-19 pandemic exposed the weaknesses and risks of global supply chains, underlining the importance of sustainable and resilient energy systems. This will prompt renewable energy companies to strengthen their efforts to improve the resilience of supply chains. While to some extent this could imply reliance on more diversified sources for components and equipment, it also could lead to the regionalization or localization of certain supply chain elements to reduce risk and lessen the impact of future trade disruptions driven by quarantine measures (Quitzow et al., 2021).

The COVID-19 shock to energy supply chains

In some respects, the COVID-19 pandemic is expected to make the power generation mix greener. The pandemic exposed vulnerabilities in energy access and affordability, which may drive a shift towards decentralized energy systems. Distributed renewable energy generation, such as rooftop solar, may see increased adoption to enhance energy reliability at the local level. Governments and businesses may now prioritize the transition to renewable energy sources as a key component of their long-term energy strategies, leading to increased investments in renewable energy projects. The pandemic also accelerated the adoption of digital technologies in the renewable energy sector. The increased availability of remote monitoring, data analytics, and smart grid technologies should improve the efficiency and reliability of renewable energy systems.

---

6 Hoang, A.T., Nižeti´c, S., Olcer, A.I., Ong, H.C., Chen, W.-H., Chong, C.T., Thomas, S., Bandh, S.A., Nguyen, X.P., 2021. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: opportunities, challenges, and policy implications. Energy Policy 154, 112322.

The decline in energy demand also reduced the production of power generation with higher variable costs, mainly fossil fuels, and thus increased the share of renewables in the power generation mix. This generation mix change accelerated the transition towards low carbon energies in the short run (Li et al., 2022). However, when considering broader factors and in the long run, the COVID-19 pandemic may undermine the energy transition. The comprised economic growth due to COVID-19 pandemic will undermine the readiness and other enabling factors of the energy transition and thus slow down the energy transition in the long run (Shen et al., 2022)

The US-PRC Trade Tensions and Its Impact on Energy Supply Chains

The US-PRC trade tensions, which began in 2018, are a protracted and escalating economic conflict between the two largest economies in the world. The trade tensions have caused disruptions in global supply chains, including the supply chains for clean energy technologies and critical minerals. The United States is actively promoting the concept of 'friend-shoring' and other strategies to strengthen and build resilient supply chains. Additionally, it aims to create a more extensive alliance among advanced economies to counter the PRC's technological advancements, as described in the Science and Chips Act of the US.

The escalation of the US-PRC trade tensions and the overall geopolitical tensions introduce a lot of uncertainties, alter trade patterns, and impact investments in the renewable energy industry. The geopolitical tensions may potentially slow down the global energy transition and hinder efforts to achieve climate goals.

The trade tensions and geopolitical tensions may disrupt established supply chains for renewable energy technologies. Disruptions in renewable energy trade and investments may impact the pace of decarbonization and the adoption of clean energy technologies. Many renewable energy products involve the sourcing of components from multiple countries. The trade tensions and geopolitical tensions may prompt countries to seek alternative sources for renewable energy technologies and components to mitigate the impact of trade restrictions. On the positive side, increased trade restrictions could lead to the emergence of new trade alliances and partnerships in the renewable energy sector and spur development in countries or regions that are otherwise not part of the energy supply chains. For example, the US tariff on the PRC's solar panels led to the relocation of assembly business to Southeast Asia (Nichola Groom, 2022).

The trade tensions and geopolitical tensions may reduce market access for renewable energy products and technologies, and lower investment in these activities. Both the US and the PRC are major players in the renewable energy industry, and the trade dispute can limit their access to each other's markets, hindering the flow of renewable energy products and services. More generally, governments may implement protectionist measures to safeguard domestic industries, which

could impact the flow of renewable energy products and services across borders. Investors may be more cautious about investing in the PRC due to increased risks and uncertainties, and host countries may become more cautious about the PRC's investment, leading to delays or cancellations of renewable energy initiatives.

The geopolitical tensions and uncertainties may slow the pace of decarbonization and the adoption of clean energy technologies. The imposition of tariffs and trade barriers or changes in trade patterns can lead to delays, higher costs, and shortages of critical components, potentially affecting their affordability and accessibility in certain markets. For example, as a result of significant disparities in energy, labour, investment, and overhead costs, manufacturing all components of the solar PV supply chain in the PRC is 10% less expensive than in India, 20% less expensive than in the United States, and 35% less expensive than in Europe (IEA, 2022b). And these tensions could lead to an escalation of broader geopolitical conflicts and rivalries. This could affect international cooperation on renewable energy initiatives and the energy transition and hinder collaborative efforts to address global climate challenges.

Geopolitical Tensions and Their Impact on Energy Supply Chains: Energy Geopolitics

The discipline of energy geopolitics and the term energy geopolitics were formed relatively late compared to when energy geopolitical wars occurred historically. Global energy geopolitics was formed long before 1960, and after decades of changes in global politics, economy, technology, and other factors, energy geopolitics has been constantly reconfigured (Amineh, 2003). Therefore, this chapter takes energy geopolitics as the research object, combs the evolution of energy geopolitics, and forecasts the changes of the future energy geopolitics pattern in combination with the epidemic situation and the Russian war in Ukraine, so as to provide some reference for global energy layout and energy development.

The Russian war in Ukraine fragmented the traditional energy supply chains and altered global energy trade routes. While the direct impact of the Russian war in Ukraine on renewable energy trade may be limited, its broader effects on global energy markets, geopolitical stability, and the investment climate have indirectly influenced the renewable energy sector.

The Russian war in Ukraine led to both physical disruption and institutional sanctions that directly affected the global energy trade. It disrupted transportation and logistics networks, which directly affected energy supply chains, including those for renewable energy technologies. Many countries implemented trade measures or sanctions that indirectly impact renewable energy trade. For example, Russia has redirected crude oil shipments to Asia as a response to the Europe's sanctions on its energy exports (IEA, 2023b). These measures may have affected the flow of raw materials, components, or finished renewable energy products across borders.

The war has had complicated impacts on the energy transition, especially in Europe, which further affect the trade of fossil fuels and renewable technologies. Russia's reduction in the supply of gas to Europe led to an increase in European coal consumption in 2021 and 2022 to partially fill gaps in the energy mix. The impact, however, is limited and temporary, as projections indicate that the demand is set to decrease below the levels seen in 2020 by the year 2025 (IEA, 2022c).

Moreover, the economic upheaval triggered by the Russian war in Ukraine has intensified efforts to expedite the energy transition. Numerous countries and regions are currently exploring policy measures to accelerate the clean energy transition through initiatives such as the Inflation Reduction Act in the US, the REPowerEU plan in Europe, and the GX Green Transformation program in Japan (IEA, 2023b). In May 2022, the European Commission unveiled the REPowerEU plan, which aims to eliminate the European Union's dependency on Russian fossil fuels by 2027. The plan also sets ambitious targets, including raising the share of renewables in final energy consumption to 45% by 2030, surpassing the previously negotiated 40% goal (IEA, 2023b).

The Energy Crisis and Energy Security

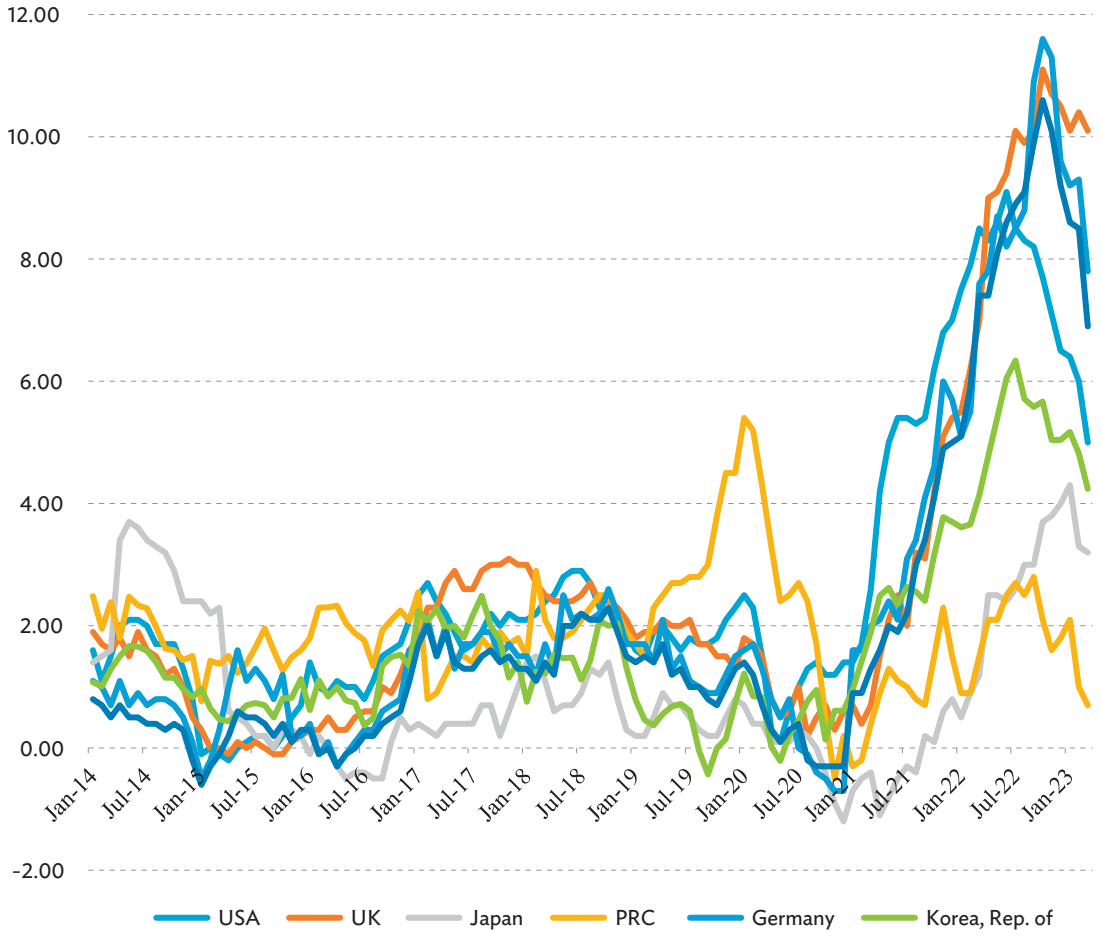
Energy security is a base or guarantee of energy supply chains. The energy price rise induced energy crises, and energy crises deepened energy insecurity and threats to the energy supply chain. According to an IEA report, the global spot price of natural gas reached an unprecedented level of over $250 per barrel in the second half of 2022, while coal prices also reached a record high level (IEA, 2022d). In addition to this, diesel prices in Northwest Europe surged after the Russian war in Ukraine, exceeding $200 per barrel, while North Sea Brent crude oil as well as Urals crude oil also saw sharp increases in the short term before falling back (IEA, 2022d).

Energy price driven inflation

After the outbreak of the Russian war in Ukraine, the restrictions on energy exports from Russia to European countries and the sanctions imposed on Russia by European and American countries led to sharp increases in global energy prices, which led to an increase in price levels in various countries (refer to Figure 3.1). Between February 2022 and September 2022, the CPI indices of the US, U.K., Germany, Republic of Korea, and Eurozone countries increased by 9.1, 10.1, 10, 6.34, and 9.9 percent, respectively.

Many governments provide energy subsidies to mitigate the direct impact of energy shortages and price increases on residents and businesses. As of August 2022, European countries have distributed $276 billion to mitigate the impact of high prices on residents and businesses. Specifically, Germany is giving a $300 one-off energy allowance to workers, while Italy is giving workers and pensioners a $200 cost-of-living bonus (refer to Visual Capitalist). In addition, the break in the energy supply chain with

Figure 3.1: Changes of Global CPI Due to Energy Shock



Source: Wind.

Russia has caused European countries to increase energy imports from countries such as the United States at higher prices, thus increasing government spending.

High prices of natural gas and coal not only bring a heavy burden to governments and businesses, but also profoundly affect the lives of the global population (IEA, 2022d). Therefore, the increase in electricity and food prices caused by the rise of fossil energy would have a far-reaching impact on the global population. As households in low-income countries spend a large portion of their income on energy and food purchases compared to high-income countries, changes in energy and food prices can have a greater impact on them and at the same time increase regional development disparities (Von Cramon, 2022). According to the IEA report, some 75 million people who recently gained access to electricity are likely to lose the ability to pay for it, the total number of people worldwide without electricity access has started to rise, and almost 100 million people may be pushed back into reliance on firewood for cooking instead of cleaner and healthier alternatives (IEA, 2022d).

European dependence on Russian energy

With the intensification of the Russian war in Ukraine, the global energy supply chain has broken down. The EU, which relied on Russia for one-fifth of primary energy consumption in 2021 (IEA, 2022a), has been severely affected. In this energy crisis, all fuels (coal, oil, etc.) are affected, but gas markets are the epicenter. Daily pipeline flows from Russia to the EU dropped by about 80% from March 2022 (Russia invaded Ukraine in late February) to October 2022 (IEA, 2022d). The Nord Stream pipeline between Russia and Europe was subject to outages, leaks, and explosions, and experienced a shutdown in August 2022. As Russia has the world's largest natural gas reserves (19.88% of the world's proven volume) and exports (7.67% of global exports) (BP, 2022), the Russian war in Ukraine has led to a broken link in the global energy (especially natural gas) supply chain, which is a huge challenge for the global economy and for European countries.

3.3 Geopolitical Changes and New Evolution of Energy Supply Chains

Historical Evolution of Energy Domination and Energy Geopolitics

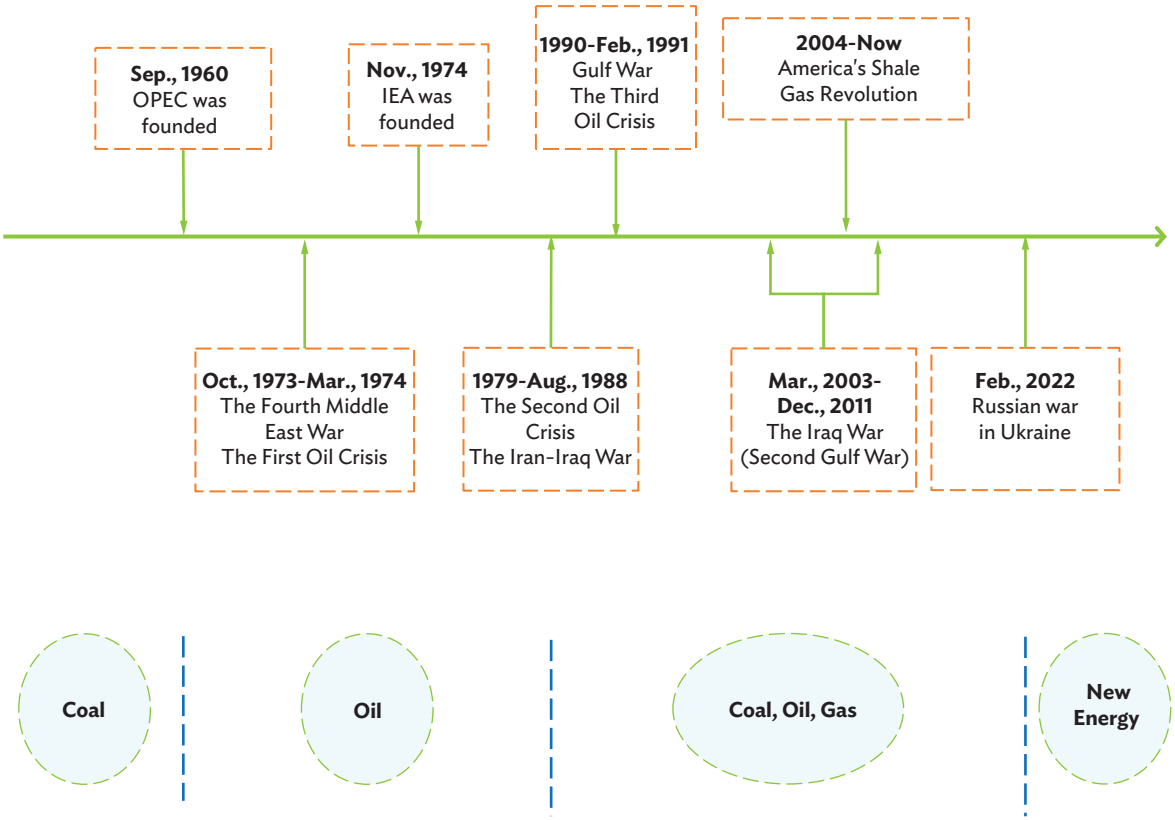
We can divide the historical evolution of the energy geopolitical scene into 4 eras, according to which source of energy was most important and the influence on world politics (Figure 3.2).

Coal-centric energy supply chain and the UK-USA Era

During the first industrial revolution, the emergence and widespread use of improved steam engines and steam turbines marked that human society entered the era of fossil energy. Coal became the primary energy product of European countries. European countries, led by the United Kingdom, through oversea expansion and long-distance transportation, built the "coal supply chains" connecting Europe with Asia, Africa, the Americas and other countries, and providing power for their industrial production. In addition, the U.K.'s advanced technology and its global network of "coal stations" enabled the U.K. to dominate coal and strengthen its control over the world's energy sources.

While the United Kingdom continued to expand its world energy footprint, to meet the energy demand from industrialization, in 1859, the United States began to develop oil commercially and established its offshore empire in the Caribbean and the Philippines. Oil is easier to extract and store, and is more efficient, compared to coal (Vaclav Smil, 2006). Oil gradually became a primary energy since the World War I and the object of the competition between Britain and the United States. At that time, the area around the Gulf of Mexico, dominated by the United States, and the Persian Gulf, dominated

Figure 3.2: Historical Evolution of Energy Domination and Energy Geopolitics



by the United Kingdom, became the world's oil centers. The signing of the Treaty of La Palo prompted the United States and Britain to cooperate in oil, thus forming a pattern in which the United States and Britain jointly controlled the world's energy.

Oil-centric energy supply chain and the OPEC Era

To counter the oil empires of Britain and America, five major oil-producing countries - Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela, established the Organization of Petroleum Exporting Countries (OPEC) in September 1960 to coordinate and unify the oil policies of member countries and to ensure the stability of oil prices. According to the record of OPEC, in 1962, the proven oil reserves of all OPEC countries were more than 60 billion tons, accounting for about 69% of the world's total. Their crude oil output and export volume accounted for about 50% and 85%, respectively, of the world's total. This helped OPEC to control oil production and exports, as well as oil pricing, and to expand its energy trading network and build a new oil empire. Furthermore, the fourth Middle East War in 1973 and the first oil crisis in 1974 confirmed OPEC's monopoly position of oil production and trade. European and American developed countries established the International Energy Agency (IEA) in November 1974 to reduce their dependence on oil imports, but OPEC's power and international influence gradually enlarged, which changed the global energy supply chains and energy geopolitical pattern.

The shale gas revolution and the oil-dollars era

The second oil crisis in 1979 and the Iran-Iraq war split OPEC's internal forces, making it gradually lose its ability to control the energy market. The Iraq War in 2003 and the American "shale gas" revolution in 2004 further weakened OPEC's power and strengthened the US's control over energy. At the same time, Russia, as a member of the "world's energy heartland," is rich in traditional fossil energy and keeps a significant position in the world energy market. In addition, North Africa, the PRC, Malaysia, Australia, Mexico, and other countries have also joined the international energy market, eroding the monopoly position of the original OPEC members, promoting the energy market to develop in a diversified direction, and gradually forming a new pattern of world energy geopolitics with mutual checks and balances.

The Russian war in Ukraine and the energy-mix era

The Russian war in Ukraine has led to the restructuring of the global energy value chain, affecting the control of energy by countries around the world and triggering new energy geopolitical changes. In addition, the traditional energy crisis has aroused global attention to new energy sources, and countries are gradually turning to the competition for new energy sources such as polysilicon, cobalt and lithium. New energy sources are gradually replacing traditional energy sources in the center of the world energy stage. As a result, a new energy geopolitical era is gradually taking shape and the energy-mix era is coming. The next section will discuss a simulation analysis for the new energy geopolitics.

The Dynamic Evolution Global Energy Supply Chains

The Russian war in Ukraine has disrupted the long-standing and relatively stable geopolitical landscape, with far-reaching implications for the global energy supply chains, driving the formation of a new global energy geopolitical landscape.

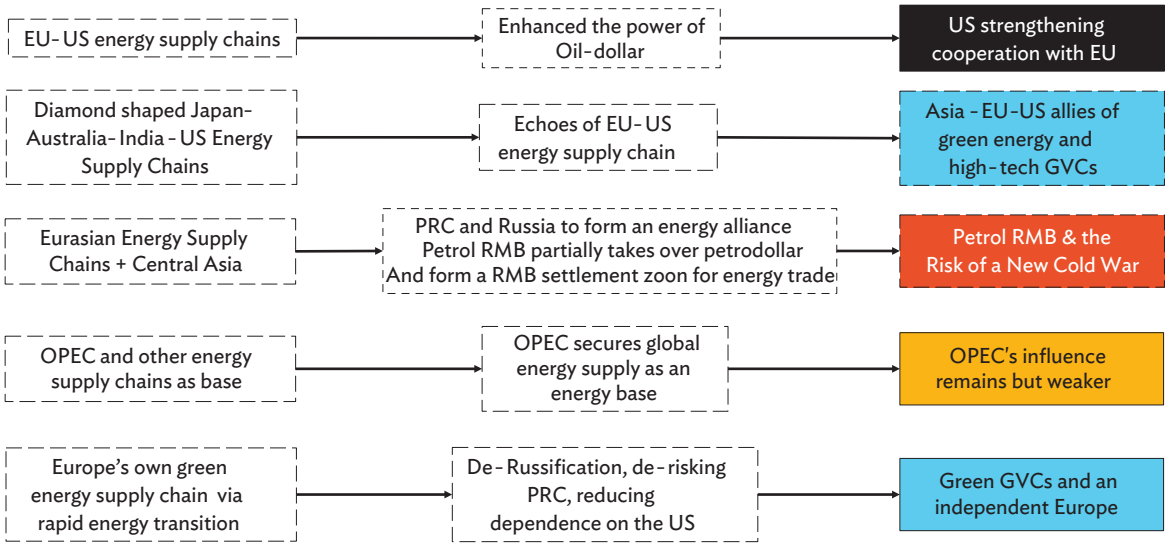
Scenario analysis of energy supply chain re-shaping

The future trend of the new energy supply chains and energy geopolitics will be shaped by developments such as US-EU cooperation, Russia-PRC cooperation, and OPEC's declining role. These developments are summarized in Figure 3.3.

The New EU-US Energy Supply Chain

The ongoing de-Russification of the EU is reducing the dependence on Russia while strengthening the energy trade between the EU and the United States by importing more American LNG and refined oil products. As a result, the United States will build a US-EU energy supply chain to replace the Russia's gas pipeline in the next few years. Consequently, the US will dominate the European energy market and maintain the strong power of the oil-dollar through increasing the volume of energy exports and international settlement by US dollars.

Figure 3.3: The Dynamic Evolution of Energy Supply Chains and Geopolitics



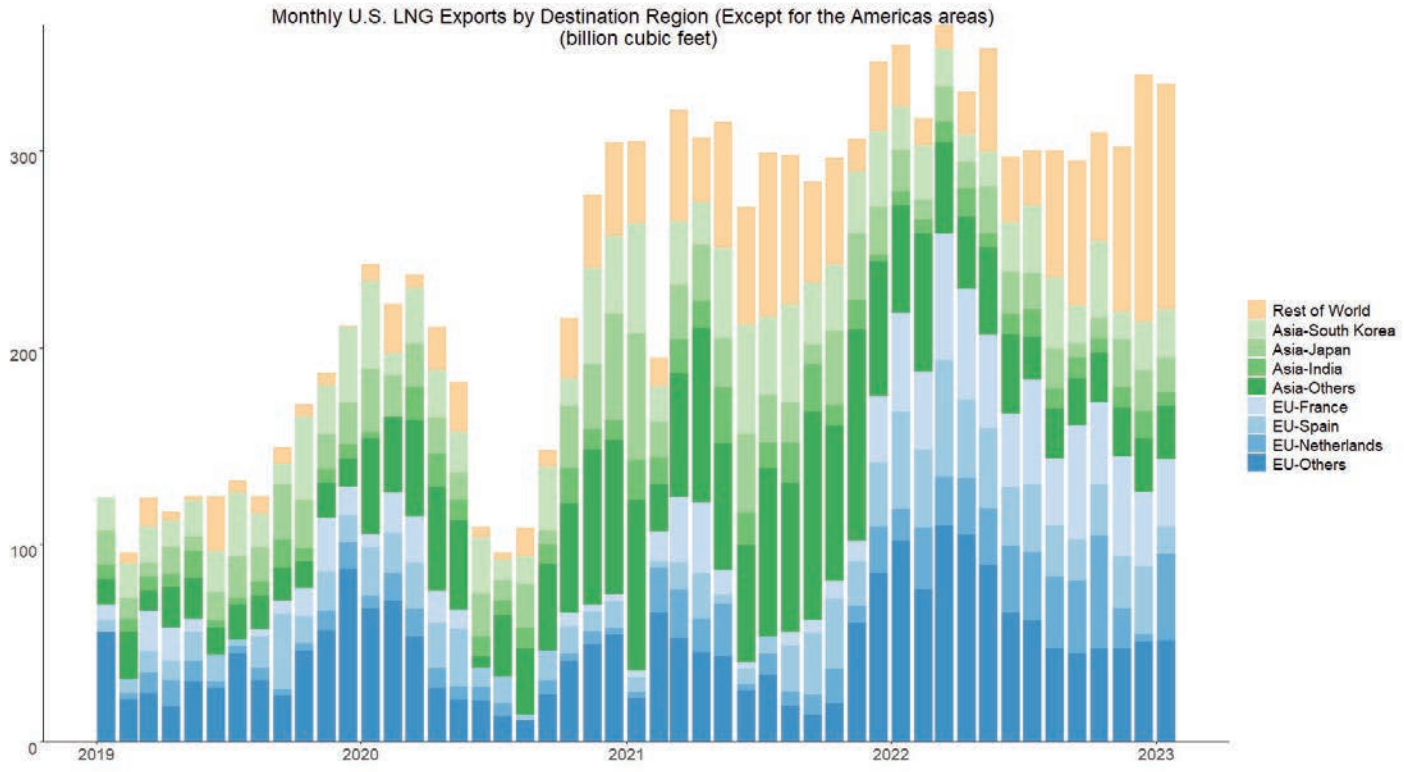
To ensure its energy security. the E.U. and other countries turned to import LNG from the US by sea. Figure 3.4 shows that before 2022, most US LNG exports went to Asian countries (e.g., Republic of Korea, Japan), while in 2022, the E.U. was the main importer of LNG from the United States. Consequently, the E.U. is practicing a strategy of transiting from over dependence on Russian gas to "de-Russification." Conversely, the EU-US energy supply chain is strengthened and the economic and political ties between the United States and the E.U. have been consolidated, making the oil-dollar stronger. As a result, the global natural gas supply chain is partially regionalized.

The "Diamond Shaped" energy supply chain in the Asia-Pacific region

Energy cooperation and energy security have an important place in the Indo-Pacific Strategy launched during the Obama administration by the United States and Japan. Since the shale gas revolution, in addition to having large coal reserves, the United States has also become a major natural gas producer, turning it from an importer to an exporter. At the same time, the rapid economic growth of the emerging economies in the Indo-Pacific region has increased energy demand. Therefore, by strengthening energy cooperation with the Indo-Pacific region through energy infrastructure construction, the "Indo-Pacific" energy cooperation model led by the United States is gradually forming[7]. As can be seen from Figure 3.5, the structure of the United States' natural gas exports changed dramatically from 2000 to 2022. In 2000, the United States exported 11.3 million tons of natural gas, primarily to countries in the Americas and Asia such as Mexico, Canada, Japan, Brazil, PRC, Chile, Guatemala, Germany, and Republic of Korea. By 2022, US natural gas exports had increased to 82.0 million tons,

7 Remarks by Senior Deputy Assistant Administrator for Asia Gloria Steele at the Asia EDGE Virtual Workshop: Supporting Indo-Pacific Industry Engagement through Asia EDGE | June 25, 2020 | Archive - US Agency for International Development (usaid.gov)

Figure 3.4: Change in US LNG Exports



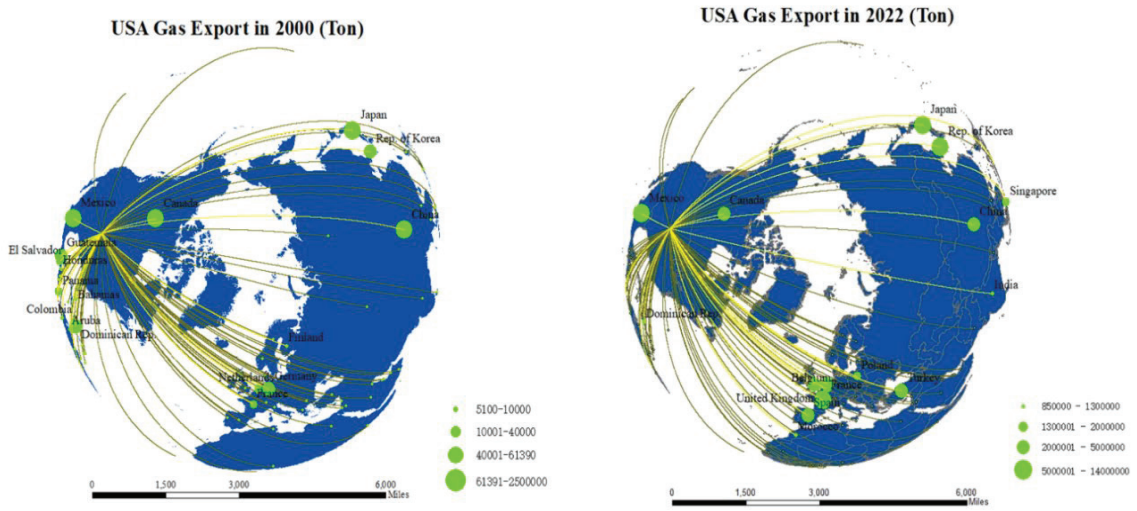
Source: EIA

a growth of 623.97%. The main export destinations included Mexico, Japan, PRC, Republic of Korea, Canada, Brazil, Türkiye, Spain, New Zealand, the UK, France, and India, spanning both Asia and Europe. This indicates that the US has intensified its energy exports to the Indo-Pacific region and Europe, securing a significant leadership role in energy consumption and supply within the Indo-Pacific area.

On July 13, 2022, in the wake of the Russian war in Ukraine and to discuss natural gas supply and future energy security issues, the "Quad Mechanism" energy ministers' meeting was convened in Australia. During the meeting, the four parties (Japan, US, Australia and India) reached a consensus on collaborating to develop the next generation of energy sources like hydrogen and ammonia, to promote future energy security. Japan actively discussed natural gas supply schemes with the United States and Australia to ensure energy supply security. In addition, the four parties agreed on the widespread adoption of technologies such as energy storage batteries that contribute to energy supply, establishing a stable "diamond" energy cooperation model and strengthening energy cooperation in the Indo-Pacific region (refer to Figure 3.6).

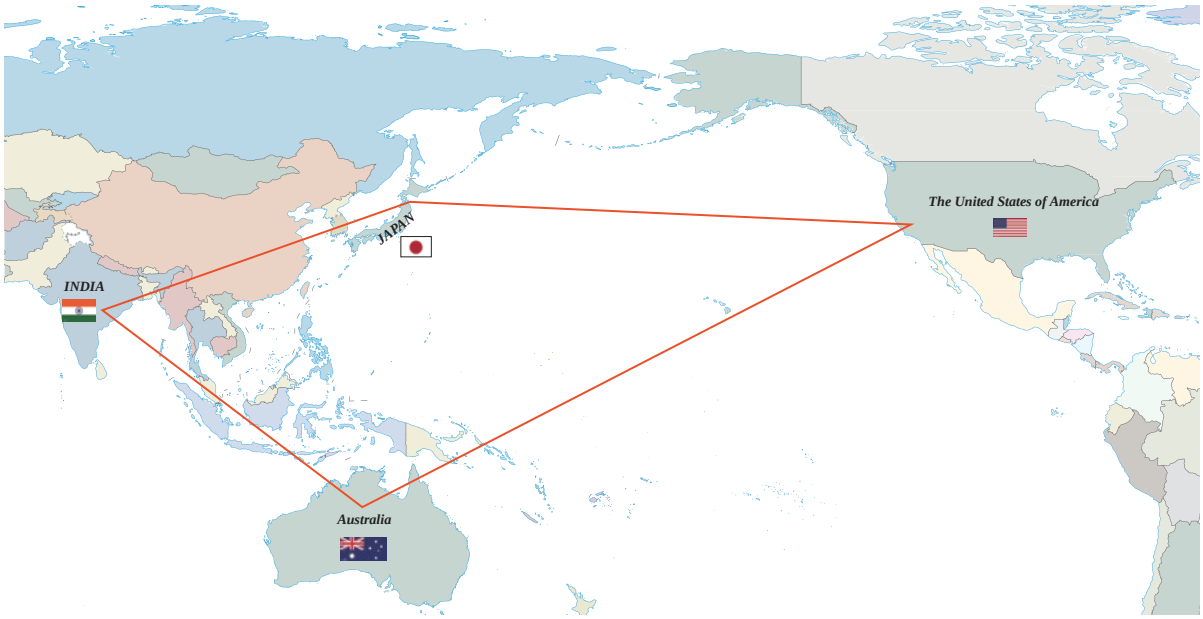
From the view of geopolitics, the "diamond" shaped energy cooperation model echoes the energy supply chains between Europe and the United States, which has consolidated the global energy dominance of the United States.

Figure 3.5: Change in US Gas Exports



Source: UN Comtrade.

Figure 3.6: The Diamond Energy Supply Chain in Asia-Pacific

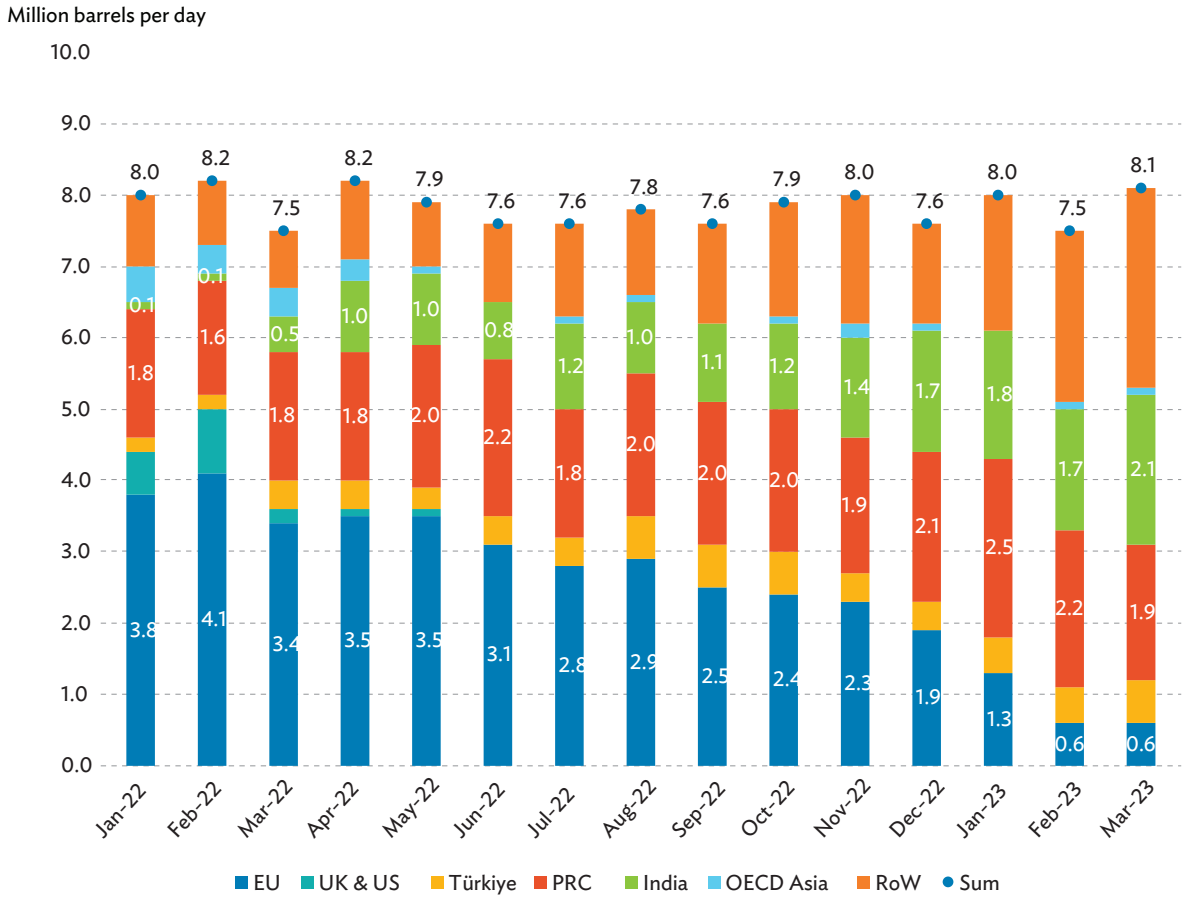


The Eurasian energy supply chain

European countries rely as much as 20-40% on Russia's oil and natural gas imports. The economic sanctions on Russia have led Russia to increase energy exports to neutral countries such as the PRC and India, making Asia a vital part of the Eurasian energy supply chain (Figure 3.7). According to the latest data, India and the PRC have become

the largest buyers of Russian energy. In June, the PRC imported record-breaking levels of Russian crude, a 44% increase compared to the same month in 2022[8]. Russia's share in India's crude oil imports soared to 19.1% from 2.0% a year ago, according to the latest annual report by the Reserve Bank of India (RBI)[9].

Figure 3.7: Change in Russian Oil Exports



Source: IEA.

The New Russia-Mongolia-PRC East Gas Pipeline

In May 2014, the PRC and Russia signed the Sino-Russian Eastern Gas Pipeline project, the first natural gas cooperation agreement between the PRC and Russia, which was officially implemented in December 2019. The pipeline starts from East Siberia, Russia, and enters Heilongjiang, the PRC from Blagoveshchensk. In the same year, the PRC and Russia signed the PRC-Russia Western Pipeline Cooperation Agreement, further strengthening the energy cooperation between the PRC and Russia. In February 2022, the cooperation between Russia and the PRC was further strengthened by signing the

8 PRC Snaps Up Record-High Volumes Of Russian Crude In The First Half Of 2023 | OilPrice.com

9 Fortune India: Business News, Strategy, Finance and Corporate Insight

Far East Gas Purchase and Sale Agreement, which plans to build the "Siberian Power 2" pipeline through Mongolia. As a result, for the first time, Russia connected the natural gas fields supplied to Europe with Asia, forming a "Eurasian energy supply chain," strengthening Russian-Chinese energy cooperation at the international level, as well as the position of the RMB and ruble in the world (Figure 3.8). In addition, the construction of the western line has laid the foundation for Russia's energy cooperation with other Asian countries, allowing it to transport natural gas to Asian nations through the PRC.

Figure 3.8: The West and East Pipeline of Russia to Asia

With the construction of the "Eurasian energy supply chain", "European and American energy supply chain", and "Diamond energy supply chain", the global energy supply chain has undergone significant changes. This has resulted in the formation of two major regional energy systems centered around PRC-Russia and the US. In this process, these two energy systems will engage in intense competition for a broader energy market and greater influence, creating a new mode of confrontation, eventually leading to the formation of a new Cold War system.

The OPEC Energy Supply Chains

As an oil monopoly, OPEC has dominated global energy supply and energy pricing for a long time. However, OPEC's position in the world energy market has declined as internal conflicts within OPEC have intensified and other energy supply chains have emerged. Especially, the large-scale development and sale of shale gas from the US strengthened the oil-dollar power and weakened OPEC's voice and influence. However, as the largest

energy supply group, OPEC still maintains its fundamental position in energy supply. In 2021, OPEC countries exported 19.7 million barrels per day of crude oil, down 0.2% from 2020, but still accounting for 47% of global crude oil exports. Thus, OPEC plays an important role in guaranteeing basic global energy supply and energy security. However, there has been some change in OPEC's behavior since the outbreak of the Russian war in Ukraine. Saudi Arabia is gradually strengthening its effective cooperation with Russia in OPEC+ and developing mutually beneficial cooperation in trade and economic matters. In addition, OPEC+ decided at the 33rd Ministerial Meeting of OPEC+ on October 5, 2022 to reduce total crude oil production by 2 million barrels per day from November, which is equivalent to about 2% of global oil demand. As a result, OPEC has strengthened its cooperation with Russia and other countries while ensuring the basic supply of global energy, which has a certain impact and influence on global energy supply lines and global energy prices in the context of the Russian war in Ukraine.

The above analysis shows that the future global energy supply chain will change in the direction of regionalization, and the energy cooperation in each region will be gradually strengthened. On the one hand, the strengthening of the US-European energy supply chain may strengthen the US influence over the EU countries and global energy market, and at the same time strengthen the petrodollar. Also, the four-sided "diamond" cooperation model formed by Japan, the US, Australia and India echo the European and US energy supply chains, forming a larger regional energy supply relationship, which to a certain extent also enhances the international status of the US dollar and further strengthens America's grip on world energy.

On the other hand, the energy cooperation between Russia and Asian countries (PRC, India, Mongolia) promotes the formation of the Eurasian energy supply chain, strengthens the international status of the RMB and ruble, and may result in a confrontational relationship with the European and American energy supply chains, eventually leading to the emergence of a new Cold War system.

The next section discusses how European countries may reduce their energy dependence on Russia and the United States due to the development of renewable energies. This would enable European countries to maintain a relatively independent position and perhaps to take a leading position in the development of renewable energy globally, thus strengthening the position of European countries and strengthening the euro.

Expectation of an independent European energy supply chain

The cost and risk of imported US energy is high in Europe, due to the long transport distance involving both sea and land, and the lack of pipeline transport. According to energy expert Laurent Segalen, the European purchase price of a ship filled with LNG from the United States in 2022 had risen to 275 million dollars, compared to the original price of $60 million. Therefore, the E.U. countries may seek to avoid excessive reliance on the US by reducing LNG imports from there. Also, the EU could seek a compromise

with Russia to maintain a basic level of gas imports, for example, according to a report from the Russian Satellite News Agency in Ankara on the 19th, President Vladimir Putin of Russia has now reached an agreement with President Recep Tayyip Erdoğan of Türkiye on the issue of the natural gas hub, allowing Europe to use Russian natural gas via Türkiye. An important alternative for the EU over the next few years would be to accelerate the development of renewable energy to speed up its energy transition and build an independent energy supply chain. The development of renewable energy can not only help European countries reduce their dependence on Russia but also lessen their reliance on the United States. This can lead to a relatively independent position.

CGE Simulation Analysis for the Impact of the Energy Supply Chains Re-Shaping

This section simulates the Russian war in Ukraine and some energy supply chain re-shaping scenarios in Section 3.2 using the GTAP-E model (Mcdougall and Golub, 2007) to predict their impact on the global economy and energy trade. This section aims to quantify the changes in the global economy and energy trade under some of the energy supply chain restructuring scenarios presented in Section 3.2. In the scenario setting, we try to capture all possible factors that have led to the formation and stabilization of various energy supply chains, The simulation assessment here is a comparative static analysis that aims to compare the difference between the designed scenario and the baseline scenario results to determine the impact of the former.

Scenario setting

Scenario 1: The Russian war in Ukraine. This scenario considers the impact of the Russian war in Ukraine on the global energy market, including the rise of global energy prices and energy transportation costs, and the restriction of Russian energy exports. Based on the data tracker, it is assumed that the Russian war in Ukraine will increase the prices of coal, oil, gas, and oil products by 10%, 2.5%, 3%, and 10% respectively, and the cost of energy transportation will rise by 10%. In addition, we simulate the decrease of Russian energy exports as a shock to the technical coefficients of the economies' energy imports from Russia.

Scenario 2: The EU-US energy supply chains. The main measures of this scenario are assumed as follows: (1) Europe and the United States impose an energy embargo on Russia. Specifically, European and US imports of coal, oil, and oil products from Russia are 0. Given Europe's dependence on Russian natural gas and the difficulty of replacing natural gas imports, it is assumed that Europe's natural gas imports from Russia are cut by 80% and US natural gas imports from Russia are 0. (2) The EU and G7 countries' energy sanctions against Russia also include the imposition of price limits on Russia's energy exports. The assumption here is that Russian gas export and coal export prices fall by 2% and oil and oil products export prices fall by 5%. (3) Europe will strengthen energy imports from the United States to replace its dependence on Russian energy. This is bound to increase the cost of European imports, which is reflected through the

following treatment: 30% of the energy subsidies of European countries are used to subsidize imports from the United States and Norway[10].

Scenario 3: Eurasian energy supply chain. This scenario includes: (1) Russia increases energy exports to neutral countries such as the PRC and India. This is achieved by simulating a fall in the cost of energy imports from Russia[11].(2) The PRC's energy supply chain from Central Asia is strengthened. This is mainly achieved through the improvement of energy trade facilitation. Assume that the PRC's oil and oil products trade facilitation from Central Asia is improved by 5% and gas trade facilitation is improved by 2.5%. (3) The Eurasian energy supply chain may face energy sanctions from the European and American Allies. Here we assume that the US and EU raise export taxes on energy products to the PRC by 1%.

Scenario 4: Japan-Australia-India-US energy supply chain. With the Indo-Pacific Strategy, Japan, India, Australia, and the United States will promote energy cooperation and accelerate infrastructure construction for the energy supply chain, assuming a 5% reduction in the cost of non-tariff barriers.

Scenario 5: This scenario is the combination of the above four scenarios.

CGE simulation results[12]

The impact on real GDP

In terms of GDP impact (Figure 3.9), the Russian war in Ukraine scenario results in varying degrees of recession in different economies, except for Norway. The strengthening of energy supply chains between the EU and the US has come at the cost of economic losses in Europe and the US. For instance, Germany's GDP is projected to decrease by 1.6 %. The effect of the Eurasian energy supply chain on the global economy

---

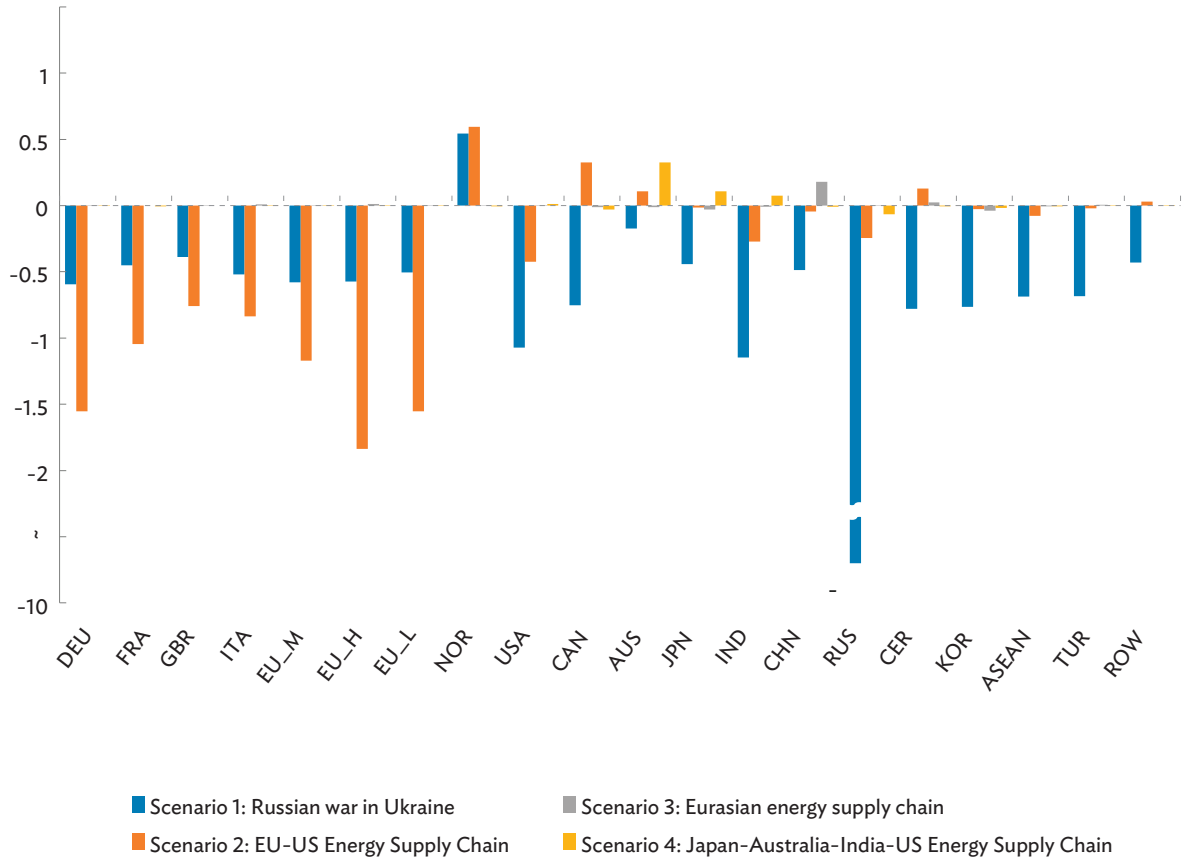
10 Bruegel reported on the proportion of fiscal subsidies provided by EU countries and the UK to GDP in response to the energy crisis(https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices). Assume that 30% of these subsidies are used to completely replace Russian gas imports with the United States and Norway. The change in natural gas import price $pims_{s,r}^{gas}$ can be obtained by the formula $pims_{s,r}^{gas} = \left(\frac{\delta_{s,r} * F_r^{gas}}{VIMS_{s,r}^{gas}} - \frac{\gamma_{s,r} * QIMS_{RUS,r}^{gas}}{QIMS_{s,r}^{gas}}\right)$ *100. Where r represents the EU countries and the UK, s represents the US and Norway, F_r^{gas} represents the amount of natural gas import subsidies for the economies of the EU countries and the UK, *VIMS* and *QIMS* are the value and quantity of imports, respectively. δ is the distribution share of natural gas import subsidies in the US and Norway, and it is assumed that the subsidies received by the US account for 0.8 of the total subsidies in the simulation, and γ is the distribution coefficient of the amount of natural gas imported to replace Russia, and γ is assumed to be 0.5 in the simulation. The change of import cost caused by import price can in turn be countered by the reduction of import tariff rate, so the tariff reduction shock is used here to simulate the substitution of natural gas imports from the US and Norway in the EU and the UK.

11 Based on the data of changes in the price of energy imported from Russia by PRC and India in 2022, it is assumed that the price of Russian oil imported by the PRC and India falls by 10% and 20% respectively, and the price of gas imported by 40% and 20% respectively. Import tariffs on coal from Russia fall to zero for the PRC and India.

12 The GTAP version 10 database used for the simulations, which has the base year of 2014, covers 121 countries as well as 20 regional collections, including 56 industry sectors (Aguiar et al., 2019), and the countries were processed in groups for the analysis, resulting in 20 country groups, as shown in the annex 3.1.

is limited, with the PRC benefiting relatively significantly. The facilitation of energy trade between Japan, Australia, India, and the US has had a minimal impact on the US but contributes to economic growth in the other three countries.

Figure 3.9: Real GDP Impact of Energy Supply Chain Restructuring (% Changes Relative to the Baseline)



Note: See annex 3.1 for a key to country abbreviations.
Source: simulation result based on GTAP-E model.

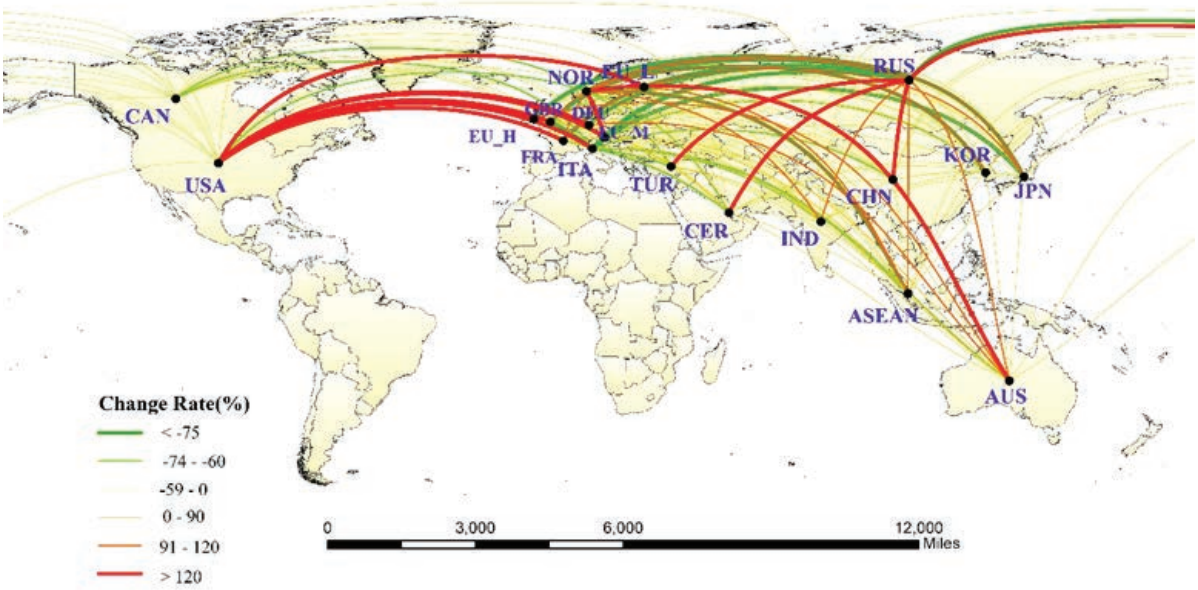
The impact on gas trade

The restructuring of energy supplies in the EU-US results in a notable decrease in their gas imports from Russia and a significant rise in US gas exports to Europe (Figure 3.10). Russian gas exports shift primarily towards Asia.

The Eurasian energy supply chain has not reshaped global gas trade as much as the EU-US energy supply chains, as the major changes in gas trade flows occur along two routes, with little impact on gas trade flows between other economies (Figure 3.11). The first route is the "Russian-Central Asia to PRC-India". Russian gas exports to the PRC and India will grow significantly by 176.1% and 93.5% respectively, while Central East Region (CER) gas exports to the PRC will also grow by 68.2%. The second route is "EU-US to PRC", where the US and the EU gas exports to the PRC are down by about 40 %.

Figure 3.10: Changes in Gas Trade Flows Under EU-US Energy Supply Chains Scenarios (% Changes Relative to the Baseline)

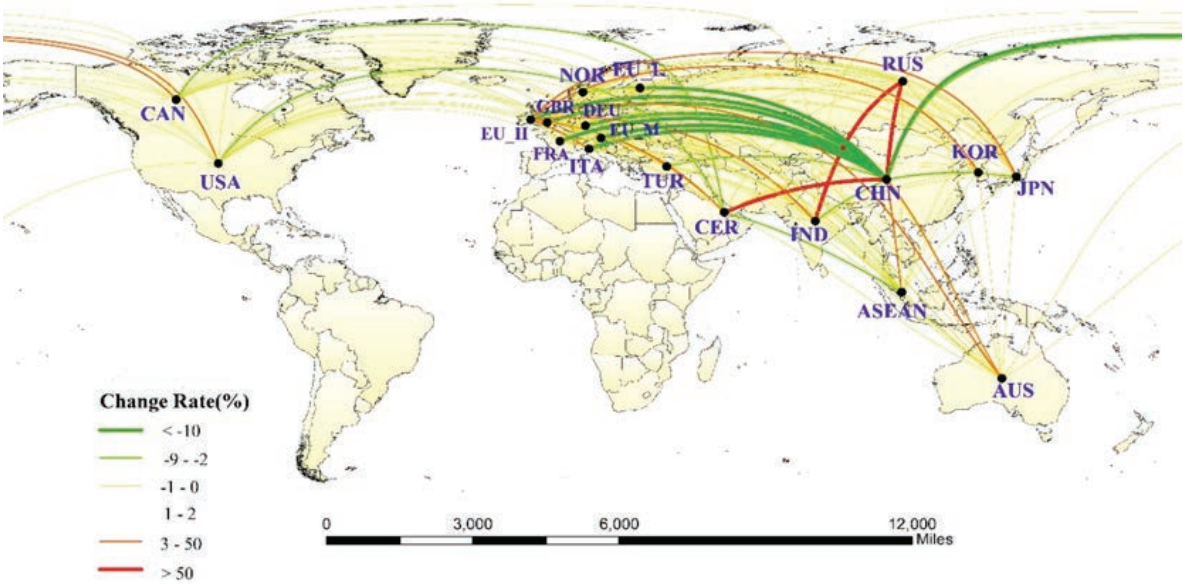
Rate of Change in Gas Trade Before and After the Shock



Source: simulation result based on GTAP-E model.

Figure 3.11: Changes in Gas Trade Flows Under Eurasian Energy Supply Chains Scenarios (% Changes Relative to the Baseline)

Rate of Change in Gas Trade Before and After the Shock



Source: simulation result based on GTAP-E model.

The impact on oil trade

Table 1 reports changes in global oil trade under all scenarios combined. Russia's oil exports to Europe and the US disappear completely. Russia's total oil exports decline by 37.9 % although there has been an increase in exports to other economies, such as a significant increase of 236.4 % to India. For the PRC, energy sanctions imposed by Europe and the United States have also affected the PRC's oil imports from other economies, making energy cooperation with Russia and CER crucial for ensuring the security of the PRC's oil imports. Some EU economies would face challenges in meeting their oil demand after the closure of the oil import route from Russia, despite an increase in oil imports from other sources. For instance, EU_L (EU economies with low dependence on Russian energy) and Germany experienced a decline in their total oil imports by 7.8% and 2.3%, respectively. The energy cooperation between the US, Japan, Australia, and India leads to significant growth in four-way oil trade, but it has had little impact on the total oil imports of these four countries.

Table 3.1: Change in Oil Trade Flows Under the Combined Scenario (% Changes Relative to the Baseline)

	ASEAN	AUS	CAN	CER	CHN	DEU	EU_H	EU_L	EU_M	FRA	GBR	IND	ITA	JPN	KOR	NOR	RUS	TUR	USA
ASEAN	-3.70	-1.11	2.46	0.74	-27.08	89.36	42.17	156.99	43.06	7.77	7.79	-0.72	41.77	-6.69	-7.30	1.99	-23.32	-8.80	1.17
AUS	-3.70	56.36	-0.17	-1.50	-27.05	84.56	38.62	150.48	39.40	5.01	5.06	102.76	38.11	46.67	-7.19	1.99	-25.28	-11.15	56.28
CAN	-2.96	1.11	2.46	0.74	-27.02	89.36	39.90	156.99	39.51	5.01	5.02	0.72	38.12	-4.23	-4.85	2.03	-23.32	-8.80	-1.45
CER	-3.69	-1.11	-0.16	-1.79	15.35	84.83	38.98	156.99	39.42	5.00	5.07	-0.73	38.16	-6.69	-7.30	1.99	-23.32	-8.80	-1.20
CHN	-2.53	-1.12	2.46	-1.45	-25.16	89.36	42.17	156.02	43.07	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
DEU	-1.15	-0.59	2.46	0.74	-32.59	89.36	42.17	156.24	39.03	4.87	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.14
EU_H	-1.15	-0.71	1.48	0.74	-32.59	89.36	42.16	150.40	39.02	0.99	4.78	1.88	37.77	-4.21	-4.85	2.00	-23.32	-8.80	1.41
EU_L	-1.15	-1.11	2.46	0.74	-32.59	84.01	40.55	149.75	39.05	5.00	4.75	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	-0.51
EU_M	-1.15	-1.07	1.65	0.58	-32.59	84.01	38.16	150.02	36.70	4.89	4.76	1.88	37.84	-4.21	-5.78	1.99	-23.32	-8.80	0.83
FRA	-1.15	-1.08	2.46	0.74	-32.59	84.44	41.55	156.99	39.42	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
GBR	-3.67	-1.08	-0.18	-1.31	-34.06	84.01	38.16	149.75	39.13	5.00	7.79	-4.00	37.77	-4.21	-7.30	1.77	-23.32	-8.80	-1.20
IND	-1.15	56.41	2.46	-1.75	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	61.15	41.77	50.57	-4.85	1.99	-23.32	-8.80	60.41
ITA	-1.15	-1.04	2.46	-5.50	-32.59	84.01	39.75	139.94	38.43	5.00	5.28	1.88	41.77	-4.21	-4.85	1.99	-23.32	-11.14	0.08
JPN	-3.71	56.37	2.46	0.74	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	61.15	41.77	50.57	-4.85	1.99	-25.03	-8.80	60.41
KOR	-3.70	-1.11	2.46	0.74	-25.16	89.36	42.17	156.99	43.07	7.77	7.79	1.88	41.77	-4.21	-4.85	1.99	-23.32	-8.80	1.41
NOR	-3.73	-1.15	-0.18	-1.85	-27.11	84.01	38.16	149.75	39.05	5.00	4.75	-0.76	37.77	-6.72	-7.33	1.99	-25.32	-11.17	-1.20
RUS	54.85	58.47	61.90	57.34	65.66	-100.00	-100.00	-100.00	-100.00	-100.00	-100.00	236.42	-100.00	48.63	48.59	63.46	26.93	42.42	-100.00
TUR	-3.69	1.18	2.46	0.74	-25.16	89.36	38.53	150.40	43.07	7.77	7.79	-0.73	38.13	-4.21	-4.85	2.17	-23.32	-8.80	1.41
USA	-3.69	56.42	-0.43	0.63	-35.80	84.49	38.59	155.34	38.88	5.90	7.25	50.62	32.43	46.69	-7.30	1.99	-23.32	-8.80	60.41

Note: The vertical coordinate represents the exporter and the horizontal coordinate represents the importer.
Source: simulation result based on GTAP-E model.

3.4 Renewable Energy and the Future Directions of Energy Supply Chains and Energy Trade

Carbon Neutrality, Energy Transition, and Renewable Energy Development

Energy transition is the key for carbon neutrality

Shifting to low-carbon renewable energy is a crucial step in meeting global climate goals outlined in agreements like the Paris Agreement. To implement the Paris agreement, most countries have committed to reduce greenhouse gas emissions and made roadmaps and timetables for carbon neutrality. To neutralize their carbon emissions, it is crucial to increase the share of renewable energy in their energy mix. For this purpose, governments worldwide have been setting renewable energy targets and increasing their investments in energy related sectors. As a result, there has been a significant expansion of renewable energy capacity across the globe, contributing to a more diversified and sustainable energy mix. Climate change mitigation efforts will lead to the implementation of policies and regulations that support renewable energy adoption. Supportive policies, such as feed-in tariffs and renewable energy standards, can incentivize investment in renewable energy projects and influence trade patterns.

Current globalizing energy supply chains

Renewable energy supply chains are global because they capitalize on diverse resources, technology specialization, economies of scale, and international collaboration. The global nature of these supply chains is essential to meet the growing demand for renewable energy and combat climate change on a global scale.

Renewable energy technologies need to be sourced from different countries with significant manufacturing capacity or natural resources such as lithium reserves, leading to a global supply chain. Renewable energy technologies are more technology and material intensive. However, the production of renewable energy technologies relies on specific raw materials and minerals. Different countries have comparative advantages in specific aspects of renewable energy technology production.
The materials that underpin renewable energy are more concentrated in fewer countries than those for fossil fuels (IEA, 2021). For example, lithium resources mainly present in Australia, Argentina, Bolivia and Chile. These comparative advantages necessitate cross-border trade and collaboration to access the best technologies and components.

Furthermore, the manufacturing characteristics of the renewable technologies lead to economies of scale, which further promote globalized energy supply chains. Renewable energy projects, such as large solar or wind farms, benefit from economies of scale. To

achieve cost-effectiveness, these projects often involve the production and assembly of components in countries with efficient manufacturing capabilities. This global approach enables the mass production of renewable energy technologies at competitive prices and has driven continuous price declines in the past (Goldthau and Hughes, 2020).

Opportunities of Renewable Energy

Renewable energy development is boosted by both supply and demand factors. On the demand side, carbon neutrality targets are stimulating the demand for renewable energy and promoting the energy transition. The energy transition will lead to a surge in demand for renewable energy technologies such as solar panels, wind turbines, and energy storage systems. Thus the energy transition will lead to greater integration of renewable energy sources into global energy systems.

On the supply side, continuous research and development (R&D) is driving innovations in renewable energy technologies, leading to increased efficiency and cost reductions. The cost of renewable energy generation has been steadily declining, making it increasingly cost-competitive with traditional energy sources. In many regions, renewable energy sources have achieved grid parity, meaning they can produce electricity at a cost comparable to or even lower than conventional sources.

According to BP Energy Outlook (2023), renewables are expected to expand rapidly in the future. Their share in the primary energy supply is forecasted to increase from 11.8% in 2019 to 34.9-64.0% in 2050. Solar and wind power will experience significant growth

Their total installed capacity is expected to increase up to 16 times in 2050, from 1231 GW in 2019 to 11420-20225 GW in 2050. The PRC dominates the growth of solar and wind capacity between 2022 and 2035. The rapid expansion of renewables will lead to significant growth of manufacturing. For example, to support these ambitious targets, global production capacity for the key building blocks of solar panels – polysilicon, ingots, wafers, cells and modules – would need to more than double by 2030 from today's levels and existing production facilities would need to be modernized (IEA, 2022b).

Renewable energy supply chains and the new world energy market and trade

As renewable energy technologies continue to advance and become more economically viable, they are expected to play a pivotal role in shaping the global energy and even political landscape. The renewable energy development will require changes in the energy infrastructure and transmission networks to accommodate the variable nature of renewable energy. This will lead to opportunities for new investment. From green bonds to carbon trading, various financial instruments are emerging to support the development and deployment of renewable energy projects.

Renewable energy technologies allow for decentralized energy production, enabling communities and individual households to generate their own electricity. In contrast, in the present fossil fuel dominant system, electricity is generated by large companies. This democratization of energy empowers consumers, reduces dependence on centralized power systems, and fosters energy independence. Aggregately, by diversifying energy sources and reducing reliance on fossil fuel imports, countries can enhance their energy security and reduce exposure to volatile global energy markets.

Renewable power development increases regional power connectivity. Renewable energy sources, such as solar, wind, and hydro, vary in abundance across different regions. To harness the full potential of renewable energy, countries often need to tap into resources found in diverse geographical locations, necessitating more interconnected energy grids. Interconnected energy grids allow the efficient transmission of renewable power over long distances, facilitating the integration of renewable energy from various sources and locations.

Adoption of renewable energy technologies could even shape trade relations and geopolitical dynamics. For example, both Republic of Korea and Japan have experienced a significant transformation in their trade relationship with the PRC, moving from a state of strong complementarities to a situation of increasing competition in key strategic industries. Key among these are car exports – including the rapidly growing market of electric vehicles (EVs). The PRC surpassed Japan in the first quarter of 2023 to become the world's largest car exporter, and Chinese producers have started to exert dominance in domestic sales, resulting in a sharp decline in the fortunes of Japanese carmakers (Michael Harley, 2023). While this already presents troubling milestones for Japan's champion automotive industry, the PRC's growth in the EV sector potentially presents bigger challenges. In 2022, the PRC managed to secure around 35% of the global EV export market, while Japan's share has declined from approximately 25% to less than 10% over a four-year period (2018-2022) (IEA, 2023a). The PRC's growing competitiveness and market share in the EV export market is viewed as a threat to Japan and the Republic of Korea, which may affect geopolitical dynamics. Moreover, with the escalating EV sector competition, EV batteries, and the critical minerals needed to produce them such as lithium, are also increasingly being considered as an economic security issue (Corey Lee Bell et al., 2023).

Challenges facing to renewable energy supply chains

One of the challenges to renewable energy has been intermittency, as sources like solar and wind depend on weather conditions. The prevailing storage technologies can only provide at a maximum short-term backup, while power system reliability needs longer-term backup. A reliable power supply needs backup in five timescales: annual, quarterly, monthly, daily, and spinning back up. In contrast, battery and pumped hydrogen storage are designed to provide back up within an hour and a day, respectively (Blakers et al., 2021)home and electric vehicle batteries. Batteries are rapidly falling in price and can compete with pumped hydro for short-term storage (minutes to hours. Although widely viewed as a stable

power supply source, hydropower can have seasonal and yearly variability, such as dry and wet seasons and years (Stokstad, 2016). In the absence of long-term storage capacity and before the extensive deployment of long-term storage technologies, mainly renewable electricity made from hydrogen, renewable energies will face increasing challenges over the term of their development.

Further advancements in energy storage technologies, such as batteries and pumped hydro storage, are required to enable greater utilization of renewable energy and ensure stable grid operations. Therefore, the crucial elements of energy innovation are breakthroughs in energy storage, grid integration, and smart energy management, which will make renewable sources more reliable and competitive.

Vulnerability of energy supply chains

Global supply chains that span multiple regions and nations can leave countries vulnerable to disruptions in international trade due to various factors. These vulnerabilities underscore the importance of carefully managing supply chains to promote the energy transition while securing the energy supply and economic development.

Countries heavily reliant on renewable energy imports may face supply shortages or increased costs during trade disruptions. For instance, trade disputes, tariffs, or geopolitical tensions can trigger disruptions in the global trade of renewable energy components and resources, leading to potential supply shortages or increased costs for countries heavily reliant on imports. According to IEA's Special Report on Solar PV Global Supply Chains, from 2011, the imposition of antidumping, countervailing, and import duties on various components of the solar PV supply chain has escalated significantly, rising from a single import tax to 17 duties and import taxes, with an additional 8 policies currently being reviewed (IEA, 2022b). Collectively, these measures now encompass 17% of global demand, excluding the PRC's domestic demand (IEA, 2022b). Moreover, some countries may introduce carbon border adjustment mechanisms to address the carbon leakage issue and protect domestic industries from imports with high carbon footprints. Such mechanisms could impact the competitiveness of renewable energy products in global markets.

Concentration of production and process of renewable energy technologies and materials leads to supply chain vulnerability. Energy production and distribution are often concentrated in specific regions or countries. For example, the PRC is set to attain a nearly 95% share of global polysilicon based on the manufacturing capacity currently under construction (IEA, 2022b). Many renewable energy technologies rely on specific raw materials that are sourced from a limited number of countries (IEA, 2021). Any disruptions, whether caused by geopolitical tensions, accidents, or extreme weather events, can lead to shortages and price spikes in the global energy market and further impact the production and deployment of renewable energy technologies globally.

Security issues with critical energy transition minerals

The energy transition requires significant development of critical mineral sectors since low-carbon technologies are mineral intensive. Due to natural resource endowment, the supply chains of critical minerals are more concentrated than those of fossil fuels(IEA, 2021). Therefore, meeting the 1.5 degree goals will require collaboration among suppliers to supply critical minerals. Despite the higher level of concentration, the energy security concerns of critical minerals should not be as serious as fossil fuels. The combination of high concentration and limited transparency renders critical minerals more susceptible to physical disruption, trade restrictions, or other developments in major producing countries compared to fossil fuels. However, unlike fossil fuels that need continuous supply of fuels, renewable energy does not need fuel and other continuous inputs.

Unfortunately, the contemporary global geopolitical environment, particularly the Sino-American competition and the global surge in protectionism, is increasingly weaponizing the critical mineral sector. An example is Canada's forced divestment of Chinese investors (Ismail Shakil and Siyi Liu, 2022).

Compromising international trade, investment and cooperation puts the energy transition at risk because low-carbon technologies rely on international trade networks and investment to keep costs down and encourage learning and innovation (Goldthau and Hughes, 2020; Helveston and Nahm, 2019) . While lithium prices have recently reached record highs, present lithium-ion battery prices per kilowatt hour are 30 times cheaper than in the early 1990s (Ziegler and Trancik, 2021).

3.5 Potential Impact of the Energy Dynamics on the Emission Goals

The IPCC Special Report on Global Warming of 1.5 °C (IPCC, October 8, 2018) urged limiting the global temperature rise within 1.5 °C by 2030 in order to avoid the catastrophic effects of extreme weather on the world. To do so, the 2019 climate Paris agreement confirmed that developed and developing countries have to achieve carbon neutrality by 2050 and 2060 respectively. Furthermore, all countries have to achieve net zero carbon dioxide emissions between 2070 and 2090, and the whole world achieve net zero greenhouse gas emissions by 2100. After the Paris agreement, most countries made plans to reach the carbon neutrality targets and attained some important achievements through developing renewable energy while reducing the use of fossil fuels. At the COP 26, more than 40 countries including US and EU countries, announced an agreement to phase-out coal by 2030 and promised to replace virtually all traditional energy with wind, solar or nuclear power and speed up energy transition around 2035. The PRC also promised to terminate oversea investment to coalfired power generation.

However, the disruption of energy supply chains during the COVID-19 pandemic (see above) and the current geopolitical changes, especially the Russian war in Ukraine, began to affect the speed of the world energy transition and the timetable for carbon neutrality. We predict the effects of the war on environment and climate governance from the perspectives of short-term and long-term.

a. Short term: energy dynamics will have an impact on global climate governance

The issue of energy supply remains severe in the short term. Since the carbon content per unit calorific value of natural gas (15.3 tC/TJ) is significantly lower than that of coal (26.37 tC/TJ), the increased use of coal by European countries in the face of the energy shortage increased carbon emissions. Similarly, to meet increasing electricity demand, the PRC has plans for more than 10 new coalfired power generation stations, some of which are under construction. And while energy-related CO_2 emissions declined during the pandemic-induced recession, this was offset by the 2021 increase of 1.9 Gt, the largest in history (IEA, 2022d).

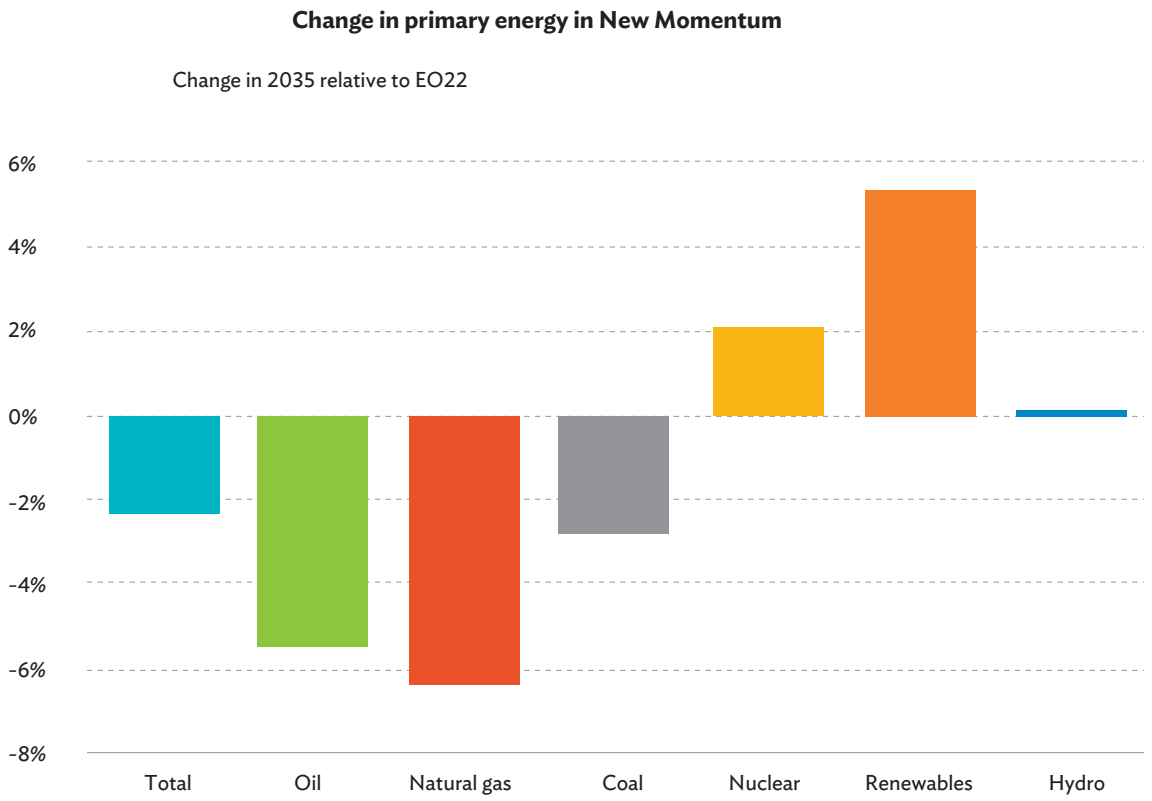
b. Long term: energy dynamics will accelerate the energy transition and promote the carbon reduction process

The disruption of Europe's natural gas supply chain has increased the impetus for investment in and use of renewable energy. On September 13, 2022, to achieve the "Fit for 55" goal, the E.U. Parliament adopted the Renewable Energy Development Directive (REDII), which stipulates that the share of renewable energy consumption will reach 45% by 2030. Thus, European countries may achieve the carbon neutrality earlier and take a leading position and voice in global environmental and climate governance.

c. Energy security and energy supply chains resilience will be the key for the future GVC design

In addition, the outbreak of the Russian war in Ukraine triggered a deeper global reflection on energy security and energy transition, with countries struggling to balance energy security, energy reliability and energy cleanliness. In terms of energy supply, global oil and gas prices have soared since the outbreak of the Russian war in Ukraine, and the subsequent sanctions imposed on Russia by Europe and the US have exacerbated the energy supply crunch. Governments around the world are bound to develop indigenous resources, many of which are not fossil fuels, on a larger scale in order to ensure energy security. This will reduce global dependence on fossil energy and change the global energy supply structure (as shown in Figure 3.12).

Figure 3.12: Change in Primary Energy in the Future

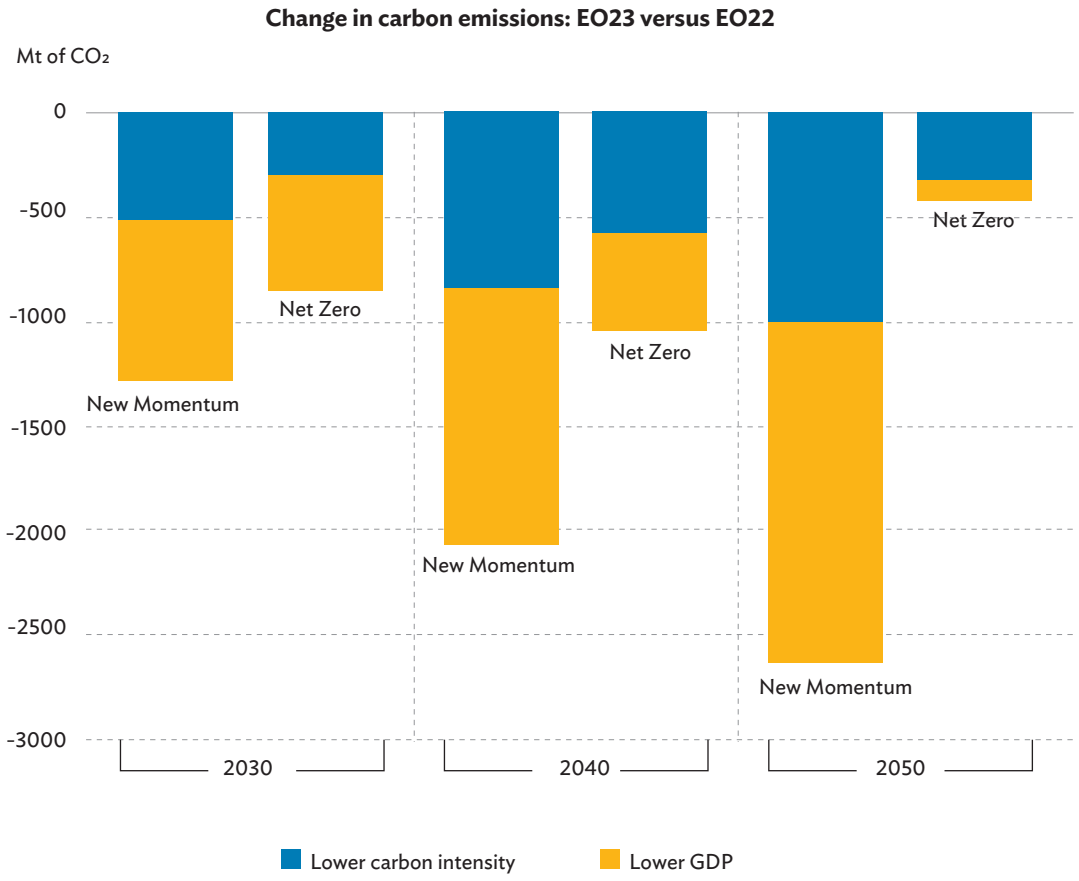


Note: New Momentum is designed to capture the broad trajectory along which the global energy system is currently travelling. It places weight on the marked increase in global ambition for decarbonization in recent years, as well as on the manner and speed of decarbonization seen over the recent New Momentum past. CO_2 emissions in New Momentum peak in the 2020s and by 2050 are around 30% below 2019 levels.

Source: BP Energy Outlook 2023. EO22 means Energy Outlook 2022

The change in the global energy structure and the increased demand for clean energy will not only improve energy security, but will also reduce global carbon emissions and accelerate the process of achieving carbon neutrality in all countries around the world. According to the BP Energy Outlook 2023, carbon emissions in this year's New Momentum scenario are around 1.3 $GtCO_2$ (3.7%) lower in 2030 than in 2022 Energy Outlook. This downward revision increases to around 2.0 $GtCO_2$ (6.4%) in 2040 and 2.6 $GtCO_2$ (9.3%) in 2050 (as shown in Figure 3.13).

Figure 3.13: CO_2 Emissions from Combusted Fuels in the Future



Note: CO_2 emissions in Net Zero by 2050 are around 95% below 2019 levels.
Source: BP Energy Outlook 2023. EO23 means Energy Outlook 2023.

Conclusions

The long-lasting Sino-US trade war and the ongoing Russian war in Ukraine are fueling geopolitical tensions and having huge impacts on global value chains, including global energy supply chains. These events have made geopolitical concerns rather than economic interests the dominant factor in shaping the policies governing energy trade.

Trade weaponization and trade sanctions are escalating. These will reshape the patterns of world energy trade to form some segmented regional energy supply chains, especially the EU-US energy supply chain and the Eurasia energy supply chain. These groupings will change the routes and patterns of world energy trade. WTO needs to follow these changes and update its functions. Shifting to green and low-carbon energy is a crucial step in meeting the net-zero-emission targets. As renewable energy technologies continue to advance and become more economically viable, renewable energy are expecting to play a pivotal role in reshaping the energy global supply chains and even political landscape.

All these dynamic movements are likely to affect the world energy transition and climate governance. One optimistic assumption is that the EU countries will use these crises as opportunities to speed up the development of renewable energy and formulate a new green energy supply chain to accelerate its energy transition and carbon neutrality.

Energy security and energy supply chain resilience will be the key for the future GVC design. Energy security is the cornerstone of stable national development, and unforeseen situations such as wars, extreme weather and large-scale pandemics can affect global energy supplies and pose a threat to energy supply chains. Therefore, ensuring the long-term security and reliability of energy supply chains is an issue that should be of concern to all countries around the world.

References

Aguiar A, Chepeliev M, Corong E, et al. The GTAP Data Base: Version 10. Journal of Global Economic Analysis, 2019, 4(1): 1-27.

Bacchus, J. «The Black Hole of National Security» CATO Policy Analysis, 9 November 2022.

Benton-Heath. «The New National Security Challenge to the Economic Order» The Yale Law Journal 129 (2020): 1022-1099.

Birkbeck, C.D., 2021. Greening International Trade Pathways Forward.

Blakers, A., Stocks, M., Lu, B., Cheng, C., 2021. A review of pumped hydro energy storage. Prog. Energy. https://doi.org/10.1088/2516-1083/abeb5b

BP Energy Outlook 2023. Energy Outlook | Energy economics | Home (bp.com)

BP Statistical Review of World Energy 2022.

Carley, S., Konisky, D.M., 2020. The justice and equity implications of the clean energy transition. Nat. Energy 5, 569–577.

Condon, M., Ignaciuk, A., 2013. Border Carbon Adjustment and International Trade. OECD Trade Environ. Work. Pap.

Corey Lee Bell, Elena Collinson, Xunpeng Shi, 2023. The China Factor in Japan-South Korea Rapprochement [WWW Document]. Dipl. URL https://thediplomat.com/2023/05/the-china-factor-in-japan-south-korea-rapprochement/ (accessed 7.28.23).

China - Rare Earths. DS432 (WTO, 2014).

Ciuriak, Dan. «Unfree Flow with No Trust: The Implications of Geoeconomics and Geopolitics for Data and Digital Trade» Centre for International Governance Innovation. 14 February 2022.

Bacchus, James; Cottier, Thomas, et et al. «Energy in WTO law and policy» www.wto.org. 2010. https://www.wto.org/english/res_e/publications_e/wtr10_7may10_e.pdf.

Dodds, Klaus. A Very Short Introduction to Geopolitics. Oxford Academic, 2019.

Dong, B., Guo, Y., 2018. The impact of the first Sino-Japanese war indemnity: Transfer problem reexamined. International Review of Economics & Finance 56, 15–26. https://doi.org/10.1016/j.iref.2018.03.013

Freeman, J., 2022. Tesla's CSR Policy.

Gavin, Brigid. «China's Growing Conflict with the WTO: The Case of Export Restrictions on Rare Earth Resources» Intereconomics, 2013.

Global Warming of 1.5 °C — (ipcc.ch)

Goldthau, A., Hughes, L., 2020. Protect global supply chains for low-carbon technologies. Nature 585, 28–30. https://doi.org/10.1038/d41586-020-02499-8

Helveston, J., Nahm, J., 2019. China's key role in scaling low-carbon energy technologies. Science (80-.). 366, 794–796. https://doi.org/10.1126/SCIENCE.AAZ1014

Helveston, J.P., He, G., Davidson, M.R., 2022. Quantifying the cost savings of global solar photovoltaic supply chains. Nat. 2022 6127938 612, 83–87. https://doi.org/10.1038/s41586-022-05316-6

Hoekman, Bernard, Petros Mavroidis, et Douglas Nelson. « Geopolitical Competition, Globalization and WTO Reform, RSC 2022/67» Robert Schuman Centre for Advanced Studies Global Governance Programme, 2022.

Howse, Robert. «Symposium On Gregory Shaffer, "Governing the Interface of US-China Trade Relations": The Limits of the WTO» AJIL Unbound, 2022.
IEA, 2021. The Role of Critical Minerals in Clean Energy Transitions. Paris. https://doi.org/10.1787/f262b91c-en
IEA, 2022a. Global Energy Review: CO2 Emissions in 2021, IEA, Paris https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2, License: CC BY 4.0
IEA, 2022b. Special Report on Solar PV Global Supply Chains [WWW Document]. Int. Energy Agency. URL https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary (accessed 7.29.23).
IEA, 2022c. The world's coal consumption is set to reach a new high in 2022 as the energy crisis shakes markets [WWW Document]. Int. Energy Agency. URL https://www.iea.org/news/the-world-s-coal-consumption-is-set-to-reach-a-new-high-in-2022-as-the-energy-crisis-shakes-markets (accessed 7.29.23).
IEA, 2022d, World Energy Outlook 2022, IEA, Paris https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)
IEA, 2023a. Global EV Outlook 2023: Catching up with climate ambitions.
IEA, 2023b. Russia's War on Ukraine [WWW Document]. Int. Energy Agency. URL https://www.iea.org/topics/russias-war-on-ukraine (accessed 7.29.23).
IEA, 2023c. Technology Collaboration Programme [WWW Document]. Int. Energy Agency. URL https://www.iea.org/programmes/technology-collaboration-programme (accessed 7.29.23).
IMF. «Staff Discussion Notes» 2023.
Ismail Shakil, Siyi Liu, 2022. Canada orders three Chinese firms to exit lithium mining [WWW Document]. Reuters. URL https://www.reuters.com/markets/commodities/canada-orders-three-foreign-firms-divest-investments-critical-minerals-2022-11-02/ (accessed 7.12.23).
Japan - Products and Technology (Korea). DS590 (WTO, 2023).
Kimura, F., Thangavelu, S.M., Narjoko, D., Findlay, C., 2020. Pandemic (COVID-19) Policy, Regional Cooperation and the Emerging Global Production Network. Asian Econ. J. 34, 3–27. https://doi.org/10.1111/asej.12198
Lee, J. «Commercializing National Security? National Security Execeptions Outer Parameters under ArticleXXI.» AJWH 13 (2018): 278-310.
Lester, et Manak. «A Proposal for a National Security Committee at the WTO» Duke Journal of Comparative & International Law 30 (2022): 267-281.
Lester, et Zhu. «A Proposal for "Rebalancing" to Deal with "National Security" Trade Restrictions.» Fordham International Law Journal, 2019.
Li, K., Qi, S., Shi, X., 2022. The COVID-19 pandemic and energy transitions: Evidence from low-carbon power generation in China. J. Clean. Prod. 368, 132994. https://doi.org/10.1016/J.JCLEPRO.2022.132994
Mackinder H. The geographical pivot of history. Geogr J 1904;23:421–42.
Manak, I. «How Deliberation Can Help the WTO, but Not Fix It , 23 February 2023.» International Law and Policy Blog. 23 February 2023.
Marceau, Gabrielle. «The WTO in the emerging energy governance debate.» www.wto.org. 2010.

Mcdougall R A, Golub A A. GTAP-E: A Revised Energy-Environmental Version of the GTAP Model-GTAP Research Memoranda, 2007.

Melvin A. Conant & Fern Racine Gold, The Geopolitics of Energy, Boulder, Colorado, Westview Pr., 1978.

Michael Harley, 2023. China Overtakes Japan As The World's Biggest Exporter Of Passenger Cars [WWW Document]. Forbes. URL https://www.forbes.com/sites/michaelharley/2023/05/22/china-overtakes-japan-as-the-worlds-biggest-exporter-of-passenger-cars/?sh=3db6db642c4f (accessed 7.28.23).

Nichola Groom, 2022. US to expand solar panel tariffs after probe finds Chinese evasion [WWW Document]. Reuters. URL https://www.reuters.com/markets/commodities/us-says-solar-imports-four-southeast-asian-countries-were-dodging-china-tariffs-2022-12-02/ (accessed 7.29.23).

Ministry of the Environmental Protection and Natural Resources (2022), "Digest of the key consequences of Russian aggression on the Ukrainian environment for June 9-15, 2022", https://mepr.gov.ua/news/39320.html

M. Parvizi Amineh. Globalisation, geopolitics and energy security in Central Eurasia and the Caspian region. 2003.

Mulder. «The Sanctions Weapon.» Finance and Development, June 2022.

Nishimara. «Speech at the CSIS, Washington DC, on 5 January 2023.» Washington, DC, 5 January 2023.

OECD. Export Restrictions on Strategic Raw Materials and Their Impact on Trade and Global. OECD, 2010.

Overland I . The geopolitics of renewable energy: Debunking four emerging myths[J]. Energy Research & Social Science, 2019, 49:36-40.

Quitzow, R., Bersalli, G., Eicke, L., Jahn, J., Lilliestam, J., Lira, F., Marian, A., Süsser, D., Thapar, S., Weko, S., Williams, S., Xue, B., 2021. The COVID-19 crisis deepens the gulf between leaders and laggards in the global energy transition. Energy Res. Soc. Sci. https://doi.org/10.1016/j.erss.2021.101981

Ratzel F. Politische geographie. München: Oldenbourg; 1897.

Roberts, Anthea, Henrique Choer Moraes, et Victor Ferguson. «Toward a Geoeconomic Order in Trade and Investment.» Journal of International Economic Law, 2019: 655.

Rudolf Kjellén | Swedish political scientist | Britannica

Russia — Measures Concerning Traffic in Transit. DS512, panel report adopted on 26 April 2019 (2019).

Sam Meredith, 2022. Energy crisis: Why has Russia cut off gas supplies to Europe? [WWW Document]. CNBC. URL https://www.cnbc.com/2022/09/06/energy-crisis-why-has-russia-cut-off-gas-supplies-to-europe.html (accessed 7.29.23).

Shagina, Maria. Drifting East: Russia's Import Substitution and Its Pivot to Asia. CEES Papers No. 3, April 2020, Center of Eastern European Studies, University of Zurich, 2020.

Shen, Y., Shi, X., Zhao, Z., 2022. Assessing energy transition vulnerability over nations and time. https://doi.org/10.21203/rs.3.rs-1440213/v1

Shi, H., Mu, C., Yang, J., Huang, W., 2021. A Sino-US comparative analysis of the hi-tech entrepreneurial model. Economic Modelling 94, 953–966. https://doi.org/10.1016/j.econmod.2020.02.036

Shi, X., Cheong, T.S., Zhou, M., 2021. COVID-19 and Global Supply Chain Configuration: Economic and Emissions Impacts of Australia-China Trade Disruptions. Front. Public Heal. 9, 1–13. https://doi.org/10.3389/fpubh.2021.752481

Shi, X., Yao, L., 2019. Prospect of China's Energy Investment in Southeast Asia under the Belt and Road Initiative: A Sense of Ownership Perspective. Energy Strateg. Rev. 25, 56–64. https://doi.org/10.1016/j.esr.2019.100365

Simon, D.W., 2022. Managing Supply Chain Disruption during Geopolitical Risk [WWW Document]. Foley Lardner LLP. URL https://www.foley.com/en/insights/publications/2022/07/avoid-supply-chain-disruption-geopolitical-risk (accessed 7.29.23).

Singh, V.K., 2022. Regulatory and Legal Framework for Promoting Green Digital Finance 3–27. https://doi.org/10.1007/978-981-19-2662-4_1

Solar Energy Industries Association, 2019. The High Cost of Section 201 Tariffs.

St. Louis Fed, 2023. Global price of LNG, Asia (PNGASJPUSDM) [WWW Document]. FRED. URL https://fred.stlouisfed.org/series/PNGASJPUSDM (accessed 7.29.23).

Stokstad, E., 2016. Power play on the nile Ethiopia stunned neighbors with a colossal dam on the blue nile. could it spread prosperity, not turmoil? Science (80-.). 351, 904–907. https://doi.org/10.1126/science.351.6276.904

Tesla, 2021. The impact report 2021.

Vaclav Smil, Energy: A Beginner's Guide, p. 121.Eurostat.

Vakulchuk R , Overland I , Scholten D . Renewable energy and geopolitics: A review[J]. Renewable and Sustainable Energy Reviews, 2020, 122.

Van den Bosche, P, et Akpofure. «The Use and Abuse of the National Security Exception under Article XXI(b)(iii) of the GATT 1994,.» WTI Working Paper No. 03/2020, (2020) (University of Bern, World Trade Institute), 2020.

Von Cramon, S. (2022): Russia's Invasion of Ukraine – Implications for Grain Markets and Food Security, GJAE 71(2022), Supplement 1-13. https://www.gjae-online.de/articles/russias-invasion-of-ukraine-implications-for-grain-markets-and-food-security

Voon, Tania. «Can International Trade Law Recover? The Security Exception in WTO Law: Entering a New Era.» American Journal of International Law, Vol. 113, 45-50 113 (2019): 45-50.

Wang, X., Shi, B., 2022. Transmission and Diffusion Effect of Sino-US Trade Friction along Global Value Chains. Finance Research Letters 46, 102057. https://doi.org/10.1016/j.frl.2021.102057

WTO. «Australia, Canada, European Union, Japan, New Zealand, Switzerland, United Kingdom, and the United States – Unilateral Trade Restrictive Measures Against Russia (ID77).» 2022.

WTO. «MC12 Outcome Document WT/MIN(22)/24.» 2022.

WTO. Trade Monitoring Report Update: A Year of Turbulence on Food and Fertilizers Markets. WTO, 2023.

WTO. Trade Monitoring Updates, 28 February 2023.
WTO. World Trade Report. Geneva: WTO, 2023.
WTO. World Trade Report 2021 - Economic Resilience and Trade. 2021, 147.
WTO. WTO Ministerial conferences - MC12 briefing note. 2022.
WTO, 2020. World Trade Report.
WTO, Measures Related to the Exportation of Products and Technology to Korea https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds590_e.htm
Xu, Q., Yu, J., Shi, X., Collinson, E., 2021. The potential of energy cooperation between China and Australia under the Belt and Road Initiative. Econ. Polit. Stud. https://doi.org/10.1080/20954816.2021.1951482
Yotov, et al. The Global Sanctions Database.» VoxEU CERP. 4 August 2020. https://cepr.org/voxeu/columns/global-sanctions-data-base.
Ziegler, M.S., Trancik, J.E., 2021. Re-examining rates of lithium-ion battery technology improvement and cost decline. Energy Environ. Sci. 14, 1635–1651. https://doi.org/10.1039/D0EE02681F

4

From Fabless to Fabs Everywhere? Semiconductor Global Value Chains in Transition

Henry Wai-chung Yeung, Shaopeng Huang, and Yuqing Xing

"Everyone wants to build their own semiconductor factories, but is that realistic? If it was that easy, there would be chipmaking plants everywhere in the world already.."
(CC Wei, CEO, TSMC, 17 December 2022)

4.1 Introduction

It is a common phenomenon that an integrated circuits (IC) – known as a semiconductor chip – used in a personal computer (PC), a mobile phone, an electric vehicle, or simply a remote-controlled toy dog is produced along a complex and highly globalized value chain. Semiconductor firms located in various economies and regions jointly finish the necessary tasks of design, wafer fabrication, assembly, packaging, and testing chips before their distribution to downstream manufacturers of final devices. In today's semiconductor GVCs, no economy has an autonomous and fully integrated semiconductor sector that needs neither foreign technologies nor materials. As will be evident throughout this chapter, all economies are interdependent in the global semiconductor industry. But not all of them need to have, or are capable of running, efficient chipmaking factories known as "fabs". Indeed, over the last three decades, the internationalization and fragmentation of semiconductor production has been largely driven by the "fabless revolution" starting in the late 1980s. The evolving sophistication of semiconductor technology and the desire for economic efficiency have further intensified the international division of labor in this high-tech industry.

One key driver has been the exponentially higher cost of building new fabs. From about $200 million in 1983, a bleeding-edge fab in the early 2020s cost well over $20 billion to build and as much to operate in the next ten years. This multibillion-dollar price tag

for a new fab has therefore become a major entry barrier in the industry.
At the 1991 In-Stat Forum held in Arizona, Jerry Sanders, the co-founder and former chairman of Advanced Micro Devices (AMD), proudly claimed that "Real men have fabs"! The statement reflects his belief (and that of AMD's then market-leading competitor Intel) that integrating chip design and chip manufacturing was crucial for a top-tier semiconductor company, and massive investment in fabs was necessary for succeeding in this highly competitive industry. However, technological innovation in chip design and production has led to changing industrial organization and the rise of semiconductor GVCs. Instead of building expensive fabs, many start-ups in Silicon Valley entered the industry by specializing in IC designs and outsourcing chip manufacturing tasks to established firms in the US and elsewhere. In short, they were "fabless" chip design firms right from the start. During the period of 1985 to 1994, about 250 fabless firms emerged in Silicon Valley alone.

The rise of these fabless semiconductor firms challenged the then conventional integrated device manufacturing (IDM) model, where a large American semiconductor firm, such as IBM Microelectronics, Intel, and Texas Instruments, internalized all tasks necessary for producing chips in their in-house fabs; it also accelerated the spatial fragmentation of production and the globalization of the semiconductor industry. Represented by such industry leaders as Apple, Nvidia, and Qualcomm, fabless now has become a mainstream business model in the global semiconductor industry. Even AMD, the company co-founded by Jerry Sanders and several others from Fairchild Semiconductor in May 1969, has spun off all fabrication facilities and turned into fabless as of 2009. The transformation saved AMD from the brink of bankruptcy. In 2020, fabless semiconductor firms' revenue totalled $153 billion, about one third of the entire industry and far higher than "merely" 7.6% in 2000.

The emergence of the fabless model has enhanced the functional and geographical specialization of the industry at the level of tasks. For instance, American fabless firms are specializing in IC designs and marketing, while semiconductor firms in East Asia are responsible for wafer fabrication and downstream production activities. As a result, wafer fabrication in the global semiconductor industry has become highly concentrated in Chinese Taipei; Republic of Korea; the People's Republic of China (PRC); Japan; and Singapore; which together accounted for some 80% of the world's total wafer fabrication capacity in the 2018-2023 period. TSMC has emerged as the world's largest pureplay foundry from this "fabless revolution" and accounted for well over 85% of the most advanced chips produced in 2022.

Global Value Chain Development Report 2021 concludes that geopolitical tensions stemming from the trade tensions between the United States and the PRC since 2018, along with the COVID-19 pandemic, have been driving geographic reconfigurations of global value chains. The semiconductor industry is no exception. The massive disruptions worldwide during the COVID-19 pandemic led to severe chip shortages that became the key concern of policy makers and business leaders in relation to the

resilience of the existing semiconductor GVCs. As the rivalry between the world's two largest economies, the US and the PRC, has intensified in both political and economic spheres, this high concentration of semiconductor fabs in East Asia is now regarded as a major vulnerability in trade disputes and geopolitical tensions. Semiconductors are a backbone of modern industries, and the advancement in semiconductor technology determines how far human beings can go in artificial intelligence, autonomous mobility, and next-generation telecommunications. Maintaining a domestic manufacturing capacity for the most advanced chips has seemingly become a critical imperative for national security among major economies.

To strengthen the resilience of semiconductor supply chains by building domestic chip manufacturing capacity, governments of major economies have resorted to industrial policy by providing massive fiscal subsidies and tax incentives. The 2022 CHIPS and Scientific Act of the US promises a $52 billion subsidy for revitalizing American semiconductor manufacturing and strengthening its competitiveness in IC research and design. To reduce the European Union's reliance on American and East Asian semiconductor manufacturers, the European parliament approved the €43 billion European Chips Act on 18 April 2023, which intends to increase the share of semiconductors manufactured in Europe from 10% to 20% by 2030. Made in the PRC 2025, an official document on the strategy of the PRC's future industry development unveiled in 2015, lists semiconductors as one of the key future industries and sets a target of 70% self-sufficiency for semiconductor production by 2025.

Other economies are also seeking greater self-sufficiency in chip making. Japan used to capture more than 50% of the world's semiconductor revenue in the 1980s, but this share dropped precipitously during the two "lost decades". In the current global race in building new fabs, the Japanese government has designated semiconductors as critical to economic activity and national security and set aside ¥2 trillion to subsidize firms up to 50% of their investment in fabrication facilities, chipmaking equipment, and semiconductor materials. Republic of Korea has set its sights on expanding its K-Semiconductor Belt with tax credits to attract up to $450 billion private investment by 2030. And even though India is not a major player in the semiconductor industry, the Modi government approved the Semicon India Program in December 2021, with a $10 billion incentive scheme for developing a sustainable semiconductor and display manufacturing ecosystem in India. All these initiatives are over and above the firm-specific investment by the industry's top three players every year during the 2021-2023 period: Samsung ($36-40 billion), TSMC ($30-36 billion), and Intel ($20-27 billion).

In 2023, the global semiconductor industry has clearly reached a new critical juncture, where resilience, national security, and competition for technology leadership are challenging the highly popular and efficient fabless model of chip design and fabrication. The rise of this new techno-nationalism is transforming the highly internationalized semiconductor industry into the age of "real nation-states should

have fabs". But as noted in this chapter's opening quote by CC Wei, TSMC's CEO, this techno-nationalist goal of "Everyone wants to build their own semiconductor factories" does not seem to be realistic.

The chapter is divided into six main sections before some concluding remarks. Section one describes current semiconductor GVCs and value distribution along a series of necessary tasks, including pre-competitive R&D; design of integrated circuits (IC); wafer fabrication; assembly, packaging and testing (APT); electronic design automation (EDA) and core intellectual property; semiconductor manufacturing equipment (SME); and materials and chemicals.

Section two reviews participation in semiconductor GVCs by economy. Massive innovations in semiconductor technologies have resulted in extremely high costs of cutting-edge chip design and manufacturing since 2010. Only a few market leaders dominate in the different segments of semiconductor global value chains, from design software and intellectual property to materials and equipment suppliers. American firms play a nearly monopolistic role in IC design software, while a small group of highly specialized firms dominate equipment manufacturers. At the same time, the ever-more sophisticated processes of chip design and production and their concomitant ecosystems of highly specialized firms today mean that no single economy can be self-sufficient in the entire semiconductor value chain.

Section three reviews briefly the evolution of the semiconductor industry from an IDM model to a fabless one. Market shifts in industrial applications towards computers/data storage and wireless communications since the 2010s are crucial in explaining the rapid growth of leading fabless firms, foundry producers, and IDM firms in microprocessors and memory chips. We emphasize that firm-specific competitive advantage, financial market pressures for economic efficiency, and changing market dynamics are the key drivers for this "fabless revolution" in the American semiconductor industry and, subsequently, the high concentration of semiconductor manufacturing facilities in East Asia. This history underlines the importance of vertical disintegration in driving the globalization of the semiconductor industry. These key factors also explain the continual hybrid co-existence of IDMs and fabless firms in different product segments (e.g. logic vs. memory chips) and industrial applications (e.g. computer/storage vs. automotive) through to the early 2020s.

In section four, we examine the role of the government in developing and, in some cases, steering its national semiconductor industry. While government expenditure in research and development (R&D) and defence procurement was significant in the industry's early development in the US and Western Europe, industrial development in East Asia benefited substantially from direct government subsidies and favorable industrial policies, particularly at the early stage. To address this importance of the "visible hand" in nurturing the semiconductor industry, we briefly discuss the historical experiences of Japan, Republic of Korea, Chinese Taipei, and Singapore up to the 1990s

and the PRC since the 2010s. Section five continues with this discussion and makes the case that the dominance of East Asia in chip manufacturing since the 2010s has less to do with government-led initiatives of industrial catching-up and much more to do with firm-specific investment in capabilities and changing market dynamics. By pursuing specialization in foundry production and memory chips, East Asian firms have deepened their trust relationships with key fabless/OEM firms and their integration with global production networks in different and yet high growth industrial markets (e.g. ICT, automotive, artificial intelligence, robotics, industrial electronics).

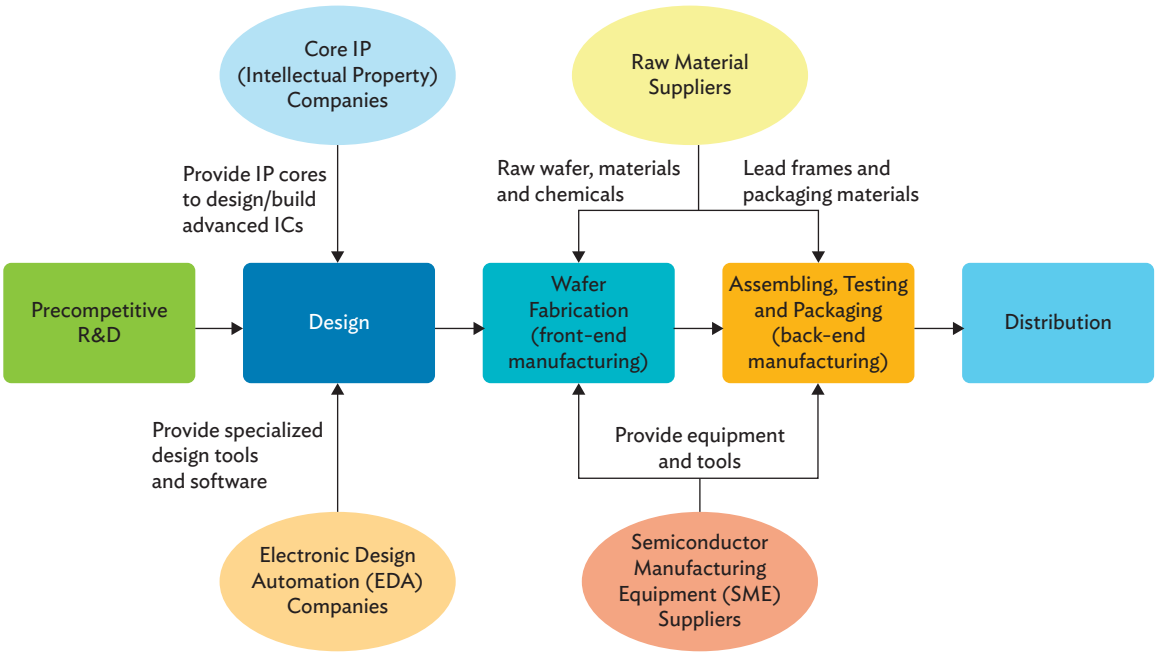
Section six focuses on the most recent years when the global semiconductor industry is increasingly shaped by techno-nationalist initiatives, as more national economies want to have own fabs for national security and risk mitigation reasons. We document policies and subsidies offered by major economies for strengthening the resilience of semiconductor supply chains and enhancing national capacity in semiconductor manufacturing and research. The pursuit of "fabs everywhere" through technological sovereignty is unlikely to be realistic because of the complex organization of existing semiconductor GVCs and the extreme demand for technological capabilities and capital investment in cutting-edge chipmaking. The race in building fabs everywhere will likely result in a fragmented rather than integrated global semiconductor market, which would inevitably undermine the sector's economies of scale and trust relationships and, even worse, lead to excess supply in semiconductor manufacturing capacity worldwide. In the concluding section, we summarize the key findings and outline some possible scenarios for the future of semiconductor global value chains.

4.2 Semiconductor Global Value Chains: Segments and Value Added Structure

There are four major segments in semiconductor global value chains, supported by a highly specialized ecosystem of three main upstream inputs, such that the entire semiconductor value chain consists of seven distinct types of activities illustrated in Figure 4.1. Together, they make up the enormous global semiconductor market of $485 billion sales in 2018, $570 billion in 2022, and a projected over $1 trillion by 2030. The following will discuss each of these seven distinctive activities (see also Suleman and Yagci, 2022a).

(i) Pre-competitive R&D. This activity aims at understanding fundamental processes that lay the foundation for chip design and manufacturing technology. It exhibits significant positive externalities and is clearly distinct from, and yet complementary with, proprietary and competitive industrial R&D. Governments often play an important role in advancing basic semiconductor research. In the US, for example, a number of major breakthroughs have emerged from federally funded research programs. The foundation for the extreme ultraviolet (EUV) photolithography technology, which currently is indispensable in manufacturing leading-edge semiconductors at 10 nm (nanometer) or

Figure 4.1: The Basic Structure of Semiconductor Value Chains



Sources: Adapted from SIA (2016: Figures 1 and 2); Capri (2020: Graph IV); and BCG and SIA (2021: Exhibit 4).

lower process nodes, was laid by the National Extreme Ultraviolet Lithography Program (NEUVLP) funded by the US Department of Energy in the 1990s. The gallium arsenide (GaAs) transistor, one of the critical technologies underlying smartphone chips, was developed in the Microwave and Millimeter Wave Integrated Circuit (MIMIC) program of the Department of Defense in the late 1980s.

(ii) Integrated circuits design. Designing semiconductors is highly knowledge- and skill-intensive, accounting for some 53% of total R&D expenditure and contributing to over 50% of the industry's total value-added in 2019 (BCG and SIA, 2021). Firms involved in chip design range from IDM firms to fabless design houses, and other new players. Section three will explain in depth the rise of these fabless firms and the changing fortunes in the global semiconductor industry since the late 1980s. Suffice it to say here that chip design takes place in IDM firms (e.g. Intel and Samsung), fabless firms (investing 10 to 20% of revenue in R&D), new players such as systems or platform companies (e.g. Apple, Alibaba, Alphabet, Amazon, Facebook, and so on) and industrial firms (e.g. Tesla). Designing cutting-edge chips, such as state-of-the-art processors or systems-on-chips, requires years of concerted effort by hundreds of engineers and is extremely costly. For example, in 2020 the cost of designing a 5 nm node chip exceeded $540 million. To amortize high design costs and to achieve economies of scale, most firms focus on designing cutting-edge general-purpose chips critical in end-market ICT devices, such as PCs and smartphones, and AI servers.

The US is by far the global leader in chip design, with a commanding 68% market share in the fabless segment in 2021 (IC Insights, 2022). With a 21% market share, Chinese Taipei also plays a prominent role in chip design. The PRC had a 15% fabless market share in 2020, but it plummeted to 9% in 2021 as a result of US sanctions on Huawei and its design subsidiary HiSilicon (Clarke, 2022). Republic of Korea, Europe, and Japan are relatively weak in the fabless IC design market, with inconsequential shares of about 1% each.

(iii) Wafer fabrication. Front-end chip manufacturing is one of the most critical segments in the semiconductor value chain, and is currently the focus of much national policy and security attention. Varying across many chip types, wafer fabrication involves 400 to 1,400 steps and takes an average of 12 weeks. Using hundreds of different inputs – including raw silicon wafers, commodity/specialty chemicals, bulk gas, and so on – as well as dozens of very expensive and proprietary processing and testing equipment/tools, the wafer fabrication process spans several stages, which, depending on the complexity of the circuit design, are often repeated hundreds of times. In 2023, a completed 12-inch wafer can contain several hundred of the most advanced chip cores in thumb-nail size, each holding ten or more billion transistors separated by a width of 3 nanometer!

Wafer fabrication, especially at the bleeding-edge nodes (5 nm in 2020, 3 nm in 2023, and an anticipated 2nm by 2025), is extremely capital-intensive and requires enormous upfront investments of tens of billions of US dollars to build highly specialized fabs. Capital expenditure of a pureplay foundry typically amounts to 30 to 40% of its annual revenue, and a state-of-the-art fab of standard capacity currently requires a capital expenditure of approximately $5 billion (for analogue fabs) to $20 billion or more (for logic/memory fabs). Wafer fabrication is also highly knowledge-intensive. Operating a fab at advanced nodes requires deep knowledge of complex processes spanning multiple scientific and engineering disciplines and necessitates the amassing of extensive technological resources and human expertise. Even Intel, the long-established top-tier wafer producer and the inventor of microprocessors in 1971, has encountered repeated setbacks in developing advanced process nodes below 10 nm since the late 2010s, and is still struggling to catch up with leading chipmakers such as Chinese Taipei's TSMC and the Republic of Korea's Samsung.

(iv) Assembly, packaging, and testing (APT). Commonly known as "back-end manufacturing", APT entails transforming silicon wafers produced by front-end fabs into finished chips ready to be fitted into electronic modules and final devices. APT activities are often outsourced to specialist firms that slice finished silicon wafers into individual chips, package them into protective shells, and test for defects before shipping them to electronics manufacturers. Back-end manufacturing is less capital-intensive and employs vastly more labor than front-end manufacturing. The total APT market size is around $30 billion (Kleinhans and Baisakova, 2020). Despite significant industry consolidation over the last decade, the APT market remains a less

concentrated segment due to lower entry barriers. Most APT activities take place in Chinese Taipei (53% in 2019) and the PRC (more than 20%). Even Amkor, the only large APT firm headquartered in the US (in Arizona), is of South Korean origin, and 19 of its 20 manufacturing operations are located in East and Southeast Asia.

(v) Electronic design automation (EDA) and core IP. Fabless design houses rely heavily on access to EDA software and core intellectual property. EDA software, widely used in the design of almost all types of chips, becomes particularly complex and technology- and knowledge-intensive for the most advanced nodes. To keep up with the industry's extremely short innovation cycles, EDA software vendors have the highest R&D spending (on average, over 35% of revenue) in the entire semiconductor value chain (Nenni and McLellan, 2019). Although the EDA sector accounts for only around 3% of the semiconductor market, EDA software vendors have been instrumental in the continuous development of novel processes, playing a disproportionately large role in the industry and its ecosystem. These features have led to an oligopolistic market structure, where three US-based firms – Cadence, Synopsys, and Mentor (acquired by Siemens in 2017) – dominate the entire EDA market, taking a total of 75% of the market share in 2021 (TrendForce, 2022). Given this extreme market concentration and heavy reliance on vendors from a single country, the EDA segment has clearly become a supply chain dependency or "chokepoint" that is highly vulnerable to geopolitical conflicts.

In Figure 4.1, "core IP" refers to proprietary and reusable design of functional components/modules of ICs. With given interfaces and functionalities (IP blocks), these designs such as circuit diagrams are licensed by core IP suppliers to chip designers, who then integrate them into their chip layout as needed. Somewhat overlapping with the EDA segment, core IP is also highly R&D intensive and heavily concentrated in the hands of a few British and American firms, with UK-based ARM topping the list with a 40% market share in 2020, along with American EDA providers Synopsys (20%) and Cadence (6%) (Clarke, 2022).

(vi) Semiconductor manufacturing equipment (SME). Semiconductor manufacturing involves more than 50 types of highly sophisticated equipment supplied by various producers, each specializing in particular steps/types of the complex chip manufacturing process. Developing and fabricating these advanced, high-precision manufacturing equipment necessitates large investments in R&D. SME firms typically invest 10 to 15% of their revenue in R&D. In 2019, the segment accounted for 9% of the entire industry's R&D, 3% of total capital expenditure, and 12% of value added (BCG and SIA, 2021). The size of the global SME industry is estimated to be $103 billion in 2021, up from $71 billion in 2020 (SEMI, 2022a) and $64 billion in 2019. Given its high R&D intensity, it is not surprising that the segment is also dominated by five top SME suppliers that account for more than 70% of the market share. With revenue ranging from $5 to $15 billion in 2019, these five SME suppliers are Applied Materials (largest), Lam Research, and KLA (smallest) from the US, ASML from the Netherlands (see Box 4.1), and Tokyo Electron from Japan.

Box 4.1: ASML and the Dominant Supplier of Semiconductor Lithography Equipment

ASML was founded in 1984 as a joint venture among three Dutch entities – electronics giant Philips, semiconductor equipment manufacturer ASMI (Advanced Semiconductor Materials International), and state-owned private equity fund MIP. Specializing in the development and manufacturing of lithography machines for the past four decades, ASML has established itself as the largest supplier for the semiconductor industry. With $23 billion revenue in 2022, ASML holds more than 90% of the lithography market and is the world's sole supplier of extreme ultraviolet (EUV) lithography machines. Building on Philips' R&D, ASML's first lithography machine (PAS 2000 stepper) was launched in its founding year. In 1991, ASML launched its highly successful PAS 5500 system, bringing on board key customers (such as IBM and Micron from the US) to turn a profit, laying the foundation for its ultimate dominance. The development of immersion lithography and EUV lithography were the next two critical steps in ASML's rise to its current global dominance. In 2003, ASML rolled out the world's first prototype immersion machine (Twinscan AT. 1150i), well ahead of Nikon's launch of both its dry 157 and 193 immersion lithography. In 2004, TSMC became the first manufacturer to produce 90 nm-node chips using ASML's immersion lithography. By 2006, ASML had replaced Nikon as the No.1 lithography vendor.

The second critical step for ASML was the invention of revolutionary EUV lithography that enables chip manufacturing at bleeding-edge process nodes. ASML kicked off its EUV program in 1997. In 1999, ASML was allowed by the US government to participate in the more powerful US-based EUV lithography R&D consortium "EUV LLC", consisting of a few key US-based semiconductor manufacturers (e.g. Intel, AMD, and Motorola) and researchers from three national labs (Lawrence Livermore, Sandia, and Lawrence Berkeley) that aimed to bring EUV lithography to the market by 2006 or earlier. In 2010, ASML delivered the first pre-production EUV system (TWINSCAN NXE:3100) to Samsung, marking the beginning of a new era of lithography. The development became so costly and complicated that ASML invited its three most important customers – Intel, Samsung, and TSMC – to join its Customer Co-Investment Program. In 2012, the three agreed to fund ASML's EUV R&D in exchange for stakes in ASML. Having acquired the American lithography light sources manufacturer, Cymer, in 2013, ASML's development of EUV accelerated. In the same year, ASML shipped the first EUV production system – the TWINSCAN NXE:3300 (second generation EUV), with the third-generation EUV system (NXE:3350) following in 2015.

At the beginning of 2020, ASML shipped its 100th EUV system as EUV entered high volume manufacturing. In early 2021, the most advanced EUV photolithography systems from ASML cost 200 million euros. Still, these EUV systems were well oversubscribed. TSMC's most advanced 3 nm Fab 18 in Tainan alone required more than 50 EUV sets, but ASML could produce only about 31 sets in 2020, 42 sets in 2021, 55 sets in 2022, and estimated 60 sets in 2023 due to its own supply chain constraints.

References

ASML (2022), 'The ongoing evolution of Moore's Law', *ASML*, 16 Febuary 2022, https://www.asml.com/en/news/stories/2022/moores-law-evolution, accessed on May 10 2023.

ASML (2023), 'History (of ASML)', *ASML*, https://www.asml.com/en/company/about-asml/history, access on May 10 2023.

Hofman, Sander (2022), 'Making EUV: from lab to fab', *ASML*, 30 March 2022, https://www.asml.com/en/news/stories/2022/making-euv-lab-to-fab, accessed on May 10 2023.

Miller, Chris (2022), *Chip War: The Fight for the World's Most Critical Technology*, New York: Simon and Schuster.

Raaijmakers, René (2018), *ASML's architects: The story of the engineers who shaped the world's most powerful chip machines*, Nijmegen: Techwatch Books.

Sterling, Toby (2022), 'Computer chip giant ASML places big bets on a tiny future', *Reuters*, May 21 2022, http://reuters.com/technology/computer-chip-giant-asml-places-big-bets-tiny-future-2022-05-20, accessed on May 10 2023.

Similar to SME supply, the demand for SME is also highly concentrated in the hands of only a few cutting-edge semiconductor manufacturers, an indication of their very close trust relationships embedded in mutually supportive ecosystems. Currently, only three giants – TSMC, Samsung, and Intel – are building bleeding-edge fabs and investing in the necessary advanced SME. The customer base for cutting-edge SME is thus relatively small and highly dependent on trade relations among customers from Chinese Taipei, Republic of Korea, the US, and increasingly the PRC (catching up in advanced chips manufacturing for self-reliance). In 2019, ASML's sales in Chinese Taipei and the Republic of Korea accounted for 64% of its global sales; Tokyo Electron generated 57% of its sales from the PRC, Republic of Korea, and Chinese Taipei; and Applied Materials' sales to TSMC alone accounted for 14% of its annual sales (Kleinhans and Baisakova, 2020). In short, while the US, Europe, and Japan are the leading locations for the production/supply of SME, they depend heavily on trusted customers

in East Asia, i.e. leading-edge fabs in Chinese Taipei, Republic of Korea, and the PRC. This in turn indicates how interdependent the semiconductor global value chain is.

(vii) Materials and chemicals. Semiconductor manufacturers necessarily rely on specialized suppliers of materials and chemicals, the majority of which are large firms serving multiple industries. Semiconductor manufacturing uses more than 300 different inputs (materials, chemicals, and gases) for various process steps such as circuit patterning, deposition, etching, polishing, and cleaning, many of which are produced with cutting-edge technologies. For example, polysilicon, used to make silicon ingots that are then sliced into silicon wafers, has extremely stringent purity requirements. There are only four technologically capable major suppliers that account for over 90% of the global market share (BCG and SIA, 2021).

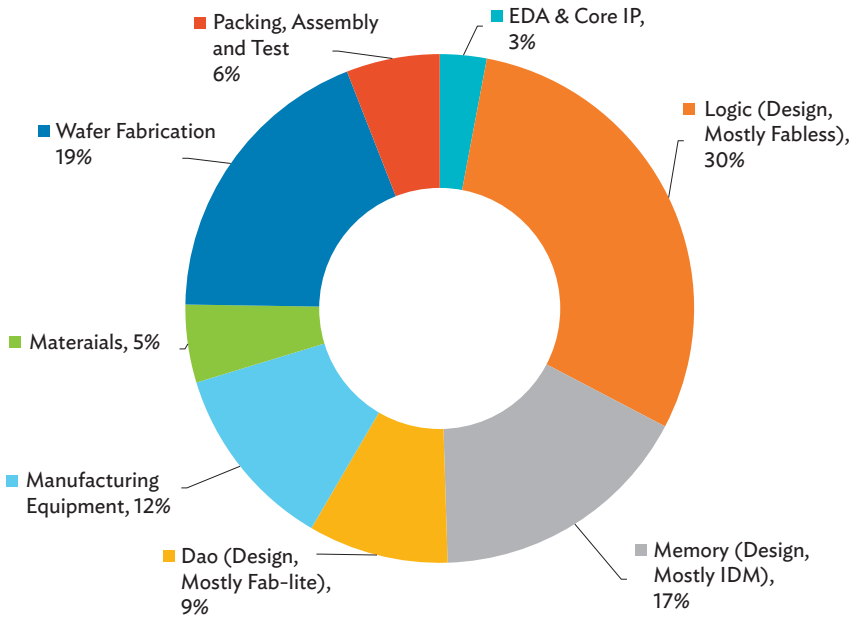
In 2019, the global market for semiconductor manufacturing materials used in front-end and back-end activities was estimated to be $52 billion. Many of the highly specialized materials are produced in mega-plants that require massive investments and exhibit strong economies of scale/scope. For the world's leading suppliers of silicon wafers, photoresists, and gases, capital expenditure typically accounts for 13% to 20% of their annual revenue. With many Japanese companies (e.g. Shin-Etsu, Sumitomo Chemicals, and Mitsui Chemicals) dominating in some sub-segments of this market, Japan is the most significant country supplier of semiconductor materials and chemicals, taking a 24% market share in the global market, followed by the US at 19%. European firms, such as BASF, Linde, and Merck KGaA, are also important chemicals suppliers (Khan et al., 2021).

These seven categories demonstrate the highly specialized semiconductor industry structure. In addition, there are three types of chips (i.e. logic, memory, and DAO – discrete, analog, and optoelectronics and sensors) that can be further differentiated at the design stage. Leaving aside pre-competitive R&D, which is largely a government function, the share of value-added in semiconductors can be broken down into eight categories illustrated in Figure 4.2. The design stage is by far the most important, divided between the design of logic chips (30% of semiconductor value added), memory chips (17%), and DAO chips (9%). This is followed, in terms of share in value-added, by wafer fabrication (19%) and manufacturing equipment (12%). The value-added of APT (6%), materials (5%), and EDA and core IP (3%) is much smaller.

4.3 Semiconductor Global Value Chains: Major Economy Participants

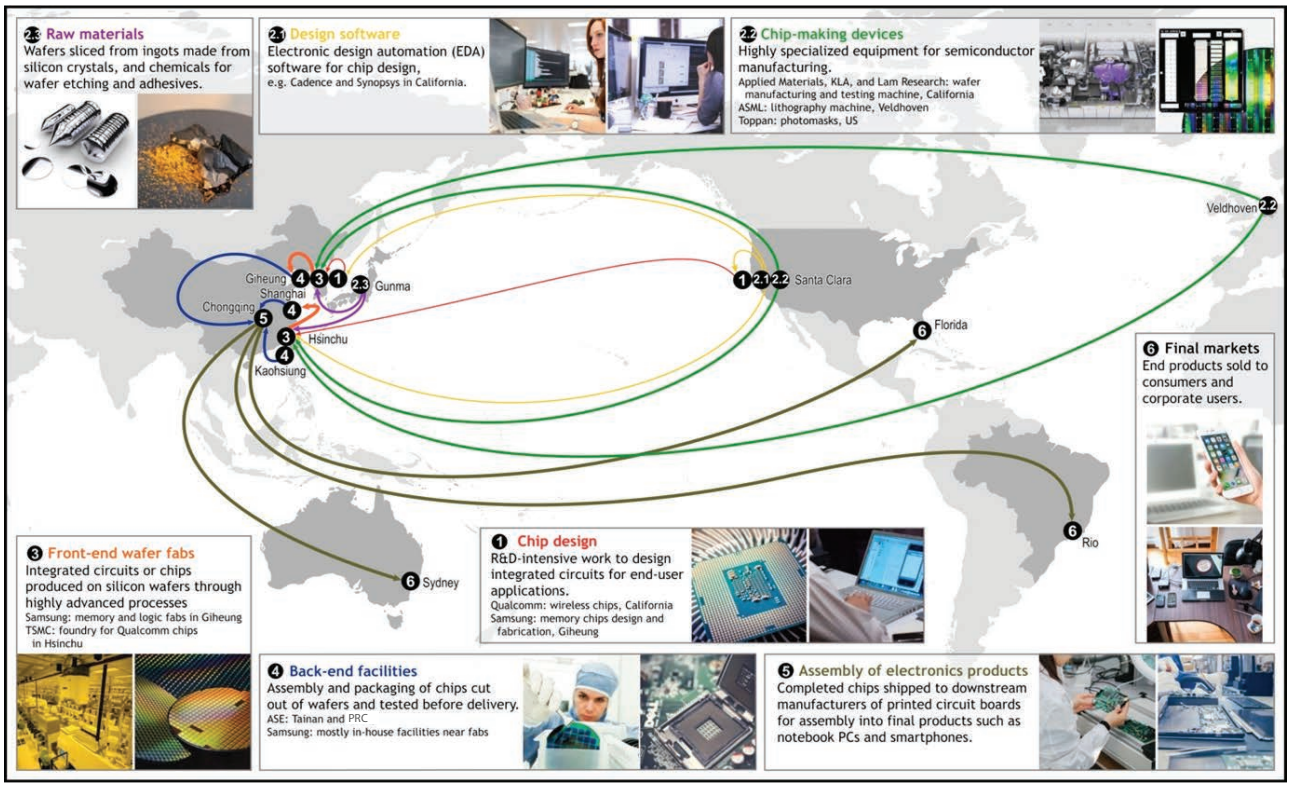
Over the past two decades, the semiconductor value chain has evolved into one of the most "global" value chains. Illustrated in a simple and stylized way in Figure 4.3, these rather complex semiconductor GVCs connect different world regions and continents and serve as crucial intermediate goods for the production of ICT and other end products for

Figure 4.2: Semiconductor Value Added by Activity, 2019 (in percent)



Source: SIA (2021).

Figure 4.3: Semiconductor Global Value Chains and the Production Networks of ICT End Products



Source: Yeung (2022a: Figure 4.2; p.141). Copyright©2022, Stanford University Press, reproduced with permission.

diverse global markets. In 2019, in terms of value-adding operations, there were six major economies/regions (the US, Europe, the PRC, Republic of Korea, Japan, Chinese Taipei, and the rest of the World) engaging in semiconductor GVCs, each contributing 8% or more of the industry's total value added (BCG and SIA, 2021; Suleman and Yagci, 2022a). As companies in different regions specialize in distinct value-adding segments, a typical semiconductor production process involves most, if not all, of the major economies and the products may cross borders 70 times (Table 4.1 further illustrates the distribution of the eight categories of value-added activities in 2021).

The US is the global leader in the most knowledge/R&D-intensive activities, including EDA and core IP (72%), logic chip design (67%), and SME (42%), where its share is higher than its overall share in the semiconductor value added (35%). Indeed, as mentioned earlier, US firms have a commanding presence in the fabless logic chip design segment, which adds the most value among the eight activities in Figure 4.2. Of the world's top 10 fabless design companies in 2021, six are American firms (Qualcomm, Nvidia, Broadcom, AMD, Marvell, and Xilinx) (IC Insights, 2022).

Table 4.1: Domestic/Regional Value Added in the Semiconductor Value Chain by Activity, 2021 (in percent)

	US	Europe	PRC	S. Korea	Japan	Chinese Taipei	Others[1]
EDA & core IP	72%	20%	3%	-	-	-	-
Design (logic), mostly fabless	67%	8%	6%	4%	4%	9%	3%
Design (memory), mostly IDM	28%	-	-	58%	8%	4%	-
Design (Dao), fab-lite	37%	18%	9%	6%	21%	4%	6%
Design subtotal	49%	8%	5%	20%	9%	6%	3%
Equipment	42%	21%	-	3%	27%	-	5%
Materials	10%	6%	19%	17%	14%	23%	12%
Wafer fabrication	11%	9%	21%	17%	16%	19%	7%
Assembly, packaging & testing (APT)	5%	4%	38%	9%	6%	19%	19%
Overall	35%	10%	11%	16%	13%	10%	5%

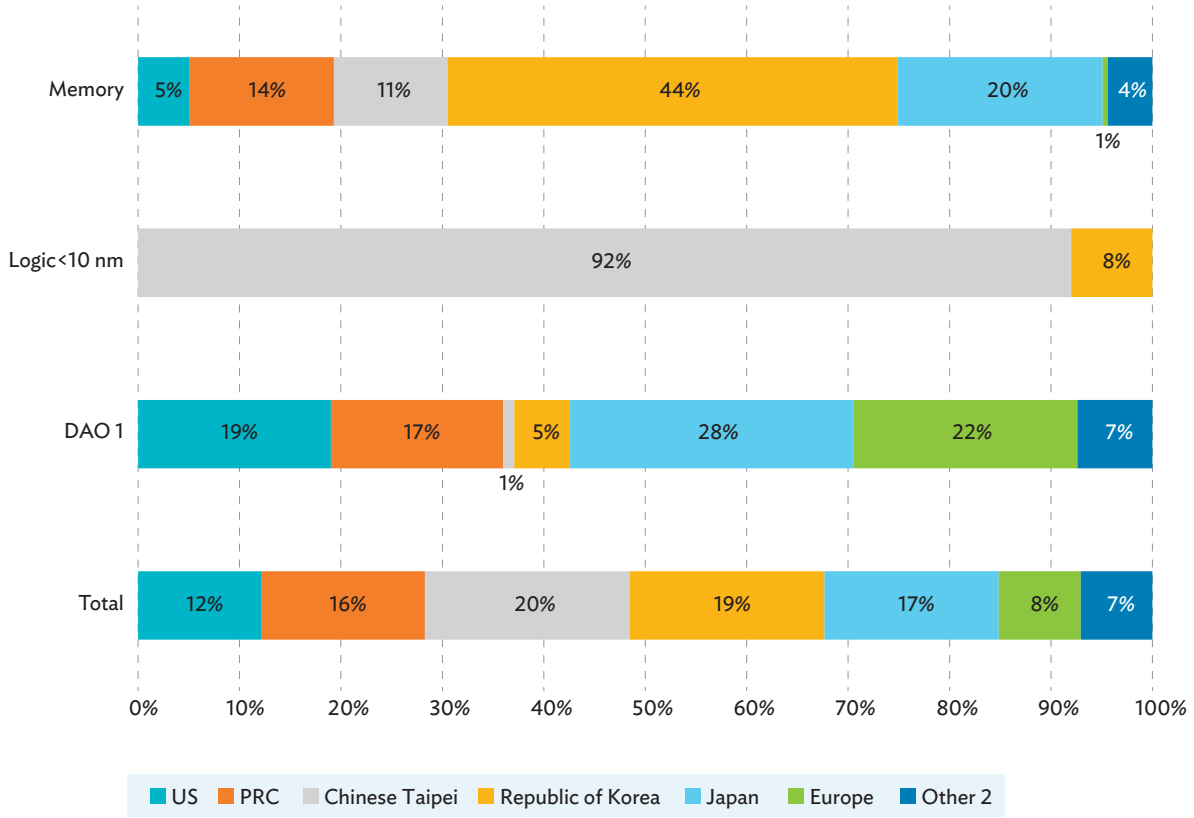
[1]Others includes Israel, Singapore, and the rest of the world.
Note: Regional breakdown on EDA, design, manufacturing equipment, and raw materials is based on company revenue and company headquarters location. Wafer fabrication and assembly, packaging, and testing are based on installed capacity and geographic location of facilities.
Source: SIA (2023).

Those more capital- and labor-intensive activities, such as semiconductor front-end (wafer fabrication) and back-end (APT) manufacturing and semiconductor materials, are largely concentrated in East Asia, including the PRC, Chinese Taipei, Republic of Korea, Singapore, and Japan. The most labor-intensive activity of APT is carried out mainly in the PRC (38%), Chinese Taipei (27%), and so on (e.g. Malaysia). About 75% of the capacity for wafer fabrication is concentrated in East Asia – respectively 19% in Chinese Taipei, 17% in the Republic of Korea, 16% in Japan, and 21% in the PRC. The same four locations also account for more than 70% of the shares in the capital-intensive segment of the

semiconductor materials. In addition, Japan has a sizable share both in the segment of SME (27%) and in DAO products (21%), whereas Republic of Korea has an overwhelming share (58%) in the increasingly commoditized memory products, where the production has been particularly capital-intensive and is dominated by IDM firms (98%).

In contrast, the US share in the labor-intensive APT segment is much smaller (5%), and its share in capital-intensive wafer manufacturing (11%) or semiconductor materials (10%) is considerably lower than its overall share of value-added in the semiconductor industry (Table 4.1). With a mere 10% share in total value-added, European firms play a relatively minor role in logic and memory chip supply. However, they show considerable strength in SME (21%), EDA and IP core (20%), DAO products (18%), and especially in automotive ICs (Kleinhans and Baisakova, 2020), but they have fallen behind in the two activities that add the most value, namely logic chip design (8%) and wafer fabrication (9%). The regional distribution of wafer capacity, particularly the high concentration of leading-edge capacity in East Asia, has been the focus of much attention in recent years and merits a more in-depth discussion (see also later in section five). In Figure 4.4, all the leading-edge logic chip capacity in 2019 was located either in Chinese Taipei (92%) or in the

Figure 4.4: Breakdown of the Global Wafer Fabrication Capacity by Region, 2019 (in percent)



[1] Discrete, analogue, and optoelectronics and sensors; [2] Others includes Israel, Singapore, and the rest of the world.
Note: The breakdown is based on location of facilities regardless of the location of company headquarter. For example, if Samsung sets up a fab in the U.S., the capacity is counted as North American capacity, not capacity in the Republic of Korea.
Source: BCG and SIA (2021).

Republic of Korea (8%). And yet this capacity for high-end chips below 10 nm represented only 2% of global semiconductor manufacturing capacity, whereas logic chips as a whole accounted for some 41% of global capacity. Moreover, Republic of Korea dominated in memory chip capacity (44%). Lastly, Japan's DAO chip capacity (28%) is the highest among all regions, followed by Europe (22%), despite US dominance in DAO design.

Given this current high geographical concentration of wafer capacity in general and leading-edge capacity in East Asia, it is obvious that natural disasters and geopolitical conflicts can pose significant threats to the configurations and stability of semiconductor GVCs, which are now widely perceived as critical matters of economic growth and national security. Before considering such chokepoints and risks in today's highly interdependent semiconductor GVCs in section six on techno-nationalism, we analyze in the next three sections (i) the changing organization of the semiconductor industry associated with the "fabless revolution", (ii) the role of the government in industry development, and (iii) the rise of East Asia in semiconductor GVCs.

4.4 Changing Fortunes in the Global Semiconductor Industry: From Integrated Fabs to the "Fabless Revolution"

The modern era of semiconductors began in the US with the almost simultaneous invention of the silicon-based bipolar integrated circuit by Jack Kilby from Texas Instruments in February 1959 and, four months later, Robert Noyce from Fairchild Semiconductor (Braun and MacDonald, 1982). By the end of 1961, some 150 to 200 semiconductor operations were spun off from a handful of these firms that had existed in the mid-1950s.

Throughout the 1960s, many smaller American firms entered into the semiconductor market as IDM producers with their own chip fabrication facilities (fabs), including two famous Fairchild "spin offs" – Intel in 1968 and AMD in 1969. Two important technological breakthroughs occurred soon at the newly founded Intel. In October 1970, Intel introduced the world's first 1KB DRAM memory chip Intel 1103. One year later, the 4-bit microprocessor Intel 4004 was born. These would have very lasting effects on Intel and the global semiconductor industry even 50 years later. In 1972, Intel's first mass-produced 1KB DRAM became the world's best-selling memory chip, contributing to 90% of its $23.4 million revenue. Half a century later in 2021, Intel remained the world's top semiconductor firm in microprocessors and achieved a record revenue of $79 billion (see Box 4.2). But by now, other semiconductor firms – many without their own integrated fabs or "fabless" – have also come to the forefront of this much more globalized industry.

Box 4.2: Intel and the American Dominance in Integrated Device Manufacturing

As the classic case of IDM firms in semiconductors, Intel remains faithful to its vertical integration strategy implemented ever since its founding in 1968 and epitomizes this close integration of R&D and manufacturing. This strategy of co-locating development and manufacturing was envisioned by Robert Noyce and Gordon Moore at their co-founding of Intel in Mountain View, California, on 18 July 1968 (Moore and Davis, 2004). Intel exited the memory business in 1986 even though its very first invention was the world's first 1KB DRAM memory chip – the Intel 1103. During the peak of its memory business as the world's largest producer in 1979, Intel's profit was $78 million. But in 1983, Intel suffered a massive loss of $114 million in the third quarter alone due to intense competition from Japanese memory producers. As lamented by its former CEO Andrew Grove (1990: 159), "Intel is a sizable and strong company, but we are located in the wrong country. All of the action in our industry is moving to Japan".

Meanwhile, Intel has enjoyed an almost monopoly position in the personal computers (PC) market for central processing unit (CPU) chips, having invented the world's first microprocessor Intel 4004 in 1971. Under Grove's leadership, Intel eventually exited the DRAM market and focused on higher margin microprocessors that remained as its overwhelming core business and accounted for over 75% of its $70 billion revenue in 2018 and $78 billion in 2021. In micro-component products for computers and other numerical control devices, the market was dominated by the founder-giant Intel that still commanded 66% of market share in 2018. Today, and if Grove's (1996) notion that "Only the paranoid survive" is applied to another strategic inflection point in the global semiconductor industry, only IDM and foundry firms with the best fabs could survive in a highly volatile environment of global competition and geopolitical tensions in the 2020s (Yeung, 2022).

Back in 2000, then industry leader Intel was operating at the cutting-edge node of 130 nm. Foundry leader TSMC's process nodes at 150 nm and 180 nm were lagging behind most top IDM firms (at 130 nm). By the late 2010s, Intel was clearly the most vertically integrated, a strategic practice enshrined as its founding principle. All of its fabs were used for making "Intel Inside" microprocessors for PCs and tablets. In 2015, TSMC's leading fab F12 at 16 nm still trailed behind Intel's 14 nm D1X fab in the US. Still, intense competition among the big three of TSMC, Samsung, and Intel in entering mass production at the most advanced nodes of 5 nm in late 2020 and then 3 nm in late 2022 seemed to favour TSMC (see Box 4.6 later) and Samsung (see Box 4.5 later), with Intel trailing due to persistent delays in its transition to 7 nm (2021) and 5 nm (2023) in its new Fab 42 in Chandler, Arizona. This implementation delay occurred due to then sluggish demand for advanced technology in its microprocessors and logic chips for PCs and servers. Moving away from its specialization as an IDM firm fabricating only its own-designed chips, Intel announced in May 2021 its new strategy of launching internal foundry operations for third-party chip-design firms through a new division known as Intel Foundry Services (IFS).

References

Grove, Andrew S. (1990), 'The future of the computer industry', *California Management Review*, 33(1), 148-160.

Grove, Andrew S. (1996), *Only the Paranoid Survive: How to Identify and Exploit the Crisis Points that Challenge Every Business,* New York: Currency.

Moore, Gordon and Davis, Kevin (2004), 'Learning the Silicon Valley way', in Timothy Bresnahan and Alfonso Gambardella (eds.), *Building High-Tech Clusters: Silicon Valley and Beyond,* Cambridge: Cambridge University Press, 7-39.

Yeung, Henry Wai-chung (2022), *Interconnected Worlds: Global Electronics and Production Networks in East Asia,* Innovation and Technology in the World Economy Series, Stanford, CA: Stanford University Press.

Table 4.2 summarizes the key trends and drivers of these changing fortunes in the global semiconductor industry from 1959 to 2022. By the late 1970s, the incredible success of these highly innovative American IDM firms, such as Texas Instruments, Motorola, and Fairchild, and the enormous strength of IBM Microelectronics division as a captive producer for its in-house mainframe computer systems meant that the US had virtually dominated the entire semiconductor industry. By the early 1980s, IBM was also the world's largest producer of integrated circuits for in-house "captive" use and a major innovator in semiconductor process and product technologies. American IDM firms had developed enormous economies of scale and scope through their vertical integration of the design, manufacturing, and marketing of their specialized semiconductor products, such as microprocessor chipsets and memory devices.

The 1980s and the 1990s witnessed major upheavals, as newcomers captured a growing share of the fabrication of memory chips, while major US firms exited. American and European firms faced incredible challenges in the DRAM market from Japanese firms and, later, South Korean firms (Brown and Linden, 2011). The top 5 market leader Intel exited the DRAM market in 1986 to focus on higher margin microprocessors and yielded its number one position in the entire semiconductor industry by 1995. By the late 1980s, nine of the 11 US-based DRAM producers exited the memory market. During the 1990s, two latecomers from the Republic of Korea – Samsung and Hyundai (today's SK Hynix) – became serious challengers in memory devices. As Japanese and, later, South Korean IDM firms became top memory producers since the mid-1980s and American IDM firms remained dominant in microprocessors, two transformative changes to the industrial organization of the global semiconductor industry started

Table 4.2: Changing Fortunes in the Global Semiconductor Industry: Key Trends and Drivers, 1959-2022

Evolution	Semiconductors
Emergence	**1959-late 1970s**
Nature	"Microelectronics revolution": invention of integrated circuits and microprocessors
Industrial organization	Vertical integration through integrated device manufacturing
Leading economies	US, Europe, and Japan
Lead firms	Fairchild, Texas Instruments, Intel, Motorola, National Semiconductor, AMD; Philips, STMicroelectronics, Siemens; Toshiba, NEC, Hitachi
Key shifts	**Mid-1980s-2010s**
Processes of transition	"Fabless revolution": the rise of the fabless-foundry model of outsourcing chip production Changing leadership in memory chips
Drivers of change	Strong command of process and manufacturing technologies Decoupling of chip design-fabrication with design automation software and intellectual property for design cores High and risky capital investment in new fabs New demand from personal computers, wireless communications, and data centers
Leading economies	Japan, Republic of Korea, Chinese Taipei, US, and Europe
Lead IDM firms	Toshiba & NEC, Samsung & Hynix, Texas Instruments, STMicroelectronics, NXP (Philips & Motorola-Freescale), and Infineon (Siemens)
Lead fabless firms	Broadcom, Qualcomm, Nvidia, Apple, AMD, MediaTek
Key manufacturing partners (East Asia)	TSMC, Samsung, UMC, GlobalFoundries (AMD), SMIC
Current status	**2020-2022**
Nature	Co-dominance of IDM and fabless/foundry firms High concentration in top 10 Cutting-edge process technology in foundry (3-5nm) Very high cost of new fabs ($20-30 billion) Dominance of end markets in computer & data storage, wireless communications Continual significance of "old guards" in automotive and other chips
Leading economies	US, Chinese Taipei, Republic of Korea, Japan, Europe, PRC, Singapore
Lead IDM firms	Intel, Micron & Texas Instruments, Samsung & Hynix, Kioxia (Toshiba) and Renesas (NEC), STMicroelectronics, NXP, and Infineon
Lead fabless firms	Broadcom, Qualcomm, Nvidia, Apple, AMD, MediaTek
Key manufacturing partners (East Asia)	TSMC, Samsung, UMC, GlobalFoundries, SMIC

Source: Yeung (2022a: Table 2.1).

to take place – the "fabless revolution" in logic or processor chip design and the rise of pureplay foundry in logic chip manufacturing (see Table 4.2). As noted earlier, chip design contributed to about half of the total value-added in the semiconductor industry by 2019. Here, we shed some empirical light on the vertical disintegration of global semiconductor production through the rise of "fabless" firms and their foundry suppliers.

The Rise of the Fabless Firms

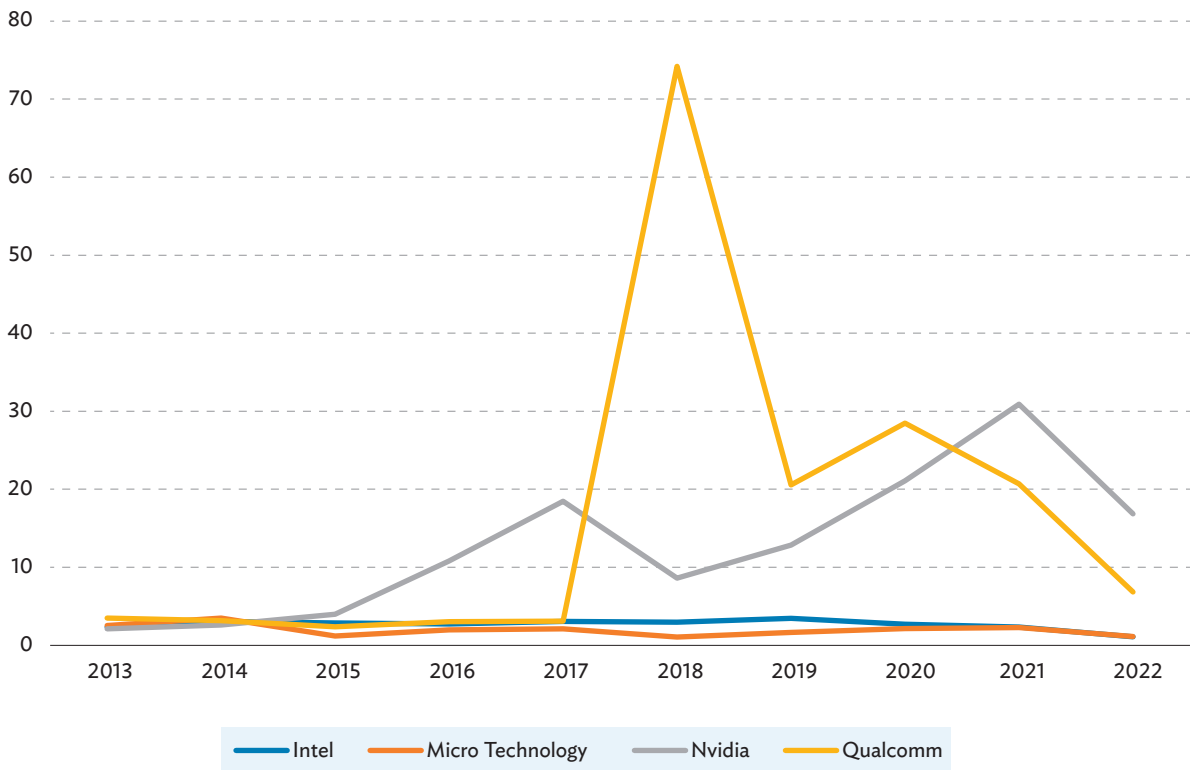
The American firm Xilinx, established in 1984, pioneered the fabless model of semiconductor production. Xilinx started its fabless business using Japan's Seiko Epson as its foundry service provider in 1985, but later engaged American IDM firm AMD as its second source. Meanwhile, Cyrix was established in 1988 as a fabless firm in microprocessors and relied on the fabs of Texas Instruments and European IDM firm SGS-Thomson Microelectronics. Between 1985 and 1994, some 250 fabless semiconductor start-ups had emerged in Silicon Valley. By 2002, the US hosted 475 of the 640 fabless firms worldwide. During this turbulent period of the "fabless revolution" that led to what Langlois (2003) termed the "vanishing hand" of vertically integrated American firms, most fabless firms were relatively small and had to rely on the "spare" capacity of the existing fabs owned by IDM firms (e.g. Texas Instruments, Motorola, Fujitsu, and Seiko Epson) or OEM firms' captive producers (e.g. IBM Microelectronics division). They became beholden to the capacity allocation of these IDM or captive firms.

Fabless firms grew rapidly from 2000 to 2020 (Table 4.3). The total revenue of all fabless firms reached $16.7 billion in 2000, or only 7.6% of the $221 billion global semiconductor market. The top fabless firm, Xilinx with $1.7 billion in revenue, was dwarfed by leader Intel's $30 billion or 14% share. By 2020, however, fabless firms' revenue had grown to $153 billion, or about a third of the entire market. The revenue of the top five fabless firms (as of 2020) increased exponentially from very modest levels in 2000 (except AMD when it was still a second-source IDM making microprocessors for IBM-compatible PCs), in part reflecting consolidation in the market and a concentration of revenue among the top 10 fabless firms. For example, the revenues of Broadcom and Qualcomm, today's two clear market leaders in wireless modem and mobile application processor chips, rose from just over $1 billion in 2000 (when Intel's revenue was already $30 billion and Toshiba was $10 billion) to $15.8 billion and $17.6 billion, respectively, in 2020, to become the fifth and sixth largest semiconductor firms worldwide. Two other market leaders in graphics processors, (Nvidia) and system-on-a-chip solutions (MediaTek), also achieved rapid growth during this period. These top fabless firms are mostly specialized in logic chips, including AMD.

This unforeseen development in the separation of semiconductor chip design and chip manufacturing was explained primarily by the rising costs of building fabs and financial market preferences in the US (Nenni and McLellan, 2019). In 1983, a bleeding-edge

fab at 1.2 micron would cost $200 million – a price tag well beyond the affordability of many of these small fabless firms in Silicon Valley. By 1990, the cost doubled to $400 million for a 0.80-micron leading fab. By 2001, a 0.13-micron (or 130 nm) fab would need $3 billion. Even Xilinx, then the fabless market leader in 2000, had revenue of "only" $1.7 billion. Moreover, the investment preference of American venture capitalists for "cheaper" and faster-return chip design work since the late 1980s has meant that few fabless firms could secure sufficient funding to build their own fabs. With very few exceptions (i.e. Intel and Micron), capital markets in the US do not favor IDM firms that incur high capital expenditure in building fabs and take far longer to return good profits (3-5 years). In Silicon Valley, venture capital prefers to invest in high value and potentially high return chip design work by American semiconductor firms that remain fabless or fab-lite and yet strong in proprietary technology and intellectual property (Kenney, 2011). Throughout the 2010s, the preferred model for Silicon Valley-based semiconductor firms was to focus on software and custom chip designs and to outsource wafer manufacturing to foundry providers and their backend service partners in chip assembly, packaging, and testing based primarily in East Asia (see section five later on this rise of East Asian partners).

Figure 4.5: Price to Book Ratios of Leading American Semiconductor Firms, 2013-2022



Source: Bloomberg, March 2023.

Table 4.3: World's Top Semiconductor Lead Firms by Type, Revenue, and Share, 2000-2020 (in US$ billions and Percent of Semiconductor Market)

	HQ[2]	2000		2005		2010		2015		2018		2020	
Lead Firm[1]		$b	%	$b	%	$b	%	$b	%	$b	%	$b	%
IDM firm													
Intel	US	30.2	13.7	35.5	14.8	40.4	13.0	51.4	14.9	69.9	14.4	72.8	15.6
Samsung Electronics	KOR	8.9	4.0	17.7	8.9	28.4	9.1	38.7	11.2	74.6	15.4	57.7	12.4
SK Hynix	KOR	5.1	2.3	5.6	2.3	10.4	3.3	16.5	4.8	36.3	7.5	25.8	5.5
Micron	US	6.3	2.9	4.8	2.0	8.9	2.9	14.1	4.1	29.7	6.1	22.0	4.7
Texas Instruments	US	9.2	4.2	10.8	4.5	13.0	4.2	12.3	3.6	15.4	3.2	13.6	2.9
Kioxia (Toshiba)[3]	JP	10.4	4.7	9.1	3.8	13.0	4.2	8.8	2.5	11.4	2.4	10.4	2.2
STMicroelectronics	IT/FR	7.9	3.6	8.9	3.7	10.3	3.3	6.9	2.0	9.7	2.0	10.2	2.2
Infineon	GE	4.6	2.1	8.3	3.5	6.3	2.0	6.8	2.0	9.1	1.9	9.6	2.1
NXP (Philips)[4]	NE	6.3	2.9	5.6	2.3	4.0	1.3	9.6	2.8	9.0	1.9	8.6	1.8
Renesas Electronics (NEC)[5]	JP	8.2	3.7	8.1	3.3	11.9	3.8	5.7	1.7	6.7	1.4	6.5	1.4
Freescale (Motorola)[4]	US	5.0	2.3	5.6	-	4.4	1.4	-	-	-	-	-	-
Fujitsu	JP	5.0	2.3	2.6	1.1	3.1	1.0	1.1	0.3	-	-	-	-
Fabless firm													
Qualcomm[6]	US	1.2	0.5	3.5	1.5	7.2	2.3	16.5	4.8	16.6	3.4	17.6	3.8
Broadcom[7]	US	1.1	0.5	2.7	1.1	6.7	2.2	8.4	2.4	17.5	3.6	15.8	3.4
MediaTek	TAP	0.4	0.2	1.4	0.6	3.5	1.1	6.7	1.9	7.9	1.6	11.0	2.4
Nvidia	US	0.7	0.3	2.1	0.9	3.1	1.0	4.4	1.3	10.4	2.1	10.6	2.3
Apple	US	-	-	-	-	-	-	6.1	1.8	6.2	1.3	10.0	2.1
AMD[8]	US	3.8	1.7	3.9	1.6	6.4	2.1	3.9	1.1	6.0	1.2	9.8	2.1
HiSilicon	CN	-	-	-	-	0.3	0.1	3.1	0.9	5.5	1.1	5.2	1.1
Total fabless firm revenue		16.7	7.6	39.8	16.6	65.4	21.0	87.5	25.3	97.4	20.1	153	32.8
Total Top 10 firm revenue		98.9	44.8	115	48.1	150	48.1	183	52.9	292	60.2	257	55.2
Total semiconductor market		**221**	**100.0**	**240**	**100.0**	**312**	**100.0**	**346**	**100.0**	**485**	**100.0**	**466**	**100.0**
Foundry firm[9]													
TSMC	TAP	5.1	38.1	8.2	37.6	12.9	39.3	26.5	53.1	31.1	50.6	46.0	54.1
Samsung (foundry)	SK	-	-	0.2	0.9	0.8	2.4	3.9	7.8	3.4	5.5	14.5	17.0
UMC	TAP	3.1	23.1	2.8	12.8	3.8	11.6	4.4	8.8	5.0	8.1	6.0	7.1
GlobalFoundries[10]	AB/US	0.5	3.7	1.1	5.0	3.5	10.7	4.8	9.6	6.2	10.1	5.7	6.7
SMIC	CN	-	-	1.2	5.5	1.6	4.9	2.1	4.2	3.0	4.9	4.2	4.9
Total foundry market		**13.4**	**100.0**	**21.8**	**100.0**	**32.8**	**100.0**	**50.2**	**100.0**	**61.5**	**100.0**	**85.1**	**100.0**

1 Lead firms in *italics* are those interviewed by one of the authors in 2017 and 2018. Multiple senior or top executives were interviewed in some of these lead firms (Samsung, STMicroelectronics, NXP, and AMD) and in different locations in Asia.

2 KOR= Republic of Korea; US=United States; JP=Japan; IT/FR = Italy/France; GE = Germany; NE = Netherlands; TAP = Chinese Taipei; and CN = PRC.

3 Toshiba's memory business was sold to a consortium led by Bain Capital in June 2018 and renamed to KIOXIA in October 2019.

4 Philips semiconductor division was sold to private equity and renamed to NXP in 2006. Freescale was spun off from Motorola's semiconductor division in 2004 and NXP acquired Freescale in 2015.

5 Renesas Electronics' data before 2010 refer to NEC that merged with Renesas Technology in April 2010 to create Renesas Electronics (a merged entity comprising Mitsubishi and Hitachi Semiconductors in November 2002).

6 Qualcomm revenue only includes its chip-making services (i.e. not including its quite substantial licensing revenue).

7 Singapore-incorporated Avago acquired LSI in 2014 and Broadcom Corp for $37 billion in 2015 to become Broadcom Inc. Its 2015 revenue is incorporated into Broadcom.

8 AMD became fabless after spinning off its wafer fabrication facilities to form GlobalFoundries in 2009.

9 Revenues by foundry firms are typically attributed as cost of revenue to fabless firms (40-45% of total revenue) and fab-lite IDM customers and therefore do not add to the total semiconductor market revenue.

10 GlobalFoundries' revenue in 2005 refers to Chartered Semiconductor from Singapore that it acquired in September 2009. It was fully acquired by Abu Dhabi's state-owned Advanced Technology Investment Company in 2012. In 2015, GlobalFoundries acquired three fabs in Burlington (Vermont) and East Fishkill (New York) from IBM Microelectronics.

Sources: Data from IHS Markit/Informa Tech Custom Research, July-October 2016 and 2019, authors' interviews, and corporate reports and websites.

Throughout this unprecedented period of growth in American fabless firms, capital market influence remained very strong through institutional investment by venture capital firms, private equities, and hedge funds. Figure 4.5 illustrates Wall Street's continual preferences for such fabless firms throughout the 2010s as their price-to-book ratios have been persistently far higher than that of the leading IDM firm Intel (hovering around 1.1 to 3.1 between 2013 and 2022). In his 2020 year-end letter to Intel's then chairman Omar Ishrak, New York-based activist hedge fund Third Point's CEO Daniel Loeb even pushed the world's leading and largest IDM firm to reconsider its strategic alternatives, including focusing on in-house processor chip design and spinning off its fabs as new solutions to retain its customers such as Apple, Microsoft, and Amazon. Having amassed nearly $1 billion stake in Intel, Loeb argued that "Without immediate change at Intel, we fear that America's access to leading-edge semiconductor supply will erode, forcing the U.S. to rely more heavily on a geopolitically unstable East Asia to power everything from PCs to data centers to critical infrastructure and more" (Herbst-Bayliss and Nellis, 2020). As noted in Box 4.2, Intel responded positively by May 2021 when it launched Intel Foundry Services (IFS), an internal foundry operation for serving third-party chip-design firms.

The Rise of the Dedicated Foundry

The pureplay model of dedicated foundry has emerged as an innovative way of organizing semiconductor production and supporting fabless chip design firms since the mid-1980s. This pureplay foundry concept started with Orbit Semiconductor, a small and dedicated foundry established by Gary Kennedy in California in 1985 to manufacture semiconductor devices for defence, aerospace, and industrial customers (Saxenian, 1994). But the model's major adopters were located in East Asia, in particular Chinese Taipei. Founded respectively in 1980 and 1987 as spin-offs of Chinese Taipei government-sponsored Industrial Technology Research Institute, United Microelectronics Company (UMC) and TSMC have been the top three foundry firms since the early 1990s. UMC started as an IDM firm in logic and memory chips throughout the 1980s, but its strategic switch to pureplay foundry occurred only in the mid-1990s, partly in response to Intel's increasing legal action against microprocessor firms from Chinese Taipei (Mathews and Cho, 2000). By 2000, the dominance of TSMC and UMC in the foundry market was established. With respective revenue of $5.1 billion and $3.1 billion in Table 4.3, they accounted for 38% and 23% of the total foundry market revenue of $13.4 billion. Taking over the reign from IDM's foundry services, the top five pureplay foundry firms contributed $9.4 billion or 70% of this market.

The importance of the foundry market is underscored by its six-fold growth from $13.4 billion in 2000 to $85.1 billion in 2020, as compared to the doubling of the overall market revenue from $221 billion in 2000 to $466 billion in 2020 (and about $600 billion in 2021-2022).

The rise of fabless firms and dedicated foundry firms has therefore revolutionized the industrial organization of semiconductor production networks. This tightly coupled fabless-foundry model has shaken up the entire industry previously dominated by American IDM firms (e.g. Intel and Texas Instruments) and captive producers (e.g. IBM Microelectronics division), and enabled the massive growth of mobile devices, such as notebooks, smartphones, tablets, and IoT products, and data and networking centres since the late 2000s (Yeung, 2022a). In this new model of semiconductor production, a fabless firm does not need to have manufacturing facilities and thus its moniker "fabless". Instead, it specializes in developing proprietary technology and designing logic and processor chipsets for information and communications technology (ICT) products, such as mobile devices, digital TVs, cloud-based servers, and automotive digital display clusters. A fabless firm normally enters into long-term contracts with dedicated or "pureplay" semiconductor foundry providers, mostly from Chinese Taipei and a few from the Republic of Korea, the PRC and the US, to produce cutting-edge chipsets and other semiconductor devices.

The arrival of this innovative "pureplay" foundry model, defined as foundry fabs dedicated to serving external customers only, means that these providers do not develop their own chip designs and/or products – the very idea of "pureplay" foundry. They are thus viewed by fabless or fab-lite customers as trusted suppliers of chip manufacturing. This trust relationship is particularly critical in cutting-edge logic chips when design costs are enormous and proprietary knowledge are embedded in circuitry blueprints necessary in foundry production. With strong inter-firm trust relationships, large capital-intensive foundry providers can meet the cutting-edge wafer fabrication needs based on proprietary designs supplied by their customers, such as fabless chip design firms.

Some IDM firms also outsource a portion of their fabrication needs to dedicated foundry firms. Some of these "fab-lite" IDM firms are unwilling to invest in cutting-edge fabs. They can also hedge the high risk of building new expensive fabs by using foundry capacity during upswings in demand or for chips with shorter product life cycles or smaller volumes, and by benchmarking in-house fabs against these pureplay foundry providers. Adopting this "fab-lite" strategy, most established IDM firms did not develop new process technology and capability to compete in the most demanding categories of integrated circuits, i.e. logic chips. Only very few IDM firms, such as Intel, Samsung, SK Hynix, and Micron, were able to invest continuously in cutting-edge fabs through to the early 2020s.

A group of five "old guard" IDM firms have gone fab-lite and remained competitive in specific product segments (e.g. analogue chips, microcontrollers, and discretes) that can be fabricated without replacing their existing equipment using mature process technologies in legacy fabs. These products also have far longer product cycles for industrial applications (e.g. 20-year qualified supply contracts in automotive chips). Lacking more advanced process technologies (<28 nm), these IDM firms typically

outsource most, if not all, of their logic chips to pureplay foundry providers. For example, in 2007 Texas Instruments was still the world's third largest IDM firm after Intel and Samsung and yet surprised the industry by announcing that it would not develop new in-house process technology after the 0.045-micron (µm) or 45 nm generation. Instead, it would rely on Chinese Taipei's TSMC and UMC for process development beginning with 32 nm node. By the time it acquired National Semiconductor in 2011, Texas Instruments had a total revenue of $14.3 billion and outsourced about 20% of its wafers (75% in advanced logic chips) to leading foundry providers.

By the late 1990s, this fabless-foundry model had enabled the internationalization of semiconductor production to newly industrialized economies in East Asia (see section five), well beyond simply the assembly, packaging, and testing of chips previously fabricated only in the US, Europe, or Japan (Henderson, 1989).

Overall Specialization in the Semiconductor Market

Thus, since the mid-2000s, the global semiconductor industry has been characterized by the hybrid co-existence of three forms of "verticality" or vertical specialization in organizing chip production networks: (i) IDM firms with advanced fabs in different locations; (ii) fabless firms partnered with trusted pureplay foundry providers; and (iii) fab-lite IDM firms with both in-house trailing-edge fabs worldwide and outsourced foundry support:

- Some IDM firms grew rapidly over the past two decades to become the largest semiconductor firms. They are mostly associated with market cycle-specific memory devices, e.g. Samsung, SK Hynix, Micron, and Toshiba. Intel's revenue more than doubled during this period, but its market share remained the same at 14-15%.
- The top fabless firms also expanded rapidly, as described above.
- Four of the five "old guard" fab-lite IDM firms, including Texas Instruments, STMicroelectronics, Infineon, and NXP (including former Motorola and Philips) achieved some growth, whereas Renesas's revenue decreased substantially between 2005 and 2020. Still, their individual ranking declined significantly among the top 15 semiconductor firms during this period because of the rising ranks of two top-3 memory IDM firms and all top-6 logic fabless firms (Table 4.3; Suleman and Yagci, 2022a).

Overall, the semiconductor industry has become much more concentrated since the mid-2000s. The share of the top 10 firms in total revenue increased from 48% in 2005 to over 60% in 2018. Most significantly, the top 5 firms in 2018 accounted for 47% of total revenue, with top-2 Samsung and Intel's combined share reaching almost 30%. Within the list of top 10 firms in different years, none was fabless in 2005 or earlier, but six were significant in 2020 – Qualcomm (see Box 4.3), Broadcom, MediaTek, Nvidia,

Apple, and AMD. This changing pecking order indicates the tremendous success of the "fabless revolution" since the mid-1980s. But what does this rise of the fabless-foundry model of semiconductor production mean in relation to AMD Jerry Sanders' proclamation that "Now hear me and hear me well. Real men have fabs!"? Must "real" semiconductor firms or even nation-states, as discussed in section six later, have fabs to stay in the game and remain competitive in this extremely technology- and capital-intensive industry by the early 2020s?

Box 4.3: Qualcomm and the "Double Revolution" of Fabless and Smartphones in the US

American fabless firm Qualcomm's massive growth from 2000 and 2020 is underpinned by its central role in two revolutions – the fabless revolution and the smartphone revolution. Qualcomm's success owes much to its dominance in the proprietary CDMA baseband processor chips (e.g. its Snapdragon series) for smartphones since the late 2000s. In particular, its close strategic relationship with Samsung, which became the early adopter of Qualcomm's CDMA-based technologies and chipsets MSM6250 in 2003, has been instrumental in its success as the dominant technology leader for wireless chipsets in mobile communications. Prior to that, Texas Instruments used to be the dominant digital baseband chip supplier accounting for more than half of the global market share in all feature phones (also known as "cell phones"), including most of those in Nokia- and Ericsson-branded phones (Glimstedt et al. 2010).

The dominance of two leading fabless firms, Qualcomm and Broadcom, in the 2010s shows that this organizational separation of the design and fabrication of semiconductor chips has offered both fabless firms and their foundries a very significant joint window of opportunity in the rapidly growing global production networks of mobile telecommunications devices (Nenni and McLellan, 2019). The enormous success of these American fabless design houses is illustrated by their massive growth between 2000 and 2020. As shown in Table 4.3, Qualcomm had revenue of just over US$1 billion in 2000. In 2010, it became a top ten semiconductor firm in the world, achieving US$10 billion sales for the first time and overtaking such IDM firms in memory chips as Hynix and Micron. In 2020, Qualcomm remained as the top fabless firm with a chip-related revenue of $17.6 billion. This would more than double two years later to $37 billion in 2022 (or $44 billion if its licensing revenue is included) and earn it the distinction as the third largest semiconductor firm worldwide (after Intel and Samsung)!

In such rapidly moving industries as mobile communications, leading fabless firms, such as Qualcomm since its inception in 1985, have eschewed the vertically integrated model of global production networks pursued by IDM firms such as Intel, and developed a horizontally organized global production network leveraging on the core competencies of and trust relationships with its foundry partners (e.g. TSMC) and downstream customers (e.g. mobile handset makers).

References

Glimstedt, Henrik, Bratt, Donald and Karlsson, Magnus P. (2010), 'The decision to make or buy a critical technology: semiconductors at Ericsson, 1980–2010', *Industrial and Corporate Change*, 19(2), 431-464.
Nenni, Daniel and McLellan, Paul (2019), *Fabless: The Transformation of the Semiconductor Industry,* SemiWiki.com Project.

These dramatic shifts in the semiconductor market point to immense challenges for innovation-based development in both existing producer economies (e.g. the US, Europe, and Japan) and other "late" latecomers (e.g. PRC, Brazil, India, and Malaysia; see Yap and Rasiah, 2017; Grimes and Du, 2022). Part of the explanation for these changing industrial-organization dynamics since the late 1980s lies in the role of the government. The next section discusses the role of the government in supporting the growth of semiconductor industry, initially in the US and Europe and later in Japan, then three East Asian "tiger" economies, and most recently the PRC.

4.5 The Role of the Government in the Development of the Semiconductor Industry

The longstanding debate over the effectiveness of industrial policy has recently come to the fore due to efforts by the US, the EU and Japan to provide incentives for domestic semiconductor production. This section sheds some light on the potential impact of government support for semiconductor production by reviewing industrial policies for the sector in advanced economies and in East Asia. In the latter case, governments indeed played an effective role in funding research, training engineers, facilitating technology transfer, and easing financial constraints.

Support in Advanced Economies for Semiconductor Production

From the 1960s to the late 1980s, techno-nationalism was the dominant development pathway in semiconductor production embedded in national innovation systems and protective regulatory regimes. In this context and as noted earlier in section one on semiconductor R&D, national governments in advanced industrialized economies competed fiercely against each other in the race to technological advancement and market dominance (Langlois et al., 1988). Governments in the US, Japan, and Western European countries funded and supported national ecosystems of innovation in semiconductors comprising universities and research institutes, private firms, and industry alliances. Many of the early innovations in large-scale computer systems and semiconductors were also related to national defense and other critical military missions (O'Mara, 2019).

When their leading domestic firms were challenged by foreign competitors, national governments engaged in techno-nationalism to regulate foreign competition through legal and bureaucratic mechanisms during the 1980s (Reich, 1987). By the early 1980s, the US deployed measures to address the growing import competition from Japanese firms to American firms in semiconductors due to the former's better process technology and fab yield (Tyson, 1993). Voluntary Import Expansions, such as the US-Japan Semiconductor Trade Agreement of 1986, were imposed on Japanese producers in order to restrict their exports of DRAM memory chips to the US for computers and other consumer electronics products (e.g. at the time, video cassette recorders). This restriction would also allow American semiconductor firms, such as Intel and National Semiconductor, to retool their production facilities to compete better in this market segment. The Agreement also guaranteed that the Japanese government would ensure at least 20% share of these American firms in the Japanese semiconductor market.

In 1987, the US government led a consortium of 14 American semiconductor firms, such as Hewlett-Packard, AT&T, IBM, and DEC, to form SEMATECH (Semiconductor Manufacturing Technology) in order to fend off Japanese competition and to regain industrial competitiveness. This consortium was funded over five years for $1 billion, half of which came from the Defense Advanced Research Projects Agency (DARPA)

of the Department of Defense. DARPA and, more broadly, the US Department of Defense, played a central role in promoting technological innovations and their commercialization all the way up to the 2010s (Weiss, 2014). In Europe, the European Strategic Programme for Research and Development in Information Technology (ESPRIT) was launched in 1983 as a ten-year effort to stimulate R&D cooperation in basic technology in semiconductors, data and knowledge processing, and office and factory automation. Its first five-year phase was funded to the tune of $1.3 billion, half from the European Economic Community (EEC) and the rest from other stakeholders (Borrus, 1988). Philips and Siemens, then two of Western Europe's largest semiconductor firms, also received some $400 million in subsidies after the 1985-1987 recession to enter the 1MB and 4MB DRAM markets.

The rise of Japan's semiconductor industry was well supported by home government in the late 1970s and up to the late 1980s. For instance, the VLSI Technology Research Association was initiated in 1976 as a four-year programme of public-private partnership and was supported by Japan's Ministry of Trade and Industry with ¥29 billion. It brought together the five largest Japanese semiconductor firms – Fujitsu, NEC, Hitachi, Mitsubishi Electric, and Toshiba – to develop 256K DRAM chips by 1980, two years ahead of the US. At its peak in 1986, Japan's share of world semiconductor market increased to 46% and surpassed the 43% share held by American firms; some 75% of world's DRAM products and 95% of the latest generation DRAM devices came from Japanese firms. As noted in Box 4.2, this dominance of Japanese memory chip makers led to Intel's reluctant exit of the very memory business it invented.

By the late 1980s, the US share had dropped further to 37%, and Japanese firms had replaced American firms as the dominant market player with almost 50% of the entire semiconductor market. As argued by Angel (1994), while Japanese government-sponsored cooperative research program in the late 1970s, such as the VLSI consortium, was instrumental in the catching up of Japanese firms in semiconductor process and manufacturing technologies, "[t]he subsequent competitive success of Japanese firms, however, had less to do with this much publicized form of government intervention than with the internal development efforts of individual firms and the superior manufacturing performance achieved by Japanese semiconductor producers throughout much of the 1980s".

Rise of the East Asian Tigers

Government support also has been crucial in the initial development of memory chip producers and foundry fabs in the East Asian economies that became major players in the semiconductor market. By the end of the 1990s, Japanese memory makers faced intense competition from a totally new cohort of chipmakers from other East Asian "tiger" economies. As indicated in section three and Table 4.3, the fortunes of Japanese makers began to dwindle during the 2000-2015 period.

In East Asia since the late 1990s, the rise of foundry wafer producers from Chinese Taipei and Singapore and memory chipmakers from the Republic of Korea (and Chinese Taipei) presaged the arrival of semiconductor manufacturing in these economies and their dominance in the subsequent two decades until today. In their early developmental periods, many of these firms required substantial investment to achieve scale economies and cost efficiency in order to catch up with pioneering first movers in advanced economies that had possessed superior technological and organizational capabilities. This longer time-horizon in initial investment prompted the governments in the three East Asian "tiger" economies to involve directly in the early founding of the semiconductor industry as an integral part of their industrialization programmes (Mathews and Cho, 2000). Table 4.4 summarizes the changing national and institutional contexts for this firm-specific capability building and industrial transformation in these three East Asian economies and the PRC that have come to play a very significant role in the global semiconductor industry since the 2000s. In general, these economies pursued target-specific industrial policies utilizing broadly a mix of the following instruments throughout the 1970s and the 1980s (Yeung, 2016; Suleman and Yagci, 2022b):

(i) Financial incentives through guaranteed loans or "policy loans", subsidies through grants, and tax rebates;
(ii) "Picking the winners" or targeting at chosen firms to be national champions;
(iii) Regulatory interventions in imports and restrictions on foreign firms to create domestic markets;
(iv) Initiating industry and technology consortiums to develop cooperative partnerships among domestic firms;
(v) Investment in research institutes to subsidize R&D costs, to initiate technology transfers, and to stimulate firm spinoffs and start-ups;
(vi) Imposition of performance requirements on recipients of incentives as a carrot-and-stick approach;
(vii) Broader development of industrial ecosystems and clusters, including linkages with foreign firms; and
(viii) Sanctioned programmes to repatriate citizen techno-entrepreneurs to helm public and private ventures, known as reverse "brain drain" or the "new argonauts" (Saxenian, 2006).

In a nutshell, the government in the Republic of Korea and Chinese Taipei actively pursued such sectoral or target-specific industrial policy during the 1970s and the 1980s but became less interventionist since the late 1990s due to the growing capabilities of domestic firms and their strategic coupling with global lead firms (e.g. fabless firms) and their production networks. The elite bureaucracy, such as Republic of Korea's Economic Planning Board and Chinese Taipei's Council for Economic Planning and Development, was either dismantled or weakened during the 1990s. Meanwhile, the Singaporean government has long been engaging in functional or horizontal industrial policy that promotes trade and investment openness. Since joining the WTO

in 2001, the PRC's domestic political economy has been characterized by dual-tracks – state promotion of national firms (mostly state-owned) through sectoral industrial policy and continual support for foreign investment through trade liberalization.

In the first group of semiconductor foundry providers, the divergent cases of Chinese Taipei and Singapore involve a unique and dynamic combination of initial government interventions and the subsequent firm-specific process of industry market specialization through continuous innovations. Prior to the mid-1990s, government-led initiatives in both Chinese Taipei and Singapore laid important foundations for these leading foundry firms. In Chinese Taipei, the government steered the industry during the 1970s and the 1980s mainly through technology transfer led by Industrial Technology Research Institute (ITRI, established in 1973), Electronics Research and Service Organization (ERSO, established in 1974), and their subsequent spin-offs, rather than through direct allocation of credits to the industry. These research institutes obtained the initial, and often obsolete, technologies in chip fabrication (7-micron LSI) from the US firm RCA in 1976 and 2-micron VLSI technologies from Philips a decade later in 1987. These technologies were transferred to UMC and TSMC at the time of their spin-offs respectively in 1980 and 1987.

Looking back, the continual firm-specific technological innovations and organizational change through specialization in foundry services have proved to be vital in the unprecedented growth of these foundries in the 2000s. The massive growth of TSMC since 1995 came about after ERSO and ITRI had withdrawn from their earlier active role as the leading actor steering the development of Chinese Taipei's semiconductor industry. It tapped well into the enormous growth of fabless design houses, particularly in wireless and mobile communications devices and digital multimedia solutions discussed in the earlier section three. As the trusted foundry house for chipsets designed by Qualcomm, Nvidia, Apple, and MediaTek for mobile devices and computers, TSMC has attained high-capacity utilization and thus gained enormously from its specialization in semiconductor manufacturing.

While some of these organizational innovations specific to TSMC can also be observed in the case of Singapore's government-funded Chartered Semiconductor Manufacturing (CSM), a well-developed domestic ecosystem in the semiconductor industry can make a critical difference. This ecosystem refers to both upstream equipment suppliers and testing and assembly services, and downstream fabless customers and their end users comprising global lead firms and their manufacturing service providers. The failure of CSM in the foundry segment points to the necessary, but insufficient condition, of government support in developing semiconductor manufacturing (see Box 4.4).

The second and much larger segment of semiconductor manufacturing refers to domestic IDM firms in Chinese Taipei and the Republic of Korea producing memory chips. As evident in Table 4.3, some of these domestic IDM firms have become the world's largest semiconductor firms. But their pathways in these two East Asian

Table 4.4: Evolving Domestic and Institutional Contexts of Industry Development in Selected East Asian Economies, 1980-2022

Historical contexts	Republic of Korea	Chinese Taipei	Singapore	PRC
1980-2000				
Development strategy	National champions and export firms	Domestic firms for exports and global economy	Foreign firms with limited domestic firms for exports and global economy	State-owned enterprises, fiscal decentralization, and foreign firms for processing exports
Policy support	Sectoral industrial policy and high selectivity	Sectoral industrial policy but low selectivity	Horizontal industrial policy and high state ownership	Horizontal industrial policy and high state ownership
Capital formation	State and domestic banks; low reliance on FDI before 1997 Asian financial crisis	Banks; medium reliance on FDI	State financial holdings; high reliance on FDI	State banks; high reliance on FDI
Business structure	Dominance of chaebol or conglomerates; high family control	Significant business groups; high family control	High state and foreign ownership; limited family control	High state and foreign ownership
Semiconductor industry	From weak to emerging domestic IDM firms	From weak to emerging foundry firms	From weak to emerging domestic foundry firm and reliance on foreign firms	Weak and limited domestic development
2001-2022				
Development strategy	Corporate restructuring, market liberalization, and financial deregulation	More market liberalization and internationalization of domestic firms	Privatization and promoting domestic firms and their internationalization	Dual tracks of promoting national (state) firms and foreign investment Towards internal circulation/domestic market
Policy support	Less interventionist industrial policy and lower selectivity More active free trade arrangements	Horizontal industrial policy promoting firm upgrading More active free trade arrangements	Horizontal industrial policy promoting firm upgrading Highly active free trade arrangements	Sectoral industrial policy, upgrading, and restructuring of state ownership WTO entry and export promotion, 2001- US-PRC trade war and sanctions, 2018-
Capital formation	Restructuring of domestic banks; more FDI and reliance on capital markets	Restructuring of domestic banks; more reliance on capital markets	Continual state financial holdings; high reliance on FDI and capital markets	Large state financial holdings; medium reliance on FDI and capital markets
Business structure	Dominance of fewer chaebol; high family control	Family business groups and rise of technology firms	Dominance of government-linked and foreign firms	High state control and medium foreign and family control
Semiconductor industry	From emerging domestic IDM firms to dominant global lead firms	From emerging to dominant foundry firms	From emerging to significant presence of foreign firms	From emerging to crippled domestic foundry and memory firms due to US sanctions

Sources: Based on analysis in Yeung (2016) and Hamilton-Hart and Yeung (2021), with further information from Ning (2009), Fuller (2016), Lee (2019), and Xing (2021).

economies have sharply diverged. Unlike their highly successful "cousins" specializing in foundry services (i.e. TSMC and UMC), most IDM firms from Chinese Taipei were lagging behind in terms of new technological and organizational innovations by the 2000s. In retrospect, Chinese Taipei's semiconductor IDM firms started off on a solid ground laid and led by government-funded ITRI in the mid-1980s. But the segment did not take off in the same manner as pureplay foundries. Between 1983 and 1998, a steady number of IDM firms specializing in DRAM and flash memory chips were

Box 4.4: Singapore's Chartered Semiconductor Manufacturing and Failed State-Led Catching Up

Established in 1987 (the same year as TSMC) and with technology transfer from two American firms – National Semiconductor (IDM) and Sierra Semiconductor (fabless), Chartered Semiconductor Manufacturing (CSM) began as a division in the state-owned Singapore Technologies group. Singapore Technologies was fully owned by the state investment vehicle Temasek Holdings until the end of 1999. By the late 1990s, Singapore Technologies had developed a vertically integrated semiconductor foundry manufacturing value chain, encompassing chip design (TriTech), wafer fabrication (CSM) and test and assembly (STATS) (Mathews and Cho, 2000).

The case of Singapore's CSM might appear to be a perfect textbook case of state-led catching up in a highly capital-intensive industry – semiconductor foundry services. It was established at the time when the developmental state's industrial policy was switching towards promoting high value-added manufacturing industries such as semiconductors. It had the technological backing of industry leaders, such as Sierra Semiconductor and Toshiba, and the full financial support of the state-owned Singapore Technologies group. By the late 1990s, CSM had been blessed with a vertically integrated foundry value chain and Singapore's semiconductor industry had been quite firmly established. By the late 2000s, the output of Singapore's semiconductor industry was valued at US$26 billion. CSM was seemingly well positioned to take on major competitors in foundry services, such as TSMC and UMC. Throughout the 2000s, it counted on Microsoft, Broadcom, and Qualcomm as its largest lead firm customers (Yeung, 2016).

But something is missing in this story because CSM did not perform well starting in the late 1990s because of the lack of a critical mass of fabless design firms and the decreasing presence of their downstream "consumers", such as contract manufacturers in electronics and computer products, in Singapore. In fact, Singapore's semiconductor industry was, and still is, dominated by foreign-owned IDMs, most of which did not engage third-party foundry services such as those offered by CSM. Consequently, CSM suffered from major losses between 1998 and 2008. In September 2009, Temasek Holdings divested and sold its entire stake in CSM to Abu Dhabi-backed GlobalFoundries that has since merged CSM's fabs in Singapore with fabrication facilities spun off from loss-making American IDM firm AMD. GlobalFoundries paid US$1.8 billion for CSM and assumed its outstanding debts of US$2.2 billion.

References

Mathews, John A. and Cho, Dong-Sung (2000), *Tiger Technology: The Creation of A Semiconductor Industry in East Asia*, Cambridge: Cambridge University Press.

Yeung, Henry Wai-chung (2016), *Strategic Coupling: East Asian Industrial Transformation in the New Global Economy,* Cornell Studies in Political Economy Series, Ithaca, NY: Cornell University Press.

established in Chinese Taipei (Mathews and Cho, 2000). From such early entrants as Mosel-Vitelic, Winbond (ERSO's "unofficial" spin-off taken over by the Walsin Lihwa group), and Macronix (a specialist maker of volatile memories) to family-owned Nanya Technology in the Formosa group (and Inotera Memories, its joint venture with Infineon) and independents, such as Powerchip Technology and Elite Semiconductor, these IDM firms had leveraged on technologies licensed from global leaders, and developed into significant producers of memory devices for different computing and telecommunications equipment and consumer electronics by the early 2000s.

In their first decade of development, these IDM firms from Chinese Taipei successfully exploited the technologies licensed, via ITRI, from leading memory chip producers from Japan, the US, and Germany. By specializing in memory devices, these Chinese Taipei's IDM firms could improve on these technologies and develop cutting-edge memory products for a rapidly growing global market in the 2000s. Intense industrial competition in the global market for memory devices occurred during the 2000s when the technologies of these devices became standardized fairly quickly, and product life cycles were compressed sharply. Many Chinese Taipei's IDM firms specializing in memory devices became victims of industrial lock-in and could not resist the inevitable trend towards declining prices and profitability. Despite government support, their overemphasis on up-scaling to lower production costs did not lead to new technological

or organizational innovations (Fuller, 2007). Most Chinese Taipei's DRAM producers became captive suppliers to their foreign partners and had to pay licensing fees and assume most of the investment risks. In the early 2000s, several top Japanese memory IDM firms also exited the market.

On the other hand, two South Korean *chaebol* giants – Samsung and SK Hynix – have been continuously developing technological innovations and achieving scale economies in memory chip production. In particular, Samsung (Box 4.5) has successfully integrated its logic chips and memory devices into a wide range of electronics products manufactured by its intra-*chaebol* divisions and other electronics giants, such as Apple's iPhones (till 2016). Arguably, the role of state-led initiatives has been important mostly at the initial stage of achieving second-mover advantages by these IDM firms from the Republic of Korea. To take advantage of President Park Chung Hee's Promulgation of Law for Electronics Industry Promotion (1969–1976) in the Republic of Korea, National Semiconductor from the US entered into a joint venture with Goldstar Electronics (the predecessor of LG Electronics) to manufacture transistors in 1969. In the same year, Samsung made its first foray into electronics through its joint ventures with Japan's Sanyo and NEC. These joint ventures laid the early foundation of these two *chaebol* giants in today's global electronics industry.

But once these leading Korean semiconductor firms have articulated into different global production networks since the 2000s, new and firm-specific technological and organizational innovations are necessary to stay ahead of their competitors and to sustain their continual growth and profitability. The Republic of Korea state implemented more liberal trade and investment policies to create a conducive environment for domestic firms to import intermediate goods crucial for their strategic partnership with global production networks and for foreign firms to invest in domestic firms in order to improve their production capacity and technological capabilities. Still, this functional industrial policy for promoting domestic R&D capacity in the semiconductor industry was superseded by private firm initiatives, as these firms found new conduits for developing such capabilities through their expanding global production networks. In the 1990s, Samsung, LG, and other chaebol began to disembed from state-sponsored R&D consortiums and accelerated their own in-house R&D activity and technological advancement to catch up with global lead firms. By the early 2000s, they had effectively taken over the control of both R&D and production activity in the domestic semiconductor industry and become the leader in steering the industry's high growth during the ensuring decade. The emergence of Samsung and SK Hynix (renamed from Hyundai after acquiring LG Semiconductor in 1999) in the global market for memory devices by the 2000s indicates that second-mover advantages, such as industrial market specialization and scale economies, can be a potent competitive advantage in favor of these South Korean chaebol IDM firms. These supply-side factors of favourable government support and firm-specific innovations are necessary elements of any explanation of the rise of East Asia in the global semiconductor industry.

Box 4.5: Republic of Korea's Samsung as a Successful Product of the Developmental State?

Samsung Electronics did not venture into semiconductors until the mid-1970s. President Park Chung Hee's fourth Five-Year Plan of 1977-1981 set the pace of development of the electronics industry as one of Republic of Korea's key sectors. In this historical context, the developmental state was imperative in the initial inducement of such chaebol as Samsung to diversify into electronics. On 1 December 1983, Samsung shocked Republic of Korea, if not the world, with a good working version of a 64K DRAM based on design technology licensed from then fledgling American DRAM producer Micron and process technology from Japan's Sharp. But state funding was no longer crucial to its massive growth by the mid-1980s. Between 1983 and 1989, Samsung, LG, and Hyundai invested some US$4 billion in VSI semiconductors. Only US$350 million of this came from state-initiated low-interest credit under the terms of the Promulgation of Basic Long Term Plan for the Semiconductor Industry (1982-1986) announced in 1981. In fact, the state-funded Electronics and Telecommunications Research Institute (ETRI)'s national R&D consortium for 4MB DRAMs between 1986 and 1989 failed to induce cooperation and sharing of technologies among its participants, such as Samsung, Hyundai, and LG, despite spending $110 million over the three years. Instead, each of them went ahead to develop their own 4MB designs through in-house R&D efforts (Dedrick and Kraemer, 1998).

Into the 1990s, Samsung closed the technology gap with its major competitors from the US and Japan (who are much weaker now, as respectively shown by Intel's exit of the memory chips market in 1986 and the bursting of the Japanese "bubble economy" in 1992). The number of Samsung's DRAM patents registered with the USPTO in the 1990-1994 period was close to those of NEC, Toshiba, and Hitachi, its three top Japanese competitors. By the mid-1990s, Samsung was able to transfer its 16MB synchronous DRAMs (SDRAMs) technology to Japan's Oki. This represents the first known case of Republic of Korea-Japan technology transfer in semiconductors. In 2001, Samsung became the first company in the world to use 300-nanometer wafer (12-inch) technology (Mathews and Cho, 2000). It would be misguided, however, to attribute the competitive success of Samsung in the 2010s exclusively to its earlier scale economies founded on the state-induced investment drive. Just like TSMC, continuous technological and organizational innovations were the more critical platforms through which Samsung could outcompete IDM firms from not just Japan and Chinese Taipei, but also the US and Western Europe. Unlike IDM firms from Chinese Taipei, Samsung has chosen a distinct developmental trajectory through path-breaking catching up in its semiconductor technologies and internationalization.

Samsung achieved rapid catching up through various technology agreements in the semiconductor industry between 1983 and 1997 (Shin, 2017). As early as in 1991, Samsung already invested 9% of its total sales in R&D, comparable to leading Japanese competitors. It became much less dependent on state-sponsored research institutes for their technological innovation. Instead, it turned to in-house R&D labs, friendly global lead firms, and international industrial associations. The success of Samsung in semiconductors was clear by the mid-1990s when it was ranked amongst the world's top ten semiconductor IDM firms. Since the late 1990s, Samsung's heavy investments in R&D and production facilities have been strategic in order to achieve further economies of scale and pose formidable barriers to entry to latecomers and other competitors from Chinese Taipei and the PRC. During the 2000s, it created a greater gap from its competitors in memory chips such as Micron (US) and Toshiba (Japan). Samsung had more DRAM patents in the 2000-2004 period than all of its Japanese competitors, except Hitachi. In the 2005-2009 period, Samsung's 61 DRAM patents were the most among all South Korean and Japanese DRAM producers. Its critical success factors were related to timely investments, speedy ramping up of production scale, and process innovations.

By the late 2010s, Samsung's competitive advantage rested well beyond its scale economies, sophisticated applied design, and process yield. Apart from its enormous lead in semiconductor technologies through continuous investments in R&D activity, Samsung had also benefited from unique organizational synergies embedded in Samsung's firm-specific business model of organizing its IDM business to supply both in-house own brand products (e.g. mobile phones and televisions) and third-party vendors, such as global lead firms in computers, telecommunications devices, and other consumer electronics (Yeung, 2022).

References

Dedrick, Jason and Kraemer, Kenneth (1998), *Asia's Computer Challenge: Threat or Opportunity for the United States and the World?* New York: Oxford University Press.

Mathews, John A. and Cho, Dong-Sung (2000), *Tiger Technology: The Creation of A Semiconductor Industry in East Asia,* Cambridge: Cambridge University Press.

Shin, Jang-Sup (2017), 'A dynamic catch-up strategy in the memory industry and changing windows of opportunity', *Research Policy,* 46(2), 404-16.

Yeung, Henry Wai-chung (2022), *Interconnected Worlds: Global Electronics and Production Networks in East Asia,* Innovation and Technology in the World Economy Series, Stanford, CA: Stanford University Press.

Since the mid-2010s, investment in new fabs has become very costly due to high capital spending, rapid depreciation, and frequent process technology upgrades. The cost of building new fabs easily exceeds $10-15 billion per fab and capital expenditure is often very large for leading semiconductor firms. In foundry services, this enormous pressure from financial discipline on the broader semiconductor industry has ironically favored only a few foundry providers from Chinese Taipei (TSMC), the Republic of Korea (Samsung foundry), and the PRC (SMIC) that invested aggressively in new fabs and capital equipment during the 2010s (Yeung, 2022a: 248-249). As a latecomer to foundry, the PRC's SMIC counts the state-backed China Integrated Circuit Industry Investment Fund – also known as the "National IC Fund" – among its major shareholders and is a major beneficiary of the "Made in China 2025" plan in 2015 to channel $150 billion over 10 years through the Fund to boost the PRC's domestic semiconductor production. Despite US sanctions on its import of American chip-making equipment and technology, SMIC remained committed to establishing new fabs to cater to applications in automotive and consumer electronics. On 18 March 2021, it announced a new $2.4 billion 28 nm fab to be built by 2022 in the southern city of Shenzhen, with 23% stake owned by the Shenzhen government. This channelling of state capital through investment funds to domestic semiconductor firms represents an institutional attempt to avoid charges of government subsidization. State ownership in SMIC increased from 15% in 2014 to 45% in 2018 – the National IC Fund (19%), state-owned Datang Telecom (19%) and Tsinghua Unigroup (7%).

While government support is useful in the initial stage of semiconductor industrial development, it is not a sufficient factor for continual success and dominance, as will be evident in the next section. The case of Wuhan Hongxin (HSMC) in Box 4.6 is highly instructive of the key difficulties of policy implementation. Despite its aggressive sectoral industrial policy since the 2000s (see Table 4.4), the PRC's position in different semiconductor product categories remains quite weak (Fuller, 2019; Yeung, 2022a: Table 4.1). As of 2018, its small number of fabs in analogue and discrete chips were all foreign-owned (e.g. Texas Instruments from the US and Rhom from Japan), and no micro-component IDM fab was located in the PRC. Despite its dominant role in the final assembly of ICT end products, the PRC's 26 domestic fabs in 2018 produced only about 6% of the domestic semiconductor market of $131 billion in 2019 and $143 billion in 2020. This share increases marginally to 16% even if large capacity foreign-owned fabs by SK Hynix, Samsung, Intel, TSMC, and UMC are included. At this pace, the PRC government's goal of 70% self-sufficiency for semiconductor production in the "Made in China 2025" initiative will not be achieved. As of 2020, the PRC's giant semiconductor market remained heavily reliant on imported chips manufactured elsewhere in East Asia (and some in the US and Europe). Since 2018, the PRC has been importing annually over $300 billion worth of chips – reaching $380 billion in 2020 and $163 billion in the first five months of 2021. About half of these imported chips went into ICT final products for domestic sales and exports.

Box 4.6: HSMC and the Problems of Industrial Policy Implementation

The PRC has made enormous efforts, both nationally and locally, to support the development of the semiconductor industry through various industrial policy instruments, such as capital injection and financial incentives, inter alias, but there are painful lessons to be learned along with successful experiences. The collapse of Wuhan Hongxin (弘芯 a.k.a. HSMC, Hongxin Semiconductor Manufacturing Co.) is probably the most dramatic case in this regard (Feng, 2021; Gan, 2021). In November 2017, three businessmen with no background in semiconductors (or anything tech-related) set up a company in Beijing, aiming to build a chip fab to challenge the PRC's national champion SMIC. Just four days later, HSMC was established in partnership with Wuhan's Dongxihu District government that provided RMB 200 million in start-up capital. Despite its lack of technology, experience, and talent, HSMC had strong backing from the local government in Wuhan. In 2018 and 2019, it was twice listed as a "Major Project of Hubei Province", with local government subsidies and extra investment following suit.

By January 2019, HSMC had received RMB 6.5 billion in investment from the local district government. In March 2019 alone, HSMC received another RMB 1.5 billion. HSMC's total planned investment was RMB 128 billion (US$18.5 billion), making it the largest single project under construction in Wuhan at the time (Caixin, 2021). But things quickly turned sour, as HSMC was soon rocked by a series of legal troubles. Due to a legal dispute with an engineering firm, a local court suspended HSMC's land tenure in November 2019 that in turn halted its fab construction on that land. In 2020, HSMC started experiencing liquidity crunches and failed to pay many of its suppliers. In July 2020, the local government acknowledged that HSMC faced a massive funding gap (RMB 112 billion out of the planned total investment of RMB 128 billion) and that the project could grind to a halt at any time as a result of its broken funding chain and legal troubles. HSMC's situation did not improve, and a total collapse of the cash-strapped project ensued. Having spent more than RMB 15 billion ($2.1 billion), HSMC failed ultimately without ever producing a single chip.

In the context of the PRC's rush to make breakthroughs in chip manufacturing, the case exposes serious loopholes in the implementation mechanism of the PRC's industrial policy. As acknowledged by a spokesman from the National Development and Reform Commission – PRC's central planning and regulating body (Qiu, 2020), HSMC manifests itself in the form of reckless entrants into the semiconductor industry "with no experience, no technology, and no experts," and in the form of blind investments by local governments that are clueless about the semiconductor industry. The lack of effective screening and accountability mechanisms – to mention a few, setting thresholds for the granting of subsidies, private matching funds requirement, performance-based phasing in/out of subsidies – means that the unfortune combination has resulted in a succession of problematic projects (Zhang, 2021).

References

Caixin (2021), 'Four things to know about China's $18.5 billion failed chip champ', *Caixin*, 2 March, http://caixinglobal.com.
Feng, E. (2021), 'A cautionary tale for China's ambitious chipmakers', *NPR*, 25 March, http://npr.org.
Gan, H.T. (2021), 'Semiconductor fraud in China highlights lack of accountability', *36 Kr (KrASIA)*, 12 Feb, https://asia.nikkei.com.
Qiu, H. (2020), 'NDRC: Regulating the development of integrated circuit industry', *People's Daily (Overseas Edition)*, 21 October, http://paper.people.com.cn.
Zhang, J. (2021), 'China's semiconductors: How Wuhan's challenger to Chinese chip champion SMIC turned from dream to nightmare', *SCMP*, 20 March, http://scmp.com.

4.6 The Rise of East Asia in Semiconductor Global Value Chains

By the turn of the new millennium and with the exception of the PRC, the role of the government in the rise of the East Asian semiconductor industry was diminished, as their domestic foundry and IDM firms had become more integrated into global value chains in both semiconductors and downstream end products such as PCs, smartphones, and servers. This was the time when industrial market specialization had become the more critical factor for success (Yeung, 2022b). Through specialization in semiconductor industrial products and niche markets, these latecomer firms in Chinese Taipei and the Republic of Korea (and later the PRC) have developed new firm-specific capabilities that fit into the description of neither first-mover (new industries) nor second-mover advantages (up-scaling). These firm-specific capabilities are manifested in three critical dimensions: new semiconductor product or process technologies,

flexible semiconductor production and product diversity, and organizational knowhow and proprietary access to market information (e.g. via fabless customers and their OEM end-users). This capability development at the firm level is also conditioned by a peculiar combination of new government roles and competitive industrial dynamics. As these new roles are less interventionist in nature, their direct influence on semiconductor firms and industrial development is also harder to trace.

Latecomer East Asian firms have developed their own and more sophisticated technologies over time on the basis of their production capability and manufacturing excellence, even after they have already achieved scale economies and out-competed first mover firms from advanced industrialized economies. These new technologies are crucial in sustaining their market leadership in the global semiconductor industry that has become more competitive over time and required greater firm-specific dynamic capabilities (e.g. continuous learning and upgrading of technologies). In some cases, East Asian semiconductor firms such as TSMC (Box 4.7) and Samsung (Box 4.5) have created dynamic capability through the non-incremental creation of complementary and integrative knowledge built on the existing incremental or under-utilized knowledge of first movers from the United States, Western Europe, and Japan.

Specialization in industrial market leadership enables East Asian semiconductor firms to develop greater economies of scope through flexible production and product diversification. While scale economies are important in their initial catching up with first movers (e.g. Samsung in memory devices), continual success in global production networks requires these East Asian semiconductor firms to engage in flexible specialization. In this capital-intensive industry, competing on the basis of lower per unit cost of each product or service is not as effective and sustainable as capturing higher value through product differentiation or service varieties. The competitive dynamics in the semiconductor industry tend to favor firms that provide both scale and scope economies in order to avoid lock-in to particular products or services (Hobday et al., 2004). Leading East Asian semiconductor firms such as TSMC tend to adopt a portfolio of strategies tailored to different products, markets, and business cycles (Dibiaggio, 2007).

As East Asian semiconductor firms deepen their integration with global production networks in different industries (e.g. ICT, automotive, artificial intelligence, robotics, industrial electronics), they develop new organizational routines and innovations that strengthen their trust relationships with key customers and suppliers, and enable them to exercise better control of market information and customer access. This unique condition of industrial dynamics increases substantially the costs of information asymmetry and market intelligence at the firm level (Epicoco, 2013). The more liberal and well-functioning trade regime in the 2000s and up to the late 2010s provided a favorable structural context for these East Asian semiconductor firms to consolidate their strategic relationships with lead firms in different global industries.

Box 4.7: TSMC and Technological Innovation in Chinese Taipei

Founded in 1987 as a spin-off of the government-sponsored Industrial Technology Research Institute (ITRI), TSMC has been a market leader in semiconductor foundry services since the early 1990s. In 1992, TSMC had sales of slightly over US$250 million. By 1997, its revenue almost doubled. In 2010, TSMC already dominated the semiconductor foundry market and accounted for almost 40% of its US$33 billion market (10% of the total sales of all semiconductor firms). Its US$13 billion revenue would place it next to only the top two IDM firms– Intel and Samsung (Table 4.3). Ten years later in 2020, its revenue more than tripled to $46 billion and its foundry market share increased further to 54%. Buoyed by demand for high-performance logic chips of its fabless customers such as Apple and Qualcomm, TSMC's revenue in 2022 grew further by 30% to exceed $70 billion for the first time.

The dominance of TSMC in the foundry market since the 2010s has benefitted all leading fabless firms. The symbiotic trust relationship between TSMC and its fabless customers goes well beyond conventional contract manufacturing found in the final assembly of electronics products (e.g. Sturgeon, 2002). In this mutually dependent relationship, TSMC not only manufactures with cutting-edge process technologies, but also provides highly process-specific design support and intellectual property (IP) library services for fabless and fab-lite IDM firms. Starting from its 65 nm process in 2005, TSMC established the Open Innovation Platform program to collaborate early on with leading vendors of design software (e.g. Synopsys and Cadence) and IP design cores (e.g. ARM). Together, TSMC and the design ecosystem operate as a virtual IDM firm that drives the development and test of the innovative technology of its fabless customers (Kapoor and McGrath, 2014). In 2018, Synopsys announced its Synopsys Cloud Solution to serve end customers developing SoCs for high performance cloud computing. This cloud-based design solution was a result of collaboration with TSMC and lead cloud providers, such as Amazon and Microsoft, and was certified for TSMC's cutting-edge processes to enable IC design and verification (Nenni and McLellan, 2019).

Aggregating the diverse demand for chip fabrication from leading fabless and fab-lite firms, TSMC can achieve better economies of scale and scope in its fab processes than IDM firms such as Intel. TSMC accumulates much greater experimental and institutional knowledge in managing complex requirements in different fab-specific process recipes, ranging from the initial qualification of a new chip device to its subsequent ramp-up and mass production. Over time, these in-house recipes of new product introduction and product life-cycle management processes would become TSMC's strongest proprietary advantage and create an enormous barrier to entry. The spokesperson from TSMC used to liken it to be the "central kitchen" making burgers and fried noodles for different semiconductor firms (Interviewed and quoted in Yeung, 2016: 142). Given its "pureplay" foundry model and high trust relationships with customers and equipment suppliers, TSMC has the organizational capability to serve more than 10 customers and fabricate more than 100 products in the same manufacturing facility.

After significant capital investment and collaborative ecosystem development during the second half of the 2010s, TSMC's cutting-edge process nodes at 3 and 5 nm in wafer fabrication was more advanced than Intel fabs in the US. Only Samsung's most advanced 3 and 5 nm fabs in the Republic of Korea were on par with TSMC's mega-fabs in Tainan, and this trend will likely persist in the mid- to late-2020s. This changing technological leadership in chip making pivoting towards top foundry fabs in East Asia has profound implications for the industrial organization of semiconductor global value chains. By the end of 2020, TSMC's 5 nm Fab 18 in Tainan had entered into mass production, initially for Apple's A14/A14X mobile application processor chips and Huawei's Kirin 1000 network processor chips. TSMC's corporate research office was also working on new 2D materials to overcome the nanometre constraints of bulk (3D) semiconductors (Li et al., 2019). By end 2022, TSMC's 3 nm Fab 18 in Tainan also entered into mass production at high yield, marking its continual technological leadership in semiconductor manufacturing.

References

Kapoor, Rahul and McGrath, Patia J. (2014), 'Unmasking the interplay between technology evolution and R&D collaboration: evidence from the global semiconductor manufacturing industry, 1990–2010', *Research Policy*, 43(3), 555-569.

Li, Ming-Yang, Su, Sheng-Kai, Wong, H-S. Philip and Li, Lain-Jong (2019), 'How 2D semiconductors could extend Moore's law', *Nature*, 567, 169-170.

Nenni, Daniel and McLellan, Paul (2019), *Fabless: The Transformation of the Semiconductor Industry,* SemiWiki.com Project.

Sturgeon, Timothy J. (2002), 'Modular production networks: a new American model of industrial organization', *Industrial and Corporate Change,* 11(3), 451-96.

Yeung, Henry Wai-chung (2016), *Strategic Coupling: East Asian Industrial Transformation in the New Global Economy,* Cornell Studies in Political Economy Series, Ithaca, NY: Cornell University Press.

By the late 2010s, the global semiconductor market became co-dominated by both IDM firms and fabless firms from the US and East Asia, together with top foundry partners mostly based in East Asia. As illustrated in Figure 4.3 earlier, their main products are in memory, logic, and microprocessor chips that drive ICT devices (e.g. smartphones, personal computers, tablets, and servers) and other industrial applications (e.g. automotive and electrical machinery). Table 4.5 maps such changing geography of chip-making capacity during the 2000-2018 period, based on the fab-by-fab aggregation

of micro data on over 300 fabs worldwide (Yeung, 2022b; see also earlier Figure 4.4). During this period, the total number of IDM and foundry fabs remained fairly stable – 325 fabs in 2000, increasing to 344 in 2010, and consolidating to 296 in 2018 (but expected to increase again to over 350 fabs when the current massive new fab construction worldwide is completed in the 2023-2025 period). However, the total capacity of these fabs worldwide increased very significantly, doubling between 2000 and 2010 and increasing further by 32% to reach almost 17 million wafers per month in 2018. This growth rate matches fairly well the semiconductor market's revenue growth during the same period – from $221 billion in 2000 to a peak at $485 billion in 2018 (and again at $590-$600 billion in 2021 and 2022).

Geographically, substantial growth in new fabs and capacity has shifted towards East Asia since the 2000s. While the two East Asian "tigers" of Republic of Korea and Chinese Taipei already had some capacity in 2000, they were still far behind Japan, the US, and, for Chinese Taipei, even Europe. Fab capacity in the PRC and Singapore was marginal. By 2018, Chinese Taipei became the world's largest producer of semiconductors at 4 million wafers per month, followed by the Republic of Korea (3.6 million), Japan (3.0 million), and the PRC (2.2 million). Even the city-state of Singapore's capacity of 1.04 million was slightly larger than the entire Europe's output of 1.02 million. The US fell to 5th place, with 1.8 million wafers per month from its 44 fabs. During the 2010s, there was a substantial consolidation of fabs in Japan, from 131 in 2010 to 87 in 2018. The US also witnessed the closure of almost a quarter of its fabs and a slight decline in total fab capacity. In terms of product applications, Chinese Taipei and the PRC were by far the largest foundry producers (mostly in logic chips), whereas the Republic of Korea and Japan led in memory chip-making, with Singapore and Chinese Taipei trailing behind. In both logic and memory chips, the US and Europe experienced declining fab numbers and capacity throughout the 2010s (see recent update in Huggins et al., 2023).

This enormous growth in global semiconductor manufacturing capacity and its pivot towards East Asia during the 2010s has been driven by the tremendous growth in intermediate market demand for logic and memory chips in several major product applications in ICT devices (PCs and smartphones), data center servers, and consumer electronics (e.g. TVs). Table 4.6 provides a firm-level perspective to the above macro-observations. In 2018, logic chips accounted for the vast majority of fab outputs by all top five foundry providers, led by TSMC (see Box 4.7). Contributing to Chinese Taipei's dominant role in foundry firms (Table 4.2), TSMC is ranked top in fabricating logic chips for smartphones, PCs, and industrial electronics, allocating some 54% of its 2018 fab capacity to making smartphone logic chips designed by Apple (24% share of TSMC's total revenue in 2019), HiSilicon (15%), Qualcomm (6%), and MediaTek (4.3%). Geographically, TSMC's enormous fab capacity of 2.3 million wafers per month is heavily concentrated in its 8 fabs in Chinese Taipei. While the US remains the dominant centre of logic chip design (i.e. fabless firms mostly based in Silicon Valley) and microprocessor design and manufacturing (i.e. Intel in Table 4.3), East Asian foundry providers are dominant in logic chip manufacturing.

Table 4.5: Geography of World Semiconductor Manufacturing by Fab Location, Product Applications, and Capacity, 2000-2018 (foreign owned in parentheses)

	2000	2000	2010	2010	2018	2018
Fab location	**Fab #**	**Capacity[1]**	**Fab #**	**Capacity[1]**	**Fab #**	**Capacity[1]**
US						
Logic	14 (2)	311 (85.5)	11 (3)	589 (309)	4 (3)	433 (370)
Memory	6 (3)	251 (134)	5 (1)	319 (36.0)	4 (0)	244 (0)
Foundry	4 (2)	90.6 (39.3)	5 (3)	125 (73.8)	8 (4)	285 (105)
Total	68 (18)	1,310 (407)	57 (14)	1,875 (529)	44 (12)	1,770 (547)
Japan						
Logic	43 (6)	509 (121)	47 (6)	696 (125)	25 (0)	481 (0)
Memory	14 (0)	359 (0)	13 (0)	1,035 (0)	14 (2)	1,658 (281)
Foundry	3 (1)	57.9 (38.3)	4 (1)	58.1 (25.7)	10 (3)	242 (76)
Total	132 (10)	1,724 (243)	131 (14)	2,667 (307)	87 (8)	2,965 (471)
Republic of Korea						
Logic	9 (0)	314 (0)	10 (0)	772 (0)	10 (0)	722 (0)
Memory	7 (0)	555 (0)	9 (0)	2,000 (0)	13 (0)	2,579 (0)
Foundry	1 (0)	28.6 (0)	2 (0)	92.3 (0)	3 (0)	211 (0)
Total	22 (3)	1,058 (107)	23 (2)	2,939 (74.4)	28 (2)	3,563 (50.8)
Chinese Taipei						
Logic	2 (0)	54.7 (0)	4 (0)	144 (0)	5 (0)	238 (0)
Memory	6 (0)	154 (0)	13 (0)	830 (0)	10 (3)	831 (393)
Foundry	17 (0)	514 (0)	24 (0)	1,630 (0)	27 (0)	2,947 (0)
Total	26 (1)	724 (1.7)	42 (1)	2,606 (1.7)	43 (4)	4,017 (395)
PRC						
Logic	1 (0)	7.2 (7.2)	1 (0)	8.1 (8.1)	1 (0)	12.9 (0)
Memory	0 (0)	0 (0)	3 (3)	189 (189)	5 (1)	728 (3.4)
Foundry	4 (0)	64.8 (0)	19 (2)	681 (92.2)	25 (4)	1,364 (264)
Total	8 (3)	84.3 (19.5)	27 (9)	913 (232)	37 (11)	2,189 (353)
Europe						
Logic	9 (3)	164 (58.0)	6 (1)	167 (36.0)	4 (0)	134 (0)
Memory	5 (2)	136 (59.6)	4 (2)	116 (55.0)	2 (0)	65.0 (0)
Foundry	3 (1)	47.3 (25.5)	7 (4)	150 (121)	8 (4)	259 (193)
Total	55 (30)	845 (437)	42 (25)	889 (441)	37 (19)	1,019 (559)
Singapore	8 (3)	167 (14.6)	14 (14)	702 (702)	12 (12)	1,042 (1,042)
Israel/Malaysia	6 (5)	77.8 (68.8)	8 (2)	290 (228)	8 (2)	431 (373)
Total	**325**	**5,991**	**344**	**12,879**	**296**	**16,997**

[1] Fab capacity in thousands of 8-inch (200 mm) equivalent wafer starts per month.
Source: Calculate from the fab-level data of each semiconductor manufacturer available from IHS Markit/Informa Tech Custom Research, July-October 2016 and 2019.

In memory devices – the largest chip application with $165 billion revenue or 34% of world market in 2018 (Table 4.6), the geography of chip manufacturing and fab locations is still based on the IDM-model of vertically integrated production networks highly concentrated in East Asia. As evident in Table 4.3, this market is controlled by four very large IDM firms – Samsung, SK Hynix, Micron, and Toshiba/Kioxia. Having emerged as the market leader in the late 1990s (Box 4.5), Samsung alone accounted for 40% of the memory market in 2018, the equivalent of the next two combined – SK Hynix (22%) and Micron (18%). Samsung and SK Hynix's memory fabs are mostly located in the Republic of Korea, whereas all of Toshiba/Kioxia's five fabs are in Japan

Table 4.6: World's Top Semiconductor Manufacturers by Fab Capacity, Main Applications, Fab Locations, and Markets, 2010 and 2018

Lead firms	Sales ($b) 2010	Sales ($b) 2018	Fab capacity[1]	Applications (% of 2018 sales)	Location of HQs and fabs	Key end market segment (% of 2018 sales)
IDM *Samsung*	28.4	74.6	2,474	Memory 88%	Republic of Korea, US, PRC	Smartphones, PCs, consumer electronics
Intel	40.4	69.9	722	Microprocessors 76%	US, Ireland, Israel, PRC	PCs, servers, and data centers
SK Hynix	10.4	36.3	1,385	Memory 99%	Republic of Korea, PRC	Smartphones and PCs
Micron	8.9	29.7	1,038	Memory 100%	US, Singapore, Chinese Taipei, Japan	PCs, servers 37 %; storage 26%; smartphones 21%
Toshiba	13.0	11.4	1,310	Memory 100%	Japan	Smartphones, PCs, consumer electronics
Foundry TSMC	12.9	31.1	2,266	Logic 87%	Chinese Taipei, PRC, US	Smartphones 54%, PCs 15%, industrial electronics 17%
Global-Foundries	3.5	6.2	592	Logic 68%	US, Germany, Singapore	Smartphones 35%, PCs 23%, consumer electronics 23%
UMC	3.8	5.0	653	Logic 84%	Chinese Taipei, PRC, Singapore	Smartphones 42%, PCs 16%, consumer electronics 28%
Samsung	0.8	3.4	371	Logic 100%	Republic of Korea, US	Smartphones and PCs
SMIC	1.6	3.0	451	Logic 53%	PRC	Smartphones and wireless 41%, consumer electronics 38%
World market	312	485	16,997	Memory 34% Logic 22% Microprocessors 12%	-	Computer & data storage 37% Wireless and smartphones 30% Industrial electronics 11% Consumer electronics 8.6%

[1] Fab capacity in thousands of 8-inch (200 mm) equivalent wafer starts per month.
Sources: Authors' interviews with IDM firms and foundry providers in *italics*, IHS Markit/Informa Tech Custom Research, July-October 2016 and 2019, and corporate reports and websites.

(Table 4.6). In comparison, American IDM Micron's seven fabs are more diversified geographically, but its four fabs in Singapore, Chinese Taipei, and Japan account for 80% of its total capacity.

The massive building of new fabs or capacity expansion in East Asian locations during the 2010s cannot be adequately explained by favorable government policies and strong support from localized ecosystems. These necessary "East Asian" conditions would be insufficient if there were no corresponding market demand for memory and logic chips utilizing this new capacity in East Asia. Top semiconductor firms in East Asia would not have incurred massive capital expenditure in the 2010s to build new fabs without anticipating future demand and/or attaining strong commitment of orders from their top customers, e.g. Apple's iPhone chips exclusively utilizing TSMC's latest process nodes in dedicated home fabs since 2016 and OEM lead firms in PCs and servers as key customers for memory chips from Samsung and SK Hynix (see also Fontana and Malerba, 2010).

Without accounting for the demand-led market dynamics driving these firm-specific strategies within their global production networks, it will be difficult to explain why

further capacity growth in Chinese Taipei and the Republic of Korea occurred in the 2010s when their respective government supports had already become weaker and less interventionist and their leading domestic semiconductor firms had depended less on government support and much more on their strategic coupling with lead firms in global production networks and value chains. But as global competition and geopolitical tensions have increased much further in the post-pandemic 2020s, more economies and macro-regions want to localize/reshore their own semiconductor value chains with "real fabs" in the spirit of AMD's Jerry Sanders. The next, penultimate section will consider this ongoing techno-nationalist approach to the question of whether nation-states are indeed more "real" by having their own fabs in semiconductor manufacturing.

4.7 Techno-Nationalism: Must Real States Have Fabs?

Recently enacted national policies, such as the CHIPS and Science Act of the United States, the EU Chip Act, and the ¥2 trillion subsidy allocated by the Japanese government to the semiconductor industry, indicate a revival of industry policy in developed nations, which in the past preferred laissez-faire to government interventions and aggressively promoted the free-market doctrine, commonly known as the Washington Consensus, to developing nations. Free market believers often dismiss the need of industry policy and use information barriers and possible rent-seeking as powerful arguments against industry policy (Rodrik, 2008). A recent report by Cato Institute "Questioning Industrial Policy" (Lincicome and Zhu, 2021) argues strongly against the adoption of new industrial policy in the US for strengthening semiconductor manufacturing and other strategic industries. On the other hand, Nobel laureate Michael Spence (2023) argues that industry policy serves not only economic but also social objectives. Economic efficiency should not be the only yardstick for assessing the efficacy of industry policy. Given the recent geopolitical tension and national security concerns, Spence claims that implementing industry policy in the US is inevitable.

Since the 2020s, the renaissance of a new wave of techno-nationalism (Capri, 2019; Luo, 2022) can be associated with three main driving forces: (i) concerns over the resilience of semiconductor GVCs; (ii) semiconductors as the foundation of national security; and (iii) the interactive process between the great powers today, notably the Sino-US race for technology leadership. We summarize recent policies enacted by all major economies to domesticize semiconductor capacity and to improve semiconductor resilience and evaluate their likely short-term effects.

First, the COVID-19 pandemic and recent geopolitical conflicts have served as catalysts for policymakers around the world to recognize the importance of supply chain resilience, i.e. the ability to recover quickly from and adapt to an unexpected shock (Pettit et al., 2010), for such critical products as semiconductors. In particular, pandemic-related and environmental disruptions have revealed long-existing

vulnerabilities in global supply chains, especially those associated with overdependency for the supply of some critical products on a single nation/region – a circumstance exacerbated by geopolitical concerns (White House, 2021). Since mid-2020 and driven mainly by the stay-at-home economy, the demand for chips has spiked, especially in the consumer electronics and automotive sectors. On the supply side, there have been bottlenecks in qualified chips manufacturing capacity (in particular, for use in the automotive industry; see Suleman and Yagci, 2022b), which are located mostly in East Asia and were adversely impacted by the COVID-19 lockdowns. Together, the two forces resulted in severe global supply shortages and rapid price increases of chips in 2021 and 2022 (LaPedus, 2021; J.P. Morgan, 2022), affecting automotive, industrial, and communications products, among others.

For several decades, GVCs have been organized and dominated by transnational corporations in the wider context of a liberal policy approach to domestic production in many nations, prioritizing efficiency, productivity, and low costs over security, sustainability, and resilience. In semiconductors, the pursuit of hyper-efficiency through the "fabless revolution" discussed in earlier sections has led to the heavy concentration of logic chip production in foundry providers based in Chinese Taipei and the Republic of Korea. Industrial policy success and market dynamics in East Asia have also created giant memory chipmakers in the Republic of Korea, Japan, and the PRC. Ironically, the same geographical concentration is evident in the supply of semiconductor manufacturing equipment and materials. According to BCG and SIA (2021), there are at least 50 chokepoints across virtually all major types of value-adding activities in semiconductor GVCs, where a single region, either in terms of physical location or ownership, accounts for 65% or more of the total global supply. All major economies are now waking up to the idea that they need to diversify their source of semiconductor imports and improve their supply chain resilience, possibly by reverting to domestic production, nearshoring, or friend-shoring to new locations (Lund et al., 2020; G7, 2023).

The fact that semiconductors are the foundation of national security would be a second reason for the rise of techno-nationalism. Indeed, more resilient and secured supply chains are deemed essential for a nation's economic security (in terms of steady employment and smooth operations of critical industries), national security, and technological leadership. More substantially, major economies around the world concur that semiconductors are the critical technological foundation of economic and national security.

In the US, policy makers believe that advances in science and technology are poised to define the geopolitical landscape of the 21st century. Together with biotech and clean tech, computing-related technologies, including microelectronics, quantum information systems, and artificial intelligence, are identified as truly "force multipliers" throughout the American tech ecosystem. Accordingly, a key element of

its new National Security Strategy is to invest in the sources of its national strength, recharging the engine of American technological dynamism and innovation, especially in these foundational sectors. At the same time, the US would adopt a "small yard, high fence" strategy for such critical technologies as semiconductors, ensuring that "choke points for foundational technologies have to be inside that yard, and the fence has to be high because these competitors should not be able to exploit American and allied technologies to undermine American and allied security" (Sullivan, 2022).

Third, and unlike the mid-1980s discussed in section four, this new techno-nationalism rests on the premise that the world has entered into a new era of systemic geopolitical rivalry between competing powerhouses with radically divergent ideological values, political systems, and economic models; it indeed is posed as a political-economic response to such structural changes. By highlighting the importance of technological autonomy/self-sufficiency (Reich, 1987; Tyson, 1993), it justifies and advocates for proactive government interventions, seeking to get an upper hand over its rivals in technological fields of strategic importance in order to attain geopolitical gains. New techno-nationalism thus exhibits a tendency toward de-globalization, decoupling, and de-risking through the imposition of restrictions on technology flows and increasingly unilateral, aggressive, and extraterritorial measures to achieve national objectives.

To strengthen semiconductor supply chain resilience and address national security concerns, governments in major economies have recently pushed for the localization and/or reshoring of chip manufacturing capacity through techno-nationalistic industrial policies, mainly in the form of the provision of direct subsidies and tax credits:

(i) The US. The CHIPS and Science Act of 2022 is the most representative sample of this new wave of interventionalist industrial policy, reflecting a broader shift of stance in American economic policy-setting. Signed into law on 9 August 2022, the Act provides $52.7 billion in emergency supplemental appropriations to support authorized semiconductors programmes, together with a semiconductor investment tax credit estimated to be worth around $24 billion. This 25% investment tax credit (ITC) for investments in semiconductor manufacturing equipment and facilities is created by the Act, serving as an additional tool to close the cost gap between semiconductor investment in the US and other countries. The Act installs strong guardrails that exhibit a strong techno-nationalist overture, such as preventing funds/ITC recipients from expanding/building manufacturing facilities below some technology threshold in the PRC or other foreign countries of concern, and restricting them from engaging in any joint research or intellectual property transaction with a foreign entity of concern. Division B of the Act authorizes – rather than appropriates, as with the semiconductor funds in the Act – nearly $170 billion in funding over five years for R&D initiatives administered by multiple federal agencies. This amounts to a $82.5 billion boost over

the baseline funding budget, representing the largest five-year investment in public R&D in US history.

(ii) PRC. Apart from the two major Chinese techno-nationalist initiatives of "Made in China 2025" and "National IC Plan" discussed earlier, the PRC has responded strongly to the American imposition of sweeping export controls toward the PRC in advanced semiconductor technology. In October 2022, Beijing reportedly planned to roll out a new 1 trillion yuan ($143 billion) fiscal incentive package for its semiconductor industry in 2023, representing a major step towards "self-reliance and strength (自立自强)" in semiconductors to counter American moves to slow its technological advancements. As such, Beijing is seemingly changing its strategy by moving away from catching up in leading-edge technology to the full-range domestication of mature-node technology. The incentive package will be allocated mainly as subsidies and tax credits to bolster the production and research activities of semiconductor and chipmaking tools at home, rather than as direct interventionist mega investments. The majority of the package will likely be used to subsidize a handful of the most successful semiconductor firms and the purchases of domestic semiconductor equipment (for up to 20% of the costs).

(iii) Europe. In February 2021, the European Parliament approved the EU's proposed €672.5 billion worth "Recovery and Resilience Facility" (RRF) in the form of grants and loans to be disbursed over the next few years. The co-legislators agreed that a minimum of 20% of the REF would be devoted to supporting the "digital transformation" of Europe, with the specific goal for the semiconductor industry. By 2030, the production of cutting-edge semiconductors in Europe should be at least 20% of the world total in value, and the manufacturing capacity below 5 nm is targeted at 2 nm and 10 times more energy efficient than today. Noting the EU's reliance on external suppliers and its diminished share in semiconductor GVCs, the European Commission decided, after the US had announced its CHIPS for America Act, in September 2021 that it too would enact a new "European Chips Act", aiming at creating a state-of-the-art European chipmaking ecosystem to keep the EU competitive and self-sufficient. In April 2023, the European parliament approved the European Chips Act. legislative proposal took shape in February 2022. It will mobilize more than €43 billion ($47 billion) worth of public and private investments by 2030 and leverage Europe's strength in world-leading R&D organizations and networks, as well as hosting pioneering equipment manufacturers.

(iv) Japan. As discussed in section four, Japanese semiconductor manufacturers held more than half of the global market share in the 1980s (see also Table 4.3). Since then, their market share has declined substantially, and, in the 2010s, Japanese chipmakers withdrew from competition in large-scale chip development. In the current context of semiconductor supply shortages and concerns for economic security and supply chain resilience, the Japanese government has been trying to establish a legal framework to subsidize the construction of new semiconductor production facilities

(especially cutting-edge processes) in Japan. A legislative proposal was submitted to the parliament in December 2021, and was approved with a ¥774 billion ($6.8 billion) supplementary budget for fiscal 2021 that would fund the subsidies for semiconductor fabs. The TSMC-Sony plant in Kumamoto announced in October 2021 would be the first beneficiary. Producing at mature nodes, the plant began in 2022 and would start mass production in 2024 – the Japanese government would provide half of the overall ¥1 trillion ($8.82 billion) in capital investment. Other possible beneficiaries include memory chipmakers such as Micron from the US and Kioxia from Japan. Under an economic security promotion law enacted in 2022, Japan further dedicated ¥1.3 trillion supplementary budget for fiscal 2022 to fund new and expanded subsidies for up to one-third of capital investment related to a variety of semiconductors, chipmaking equipment and components, and up to half of investment in raw materials. Both domestic and foreign firms investing in Japan can qualify for such subsidies. Rapidus, a newly founded Japanese chipmaker aiming to produce 2nm chips, received ¥330 billion subsidy from the Japanese government. American company Micron would receive ¥200 billion subsidy for expanding its factory in Hiroshima.

(v) India. In December 2021, India approved the Semicon India Program (Program for Development of Semiconductors and Display Manufacturing Ecosystem in India) that comes with an outlay of $10 billion to an incentive scheme for the development of a sustainable semiconductor and display manufacturing ecosystem in India. The program aims to provide attractive incentives to bring in a total of $25 billion investment in semiconductors and display manufacturing. The aim is to increase India's semiconductor self-sufficiency and to make India a key player in semiconductor GVCs. More broadly, incentives worth $30 billions will be available to position India as a global hub for electronics manufacturing.

Taken together, the short-term effects of these techno-nationalist policies are rather obvious – the massive increase in fab capacity worldwide or "fabs everywhere". From 2021 to 2023, the global semiconductor industry is projected to invest more than $500 billion in 84 new high-volume front-end chipmaking facilities, with the number for the three years being 23, 33 (a record high), and 28 respectively (SEMI, 2022b). While East Asia still accounts for the majority of this new capacity, its global distribution is significantly more diverse than before. Not surprisingly, the US has become a top location for new capital spending around the world. From 2021 to 2023, 18 new facilities are forecasted to start construction in the US alone. The PRC is expected to outnumber all other locations in new chip manufacturing facilities, with 20 mature-node facilities planned. Propelled by the European Chips Act, European investment in new semiconductor facilities is expected to reach a historic high, with 17 new fabs planned between 2021 and 2023. In the same period, Chinese Taipei is expected to start construction of 14 new facilities, while Japan and Southeast Asia are each projected to begin building six new facilities, and the Republic of Korea is forecast to start construction of three large facilities.

But is this "fabs everywhere" phenomenon realistic for the coming decade? Before we offer some concluding remarks, we examine briefly this phenomenon in the context of the PRC-US race for technology leadership and the PRC's drive for semiconductor self-sufficiency. It has long been argued that policymakers with a techno-nationalist mindset would not hesitate to curtail or sever economic and technological ties with rivals if they believe that such ties benefit their rivals more (e.g. Nelson and Ostry, 1995). Indeed, this is what is happening among major competing geopolitical powers during the 2020s. The evolution of the new wave of techno-nationalism can be viewed as an interactive process between the great powers, notably the US and the PRC. This wave first emerged in the 2010s, when the PRC introduced a series of massive industrial policy initiatives. Inspired by the successful experiences of industrial policies in many East Asian economies, especially in the semiconductor industry discussed earlier in section four, the PRC launched multiple mega industrial policy initiatives in the 2010s, notably the "Made in China 2025" initiative in 2015 and the somewhat overlappingly "Guideline for the Promotion of the Development of the National Integrated Circuit Industry" (a.k.a. the "National IC Plan") that comes with the accompanying "National IC Industry Investment Fund" (a.k.a. the "Big Fund") in 2014 (VerWey, 2019; Capri, 2020).

It is estimated that the Chinese government's overall funding commitment to these initiatives amounts to an almost unprecedented scale of $300 billion, with the ultimate goal of nurturing the next generation of "national champions" in key strategic areas such as semiconductors. While there have been painful lessons in policy implementation such as the Hongxin Semiconductor Manufacturing debacle (Box 4.6), the PRC has steadily closed the technology gap with global leaders and established itself as one of the leading players in many foundational and emerging technologies of the future (Manyika et al., 2019). In semiconductors, a well-known example is Huawei. Its rapid rise to the world's largest telecommunication equipment manufacturer and one the world's top semiconductor firms via its chip design subsidiary HiSilicon (see Table 4.3) has amplified the long-standing allegations about its connection to the state and the sources of its competitive edge (Berman et al., 2020).

By the late 2010s, many in America's political establishment had increasingly perceived the PRC as engaging in a broader campaign to challenge America's great power status. Consequently, technology transfer to and technological cooperation with the PRC was viewed not just on its commercial merits, but also as a potential national security risk. This heightened anxiety then prompted the US to initiate the process of trying to decouple from the PRC in certain technological sectors since 2020. In particular, the US has two significant issues with the PRC's industrial policy in semiconductors (Hodiak and Harold, 2020). First, the sheer scale of state-backed financial support of the PRC's semiconductor industry has raised concerns about the resulting market distortions. Second, worries over the PRC's relatively lax intellectual property protection have further heightened skepticism about how the PRC would achieve parity with leading-edge design and manufacturing in this sector without technology transfer from foreign firms. By around 2020, there was a growing conviction in Washington and among its allies that the

PRC's industrial initiatives were motivated by geopolitical ambitions beyond economic considerations.

Starting with the Trump Administration, the US has taken a flurry of techno-nationalist countermeasures, including the tightening of control over "dual use" technologies, the imposition of sanctions and restrictions on a few high-profile hi-tech Chinese firms, and the rolling out of fully-fledged semiconductor export controls toward the PRC. Suleman and Yagci (2022a: 12) argue that such moves represent a strategic orientation by the US to ensure its leading position in critical supply chains such as semiconductors. In part as a response to Beijing's mega industrial policy initiatives, the US congress passed the Export Control Reform Act (ECRA) in 2018. Focusing on "emerging" and "foundational" technologies, the act expands the scope of dual-use technologies on US Department of Commerce's Controlled Commodity List (CCL), placing all 10 categories of technologies targeted in "Made in China 2025" under the umbrella of "dual-use". This means most, if not all, US-PRC technology transfers are now susceptible to stricter export controls and license requirements. Moreover, the US has imposed sweeping sanctions and restrictions on Huawei and other hi-tech Chinese firms (see Box 4.8). Washington has singled out Huawei and other Chinese high-tech firms, such as ZTE and SMIC, in the context of US-PRC techno-nationalist innovation race, denied their access to US (telecommunications) market, and imposed stringent export controls against them.

Most recently in October 2022, the strong US reaction to the PRC's technological and geopolitical ambitions culminated in the Biden administration imposing the most stringent restrictions on technology exports to the PRC in decades. These sweeping restrictions, in essence, prohibit the PRC from access to the most advanced chips made with American software and/or equipment in design and manufacturing, as well as by fabs hiring Americans to work in them. The holistic nature of these highly targeted restrictions comprises interlocking elements targeting the different segments of semiconductor GVCs, each leveraging American dominance in a specific chokepoint while all working together to serve the overarching goals (Allen, 2022; Suleman and Yagci, 2022a). In March 2023, Japan and the Netherlands followed suit without explicitly referencing the PRC and announced new export controls on key semiconductor technology to prevent undesirable end use (e.g. military deployment) and unwanted long-term strategic dependencies, and to maintain their domestic technological leadership. These controls will take effect respectively in July and September 2023.

Not surprisingly, the PRC has also taken tit-for-tat countermeasures against these US-led sanctions. Two recent moves stand out. On 23 May 2023, in a first big move against an American semiconductor company Micron, the Cyberspace Administration of the PRC (2023) announced that it would ban the PRC's domestic operators of critical information infrastructure from purchasing Micron's product, citing national security reasons. Micron is the leading US memory chips manufacturer, with 25% of its global sale coming from the PRC and Hong Kong, China (Olcott and Sevastopulo 2023).

Box 4.8: The Impacts of US Sanctions on Huawei

Semiconductors have been at the heart of US-PRC trade war. The US strategy is to limit the PRC's access to critical technologies in an attempt to slow down its technological progress in the sector, whereas Huawei is the most affected ICT firm based in the PRC (Suleman and Yagci, 2022).

On 19 May and 19 August 2019, the US Department of Commerce added Huawei and its subsidiaries to the Export Administration Regulations (EAR) "Entity List". Prior to its addition to the list, Huawei was the world's largest telecoms equipment manufacturer and third-largest smartphone vendor, sourcing more than $10 billion worth of goods and components from the US annually. On 15 May and 17 August 2020, the US Department of Commerce further announced two more expansions of export controls on Huawei. Apart from adding 152 more associates of Huawei to the entity list, the most critical element of the new restrictions is to impose license requirements not only on US-made items, but on any foreign-made item that incorporates more than a de minimis amount of controlled US-origin items, or that is the direct product of a controlled software or technology. Under this new rule, US authority effectively prohibits Huawei's non-US suppliers that rely critically on US equipment or technology from supplying chips to Huawei and its affiliates.

As a result of the sanctions, HiSilicon, Huawei's chip design arm aiming to rival market leader Qualcomm, was cut off from access to updates and technical support for mainstream EDA software (Nikkei 2019), a segment dominated by three US-based firms. Even worse, subject to US restrictions, as of 15 September 2020, TSMC stopped providing foundry services to Huawei for advanced chips designed by HiSilicon (e.g. Kirin chipsets for smartphones). The combination of strikes has all but crippled Huawei's semiconductor design operations. Since the second half of 2020, HiSilicon's market position and sales revenue have plummeted dramatically (IC Insights, 2020; 2021). Moreover, the new restrictions have also blocked Huawei's access to advanced chips and other critical components. The impact of these restrictions on Huawei is most pronounced in its rapidly diminishing share in the global smartphone market. In 2019 Q1, Huawei shipped 59.1 million smartphones, giving it a 17% global share. In 2021 Q1, Huawei's global share fell sharply to only 4% (mostly in the domestic market), with the shipment being only 15 million units (Counterpoint, 2021). Due to the rapid loss of smartphone market share, Huawei's smartphone business literally collapsed by 2021 (Strumpf 2021).

Meanwhile, Huawei's telecoms carrier equipment business has also been suffering from the shortage of critical chips and components, albeit to a lesser extent. In 2021, Huawei's carrier business posted a revenue of 281.5 billion yuan, down around 7% year-on-year (Kharpal 2023). Overall, the negative impacts of US sanctions on Huawei were most deeply felt in 2021, when Huawei's revenue fell by 29% year-on-year to $99.9 billion (636.8 billion yuan), marking its first yearly decline. In 2022, Huawei's revenue stabilized at 642.3 billion yuan (a 0.9% year-on-year rise) as the company diversified into new areas such as cloud computing and automotive technology. However, its 2022 profit plunged 69% year-on-year to $5.18 billion (35.6 billion yuan), making a record-low net margin of 5.5% due to the continual pressure from U.S. sanctions and the PRC's pandemic controls (Kharpal 2023).

References

Counterpoint (2021), *China Smartphone Market Share: By Quarter,* https://www.counterpointresearch.com/china-smartphone-share
IC Insights (2020), *China-Based HiSilicon's Time in the Top-10 Ranking May be Short Lived*, https://www.icinsights.com.
IC Insights (2021), *Top-15 Semi Companies Log Year-Over-Year Growth of 21% in 1Q21*, https://www.icinsights.com.
Kharpal, A. (2023), 'Huawei reports biggest profit decline ever as U.S. sanctions, pandemic controls hit Chinese giant', *CNBC*, 31 March, https://www.cnbc.com.
Nikkei (2019), 'Huawei loses access to vital chip design updates from Synopsys', *Nikkei Asia*, 31 May, https://asia.nikkei.com.
Strumpf, D. (2021), 'U.S. restrictions push Huawei's revenue down by nearly a third', *WSJ*, 31 December, https://www.wsj.com.
Suleman, Areef and Yagci, Mustafa (2022), *The Impact of Sanctions on Global Value Chains,* Background Paper for the Workshop on *"Global Value Chain Development Report 2023:* Resilient and Sustainable GVCs in Turbulent Times", Geneva: World Trade Organization.

The PRC's second countermeasure came on 3 July 2023, when the Chinese Ministry of Commerce (2023) imposed new export restrictions on gallium, germanium, and their compounds, again citing national security reasons and in an apparent retaliation for new US-led Western sanctions on its semiconductor industry. The two rare metal elements are critical to the manufacture of semiconductors, for which the PRC is the world's largest producer, accounting for more than 95% and 67% of their respective global outputs (Zhen 2023). Clearly, the prospect of a rapid escalation of US-PRC tension creates great uncertainty for the future of global semiconductor value chains.

Conclusions

The recent COVID-19 pandemic, global chip shortages, and the US export restrictions on semiconductor technologies have focused worldwide attention on this important high-tech sector. Many national governments in advanced economies have now placed far greater urgency on, and enacted specific industrial policies for, (re)building their domestic semiconductor manufacturing capacity or wafer fabrication (fabs). From the US and the EU to Japan, the Republic of Korea, India, and the PRC, these government-led initiatives are often couched in the name of supply chain resilience and national security considerations. In this global race to build "fabs everywhere", there is a common neglect of the fact that semiconductor global value chains (GVCs) are themselves in massive transition from previously fully integrated devices based on in-house design and manufacturing within the same semiconductor firm to – increasingly since the 1990s – the organizational and geographical separation of the design and fabrication of these devices. In this "fabless revolution" since the late 1980s, chip design and production can be completed in entirely different firms and geographical locations. Meanwhile, ingenious technological innovations in semiconductor design and manufacturing have continued unabated to push the frontiers of the so-called "Moore's Law" of shrinking chips with far greater computing power. Coupled with the incessant demand for such smaller and more powerful chips in new industrial applications such as personal computers, smartphones, and servers in the past two decades, semiconductor manufacturing has become far more sophisticated in technological terms and capital-intensive in financial commitments. By the late-2010s, only three semiconductor firms were able to invest continuously in new leading-edge fabs (defined as process technologies at the 10 nanometre or smaller nodes).

These industry-specific characteristics have posed fundamental challenges to the current national policy initiatives in building "fabs everywhere". As we opened the chapter with a quote from the CEO of TSMC – currently the world's leading chip manufacturer, these policy efforts must be viewed with some circumspection because it is neither realistic nor easy for every nation to build their own fabs. Indeed, this chapter has demonstrated with substantial evidence that semiconductor GVCs are far more complicated in both organizational and geographical terms than what most policy advocates of "own fabs" would have thought. The chapter has shown that the top semiconductor lead firms have increased their collective market share during the past ten years, particularly in two types of chips – logic and memory. While only a few market leaders dominate in the different segments of semiconductor GVCs, from design software and intellectual properties to materials and manufacturing equipment, each of these segments in turn depends on a wide range of trusted key suppliers and technology leaders worldwide. Even ASML from the Netherlands, as the sole provider of the most sophisticated lithography machines for chipmaking, is dependent on hundreds of specialized suppliers for its very limited annual production of the €200 million EUV lithography machine indispensable in any bleeding-edge fab.

To account for these transformative shifts in semiconductor GVCs up to the early 2020s, the chapter's third main section has examined the changing fortunes in the industry by focusing on the rise of fabless logic chip design firms and their manufacturing partners, known as pureplay foundry firms such as TSMC, since the 1990s. Our findings have pointed to the significant role of high costs in chip design and production, capital market preferences, necessary economies of scale, and changing market dynamics in driving this "fabless revolution". As logic chips become ever more sophisticated with higher computational power and energy efficiency, their design and production require even more costly human capital, electronic design automation software, intellectual property, and highly specialized manufacturing equipment that only a few can afford. In the US and Silicon Valley in particular, the preference of venture capital for asset-lite semiconductor firms has compelled more American start-ups to go fabless. But who gets to make the chips for these fabless firms? The clear answer lies in the rise of pureplay foundry fabs based in East Asia, such as Chinese Taipei, the Republic of Korea, Singapore, and, most recently, the PRC. Empirical evidence in this chapter supports our arguments outlined in Introduction, that such vertical disintegration in chip design and manufacturing has indeed driven the globalization of semiconductor production and the global reach of semiconductor GVCs.

But such "fabless revolution" has not happened in every product category of semiconductors: there have been different forms of "verticality" or vertical specialization in semiconductor GVCs since the 2010s. Our analysis has shown that the fabless-foundry model of semiconductor GVCs is particularly strong and efficient in application-specific logic chips. But in memory chips, another key product category in the currently $600 billion global semiconductor market, integrated device manufacturing (IDM) or vertical integration remains the dominant mode of organizing global production networks and global value chains. The same kind of IDM-led chip design and production is also prevalent in microcomponent, analogue, and discrete chips. In all these product categories, leading IDM firms (except Intel in microprocessors) take a hybrid approach to organizing their production networks characterized by in-house fabs for mature technology nodes and the complete outsourcing of advanced logic chips to leading foundry providers such as TSMC and GlobalFoundries. Through this fab-lite approach, these IDM firms are able to capitalize on their existing and well depreciated fabs and to avoid the tremendous costs of investing in new cutting-edge fabs. This dependency of fab-lite IDM firms on leading foundry providers in turn explains why their customers, many in the automotive sector, suffered from global chip shortages during the 2021-2023 period.

In terms of industrial concentration, East Asia has now played a dominant role in logic and memory chip production because of several top pureplay foundry providers (TSMC, Samsung Foundry, UMC, and SMIC) and IDM firms (Samsung, SK Hynix, and Kioxia/Toshiba). Empirical discussion in the fourth section has provided some evidence to support our argument that the government support in Japan, Republic of

Korea, Chinese Taipei, and Singapore was crucial in supporting the initial development of champions in foundry and memory chip production in the 1970s through to the early 1990s. Through a mix of government-sponsored industry consortia, favourable financial support through loans and grants, technology transfer facilitated by national research institutes, and policy preference for specific firms (i.e. "picking the winner"), these East Asian economies were able to achieve, in successive historical periods starting with Japan in the late 1970s, rapid catching-up in semiconductor process and manufacturing technologies. And yet it is critical to note that not all East Asian government-led initiatives have been successful. While Chinese Taipei's achievement in semiconductor foundries, as epitomized by TSMC and to a lesser extent UMC, is well known by now, its policy support for IDM producers in memory chips has been far less successful. Similarly and as evident in Box 4.4, Singapore's state-led push for a national champion in pureplay foundry has also not been effective in attracting foreign semiconductor firms, such as Micron in memory chips and UMC in foundry.

One key reason for such a checkered historical experience of government-led initiatives in semiconductor catching-up and/or building cutting-edge fabs is the often-overlooked "demand-side" explanation of semiconductor GVCs – the critical role of market dynamics.

The chapter's fifth section has provided empirical data on how market shifts in industrial applications towards computers/data storage and wireless communications since the 2010s have been crucial in explaining the rapid growth of leading fabless firms and foundry producers in logic chips and IDM firms in microprocessors and memory chips. While the role of East Asian governments remains supportive through a more horizontal kind of industrial policy (e.g. institutional support for R&D and industrial clusters and trade liberalization), their role in directly steering the development and transformation of domestic firms in the semiconductor industry has become much less visible and feasible, with the exception of the PRC – a late latecomer. Instead, East Asian lead firms in semiconductor manufacturing have capitalized on new market dynamics supported by the "fabless revolution" and massive demand from new industrial applications in computing, data centres, and wireless communications. Through firm-specific capability enhancement and industrial specialization, these East Asian firms have developed new semiconductor product or process technologies, flexible chip production and product diversity, and sophisticated organizational knowhow and proprietary access to market information (e.g. via fabless customers and their OEM end-users).

By the turn of the 2020s, semiconductor GVCs could no longer be contained within any specific firm nor national territory. The chapter's final two sections have provided further evidence to support the conclusion that even though more national governments want to be "real states" by having their "own fabs" for national security and risk mitigation reasons, the prospect for such a techno-nationalist drive towards

technological sovereignty in semiconductor manufacturing in the post-pandemic era is neither easy nor credible. Without a realistic assessment of how both demand- and supply-side explanations have accounted for the transformative shifts in semiconductor GVCs over the past two decades, such a global race in building "fabs everywhere" will likely lead to excess capacity, underutilized fabs, market fragmentation, and technological bifurcation worldwide. Even though some of these "costs" are part and parcel of the techno-nationalist policy goals, their prospect in achieving technological sovereignty cannot be guaranteed.

Bearing in mind these potential costs of pursuing "fabs everywhere", it is useful to conclude with an outline of three possible scenarios for the future of semiconductor GVCs throughout the 2020s. The first and most likely scenario will be the muddling-through of the current organization and geographical distribution of semiconductor value chains. While more chip production capacity will be added in the US and the EU through recent techno-nationalist industrial policies, this extra capacity will remain relatively modest and not at the bleeding-edge and will not fundamentally reshape the competitive dynamics of semiconductor GVCs. But as discussed in the penultimate section, these policies may not be efficacious in every national economy and thus their impact on the existing centres of excellence, i.e. US in chip design; the US, the EU, and Japan in equipment and materials; and East Asia and the US in chip manufacturing, will be relatively modest. In this scenario, the PRC will remain as a major player only in the mature nodes of logic and memory chips.

The second and third scenarios will be far more radical and perhaps even revolutionary. In the less likely second scenario of major technological innovations, one or more national economies such as the PRC or the US develops new breakthrough platforms for producing integrated circuits beyond the use of semiconductors. Intensive R&D efforts and financial resources are clearly necessary for these radical innovations to take place. So is the end-market demand for such ICs based on new materials or process breakthroughs. This revolutionary scenario is based on the key assumption of no substantial worsening of the existing US-PRC relations, world trade regimes, and global neoliberal order that would hamper technological change. The existing semiconductor GVCs will then be challenged by these revolutionary platforms that may possibly lead to a major shift of gravity in the entire industry away from the existing dominant centres of excellence.

A third and most destructive scenario is the escalation of geopolitical rivalries, government interventions, and even military conflicts that will fundamentally disrupt or even destroy semiconductor GVCs. Here, the Cross-Strait relation between the PRC and Chinese Taipei can be a major force and inflection point in reshaping global semiconductor production and markets. An equally severe change is the further trade restrictions and technology sanctions imposed by the US on the PRC that might cover all semiconductor technology classes, key inputs, and major industrial applications. This escalation in government regulation or even hostility can turn the entire global

semiconductor industry upside down precisely because of the vast diversity of end users of chips identified right at the beginning of this chapter. In either case of further escalations in military or trade/technology tensions, the interconnected world of semiconductor GVCs will likely end, and a new and perhaps worse world will emerge in its wake. What we know for sure is that "fabs everywhere" will remain a pipe dream in such a new era of global disintegration.

References

Allen, G.C. (2022), *Choking Off China's Access to the Future of AI*, Center for Strategic and International Studies (CSIS).

Angel, David P. (1994), *Restructuring for Innovation: The Remaking of the U.S. Semiconductor Industry*, New York: Guilford.

BCG and SIA (2021), *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*, https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf, accessed on 10 May 2023.

Berman, Noah, Maizland, Lindsay, and Chatzky, Andrew (2020), *Huawei: China's Controversial Tech Giant*, Council on Foreign Relations Backgrounders, 8 February 2023, https://www.cfr.org/backgrounder/chinas-huawei-threat-us-national-security, accessed on 10 May 2023.

Borrus, Michael G. (1988), *Competing for Control: America's Stake in Microelectronics*, Cambridge, MA: Ballinger Publishing.

Braun, Ernest and MacDonald, Stuart (1982), *Revolution in Miniature: The History and Impact of Semiconductor Electronics*, Second Edition, Cambridge: Cambridge University Press.

Brown, Clair and Linden, Greg (2011), *Chips and Change: How Crisis Reshapes the Semiconductor Industry*, Paperback Edition, Cambridge, MA: MIT Press.

Capri, A. (2019), 'Techno-nationalism: What is it and how will it change global commerce?', *Forbes*, December 20.

Capri, Alex (2020), *Semiconductors at the Heart of the US-China Tech War*, Hinrich Foundation.

Clarke, Peter (2022), 'China's share of global fabless IC market collapsed in 2021', *EENews,* 8 April 2022, https://www.eenewseurope.com/en/chinas-share-of-global-fabless-ic-market-collapsed-in-2021, accessed on 10 May 2023.

Cyberspace Administration of China (2023), *Micron's Products Sold in China Fail Cybersecurity Review*, http://www.cac.gov.cn/2023-05/21/c_1686348043518073.htm, in Chinese, accessed on 19 July 2023.

Dibiaggio, Ludovic (2007), 'Design complexity, vertical disintegration and knowledge organization in the semiconductor industry', *Industrial and Corporate Change*, 16(2), 239-267.

Epicoco, Marianna (2013), 'Knowledge patterns and sources of leadership: mapping the semiconductor miniaturization trajectory', *Research Policy*, 42(1), 180-195.

Fontana, Roberto and Malerba, Franco (2010), 'Demand as a source of entry and the survival of new semiconductor firms', *Industrial and Corporate Change*, 19(5), 1629-1654.

Fuller, Douglas B. (2007), 'Globalization for nation-building', *Journal of Interdisciplinary Economics*, 18(2/3), 203-24.

Fuller, Douglas B. (2016), *Paper Tigers, Hidden Dragons: Firms and the Political Economy of China's Technological Development*, Oxford: Oxford University Press.

Fuller, Douglas B. (2019), 'Growth, upgrading, and limited catch-up in china's semiconductor industry', in Loren Brandt and Thomas G. Rawski (eds.), *Policy, Regulation and Innovation in China's Electricity and Telecom Industries*, Cambridge: Cambridge University Press, 262-303.

G7 (2023), *G7 Leaders' Statement on Economic Resilience and Economic Security*, European Council, 20 May 2023, https://www.consilium.europa.eu/media/64501/g7-statement-on-economic-resilience-and-economic-security.pdf, accessed on 22 May 2023

Grimes, Seamus and Du, Debin (2022), 'China's emerging role in the global semiconductor value chain', *Telecommunications Policy*, 46(2). https://doi.org/10.1016/j.telpol.2020.101959

Hamilton-Hart, Natasha and Yeung, Henry Wai-chung (2021), 'Institutions under pressure: East Asian states, global markets and national firms', *Review of International Political Economy*, 28(1), 11-35.

Henderson, Jeffrey (1989), *The Globalisation of High Technology Production*, London: Routledge.

Herbst-Bayliss, Svea and Nellis, Stephen (2020), 'Exclusive: Hedge fund Third Point urges Intel to explore deal options', *Reuters*, 30 December 2020, https://www.reuters.com/article/uk-intel-thirdpoint-exclusive-idINKBN2931PW, accessed on 6 April 2023.

Hobday, Michael, Rush, Howard and Bessant, John (2004), 'Approaching the innovation frontier in Korea: The transition phase to leadership', *Research Policy*, 33(10), 1433–1457.

Hodiak, Justin and Harold, Scott W. (2020), 'Can China become the world leader in semiconductors?', *The Diplomat*, September 25 2020, https://thediplomat.com/2020/09/can-china-become-the-world-leader-in-semiconductors, accessed on 10 May 2023.

Huggins, Robert, Johnston, Andrew, Munday, Max and Xu, Chen (2023), 'Competition, open innovation, and growth challenges in the semiconductor industry: the case of Europe's clusters', *Science and Public Policy*, scad005, https://doi.org/10.1093/scipol/scad005

IC Insights (2022), 'Chinese companies hold only 4% of global IC marketshare', *IC Insights Research Bulletin*, 5 April 2022, https://www.icinsights.com/data/articles/documents/1444.pdf, accessed on 10 October 2022.

J.P. Morgan (2022), *Supply Chain Issues and Autos: When Will the Chip Shortage End?*, Global Research Reports, 18 April 2023, https://www.jpmorgan.com/insights/research/supply-chain-chip-shortage, accessed on 10 May 2023.

Kenney, Martin (2011), 'How venture capital became a component of the US national system of innovation', *Industrial and Corporate Change*, 20(6), 1677-1723.

Khan, Saif, Mann, Alexander and Peterson, Dahlia (2021), *The Semiconductor Supply Chain: Assessing National Competitiveness*, Center for Security and Emerging Technology 8 (8). https://doi.org/10.51593/20190016

Kleinhans, Jan-Peter and Baisakova, Nurzat (2020), *The Global Semiconductor Value Chain: A Technology Primer for Policy Makers*, Berlin: Stiftung Neue Verantwortung.

Langlois, Richard N. (2003), 'The vanishing hand: the changing dynamics of industrial capitalism', *Industrial and Corporate Change*, 12(2), 351–385.

Langlois, Richard N., Pugel, Thomas A., Haklisch, Carmela S., Nelson, Richard R. and Egelhoff, William G. (1988), *Micro-Electronics: An Industry in Transition*, Boston: Unwin Hyman.

LaPedus, Mark (2021), 'End in sight for chip shortages?', *Semiconductor Engineering*, 18 November 2021, https://semiengineering.com/end-in-sight-for-chip-shortages/, accessed on 10 May 2023.

Lee, Keun (2019), *The Art of Economic Catch-Up: Barriers, Detours and Leapfrogging in Innovation Systems*, Cambridge: Cambridge University Press.

Lincicome, Scott and Zhu, Huan (2021), Questioning Industrial Policy: Why Government Manufacturing Plans Are Ineffective and Unnecessary, White Paper 2021, Washington, DC: Cato Institute. https://ssrn.com/abstract=3965762

Lund, Susan, Manyika, James, Woetzel, Jonathan, *et al*. (2020), *Risk, Resilience, and Rebalancing in Global Value Chains*, McKinsey Global Institute.

Luo, Yadong (2022), 'Illusions of techno-nationalism', *Journal of International Business Studies*, 53, 550-567.

Manyika, James, McRaven, William H, and Segal, Adam (2019), *Innovation and National Security: Keeping Our Edge*, Council on Foreign Relations Report No. 77, https://www.cfr.org/report/keeping-our-edge/pdf/TFR_Innovation_Strategy.pdf, accessed on 10 May 2023.

Mathews, John A. and Cho, Dong-Sung (2000), *Tiger Technology: The Creation of A Semiconductor Industry in East Asia*, Cambridge: Cambridge University Press.

Ministry of Commerce of the PRC (2023), *Announcement on Export Controls on Gallium and Germanium Related Items*, http://www.mofcom.gov.cn/article/zwgk/gkzcfb/202307/20230703419666.shtml, in Chinese, accessed on 19 July 2023.

Nelson, R.R. and Ostry, S. (1995), *Techno-nationalism and Techno-globalism*, Washington DC: The Brookings Institution.

Nenni, Daniel and McLellan, Paul (2019), *Fabless: The Transformation of the Semiconductor Industry*, SemiWiki.com Project.

Ning, Lutao (2009), *China's Rise in the World ICT Industry: Industrial Strategies and the Catch-Up Development Model*, London: Routledge.

Pettit, Timothy J., Fiksel, Joseph and Croxton, Keely L. (2010), 'Ensuring supply chain resilience: development of a conceptual framework,' *Journal of Business Logistics*, 31(1), 1-20.

O'Mara, Margaret (2019), *The Code: Silicon Valley and the Remaking of America*, New York: Penguin.

Olcott, Eleanor and Sevastopulo, Demetri (2023), 'China bans Micron's products from key infrastructure over security risk', *Financial Times*, 22 May, https://www.ft.com.

Reich, Robert (1987), 'The rise of techno-nationalism', *The Atlantic Monthly*, 259, 63-69.

Rodrik, Dani (2008), *Industry Policy for the Twenty-First Century*, Working Paper 4767, Harvard Kennedy School, Harvard University.

Saxenian, AnnaLee (1994), *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Cambridge, MA: Harvard University Press.

Saxenian, AnnaLee (2006), *The New Argonauts: Regional Advantage in a Global Economy*, Cambridge, MA: Harvard University Press.

SEMI (2022a), *2021 Global Semiconductor Equipment Sales Surge 44% To Industry Record $102.6 Billion*, SEMI Reports. https://www.semi.org/en/news-media-press-releases/semi-press-releases/2021-global-semiconductor-equipment-sales-surge-44%25-to-industry-record-%24102.6-billion-semi-reports

SEMI (2022b), 'Global chip industry projected to invest more than $500 billion in new factories by 2024, SEMI Reports', *SEMI Press Releases*, 12 Dec 2022, https://www.semi.org/en/news-media-press-releases/semi-press-releases/global-chip-industry-projected-to-invest-more-than-%24500-billion-in-new-factories-by-2024-semi-reports, accessed on 10 May 2023.

SIA (2016), *Beyond Borders: How an Interconnected Industry Promotes Innovation and Growth*, Semiconductor Industry Association, https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf

SIA (2021), *2020 State of the U.S. Semiconductor Industry*, Semiconductor Industry Association, https://www.semiconductors.org/wp-content/uploads/2020/07/2020-SIA-State-of-the-Industry-Report-FINAL-1.pdf

SIA (2023), *2022 State of the U.S. Semiconductor Industry*, Semiconductor Industry Association https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf

Spence, Michael (2023), 'In defense of industrial policy', *Project Syndicate*, 5 May 2023. https://www.project-syndicate.org/commentary/industrial-policy-us-chips-and-science-act-debate-by-michael-spence-2023-05

Suleman, Areef and Yagci, Mustafa (2022a), *The Impact of Sanctions on Global Value Chains*, Background Paper for the Workshop on "*Global Value Chain Development Report 2023*: Resilient and Sustainable GVCs in Turbulent Times", Geneva: World Trade Organization.

Suleman, Areef and Yagci, Mustafa (2022b), *The Rising Role of the State in the Governance of Global Value Chains*, Background Paper for the Workshop on "*Global Value Chain Development Report 2023*: Resilient and Sustainable GVCs in Turbulent Times", Geneva: World Trade Organization.

Sullivan, Jake (2022), *Remarks by National Security Advisor Jake Sullivan on the Biden-Harris Administration's National Security Strategy*, The White House, 10 October 2022, https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/10/13/remarks-by-national-security-advisor-jake-sullivan-on-the-biden-harris-administrations-national-security-strategy/, accessed on 10 May 2023.

TrendForce (2022b), 'New US EDA software ban may affect China's advanced IC design, says TrendForce', 15 August 2022, https://www.trendforce.com/presscenter/news/20220815-11338.html, accessed on 10 May 2023.

Tyson, Laura D'Andrea (1993), *Who's Bashing Whom? Trade Conflicts in High-Technology Industries*, Washington, DC: Institute for International Economics.

VerWey, J. (2019), 'Chinese semiconductor industrial policy: past and present', *Journal of International Commerce and Econ*omics, 1.

Weiss, Linda (2014), *America Inc.? Innovation and Enterprise in the National Security State*, Ithaca, NY: Cornell University Press.

White House (2021), *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-based Growth: 100-day Reviews Under Executive Order 14017*, DC: White House.

Xing, Yuqing (2021), *Decoding China's Export Miracle: A Global Value Chain Analysis*, Singapore: World Scientific.

Yap, Xiao-Shan and Rasiah, Rajah (2017), *Catching Up and Leapfrogging: The New Latecomers in the Integrated Circuits Industry*, New York: Routledge.

Yeung, Henry Wai-chung (2016), *Strategic Coupling: East Asian Industrial Transformation in the New Global Economy*, Cornell Studies in Political Economy Series, Ithaca, NY: Cornell University Press.

Yeung, Henry Wai-chung (2022a), *Interconnected Worlds: Global Electronics and Production Networks in East Asia*, Innovation and Technology in the World Economy Series, Stanford, CA: Stanford University Press.

Yeung, Henry Wai-chung (2022b), 'Explaining geographic shifts of chip making toward East Asia: market dynamics in semiconductor global production networks', *Economic Geography*, 98(3), 272-298.

Zhen, Liu (2023), 'China curbs critical metal exports in retaliation for Western restrictions on chip industry', *SCMP*, 3 July, https://www.scmp.com.

5

Tracing Carbon Dioxide Emissions along Global Value Chains

Bo Meng, Ran Wang, Meng Li

The rise of global value chains (GVCs), which are regarded as one of the most important features of the 21st century economic globalization (Baldwin, 2013, WTO-IDE, 2011, Antràs and de Gortari, 2020), has not only enabled global firms to achieve greater economic efficiency (Bloom et al., 2012, Melitz and Trefler, 2012), but also helped both the developed and developing economies to utilize their comparative advantages and gain value-added, income and job opportunities (Gereffi and Fernandez-Stark, 2016, Meng et al., 2020, Meng and Ye, 2022). However, along with value creation through global production sharing, GVCs have also generated or are associated with massive greenhouse gas emissions and pollution at energy-intensive production stages in different countries as a by-product (Meng et al., 2023). Moreover, the increasing complexity and uncertainty of GVCs, characterized by multiple and frequent cross-border trades in intermediates and foreign direct investment (FDI), have made it difficult to understand "who emits emissions for whom," thus posing great challenges to designing environmental policies (including domestic and international regulation, taxation, carbon pricing etc.) that enable countries, industries, and firms to clearly identify their climate change responsibilities.

Identifying each country's responsibility for carbon dioxide (CO_2) emissions is essential for effective international cooperation to address climate change. Countries will have little incentive to bear the costs of emissions reductions if there is no sense that they are contributing to a global movement that has the potential for achieving climate goals. And ensuring a general perception that the allocation of emission reductions across countries corresponds to responsibility for the production of emissions will be an important element in achieving international consensus on a green agenda.

This chapter presents a unified accounting framework for tracing CO_2 emissions along GVCs at country, sector, and bilateral levels, which can be used to better understand the emission responsibilities of GVC participants in various roles, such as producers,

consumers, exporters, importers, investors, and investees. We then demonstrate how this framework can provide useful insights for improving environmental policy design, climate change negotiation and green GVC governance, so that those benefiting from productive activities that generate emissions can bear a more appropriate share of the costs of emissions reductions. Our main findings include 1) Since 2001, developing economies have doubled their CO_2 emissions from purely domestic value chains that serve their own final demands. These emissions are now about twice as large as those of developed economies. Given that GVCs are rooted in domestic sources, it is imperative to curb these emissions with more effective tools, such as environmental regulation, taxation, and the introduction of carbon trading schemes domestically. By greening their domestic production, developing economies can also green their exports via GVCs. 2) The carbon intensity of GVCs has decreased in both developed and developing economies between 1995 and 2021. However, creating GDP through international trade is still more carbon-intensive than doing that through purely domestic value chains. Therefore, it is important to introduce carbon pricing along GVCs to substantially raise the cost of emissions globally in the Paris Agreement era. 3) GVCs increase carbon leakage through both international trade and cross-border investment (e.g., FDI) channels. However, the current emission reduction targets do not explicitly and consistently account for the different roles and responsibilities of GVC actors, such as producers, consumers, exporters, importers, investors, and investees. This puts more burden on domestic firms than multinational enterprises (MNEs) for GVC-related emissions. Therefore, MNEs should play more active roles to fight climate change along their GVCs.

In the next section, we first provide an overview of the climate change challenges caused by the rapid increase of CO_2 emissions and show how difficult it will be to achieve carbon neutrality targets in the coming 2-3 decades. In section 3, we introduce the accounting framework according to the traditional territory-based approach for tracing both CO_2 emissions and value-added along GVCs upstream and downstream at country, sector, and bilateral levels. Based on this framework, we have developed a new methodology to identify both self- and shared emission responsibilities at the country level and applied it to the real data. In section 4, we incorporate firm heterogeneity information into our accounting framework, in which we can distinguish the roles of MNEs and domestically owned firms when they generate and induce emissions along GVCs. In section 5, we further update the territorial-based emission accounting to firm-control-based accounting by using the concept of trade in factor income. This can help to better understand the relationship between emission responsibility and firm control in terms of MNEs' FDI activities. We conclude our chapter with some policy suggestions.

5.1 Historical CO_2 Emissions and Climate Change Challenges

Climate change is one of the most pressing challenges facing humanity in the 21st century. It poses significant risks to the environment, the economy, and human well-

being. This section first provides an intuitive image of the impacts of climate change due to increasing CO_2 emissions, using NASA's visualization figures. We then show the major economies' historical evolution of their emissions generation and how challenging it will be to achieve their carbon neutrality targets going forward.

5.2 Visible Impacts of Climate Change

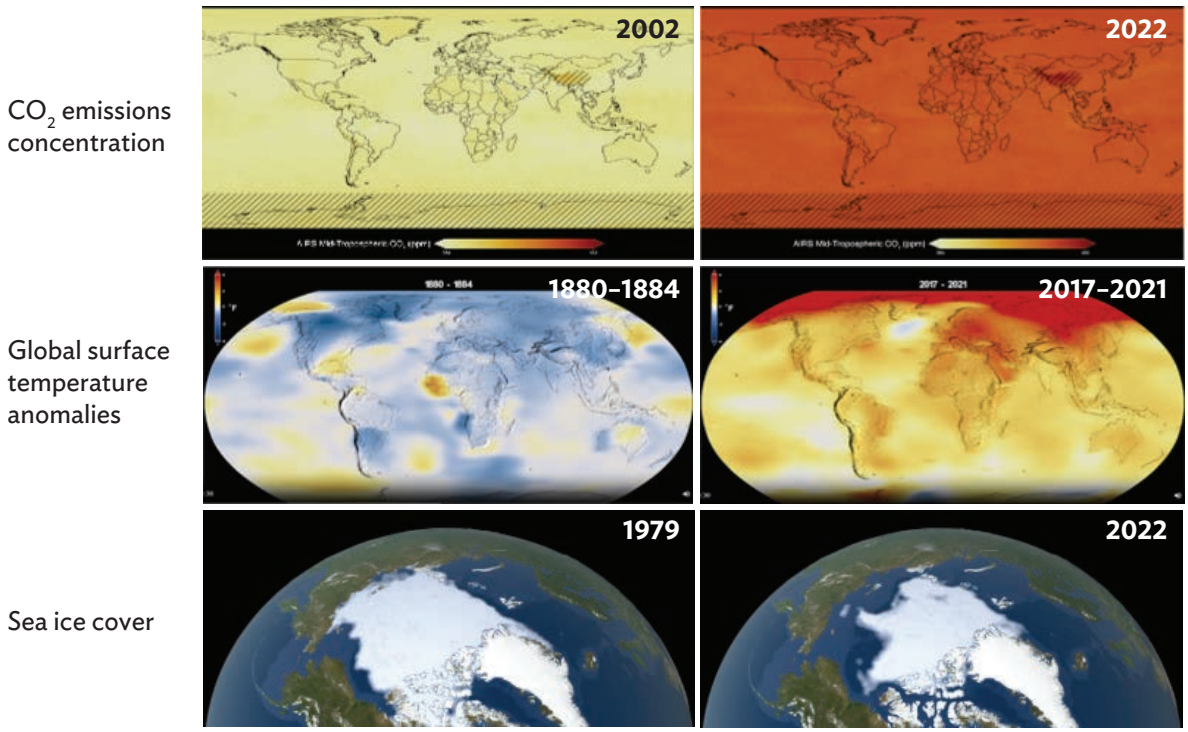
Figure 5.1 (based on the visualization tools by NASA) shows the significant and visible changes in CO_2 emissions concentration, temperature, and sea ice cover. The upper panel in this figure presents the global changes in the concentration and distribution of CO_2 emissions between 2002 and 2022 at an altitude range of 1.9 to 8 miles. The yellow-to-red regions indicate higher concentrations of CO_2 emissions, while blue-to-green areas indicate lower concentrations, measured in parts per million. A clear upward trend can be easily observed, and indeed, there's more carbon dioxide in the atmosphere now than at any other time in at least 650,000 years (Hopkin, 2005, Lüthi et al., 2008). The middle panel of the same figure (the color-coded map) shows the progression of changing global surface temperature anomalies between 1880-1884 and 2017-2021. Higher and lower than normal temperatures (normal temperatures are shown in white and are calculated over the 30-year baseline period 1951-1980) are shown in red and blue respectively. A remarkable change in color can be easily seen. In fact, the average global temperature on Earth has increased by at least 1.1° Celsius (1.9° Fahrenheit) since 1880, and the majority of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20°C per decade (GISS-NASA, 2023). In addition, significant changes have also been observed for sea ice cover. The bottom panel in Figure 5.1 shows the annual Arctic Sea ice minimum between 1979 and 2022. At the end of each summer, the sea ice cover reaches its minimum extent, leaving what is called the perennial ice cover. The area of the perennial ice has been steadily decreasing since the satellite record began in 1979, falling by 12.6 percent per decade compared to its average extent during the period from 1981 to 2010.

5.3 Historical CO_2 Emissions and Challenges Towards the Achievement of Carbon Neutrality

Using the above NASA's visualization, we can see how the impacts of climate change have progressed significantly over the years. One of the main sources of climate change is greenhouse gas emissions from fossil fuel combustion, in which CO_2 emissions account for the majority (more than 75%). Figure 5.2 shows the historical evolution of CO_2 emissions generated by both advanced and emerging large economies from 1830 to 2021, and the carbon neutrality targets announced by those countries (up to 2070).

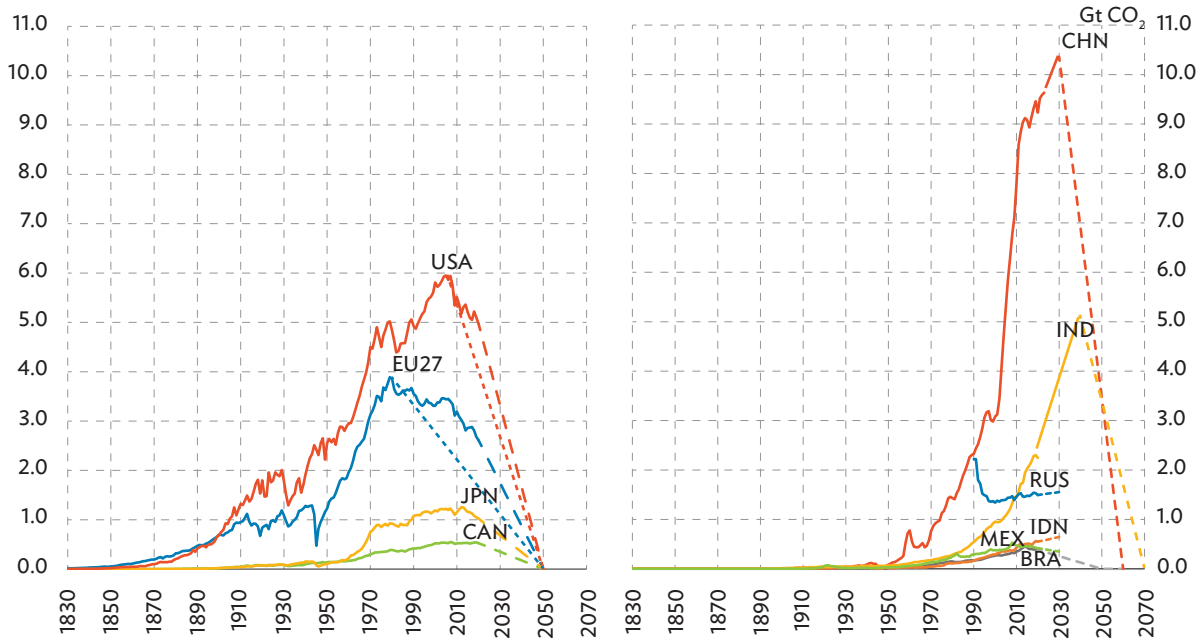
Obviously, the United States (US) is the largest emitter followed by the EU27, Japan, and Canada in the advanced economies group. Both the US and EU27 experienced a

Figure 5.1: Visualization of Climate Change Impacts



Source: NASA's Atmospheric Infrared Sounder (AIRS), GISS Surface Temperature Analysis (GISTEMP v4), and Scientific Visualization Studio (SVS)

Figure 5.2: Major Economies' Historical CO_2 Emissions from 1830 to 2021 and their Targeting Years for Carbon Neutrality

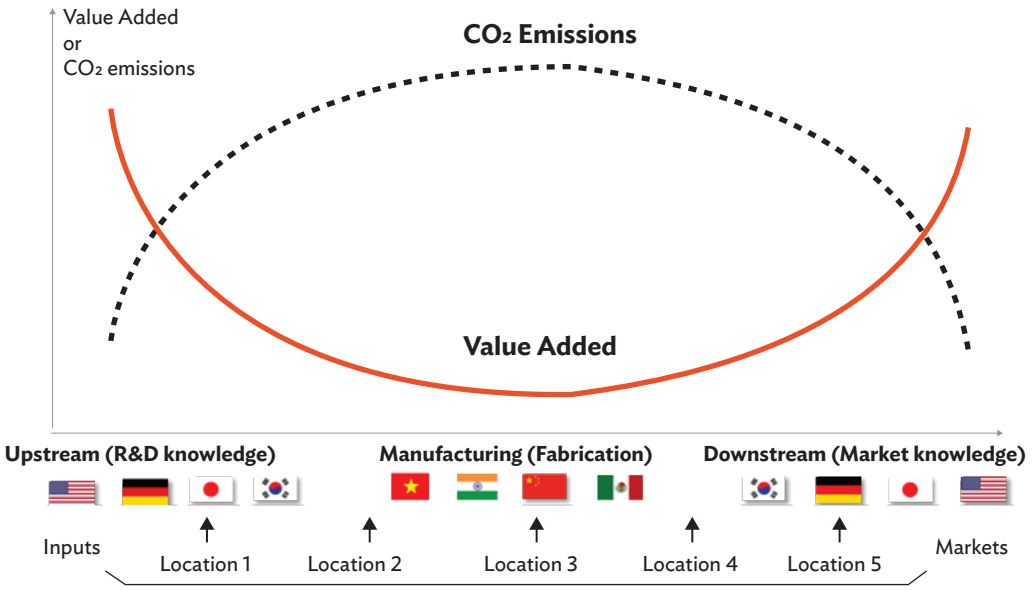


Note: The historical CO_2 emissions data is from the PRIMAP-hist national historical emissions time series (see Gütschow et al., 2016). The climate targets of countries are gathered from the Climate Action Tracker (https://climateactiontracker.org).

significant increase in their CO_2 emissions after World War II up to 1980. The main difference between the US and EU27 is that emissions by the EU27 peaked in 1980 and declined gradually afterwards, while the US' emissions continued to increase for about 25 years after 1980 and peaked at around 2008. The rapid increase in Japan's CO_2 emissions accompanied its economic takeoff between 1960 and 1970. Similar to the pattern of the US but with a relatively lower increasing tendency, Japan experienced an emission increase after 1980, and emissions peaked in 2012. From a historical perspective, the accumulated CO_2 emissions generated by the advanced economies from the Industrial Revolution to World War II account for only a small portion (about 20%) of their total accumulated emissions (more than 80% of their emissions happened after World War II). Compared to the changing pattern of advanced economies' CO_2 emissions, in the emerging economies group, the People's Republic of China (PRC) dominated the emissions with a much steeper increase after its WTO accession in 2001, followed by India which also experienced a rapid increase in emissions after 2000. The common feature of the PRC and India's rapid emission increase is that it accompanied these two countries' active participation in GVCs as important production centers and hubs of the so-called Factory Asia.

The major challenge ahead in fighting against climate change is about how to reduce CO_2 emissions. The advanced economies group in Figure 5.2 has committed to achieve carbon neutrality (net zero carbon) by the end of 2050. On the other hand, the two largest emerging countries, the PRC, and India, aim to reach carbon neutrality in 2060 and 2070 respectively. Assuming advanced economies follow a linear trend in emissions from now on to reach net carbon zero by 2050, we can observe the speed of the decline in emissions required by the slope of the dotted lines linking their current emissions level and their 2050 net zero targets. By this metric, the US is facing the most difficult challenge, followed by EU27. Japan and Canada have been relatively low-carbon societies, thus the reduction in emissions required to achieve carbon neutrality is less than in the US and EU27, marginally less effort is needed. In addition, if the US and EU27 had taken more actions much earlier starting from their peak carbon years (thinner dotted lines), their path to achieving carbon neutrality might be easier. On the other hand, for the emerging economies, especially for the PRC and India, their CO_2 emissions will keep increasing until they reach a future peak, which poses more challenges. Assuming the PRC can achieve its pledge to reach peak CO_2 emissions in 2030, reaching net zero carbon by 2060 will be a tough mission, since the slope of the dotted reduction line is very steep. Other emerging economies, such as India, will also face difficult challenges. If India follows the same increasing tendency of CO_2 emissions as the PRC has done and reaches peak emissions 10 years later than the PRC, achieving carbon neutrality by 2070 would require a very large, rapid reduction in emissions. Even if India can achieve the same level of industrialization with half the peaking level of the PRC's CO_2 emissions in 2040, for example due to the diffusion or spillover of green technologies, achieving carbon neutrality in 2070 will still require great efforts.

Figure 5.3: Smile Curve of Value-Added vs Crying Curve of CO_2 Emissions along GVCs



Source: designed by the authors based on the discussion with Yuqing Xing.

It should be noted that emissions shown in Figure 5.2 are territory-based emissions, which does not necessarily imply that the country that generates emissions should be 100 percent responsible for those emissions. This is mainly because emissions that happen in a country might be due to the production meeting other countries' final demand via complex routes of international trade and investment in the era of GVCs. In other words, given the fact that there is no commonly accepted global carbon price, the market mechanism cannot be used to solve all the problems of carbon leakage that happens via international trade and investment, as discussed by the so-called "Pollution Haven" and "Race to the Bottom"[1] hypotheses related literature (Copeland and Taylor, 1994, Taylor, 2005, Xing and Kolstad, 2002, Konisky, 2007, Bu and Wagner, 2016, Avendano et al., 2023). More importantly, as shown in Figure 5.3, the GVC strategy allows MNEs to separate headquarters and factory functions (the so-called "second unbundling" (Baldwin, 2013)), which has resulted in an asymmetric distribution of value added and carbon emissions along GVCs. Specifically, countries specializing in low value-added tasks such as manufacturing and assembling are burdened with high carbon emissions, while countries engaging in R&D and marketing capture more value added but bear less carbon emissions. For example, about 70% of Apple's total carbon footprint is generated in the manufacturing process (Apple, 2022), which is located outside of the United States, but the manufacturing process is indispensable for Apple to realize the value of its brand, software and other intangible assets, and Apple gains the largest share of the value added of the products manufactured by its foreign contract

[1] The origins of the phrase race to the bottom are often traced to U.S. Supreme Court Justice Louis Brandeis in his dissenting opinion in Liggatt v Lee where he describes how firms were formed in U.S. "states where the cost was lowest and the laws least restrictive" which led to a race "not of diligence but of laxity" (Louis K. Liggett CO v. Lee, 288 U.S. 517, 1933).

makers. Developing countries participating in GVCs generally specialize in low value-added tasks with relatively high carbon emissions. To a certain extent, the increase in the carbon emissions of developing countries is attributed to the proliferation of GVCs in the last decades. A crucial issue for addressing climate change is how to help developing economies, which have been part of GVCs dominated by MNEs, and also the major generators of CO_2 emissions from now on but have relatively less advanced emissions reduction technologies and weaker regulations and face great challenges of economic development and poverty reduction, to be essentially and actively involved in the global action of emissions mitigation in the era of GVCs.

5.4 CO_2 Emissions and Their Responsibilities along Global Value Chains

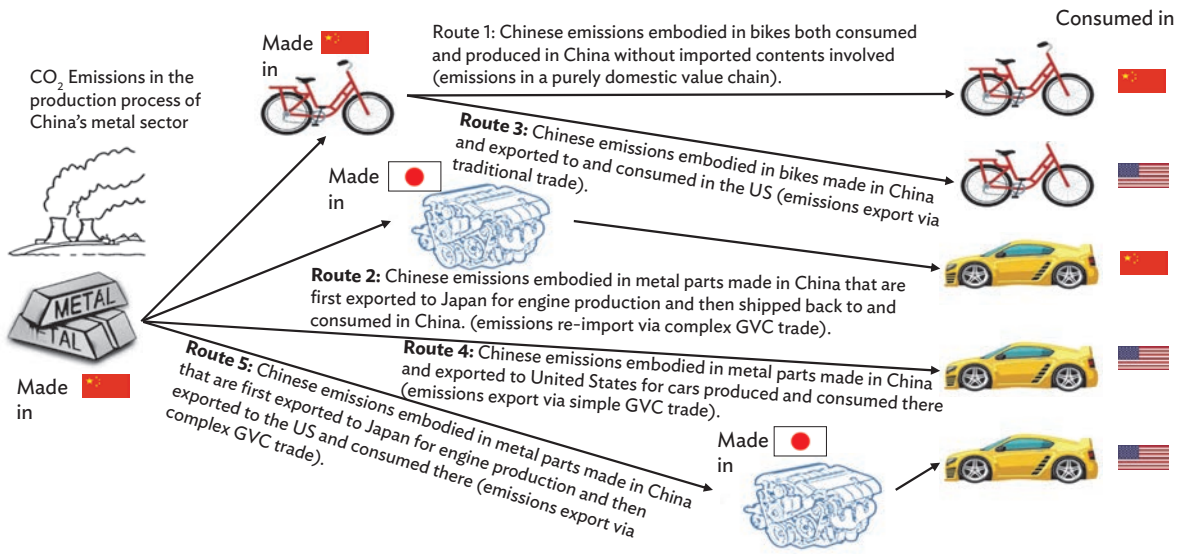
CO_2 emissions happen along GVCs, which involve both domestic and international segments of complex production networks. Before the policy-oriented discussion about emission responsibilities and how to reduce emissions along GVCs, we need to have a clear picture of the creation, transfer, and absorption of emissions along GVCs. This requires building a consistent and systematic account to trace emissions at country, sector, and bilateral levels. This section first introduces a GVC-based emission tracing system and proposes a way to share emission responsibilities between producers and consumers along GVCs.

5.5 Tracing CO_2 Emissions in Global Value Chains

Regarding the connection between international trade and emissions, a large body of literature has explored the concept of both production-based (or territory-based) and consumption-based accounting (Peters, 2008, Hoekstra and Wiedmann, 2014, Kander et al., 2016). Similar applications can be found in relation to numerous environmental issues, including climate change, energy use, air pollution, material use, land use, biomass, water quality, and biodiversity (Wiedmann, 2009, Tukker and Dietzenbacher, 2013). This accounting has considerable methodological and conceptual overlap with studies on "trade in value-added" in relation to GVCs (Johnson and Noguera, 2012, Koopman et al., 2014, Timmer et al., 2014). Using a multiregional input–output (MRIO) model, Meng et al. (2018) consistently link these two independent lines of research in the context of both climate change and GVCs. The main advantage of their accounting is that it can trace both emissions and value-added at each stage from the perspectives of production, consumption, and trade. In their accounting, international trade-related emissions are further divided into traditional trade (i.e., classical Ricardian-type trade such as "French wine in exchange for English cloth," in which there is no international production-sharing), simple GVC trade (in which factor contents cross national borders once), and complex GVC trade (in which factor contents cross national borders more than once). In addition, using this framework, we can clearly distinguish self-responsibility-based emissions (that is, emissions generated in a purely domestic value chain for domestic final use that does not involve international trade).

The accounting framework used in this Chapter mainly follows Meng et al. (2018). As illustrated in Figure 5.4, the logic behind this framework is that a country or sector's production-based emissions are both directly and indirectly embodied in all downstream countries and sectors via numerous value chain routes and are eventually absorbed by domestic or foreign final demand (tracing emissions from upstream to downstream). In turn, the production of any specific final product induces emissions of direct and indirect intermediates suppliers upstream, in this sense, emissions can also be traced from downstream to upstream in the same accounting framework (in theory, they can be defined as consumption-based emissions). To facilitate the analysis of complex trade flows, which might cross multiple borders multiple times, we divide trade into five routes, as shown in Figure 5.4.

Figure 5.4: GVC-Based Accounting Framework for Tracing Emissions



Source: Meng et al. (2023)

Emissions along Route 1 are generated through the creation of a country's gross domestic product (GDP) to satisfy the country's final demand for domestically produced goods and services (i.e., a purely domestic value chain). In this case, the country has "self-responsibility" for these emissions. Emissions along Route 2 are generated and absorbed solely within a country, but also involve international trade in which factor contents cross national borders more than once, and thus belong to the category of re-imported emissions via complex GVC trade. Emissions along Routes 3, 4, and 5 refer to emissions exports via traditional trade, simple GVC trade, and complex GVC trade, respectively. The sum of emissions along Routes 2, 3, 4, and 5 in each bilateral trade yields emissions embodied in bilateral trade (EEBT, which is consistent with the definition proposed by Peters, 2008). Therefore, our GVC-based accounting approach consistently integrates existing production-based emissions, consumption-based emissions, emissions exports, emissions imports, emissions re-imports, and EEBT

under a single unified framework. Emissions from direct household combustion are not included in the above framework because they do not belong to the production process involved in the creation of GDP, but rather are simply considered part of the consuming country's self-responsibility-based emissions.

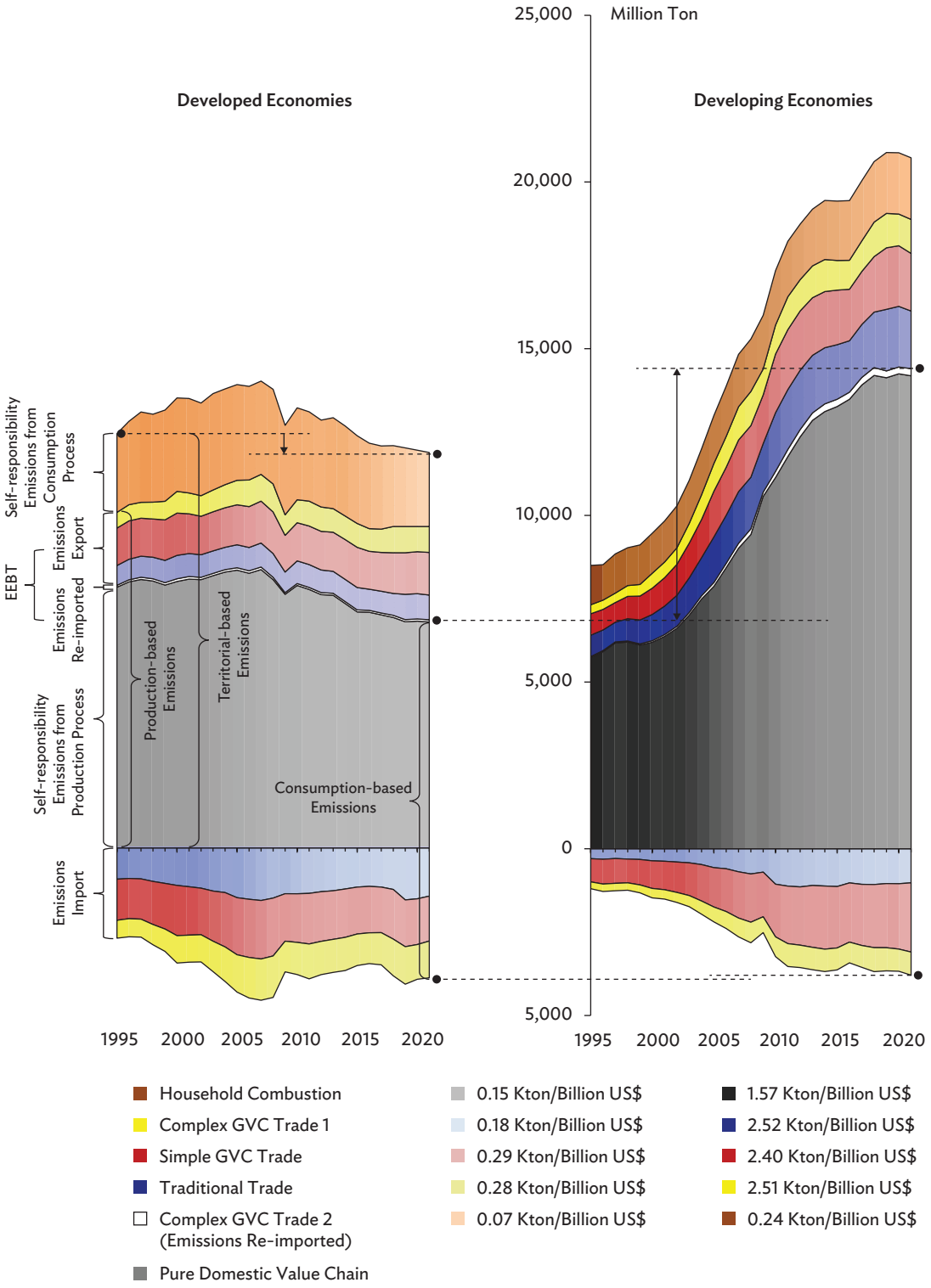
5.6 Production- vs Consumption-Based Emissions and Emissions Transfers along GVCs

By applying the above accounting framework to the long time series MRIO data (combined from the World Input–Output Database, and Asian Development Bank's Multiregional Input–Output Tables), we estimate production-based and consumption-based emissions from 1995 to 2021 for both developed and developing economies, and demonstrate how the international transfer of emissions occurs through various routes with different carbon intensities (e.g., emissions per USD of GDP created at 2015 constant prices).

Figure 5.5 shows that territorial-based CO_2 emissions by developed economies increased gradually during the period 1995–2007 (peaking in 2007), showing clear declines after 2008, and reached 11.9 Gt in 2021, which was already lower than the 1995 level of 12.4 Gt. During this period, emissions exports for the purpose of satisfying foreign final demand were the main driving force of the increasing trend from 1995 to 2007, self-responsibility-based emissions generated by the production process were the main driver leading the decreasing trend during the period 2008–2021, and self-responsibility-based emissions generated through individual household combustion were relatively stable over the entire period for both economy groups. It should be noted that developed economies' emission exports after 2018 showed a slight increasing tendency. Consumption-based emissions by developed countries increased during the period 1995–2007 as a result of rising emissions imports and decreased during the period 2008–2018, mainly because of a decrease in self-responsibility-based emissions from production processes. Developed economies' emission imports, especially via traditional trade routes rebounded again showing increasing trends after 2018. This evolution is likely due to several reasons; increased final goods imports, especially from the PRC during the COVID-19 pandemic, is one.

Developing economies showed larger increases in both self-responsibility-based emissions and emissions export and import than developed countries did. Self-responsibility-based emissions from production, production-based emissions, and territorial-based emissions by developing economies during the period 2004–2018 largely exceeded the peak levels in developed countries that occurred in 2007. Furthermore, developing economies' self-responsibility-based emissions from production processes were 2.1 times larger than those of developed countries in 2021. On a positive note, this trend shows a clear decline after 2019, but it remains to be seen whether it will continue, given the mixed factors behind this phenomenon, such

Figure 5.5: Developed and Developing Economies' CO_2 Emissions along GVCs.



Note: The colors in the figure show the emissions from different types of trade routes. Black means emissions from pure domestic value chains. Blue means emissions from traditional trade of final goods. Red means emissions from simple GVC trade, where intermediate goods cross borders once. Yellow means emissions from complex GVC trade, where intermediate goods cross borders multiple times. White means emissions from complex GVC trade that involves re-importing emissions to the country of origin. The darker the color, the higher the carbon intensity (emissions per USD of GDP at 2015 constant prices).

Source: authors' estimation based on Meng et al. (2023).

as the impacts of COVID-19 and geopolitical risks. Meanwhile, developing economies' imported emissions showed significant increasing trends and were very close to the level of developed countries in 2021. Looking at the structure of increasing emissions trade based on different GVC routes for developing economies, their emissions exports and imports increased about 3.0 and 3.3 times respectively between 1995 and 2021, with GVC trade-related emissions accounting for the majority (for emission exports, it was 63.2%, for emission imports, it was 74.5%).

The main information about carbon intensity and its evolution shown in Figure 5.5 can be summarized as follows. Carbon intensity shows a decreasing trend in both developed and developing economies via all routes between 1995 and 2021. However, the carbon intensity of developing economies in 2021 remained much higher than that of developed countries. In addition, the ever-increasing territorial-based emissions in developing economies imply that the decrease in carbon intensity in these countries did not offset the increased emissions, probably because of rapid economic and population growth (Peters et al., 2007).

5.7 Sharing CO_2 Emissions Responsibilities Across Economies along Global Value Chains

Currently, the Paris Agreement is focused on territorial-based emissions (which are easy to monitor), while consumption-based emissions are used as a reference point in designing possible transnational financial support mechanisms to enable developed countries to help developing economies reduce their emissions. Unfortunately, neither territorial- nor consumption-based accounting (both of which allocate full responsibility to either the producers or the consumers) provides sufficient incentive for countries to pursue emissions reduction efforts because of a lack of consensus regarding responsibility sharing. Although several pioneering studies have discussed the topic of producers and consumers sharing responsibility for emissions (e.g., Kondo et al., 1998, Bastianoni et al., 2004, Lenzen et al., 2007, Andrew and Forgie, 2008, Cadarso et al., 2012, Dietzenbacher et al., 2020), two problems still need to be addressed. One is how to identify a country's self-responsibility for emissions. Without an accurate measure, we are unable to even determine the amount of emissions for which responsibility should be shared among the various related parties. The other problem is how to determine the appropriate weights to enable proper distribution of responsibility for emissions among the various producers and consumers along GVCs.

As previously shown, self-responsibility-based emissions in relation to the production processes can be identified by using IO based decomposition method to separate GVCs into pure domestic and international segments, while self-responsibility-based emissions in relation to the direct household combustion processes can be directly defined. Thus, the remaining issue is how to allocate responsibility for CO_2 emissions transfers among various producers and consumers along GVCs. Here, we introduce a

new method to estimate carbon leakage, which is the bilateral transfer of embodied emissions in trade (a narrow definition) from both producers' and consumers' perspectives based on the following logic. First, if a country wants to maintain its current final demand level in relation to domestically produced goods and services in monetary terms (keeping the same amount of spending of final demand in USD) under a no-trade (NT) scenario (i.e., a form of economic self-sufficiency or autarky), its emissions are defined as NT emissions. Under this NT scenario, it is self-evident that a country's production-based emissions are equal to its consumption-based emissions at the country level. Thus, the difference between the actual production-based emissions and NT emissions can be defined as production-based carbon leakage, and the difference between the actual consumption-based emissions and NT emissions can be defined as consumption-based carbon leakage. This could be a new way to measure "avoided emissions" (emissions savings that occur outside a company's value chain) based on the GHG Protocol for Project Accounting (Greenhouse Gas Protocol, 2011, Rocchi et al., 2018).

Given this narrow definition of carbon leakage from both the production and consumption sides, we can then develop two kinds of ratios to measure emissions responsibility. One is the ratio of production-based carbon leakage to total carbon leakage (production-based carbon leakage + consumption-based carbon leakage) for a specific country. This is used to measure the relative importance of a country's carbon leakage as both a producer and a consumer (i.e., a form of horizontal comparison). The other is the ratio of a country's production-based carbon leakage to global production-based carbon leakage. This is used to measure the importance of a specific country in relation to global production-based carbon leakage (i.e., a form of vertical comparison). These ratios can also be applied to consumption-based carbon leakage in the same manner. Because self-responsibility-based emissions from production processes can be measured using our accounting framework, the responsibility that should be shared from the production (or consumption) side can be defined as the difference between production-based emissions (or consumption-based emissions) and self-responsibility-based emissions. Finally, by simultaneously applying these two types of ratios (horizontally and vertically), a country's total responsibility as both a producer and a consumer can be estimated step-by-step based on our algorithm, which can be mathematically proven to be a convergent function when the steps iteratively approach infinity (conventional ways treat the importance of carbon leakage responsibilities from both the production-side and consumption-side equal, but in our method, they are considered different according to 1) the relative contribution of production-based leakage and consumption-based leakage inside a country, and 2) the relative contribution of each type of leakage compared to other countries' leakage level in the world. For detailed mathematical proof, see Meng et al., 2023).

Table 5.1 shows the results of shared global CO_2 emissions by producers and consumers for the 10 largest emitters in 2021. In the extreme case in which all responsibility for emissions transfers is assigned to producers, the PRC accounted for 32.6% of all emissions, followed by the US (13.5%). If all responsibility for emissions transfers is assigned to consumers, the PRC accounted for 29.2% of all emissions, followed by the US (16.7%). On the basis of our shared-responsibility model, the PRC accounted for 31.4% of all emissions, followed by the US (16.1%). In total, developing economies' share of responsibility for emissions has exceeded that of developed countries since 2012. Looking at the shared responsibility for emissions transfer by route, obviously GVC trade accounts for the majority (69.0%, of which 42.9% was from simple GVC trade and 26.1% was from complex GVC trade). Developed and developing economies' shares of responsibility for global emissions for the period 1995–2021 were 45.9% and 54.1%, respectively, whereas at the country level, the PRC's share of responsibility (24.9%) was greater than that of the US (19.6%), India (5.3%), Russia (5.1%), Japan (4.8%), and Germany (2.8%). The above result clearly differs from the results obtained using existing methods, which assign responsibilities based on either a linear combination of production-based and consumption-based emissions (Kondo et al. 1998), or along the demand and supply chains based on the production process (Lenzen et al., 2007) with a weight by value-added gain, or the volume of emissions that are saved globally because of trade (Dietzenbacher et al., 2020). Our purpose is in line with those of the

Table 5.1: Sharing Emission Responsibilities along GVCs

Unit: $MtCO_2$	Producers take all responsibility for emission transfer (2021)	Consumers take all responsibility for emission transfer (2021)	Shared responsibility between producers and consumers (2021)	Shared responsibility for emission transfer by three trading routes (2021)				Total responsibility on 1995–2021 cumulative global emissions
				Total trade	Traditional Trade	Simple GVCtrade	Complex GVCtrade	
PRC	9424.2 (32.6%)	8458.8 (29.2%)	9092.7 (31.4%)	1744.2 (21.9%)	540.4 (6.8%)	749 (9.4%)	454.8 (5.7%)	161885.2 (24.9%)
United States	3912.2 (13.5%)	4845.4 (16.7%)	4649.4 (16.1%)	1156.2 (14.5%)	358.2 (4.5%)	496.5 (6.2%)	301.5 (3.8%)	127559.9 (19.6%)
India	2151.1 (7.4%)	2003.8 (6.9%)	2044.1 (7.1%)	333.4 (4.2%)	103.3 (1.3%)	143.2 (1.8%)	86.9 (1.1%)	34582.3 (5.3%)
Russia	1372.4 (4.7%)	905.6 (3.1%)	1321.9 (4.6%)	535 (6.7%)	165.8 (2.1%)	229.8 (2.9%)	139.5 (1.8%)	33347.1 (5.1%)
Japan	997.8 (3.4%)	1057 (3.7%)	993.7 (3.4%)	276.6 (3.5%)	85.7 (1.1%)	118.8 (1.5%)	72.1 (0.9%)	31222 (4.8%)
Germany	554.9 (1.9%)	692.2 (2.4%)	624 (2.2%)	312 (3.9%)	96.7(1.2%)	134 (1.7%)	81.4 (1.0%)	18479.1 (2.8%)
Indonesia	482.3 (1.7%)	485.4 (1.7%)	475.5 (1.6%)	83.1(1.0%)	25.7 (0.3%)	35.7 (0.4%)	21.7(0.3%)	8919.6 (1.4%)
Mexico	340.4 (1.2%)	349.8 (1.2%)	315.3 (1.1%)	103.2 (1.3%)	32 (0.4%)	44.3 (0.6%)	26.9 (0.3%)	8616.7 (1.3%)
Brazil	310.4 (1.1%)	326.7 (1.1%)	310.3 (1.1%)	92.6 (1.2%)	28.7 (0.4%)	39.8 (0.5%)	24.1 (0.3%)	7867.8 (1.2%)
United Kingdom	266 (0.9%)	439.4 (1.5%)	394.9 (1.4%)	213.5 (2.7%)	66.2 (0.8%)	91.7 (1.2%)	55.7 (0.7%)	12077.6 (1.9%)
RoW	9131.7 (31.6%)	9379.5 (32.4%)	8721.5 (30.1%)	3121.9 (39.2%)	967.2 (12.1%)	1340.6 (16.8%)	814.1 (10.2%)	205547.9 (31.6%)
World	28943.4 (100.0%)	28943.4 (100.0%)	28943.4 (100.0%)	7971.7 (100.0%)	2469.7 (31.0%)	3423.3 (42.9%)	2078.7 (26.1%)	650105.2 (100.0%)
Developed Countries	9651.4 (33.3%)	10749.4 (37.1%)	10530.4 (36.4%)	3746.3 (47.0%)	1160.6 (14.6%)	1608.8 (20.2%)	976.9 (12.3%)	298685.8 (45.9%)
Developing Countries	19292.1 (66.7%)	18194 (62.9%)	18413.1 (63.6%)	4225.4 (53.0%)	1309.1 (16.4%)	1814.5 (22.8%)	1101.8 (13.8%)	351419.5 (54.1%)

Source: authors' estimation based on Meng et al. (2023)

above-mentioned pioneering works, but our method (idea) goes further by explicitly considering the role of GVC-based emissions accounting. The inherent innovation of our method is that we assign responsibility to producers and consumers based on their contribution (using both horizontal and vertical weights) to GVC-based carbon leakage as defined by the difference between their emissions under the NT scenario (where by definition production-based emissions are equal to consumption-based emissions at the country level) and their actual production-based and consumption-based emissions. This makes our results systematically more reasonable.

5.8 Tracing CO_2 Emissions of Multinational Enterprises in Global Value Chains

Climate change is a global issue of great concern that is significantly impacted by MNEs (Pinkse and Kolk, 2012). MNEs, as organizers of GVCs, coordinate the global production division through cross-border trade and FDI (Wang et al., 2021). MNEs account for almost 80% of global trade (WorldBank, 2020) and exert an important impact on greenhouse gas emissions at the global and national levels (Zhu et al., 2022). The Paris Agreement requires its members to submit their nationally determined contributions (NDCs) to meet the 1.5 °C target (UNFCCC, 2015). Under production-based accounting principles, countries can transfer their own emissions to other countries through FDI. This undermines the mitigation efforts of the host country. Consequently, it is crucial to clarify the CO_2 emissions behaviors of MNEs and raise their mitigation incentive via effective policy design.

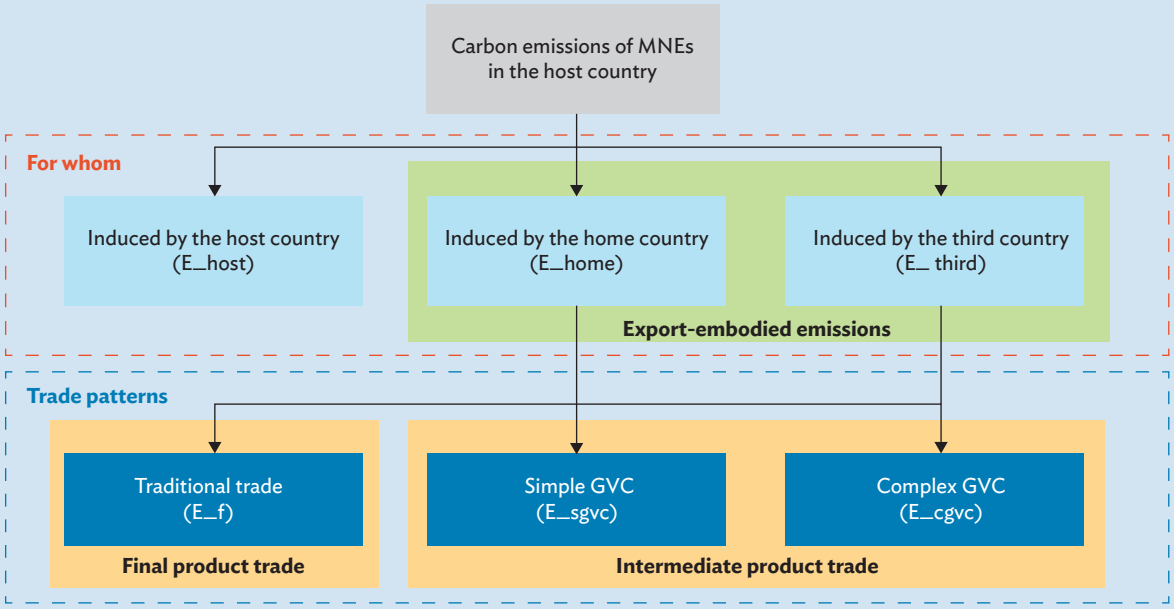
5.9 Measuring the CO_2 Emissions of MNEs in GVCs

The outward investment activities of MNEs involve not only the destination of the investment (host country) and the country of investment (home country), but the demand of third countries (countries that are neither host nor home countries) also triggers production behavior in the host country, inducing CO_2 emissions at the same time. This section therefore aims to answer the question of "MNEs emit CO_2 for whom" and to explore the reasons for the flow of MNEs' CO_2 emissions to different destinations, especially to third countries. In addition, this section also distinguishes the CO_2 emissions of MNEs embodied in different trade patterns.

Box 5.1: Accounting for CO_2 Emissions of MNEs in Global Value Chains

The figure illustrates an accounting framework that quantifies the CO_2 emissions of MNEs in GVCs, while distinguishing the destinations of CO_2 emissions and trade patterns.

CO_2 emission Accounting Framework of MNEs (GVC Forward Linkage-based Decomposition)



Source: authors' compilation based on Wang et al. (2017) and Yan et al. (2023d).

For MNEs producing in one country, the accounting framework can decompose their total CO_2 emissions into seven routes based on the GVC forward linkage as follows:
Route 1: The emissions of MNEs induced by the host country.
Route 2: The emissions of MNEs embodied in the final products exported to MNEs' home counties.
Route 3: The emissions of MNEs embodied in the intermediate products exported to and consumed in MNEs' home counties. In this process, MNEs participate in simple GVC activities.
Route 4: The emissions of MNEs embodied in the intermediate products exported to MNEs' home counties, and the home countries use these intermediate products to produce export products. In this process, MNEs participate in complex GVC activities.
Route 5: The emissions of MNEs embodied in the final products exported to a third country.[a]
Route 6: The emissions of MNEs embodied in the intermediate products exported to and consumed in a third country. In this process, MNEs participate in simple GVC activities.
Route 7: The emissions of MNEs embodied in the intermediate products exported to a third country, and the third country uses these intermediate products to produce export products. In this process, MNEs participate in complex GVC activities.
Route 2-7 could be regarded as the CO_2 emissions induced by foreign countries, in other words, the emissions embodied in MNEs' exports. Following different trade patterns, the emissions embodied in MNEs' exports could be decomposed into two parts: the emissions embodied in the final product trade and those embodied in the intermediate product trade. When considering the number of times that intermediate products cross borders, the emissions embodied in the intermediate product trade of MNEs could be further decomposed into the emissions embodied in simple GVC activities (the intermediate products crossing borders once for production) or complex GVC activities (the intermediate products crossing borders at least twice for production) (Wang et al., 2017).

This framework is operationalized using the Organisation for Economic Co-operation and Development's Analytical Activities of Multinational Enterprises (AMNE) database (Cadestin et al., 2018), which breaks down the sectors according to the shares of domestic- or foreign-owned firms.

[a] The third country in this paper represents "countries/regions other than the host country of MNEs and the home country of MNEs".

References

Cadestin C, de Backer K, Desnoyers-James I, Miroudot S, Rigo D, and Ye M. 2018. Multinational enterprises and global value chains: The OECD analytical AMNE database. OECD Trade Policy Papers. No. 211.
Wang Z, Wei S, Yu X, Zhu K. 2017. Measures of participation in global value chains and global business cycles. NBER Working Paper. No.23222.
Yan Y, Li X, Wang R, Zhou Y, Zhao Z. 2023d. Is there a "third-country effect" in global carbon emission transfer? New insights from multinational enterprises on the trade-investment nexus. GVC Development Report Background Paper.

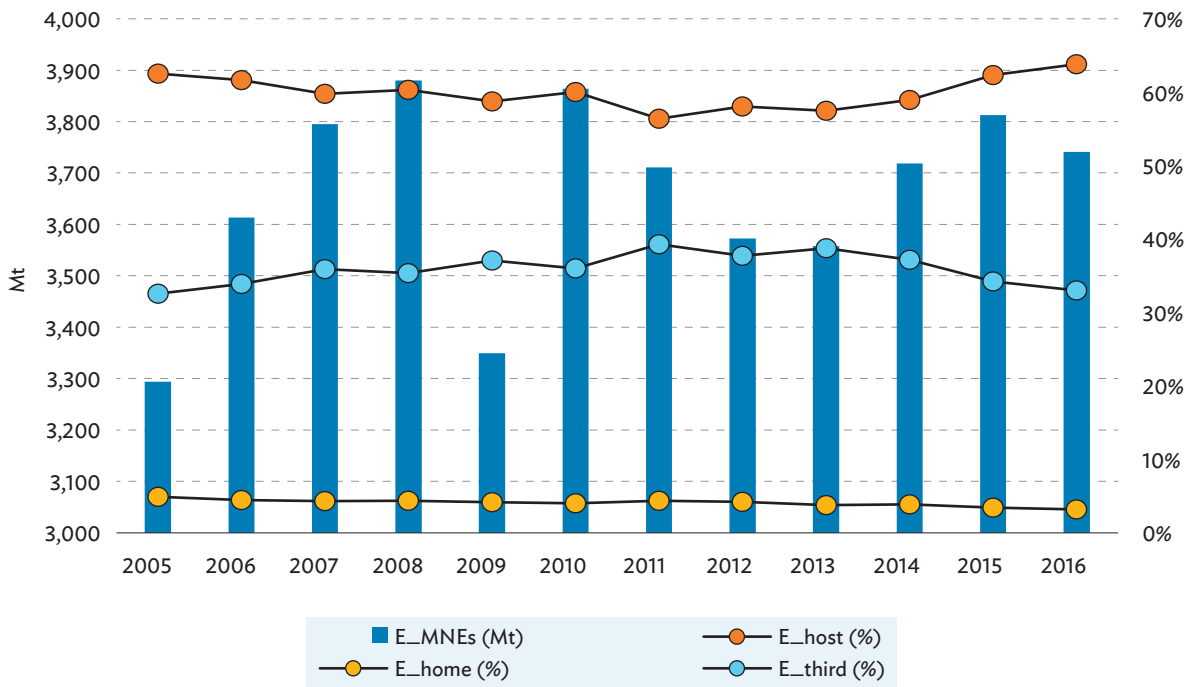
5.10 Changing Trends in MNEs' CO_2 Emissions

The MNEs' CO_2 emissions range between 3,294.0 Mt and 3,879.7 Mt (see Figure 5.6), accounting for 10% to 13% of global CO_2 emissions. MNEs' CO_2 emissions grew sharply before 2009 and decreased to a low point of 3,349.0 Mt due to the impact of the financial and economic crisis. And then further increased to a pre-crisis level of 3,868.2 Mt in 2010 but dropped again. From 2014 to 2016, MNEs' emissions rose slightly compared with the previous years with the recovery of global FDI activity but remained below their 2008 peak.

About the structure of MNEs' CO_2 emissions, it is clear that E_host (60%-70%) and E_third (30%-40%) are the two larger parts. The share of the former decreased from 62.5% to 56.4%, while the share of the latter increased from 32.6% to 39.3% during 2005 to 2011, reflecting the rapid development of global production fragmentation. After 2011, the pair exhibited an opposite trend, suggesting that the motivations for outward investments of several MNEs may have changed, and the focus gradually shifted from export-platform- and efficiency-seeking to market- and strategic asset-seeking. E_home, however, is less than 5% and declines gradually over the whole study period.

CO_2 emissions of MNEs are mainly concentrated in developed countries, such as the US, Germany, Canada, and the UK, which have the advanced technology and large consumer markets to attract a considerable volume of FDI (Figure 5.7). The US, Germany and the PRC were the top three economies in terms of CO_2 emissions by MNEs in 2016, and the

Figure 5.6: Changing Trends and Decompositions of MNEs' CO_2 Emissions (2005-2016)



Notes: E_MNEs represents MNEs' CO_2 emissions, E_host represents MNEs' emissions induced by the host country, E_home means MNEs' emissions induced by the home country, E_third indicates MNEs' emissions induced by the third country.
Source: authors' estimation using the OECD AMNE ICIO data

CO_2 emissions of these countries' MNEs increased by 49.7%, 23.0% and 23.7%, respectively, over the period 2005 to 2016. Large CO_2 emissions by MNEs reflect these economies' heavy involvement in global production fragmentation (ADB, 2021) and their essential role in inter- and intra-regional production-sharing activities.

The EU as a whole achieved an 8.3% decrease in CO_2 emissions of MNEs from 2005 to 2016, for two main reasons First, the establishment of a CO_2 emissions trading system (the European Union Emission Trading Scheme, EU-ETS), making the EU the world's most environmentally regulated region, led to the reliance on more non-fossil energy in production. For example, the share of non-fossil energy use in France increased by 10% between 2005 and 2016.[2] Second, strict environmental regulations have driven some intra-region MNEs to transfer their carbon-intensive production activities to overseas economies with lower environmental standards (usually developing economies), which has reduced emissions from EU members but induced carbon leakage to other economies (Koch and Basse Mama, 2019).

While the volume of MNEs' CO_2 emissions within developing economies is small, emissions have grown rapidly, for example from India (90.9%), Mexico (27.4%) and South Africa (40.3%). This suggests that some developed economies have shifted their production to developing economies through FDI. This allows developing economies to become involved in GVCs and provides new opportunities for them to integrate into the global economy. However, this process is accompanied by significant carbon transfers from developed to developing economies.

Figure 5.7 also clarifies the question "MNEs emit CO_2 emissions for whom". Differences in the motivation of MNEs to invest in an economy lead to variations in the structure of MNEs' CO_2 emissions. For "large economies", MNEs' CO_2 emissions are mainly induced by the production and consumption of host countries. E_host in the US, PRC, Germany, and the UK, for example, accounted for 83%, 71%, 58%, and 67% of MNEs' CO_2 emissions in 2016, respectively. The incentive for MNEs to invest in these countries is primarily market-seeking, i.e., to capture market share in the world's largest consumer market. As a result, the products of foreign-invested companies are mainly consumed in the domestic market.

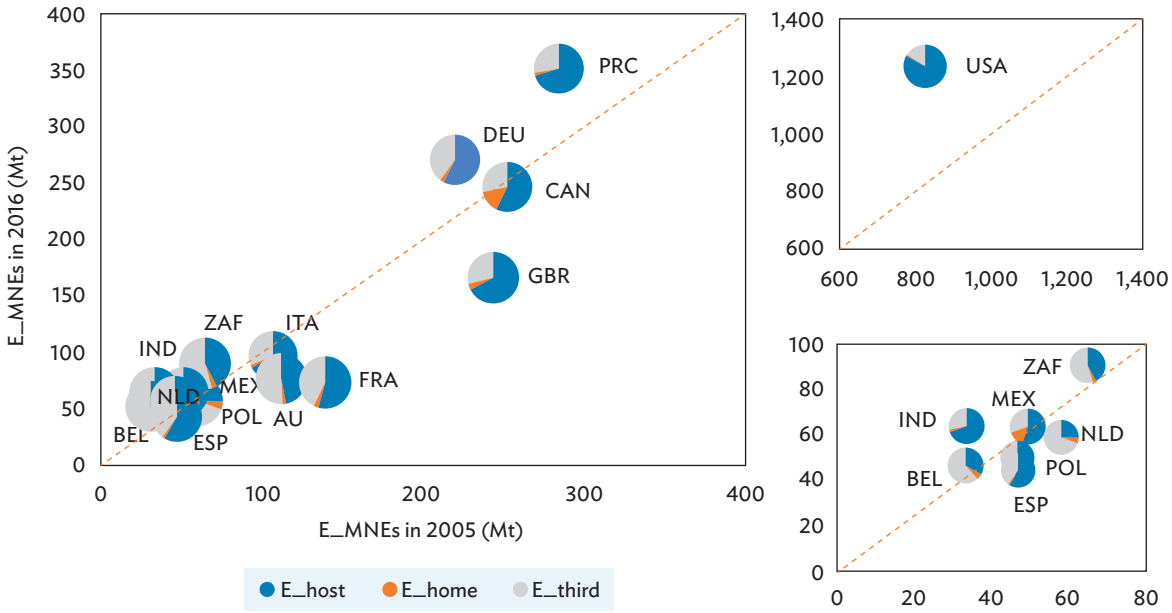
The economies with a high E_third share include not only developing economies, such as South Africa (54%), but also some developed economies, such as the Netherlands (69%). This indicates that when MNEs invest in these economies, they not only consider the factor endowments of the host country such as low-cost labor, but also the geographical location, GVC networks and trade agreements, all of which can reduce inter-regional or intra-regional trade costs and facilitate exports to third countries. Some researchers refer to this FDI investment motivation as "third-country export-platform" FDI (Ekholm et al., 2007; Ito, 2013).

---

2 Data source: https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser, accessed 13 May 2023

There is a noticeable "US effect" on the MNEs' CO_2 emissions in Canada and Mexico. The shares of E_home in both economies are significantly higher than those in the other economies. Tracing the home countries of MNEs shows that the US induced more than 95% of E_home in these two economies. This indicates that American MNEs have established regional production networks with the US as the hub through their "home-country export-platform" FDI (Ekholm et al., 2007).

Figure 5.7: Changing Trends and Decompositions of MNEs' CO_2 Emissions in Selected Countries



Notes: Top fifteen economies with the highest CO_2 emissions of MNEs are selected in this figure. The horizontal axis of the graph represents E_MNEs in 2005, the vertical axis represents E_MNEs in 2016; The red line is the 45-degree line. The economies above the 45-degree line had higher E_MNEs in 2016 than in 2005, and the economies below the 45-degree line had lower E_MNEs in 2016 than in 2005. The colours of the circles represent the proportion of MNEs' CO_2 emissions caused by different destinations in 2016. The meaning of E_MNEs, E_host, E_home and E_third are the same as that shown in notes in Figure 5.6.

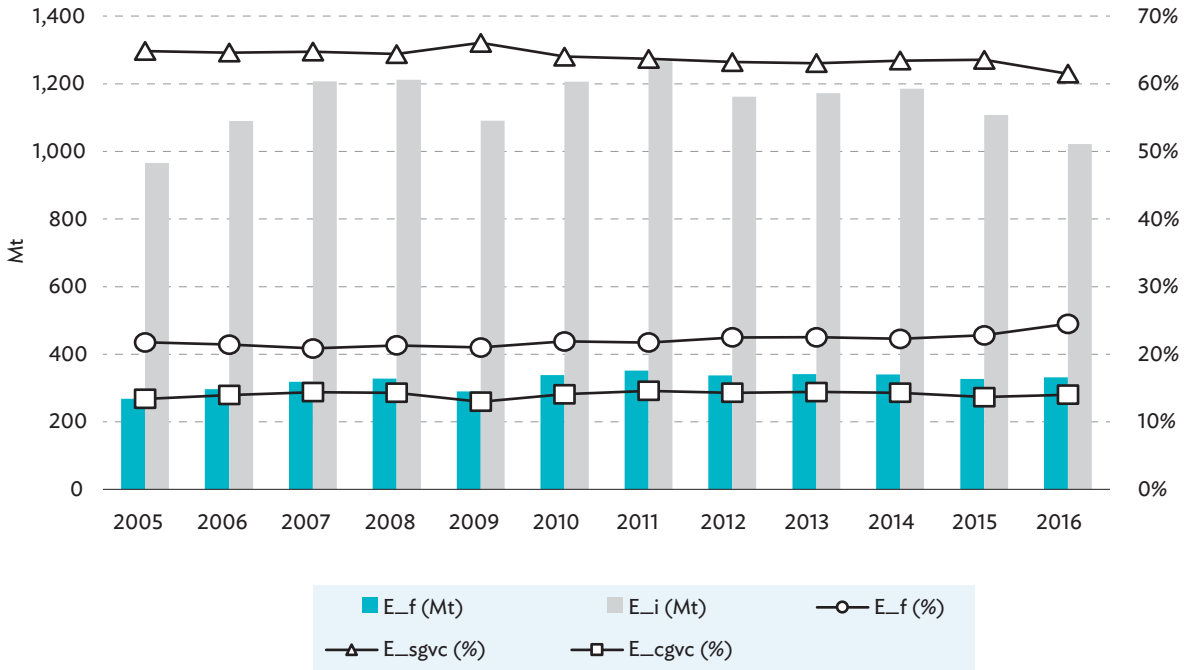
Source: authors' estimation using the OECD AMNE ICIO data.

5.11 Decomposing MNEs' CO_2 Emissions by Trade Patterns

Over 2005 to 2016, emissions embodied in intermediate product trade (E_i) were three to four times the emissions embodied in final product trade (E_f) (see Figure 5.8). This suggests that the production arrangements of GVCs drive the export activities of MNEs. Figure 5.8 also shows that E_f remained relatively stable over 2005-16, while E_i showed significant upturn and downturn. In particular, after 2011, the former showed almost no change, while the latter declined significantly. This implies that, compared with traditional international trade, intermediate product trade, which is part of international production-sharing activities, is more sensitive to global economic fluctuations and changes in the trade policies of various economies and is more vulnerable to economic shocks.

Most emissions from intermediate goods trade are associated with simple GVC activities. Emissions embodied in intermediate goods trade (E_i) can be further decomposed into two parts, emissions embodied in simple GVC activities (E_sgvc) and those embodied in complex GVC activities (E_cgvc), From 2005-2016, over 60% of total MNEs' CO_2 emissions were associated with simple GVC activities and only 15% with complex GVC activities (the remainder were emissions associated with final goods trade). Compared to the finding of Zhang et al. (2017), where emissions embodied in GVC activities account for about 55% of total global emissions without distinguishing firm heterogeneity (i.e., considering emissions generated by both domestic and foreign firms), the results here reflect that MNEs are more deeply embedded in GVC networks than domestic firms.

Figure 5.8: Decomposition of MNEs' Export-Embodied Emissions (2005-2016)



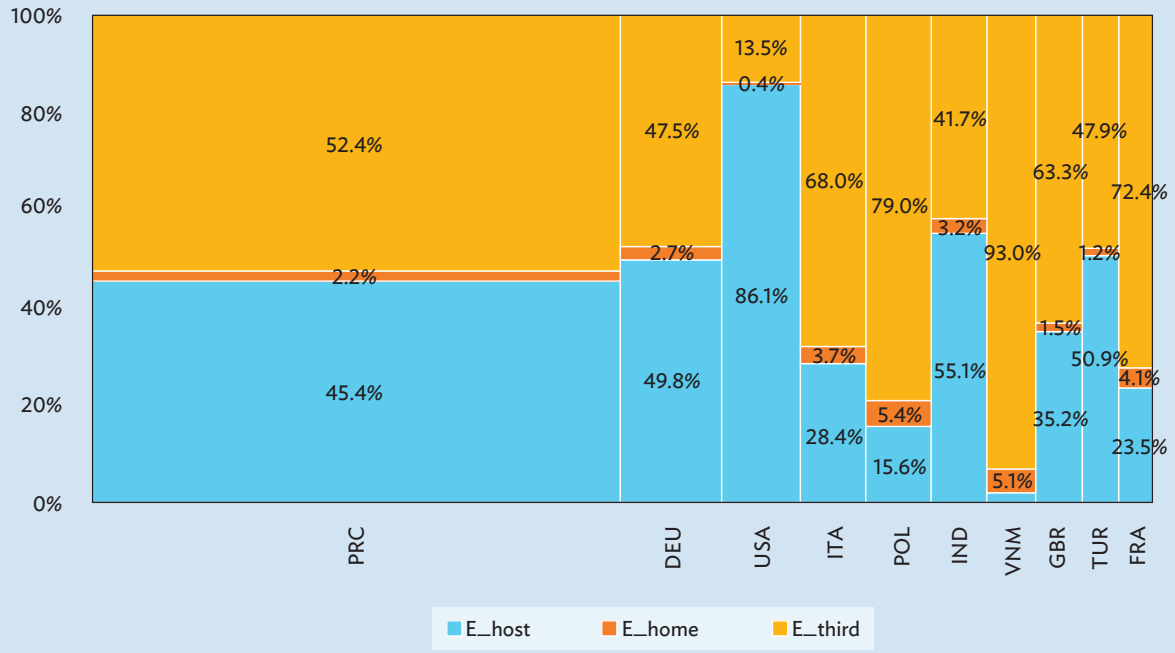
Notes: E_f indicates MNEs' emissions embodied in final product trade, E_i indicates MNEs' emissions embodied in intermediate product trade, E_sgvc represents MNEs' emissions embodied in simple GVC activities, and E_cgvc means MNEs' emissions embodied in complex GVC activities.
Source: Yan et al. (2023a).

The decline in MNEs' export-embodied emissions is largely driven by a decline in emissions embodied in simple GVC trade. While the share of MNEs' export-embodied emissions accounted for by simple GVC activities (E_sgvc) fell by 3.4 percentage points from 2005-2016, the share of MNEs' emissions embodied in final goods trade (E_f) increased by 2.7 percentage points and of emissions embodied in complex GVC activities (E_cgvc) remained relatively stable. These patterns reflected MNEs' efforts to integrate their cross-border production activities in the face of increasing risks of disruption to

Box 5.2: Sectoral Level Analysis: Textile Industry

Figure 5.9 shows that in the textile sector, the emissions of MNEs generated in the PRC far exceed those of other countries, accounting for about 36.4% of the total CO_2 emissions MNEs generated. From the perspective of component structure, MNEs' emissions in the US textile sector are mainly caused by domestic demand; on the contrary, these emissions in the textile sector of the UK, Italy, France, Poland and especially Viet Nam are primarily induced by third countries; and in textile sector of the PRC, India, Türkiye and Germany, the proportions of MNEs' emissions induced by domestic demand and third countries' demand are relatively close.

Figure 5.9: CO_2 Emissions of MNEs in the Textile Sector of Top 10 Economies (2016)



Notes: Top ten economies with the highest CO_2 emissions of MNEs in the textile sector are selected in this figure. The CO_2 emissions of MNEs in these economies account for more than 70% of all CO_2 emissions of MNEs in the textile sector, hence they are highly representative; the width of each bar on the horizontal axis is proportional to the share of MNEs' CO_2 emissions in the textile sector of one country in the total MNEs' CO_2 emissions in the global textile sector; the wider the bar, the greater the share.

Source: authors' estimation using the OECD AMNE ICIO data.

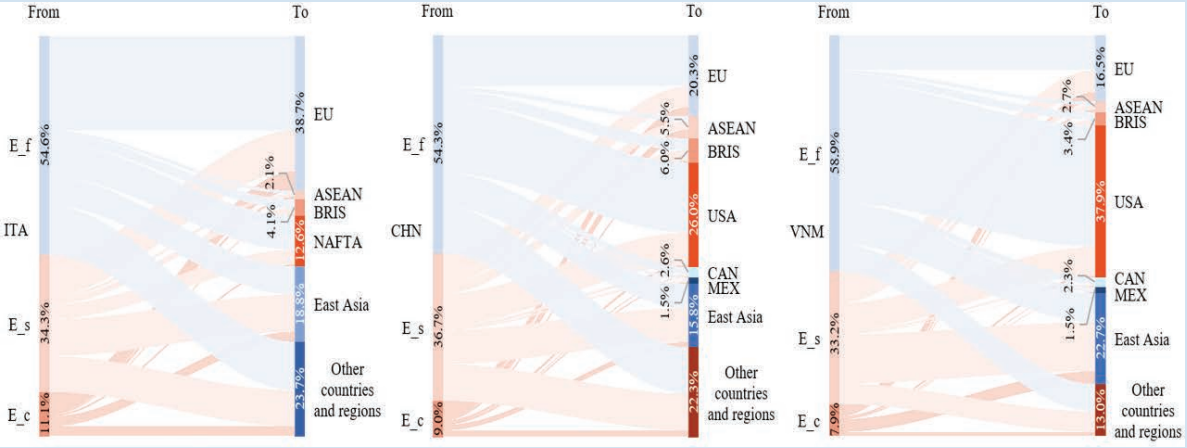
Using the PRC, Italy, and Viet Nam as examples, we can analyze the regional distributions and trade patterns of their CO_2 emissions induced by third countries (see Figure 5.10). In terms of the regional distribution of E_third, the largest share of Italy's E_third flows to the EU, and Viet Nam's and PRC's E_third flowing to the US correspond to the largest share. Furthermore, all three economies' E_third that flows to economies in East Asia and ASEAN are mainly through intermediate products trade, while their emissions flowing to the US are primarily through trade in final products. It indicates that the positions of these three economies in production-sharing activities with economies in East Asia and ASEAN are much closer to the upstream production stages, while in production-sharing activities with the US, they are closer to the downstream production stages.

Just like much literature discussed before, without considering the raw materials trade, economies located upstream of GVCs tend to export more intermediates products, in contrast, those located downstream of GVCs, tend to export more final products (Koopman et al., 2014; Meng et al., 2018; Wang et al., 2013; Zhang et al., 2017). And this finding holds for MNEs hosted by these economies as well: since the production activities of MNEs in host countries mainly use the local factors of production, the relative position of host countries in GVCs would affect the type of goods that their MNEs export.

continued on next page

Box 5.2: continued

Figure 5.10: Decomposition of Third-Country-Induced Emissions of MNEs in the Textile Sector of Selected Economies (2016)



Source: authors' estimation using the OECD AMNE ICIO data.

References

Koopman R, Wang Z, Wei S. 2014. Tracing value-added and double counting in gross exports. American Economic Review. 104, 459-494.
Meng B, Peters GP, Wang Z, Li M. 2018. Tracing CO2 emissions in global value chains. Energy Economics. 73, 24-42.
Wang Z, Wei S, Zhu K. 2013. Quantifying international production sharing at the bilateral and sector levels. NBER Working Paper. No.19677.
Zhang Z, Zhu K, Hewings GJD. 2017. A multi-regional input–output analysis of the pollution haven hypothesis from the perspective of global production fragmentation. Energy Economics. 64, 13-23.

global supply chains driven by the rise of trade protectionism and deglobalization since the financial crises. Such efforts involved cutting down the production length and number of times intermediate inputs cross borders to ensure the stability of their supply chains, such as production nearshoring and reshoring initiative. And this has largely involved replacing intermediate products related to simple GVCs with products generated domestically, as the former only cross borders once, it may be easier and less disruptive to find domestic substitutes than for intermediate goods traded in complex GVC activities. The production-sharing activities of complex GVC involve intermediate goods crossing borders multiple times, shaping production networks that encompass many economies. It is relatively hard for MNEs to reshape the production arrangements of complex GVCs. Thus, it is not surprising that the share of E_cgvc remained almost unchanged over the period.

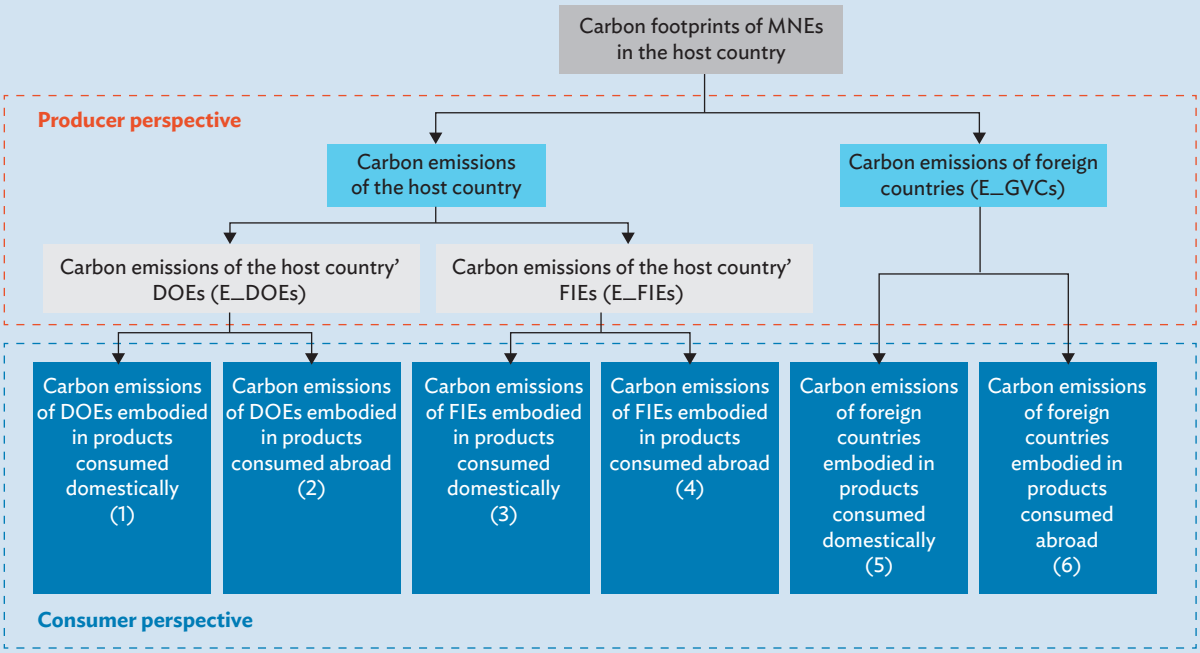
5.12 Measuring the Carbon Footprints of MNEs in GVCs

With FDI becoming an important means for MNEs to conduct globalized production, the environmental impact of MNEs, through GVCs, transcends not only these companies but also their national boundaries as they affect climate change worldwide. This part therefore aims to clarify the source of upstream inputs used by MNEs' final products production and CO_2 emissions they induce as well as the consumption destination of MNEs' final products and CO_2 emissions embodied in.

Box 5.3: Accounting for Carbon Footprints of MNEs in Global Value Chains

The figure illustrates an accounting framework proposed by Yan et al. (2023b) that quantifies the carbon footprints of MNEs in Global Value Chains, while distinguishing sources and destinations of carbon footprints.

Carbon Footprints Accounting Framework of MNEs (GVC Backward Linkage-based Decomposition)



Source: Yan et al. (2023b).

For MNEs producing in one country, the accounting framework can decompose their total carbon footprints into six routes based on the GVC backward linkage as follows:
Route 1: CO_2 emissions of the host country's DOEs (domestically owned enterprises) that are induced by MNEs' final product production (E_DOEs), and these final product productions are consumed domestically.
Route 2: CO_2 emissions of the host country's DOEs that are induced by MNEs' final product production, and these final productions are consumed abroad.
Route 3: CO_2 emissions of MNEs' foreign affiliates (i.e., the FIEs) in the host country that are induced by MNEs' final product production (E_FIEs), and these productions are consumed domestically.
Route 4: CO_2 emissions of FIEs in the host country that are induced by MNEs' final product production, and these productions are consumed abroad.
Route 5: CO_2 emissions of foreign countries that are induced by MNEs' final product production through GVCs (E_GVCs), and these productions are consumed domestically.
Route 6: CO_2 emissions of foreign countries that are induced by MNEs' final product production through GVCs, and these productions are consumed abroad.

This framework is operationalized using the Organization for Economic Co-operation and Development's Analytical Activities of Multinational Enterprises (AMNE) database (Cadestin et al., 2018), which breaks down the sectors according to the shares of domestic- or foreign-owned firms.

References

Cadestin C, de Backer K, Desnoyers-James I, Miroudot S, Rigo D, and Ye M. 2018. Multinational enterprises and global value chains: The OECD analytical AMNE database. OECD Trade Policy Papers. No. 211.
Yan Y, Li X, Wang R, Zhao Z, Jiao A. 2023b. Decomposing the carbon footprints of multinational enterprises along global value chains. Structural Change and Economic Dynamics. 66, 13-28.

5.13 Component Structure of MNEs' Carbon Footprints, A Producer Perspective

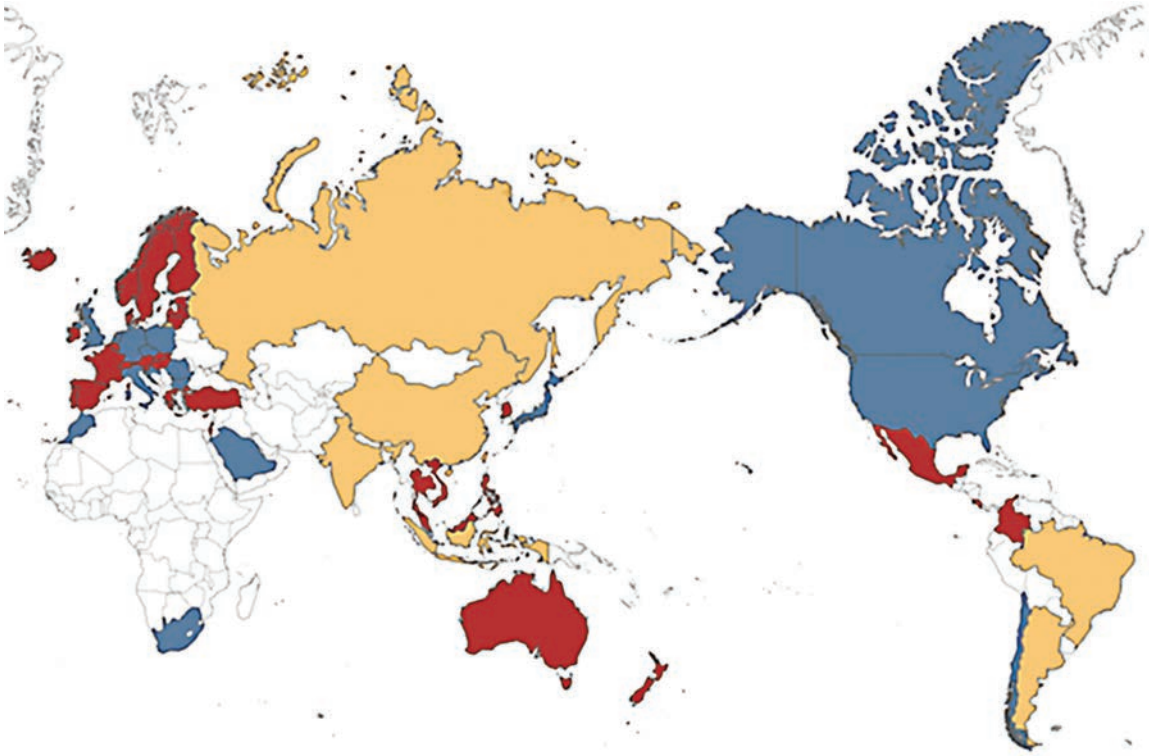
Figure. 5.11 decomposed MNEs' carbon footprints (CFs) from a producer perspective. Clearly, in major developed economies, especially G7 countries that are located upstream of GVCs and focus on innovative activities, as well as parts of economies in Europe, MNEs' CFs consist mainly of emissions generated by their affiliates; that is, the emissions of FIEs (E_FIEs). For example, in the US and Germany, E_FIEs account for between 50% and 60% of total CO_2 emissions induced by MNEs' final production. For some developing economies, particularly those BRIC countries with larger economies but that are normally located relatively downstream of GVCs, the emissions of DOEs (E_DOEs) account for the lion's share of MNEs' CFs; for instance, in the two largest emerging economies, the PRC and India, E_DOEs account for 74.0% of MNEs' total induced emissions in the former and 53.4% in the latter. This is not only because DOEs' carbon intensities in these economies are significantly higher than those of FIEs, but it is also because these domestic-owned firms are increasingly engaged in production-sharing activities with MNEs, particularly as upstream intermediate goods suppliers of MNEs (Wang et al., 2021). In the majority of countries in South and Southeast Asia, Latin America, and Europe, especially those countries with relatively small economies, the CFs of MNEs consist mainly of foreign emissions induced through GVCs (E_GVCs), typically in Singapore and Mexico. In 2016, foreign emissions induced by Singapore-hosted MNEs accounted for 78.9% of that country's total induced emissions through imports of intermediates related to GVC activities, the share in Mexico was 42.7%, showing the very open nature of these two economies' markets and their high dependence on GVCs.

5.14 Component Structure of MNEs' Carbon Footprints, A Consumer Perspective

It is also very important to analyze the MNEs' CFs along GVCs from the downstream final consumer perspective as it helps to understand how the final use could trigger the emissions embodied in the entire upstream supply chain. Figure. 5.12 decomposes MNEs' CFs from a consumer perspective.

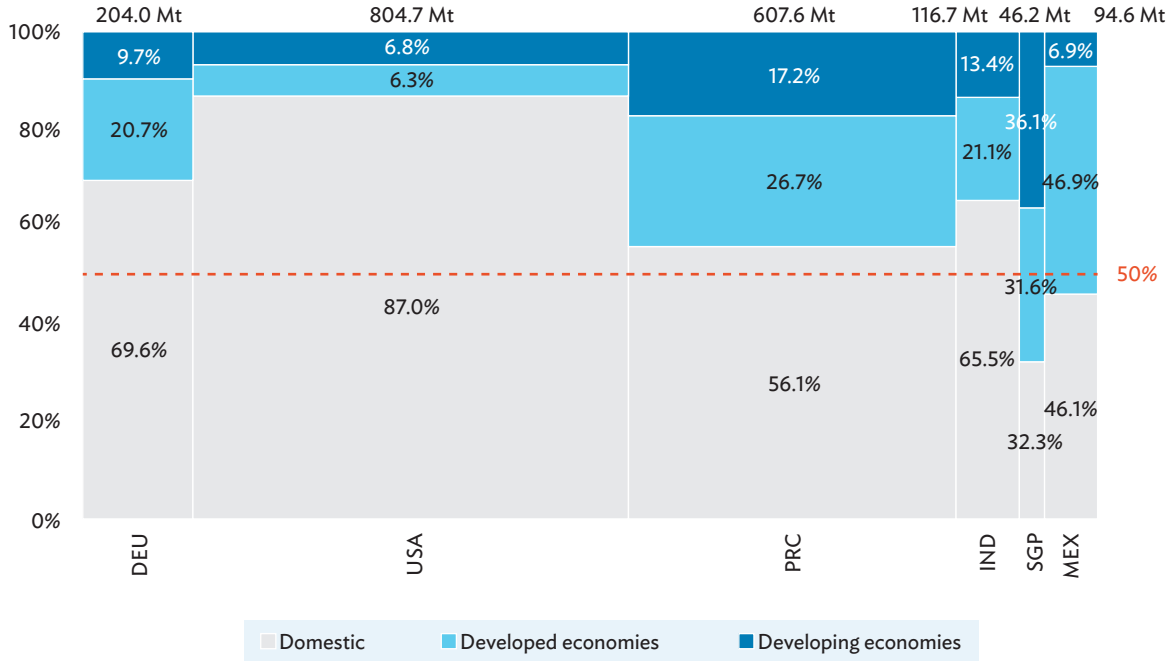
As we can see, in the US, Germany, the PRC and India, all MNEs-induced emissions are mainly embodied in products consumed domestically. Especially in the US, where emissions embodied in domestically consumed products account for 87.0%. It means that most domestic (either DOEs or FIEs) and foreign upstream suppliers' products are generated to fulfill the own demands of the US because of its huge local markets and strong domestic purchasing power. In contrast, for Singapore, 67.7% of MNEs' CFs are linked to foreign final demands. And more importantly, shares of emissions induced by developed economies as well as developing economies are relatively close. Due to its position in GVCs and its factor endowments, Singapore's economy is oriented

Figure 5.11: Component Structure of MNEs' Carbon Footprints, a Producer's Perspective (2016).



Note: Economies marked in blue represent MNEs' CFs consisting mainly of emissions generated by FIEs, and those marked in yellow and red represent MNEs' CFs consisting mainly of emissions generated by DOEs and emissions generated abroad, respectively.
Source: Yan et al. (2023b).

Figure 5.12: Component Structure of MNEs' Carbon Footprints in Selected Economies, A Consumer's Perspective (2016).



Notes: The data at the top of the chart shows the carbon footprints of MNEs hosted by each economy.
Source: Yan et al. (2023b).

toward both developed and developing economies. On the one hand, it makes up for the lack of productive capacity in developing economies by exporting high-value-added intermediate products; on the other hand, it is also closely integrated into the production networks of developed countries, becoming an essential hub in the global production network. Another interesting finding is that compared with developed economies, foreign final demands correspond to a much larger share of MNEs' CFs in the PRC, India, and Mexico, and most of these demands come from developed economies. Mexico is of particular concern since 46.9% of its MNEs' CFs are associated with the demands of developed economies, while this share of the PRC and India are 26.7% and 21.1%, respectively. And relatively lower consumption power of the domestic market and the deeper embedding of GVCs are the main reasons for this phenomenon.

5.15 Re-evaluating the Carbon Mitigation Responsibilities of MNEs in Global Value Chains: From a Factor Income Perspective

Tracing MNEs' emissions along GVCs, as the previous section does, misses a crucial aspect: redistribution of emission responsibility. Transnational investment of MNEs promotes the redistribution of environmental costs and economic benefits across countries. As pointed out by Bohn et al. (2021), "value-added generated within a country does not necessarily result in income for that country. Although a large share of the value-added is absorbed by the host country's residents in the form of wages, reinvested earnings, and profits, a substantial share of MNEs' earnings is repatriated as income to owners in the home country of the MNEs". If taking all CO_2 emissions MNEs' generated into host/ home countries' environmental costs, that would lead to an overestimation or underestimation of emissions responsibility among different countries.

In this section, we follow the study of Meng et al. (2022), not only proposing a new accounting criterion in terms of factor income for both CO_2 emissions and value-added of MNEs, the factor income-based accounting (FIBA). Such accounting can be used to show the unequal allocation of environmental costs and economic benefits between developing economies and advanced economies. We also propose an incentive fund led by MNEs of advanced economies as a complement to the Green Climate Fund (GCF), to reward emerging markets and developing economies that are aggressive in reducing emissions by providing financial support for their renewable energy projects and innovations that reduce the cost of carbon capture and storage.

Box 5.4: The Concept of Trade in Factor Income and its Relationship with Gross Trade Volume and Trade in Value-Added (using US exports to PRC as an example).

In an input–output (IO) system, value-added in relation to factor income is composed of labor compensation, net taxes, and returns on capital (including both tangible and intangible assets; in practice, i.e., gross operating surplus including capital depreciation). In gross terms, US exports (1 + 2 + 3 + 6 + 7 + 8 + *) include the domestic value-added of US- (1 + 2 + 3) and foreign-owned firms (6 + 7 + 8) in the US and foreign value-added and double-counted parts of intermediates embodied in those exports (*). In value-added terms, US exports (1 + 2 + 3 + 6 + 7 + 8) are the pure domestic value-added (1 + 2 + 3 + 6 + 7 + 8), that is, no foreign value-added or double counting is involved. In factor income terms, US exports (1 + 2 + 3 + 4 + 5 + 6 + 7) include the domestic value-added of US-owned firms (1 + 2 + 3), returns on capital of US-owned firms located in the PRC (4) and third countries (5), labor compensation for foreign-owned firms in the US (6), and net taxes on the products of foreign-owned firms located in the US (7).

Firm Location / Firm ownership	Located in the US			Located in the PRC			Located in Third Countries		
American-owned Firms	Labor Compensation 1	Net taxed on products 2	Return to Capital 3	Labor Compensation *	Net taxed on products *	Return to Capital 4 *	Labor Compensation *	Net taxed on products *	Return to Capital 5 *
Foreign-owned Firms (including Chinese-owned Firms)	Labor Compensation 6	Net taxed on products 7	Return to Capital 8	Labor Compensation *	Net taxed on products *	Return to Capital *	Labor Compensation *	Net taxed on products *	Return to Capital *

Notes: * refers to the foreign value-added and double counting embodied in US gross exports to the PRC; Net taxes refers to taxes minus subsidies on products.
US exports to PRC measured in different ways:
Gross Exports = 1 + 2 + 3 + 6 + 7 + 8 + *.
Trade in Value-Added (TiVA) = 1 + 2 + 3 + 6 + 7 + 8.
Trade in Factor Income (TiFI) = 1 + 2 + 3 + 4 + 5 + 6 + 7.
Source: Meng et al. (2022)

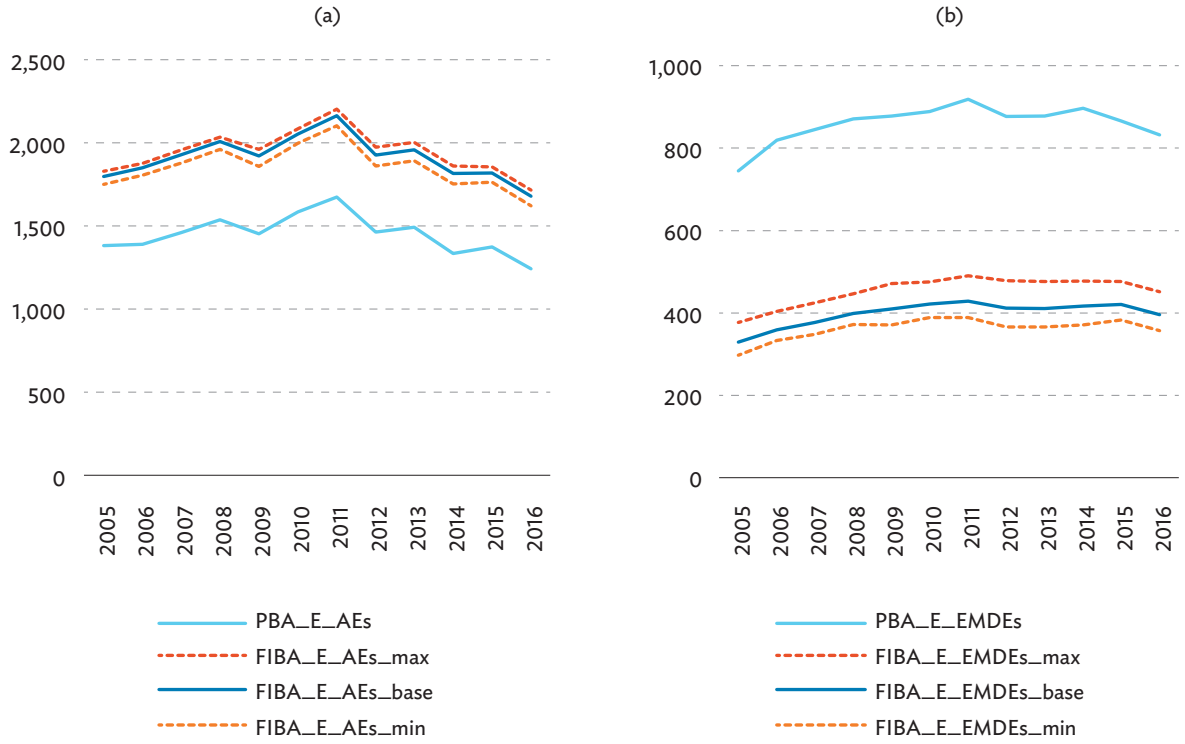
References

Meng B, Gao Y, Ye J, Zhang M, Xing Y. 2022. Trade in factor income and the US-PRC trade balance. China Economic Review. 73, 101792.

5.16 Environmental Costs and Economic Benefits of MNEs

Figure 5.13a and b show emissions of advanced economies as well as emerging markets and developing economies because of the production of MNEs' affiliates, as measured by production-based accounting (PBA) and FIBA. MNEs' emissions from emerging markets and developing economies measured by PBA are much higher than their emissions measured by FIBA, whereas for advanced economies, MNEs' emissions estimated by the PBA method are far lower than those estimated by the FIBA method. This suggests that emissions of emerging markets and developing economies due to inward FDI are higher than the emissions due to their outward FDI, and the advanced economies are the opposite. This result, to a certain extent, supports the pollution haven hypothesis discussed by Sapkota and Bastola (2017), Shao (2017), Shahbaz et al. (2018) and Avendano et al. (2023). That is, FDI becomes the framework for MNEs of advanced economies to transfer pollution and emissions to emerging markets and developing economies with lower environmental standards to reduce their implementation costs and carbon tax (Singhania and Saini, 2021).

Figure 5.13: CO_2 Emissions Measured by PBA and FIBA between 2005 and 2016 (Mt)



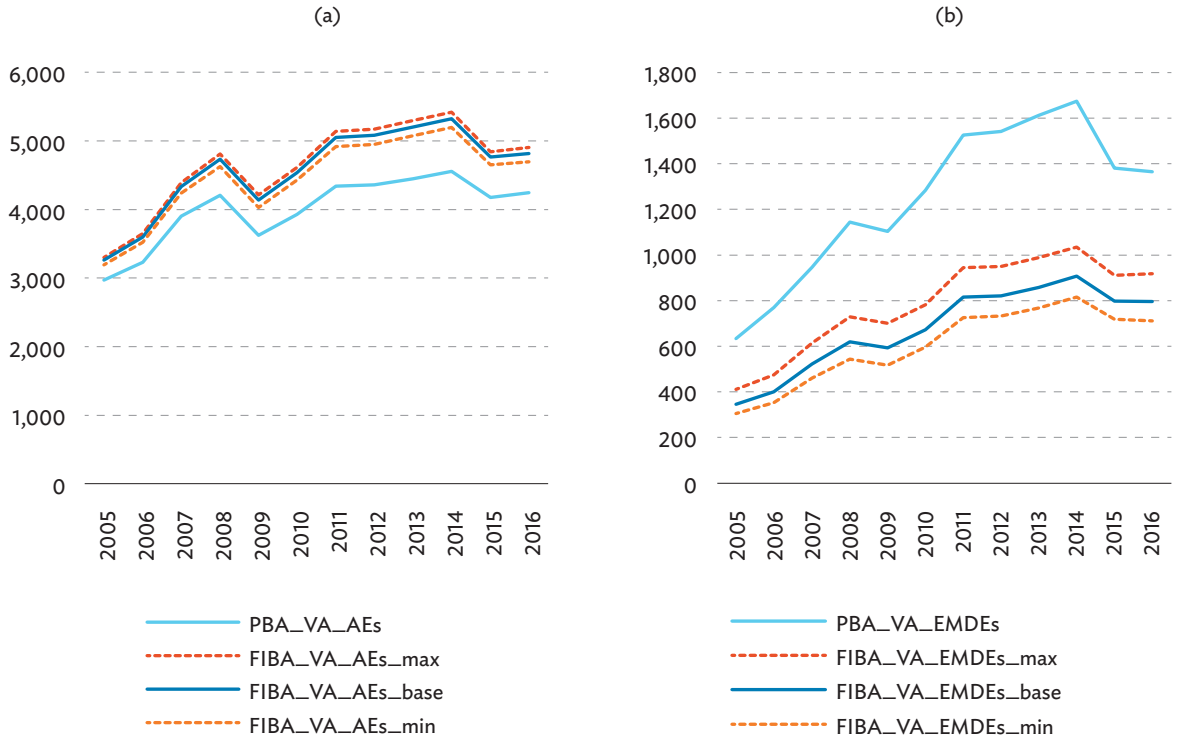
Notes: PBA_E represents CO_2 emissions that are calculated by the PBA method, FIBA_E indicates CO_2 emissions that are calculated by the FIBA method; AEs means advanced economies, EMDEs means emerging markets and developing economies; "min", "base", and "max" show the lower bound, baseline and upper bound of CO_2 emissions calculated by FIBA method (the bound setting is based on production technology assumptions).

Source: Yan et al. (forthcoming).

Now, let us turn our attention to the value-added created by MNEs' affiliates (Figure 5.14). The PBA value-added of emerging markets and developing economies is more than twice as much as their FIBA value-added. In contrast, advanced economies' PBA value-added is much lower than their FIBA value-added. Thus, advanced economies captured significant capital gains from emerging markets and developing economies through FDI activities, whereas emerging markets and developing economies experience a net outflow of factor income in terms of capital return from MNEs' activities.

Overall, flows of FDI not only lead to carbon transfers between host and home countries but also facilitate the redistribution of value-added and benefits between them. While MNEs' affiliates create a large amount of value-added in host countries, the benefits of this value-added might not entirely belong to in these countries (Bohn et al., 2021; Meng et al., 2022). However, CO_2 emissions generated in the process of creating this value-added are all accounted for (under PBA) by host countries' territorial emissions, which leads to the imbalance between benefits and environmental pollution in some economies. In global cross-border investment activities: the "real" value-added and CO_2 emissions generated through FDI in advanced economies, may be underestimated, while those in

Figure 5.14: Value-Added Calculated by PBA and FIBA between 2005 and 2016 (Billion USD)



Notes: PBA_VA represents value-added that calculated by the PBA method, FIBA_VA indicates value-added that calculated by the FIBA method; AEs means advanced economies, EMDEs means emerging markets and developing economies; "min", "base", and "max" show the lower bound, baseline and upper bound of value-added calculated by FIBA method (the bound setting is based on production technology assumptions).

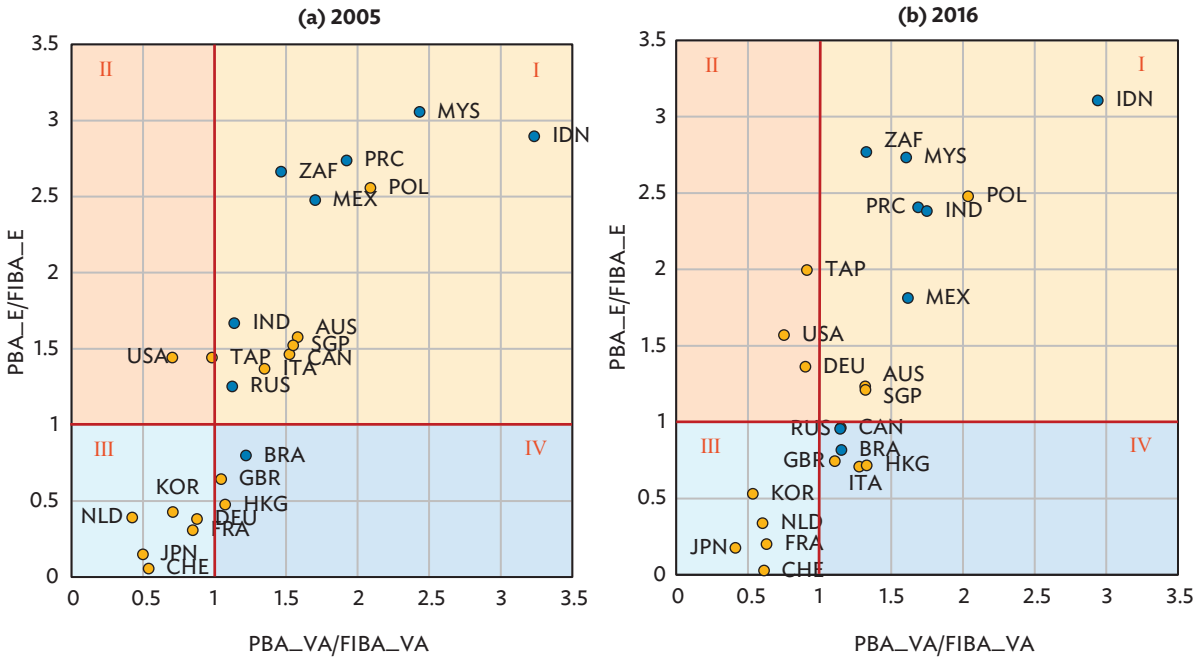
Source: Yan et al. (forthcoming).

emerging markets and developing economies may be overestimated. This overestimation and underestimation are masked in the traditional PBA framework. Advanced economies actually gain higher economic benefits than those of traditional statistical caliber, while the environmental costs they are allocated are far lower than their actual responsibility. Whereas emerging markets and developing economies do the exact opposite, they got a smaller factor income in terms of capital return while higher environmental costs than those of traditional statistical caliber.

At the country level, Figure 5.15 separates selected economies into four categories. Category III, the lower left quadrant, includes major FDI-outflowing countries (e.g., Republic of Korea, Japan, Netherlands, France, and Switzerland)[3] where PBA MNEs' emissions and value-added are lower than FIBA MNEs' emissions and value-added. These economies via outward FDI not only transfer a large volume of CO_2 emissions but also gain a large amount of capital gain-based factor income.

[3] In 2016, the outward FDI flows of Netherlands, Japan, Switzerland, France and the Republic of Korea ranked 3rd, 4th, 5th, 7th, and 11th respectively in the world, and their outward FDI stocks ranked 2nd, 6th, 8th, 9th and 15th respectively in the world. More details see https://data.oecd.org/fdi/fdi-flows.htm#indicator-chart.

Figure 5.15: PBA and FIBA MNEs' CO_2 Emissions and Value-Added of Selected Economies (2005 and 2016)



Notes: PBA_VA and PBA_E represent MNEs' value-added and CO_2 emissions calculated by the PBA method, FIBA_VA and FIBA_E indicate MNEs' value-added and CO_2 emissions calculated by the FIBA method; the vertical axis shows the ratio of PBA_E to FIBA_E. If PBA_E/FIBA_E>1, PBA CO_2 emissions are larger than FIBA CO_2 emissions, whereas if PBA_E/FIBA_E<1, PBA CO_2 emissions are smaller than FIBA CO_2 emissions. The horizontal axis shows PBA_VA/FIBA_VA. If PBA_VA/FIBA_VA>1, PBA value-added is larger than FIBA value-added; otherwise, PBA value-added is equal to or smaller than FIBA value-added.

Source: Yan et al. (forthcoming).

Most leading emerging markets and developing economies that receive large inward FDI such as the PRC, India, Mexico, and South Africa, fall into category I (upper right quadrant). Both PBA MNEs' emissions and value-added of these economies are far larger than their FIBA MNEs' emissions and value-added, which suggests that in the process of FDI-driven globalized production, emerging markets and developing economies paid relatively higher environmental costs (i.e., the CO_2 emission inflows via inward FDI) compared to their relatively smaller gain of factor income (i.e., the value-added outflows via inward FDI).

In category II (upper left quadrant of Figure 5.15), the US is typical. CO_2 emissions of MNEs computed by PBA are larger than those computed by FIBA, while the PBA MNEs' value-added is smaller than the FIBA MNEs' value-added, implying the US has net inflows in both CO_2 emissions and value-added under transnational investment. This phenomenon may contradict the general intuition since the US has the world's largest FDI outflows. One reason is that the US MNEs focus on services sectors which are relatively green that carbon intensive manufacturing sectors. Another possible explanation is that a large portion of US FDI flows to destination countries through tax havens, and these investments are not directly counted as US outward FDI (Coppola et al., 2021). If all these hidden investments were included in US outward FDI, then its carbon transfer and income via investment might be much larger than the values currently calculated.

For economies in category IV (lower right quadrant), CO_2 emissions of MNEs calculated by the PBA method are smaller than those calculated by the FIBA method, whereas the PBA MNEs' value-added is larger than the FIBA MNEs' value-added. Thus, while these economies transfer part of their CO_2 emissions through outward FDI activities, simultaneously, the inward FDI flowing to them also leads to a net outflow of their value-added. The UK is a prime example. Like many advanced economies, through outward FDI activities, the UK transfers a larger volume of emissions abroad and thereby expresses a net benefit in terms of the environment.

The ratios of PBA_VA/FIBA_VA and PBA_E/FIBA_E of emerging markets and developing economies, especially that of the PRC and Malaysia, declined markedly from 2005-2016. This was mainly caused by their growing outward FDI.[4] Another finding is that in both Canada and Italy, because of the decline in CO_2 emission intensities of their hosted MNEs,[5] the values of PBA_E/FIBA_E have decreased remarkably, shifting them from category I to category IV. In contrast, owing to the growing carbon coefficients as well as expanding outputs of foreign affiliates,[6] this value of Germany shows a significant upturn, which leads it to shift from category III to category II.

From the sector perspective, Figure 5.16 presents PBA and FIBA MNEs' CO_2 emissions and value-added of the basic metals sector in selected economies. More than half of MNEs' emissions were generated in emerging markets and developing economies (Figure. 5.16(a)). Among them, PBA MNEs' emissions in the PRC, other emerging markets and developing economies accounted for 34.2% and 23.9% of the total emissions generated by MNEs, respectively. In contrast, the share of PBA emissions of advanced economies in MNEs' total emissions was approximately 40%, most of which were mainly generated in the EU23 (25.6%), while only 8.4% and 7.9% were emitted in the US and other advanced economies, respectively. Notably, although MNEs emitted approximately 1/3 of their total emissions within the PRC's territory, the share of value-added they created in the PRC was only 14.1%. In contrast, these firms generated 25.6% and 7.9% of their total emissions in the EU23 and other advanced economies, respectively, whereas the shares of value-added they created were 40.7% and 15.0%, respectively. This highlights the high emissions and low value-added production characteristics of foreign affiliates in the Chinese metals industry.

Next, we consider FIBA-based MNEs' emissions. The FIBA emissions of emerging markets and developing economies, including the PRC, accounted for approximately 30% of the total global emissions generated by MNEs, whereas the share of advanced economies represented by the US and EU23 was approximately 70%. However, FIBA value-added to emerging markets and developing economies was only 18%, and

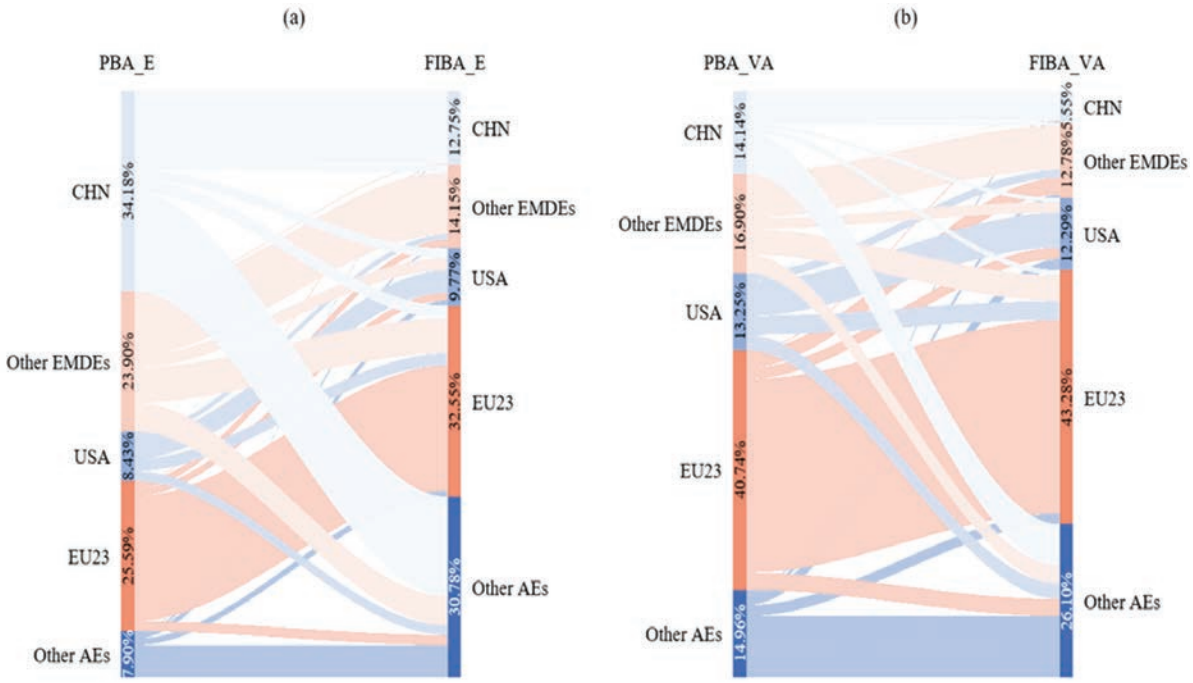
---

4 In 2005, the outward FDI stocks of the PRC and Malaysia are 57.2 billion USD and 22.0 billion USD, while in 2016, their outward FDI stocks grow to 1,357.4 billion USD (+2372.8%) and 126.02 billion USD (+571.9%).

5 The CO_2 emission intensities of foreign MNEs in Canada and Italy declined from 0.29kg/USD and 0.09kg/USD in 2005 to 0.16kg/USD and 0.06kg/USD in 2016.

6 The CO_2 emission intensities of Germany-hosted MNEs increased from 0.07kg/USD in 2005 to 0.17kg/USD in 2016.

Figure 5.16: PBA and FIBA MNEs' CO_2 Emissions and Value-Added of the Basic Metals Sector in Selected Economies (2016)



Notes: PBA_VA and PBA_E represent value-added and CO_2 emissions that are calculated by the PBA method, and FIBA_VA and FIBA_E indicate value-added and CO_2 emissions that are calculated by the FIBA method. EU23 indicates 23 advanced economies in the EU, other AEs represents other advanced economies, and other EMDEs means emerging markets and developing economies except for the PRC. The wavy lines show the flows of CO_2 emissions and value-added.

Source: Yan et al. (forthcoming).

approximately 82% of the value-added was acquired by MNEs controlled by advanced economies (Figure. 5.16(b)). Special attention should focus on the unbalanced environmental costs and economic benefits between other advanced economies and the PRC; the former bear approximately 7.9% of the total MNEs' emissions while gaining more than 1/4 of their factor income-based benefits via outward FDI activities, whereas the latter undertakes approximately 1/3 of the total emissions generated by MNEs, but only captures less than 6% of their factor income-based benefits.

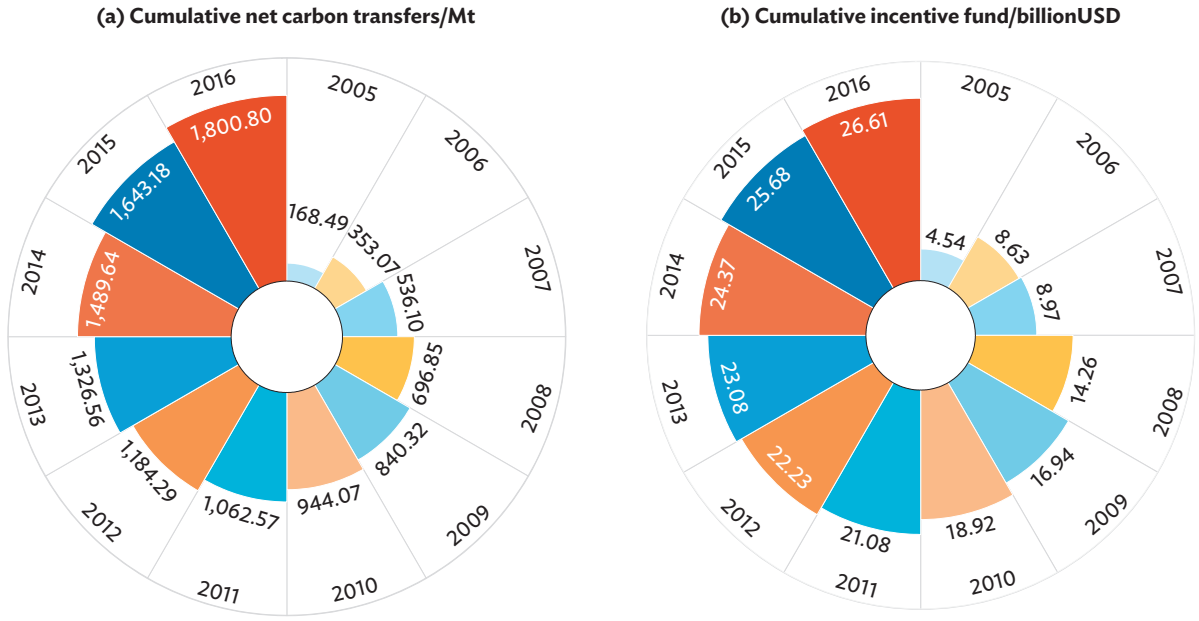
According to the composition of territorial emissions, 96.4% of the PRC's FIBA MNEs' emissions are those emitted domestically; for other emerging markets and developing economies, 74.7% of their FIBA MNEs' emissions are generated within their borders, and approximately 17% are emitted in advanced economies. However, in contrast to emerging markets and developing economies, more than 50% of the advanced economies' FIBA MNEs' emissions are generated abroad. Specifically, the US emits16.9% and 21.8% of their FIBA MNEs' emissions in the PRC as well as other emerging markets and developing economies, respectively; the EU23 generated 6.6%, 18.4%, and 6.3% of their FIBA-based MNEs' emissions in the PRC, other emerging markets and developing economies, and the US, respectively; and for other advanced economies, of all their FIBA MNEs' emissions, only 17.9% were emitted domestically, while 54.9% and 16.0% were emitted in the PRC and other emerging markets and developing economies, respectively.

5.17 Possible Incentive Fund Led by MNEs

Under the FIBA framework, the "real" emissions of advanced economies are much higher than those calculated under the PBA accounting framework used by the Intergovernmental Panel on Climate Change (IPCC). And these excess emissions are net carbon transfers from advanced economies to emerging markets and developing economies through MNEs' investment. As shown in Figure 5.17a, globally, the cumulative net carbon transfers from advanced economies to emerging markets and developing economies were as high as 1800.8 Mt as of 2016, which has significantly increased both environmental costs and emission mitigation pressures on emerging markets and developing economies, albeit under "common but differentiated responsibilities".

In light of this phenomenon, Yan et al. (forthcoming) proposed to build an incentive fund led by MNEs of advanced economies as a supplementary for GCF, to support the development of renewable energy projects as well as carbon capture and storage technology in emerging markets and developing economies, helping them adapt to and mitigate climate change. The funds transferred could be set equal to the cumulative net carbon transfers from advanced economies to EMDEs, multiplied by an estimate of the price of carbon. Our initial estimation uses the average carbon price[7] of the EU for each

Figure 5.17: Cumulative Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies through MNEs (2005-2016)



Source: Yan et al. (forthcoming).

7 A proper way to calculate the responsibility of MNEs' cumulative net carbon transfers in monetary terms is to use the difference of carbon costs (prices) between FDI home and host countries if such data are available.

year of the 2005-16 period. This would result in a transfer of 26.6 billion USD from advanced economies' MNEs to emerging markets and developing economies. While the use of other estimates of the price of carbon and a different time period would generate different results, there is no doubt that this incentive fund would be a strong addition to the GCF if MNEs can reach a consensus on it (Figure 5.17b).

Table 5.2 further illustrates net carbon transfers from advanced economies to emerging markets and developing economies of different industries in 2016, as well as the incentive fund expected to be mobilized from MNEs owned by developed economies. It is clear that the largest carbon transfers from advanced economies to emerging markets and developing economies occur in utilities (267.6 Mt), followed by medium low-tech manufacturing (115.4 Mt). For those carbon transfers, MNEs of advanced economies would pay 1584.1 million USD and 683.3 million USD respectively, which account for 3.3% and 0.4% of the total value-added these firms obtained from emerging markets and developing economies in 2016, to establish the incentive fund, helping developing economies address climate change and carbon mitigation. It must be emphasized that, in contrast to medium low-tech manufacturing, special attention should be paid to mobilizing sufficient incentive funds from MNEs for supporting emission mitigation in utilities of emerging markets and developing economies. This sector is not only more carbon-intensive but also has a much lower labor compensation rate than other industries. In other words, MNEs of advanced economies shift more CO_2 emissions at a smaller economic cost, which undoubtedly increases the pressure on emissions reductions of emerging markets and developing economies.

Table 5.2: Net Carbon Transfer and Incentive Fund of Advanced Economies to Emerging Markets and Developing Economies in Selected Industries through MNEs (2016)

Industry	Net carbon transfer/Mt	Value-added /Million USD	Incentive fund /Million USD	Shares
Primary products	3.63	82,318.33	21.51	0.03%
Low-tech manufacturing	10.00	139,346.78	59.23	0.04%
Medium low-tech manufacturing	115.42	162,676.81	683.30	0.42%
Medium high/high-tech manufacturing	17.22	104,779.79	101.95	0.10%
Utilities	267.57	47,852.21	1,584.10	3.31%
Construction	11.60	97,121.46	68.69	0.07%
Services	9.34	469,348.87	55.32	0.01%

Notes: The 34 sectors are classified as primary products, low-tech, medium low-tech, medium high/high-tech manufacturing, utilities, construction, and services, according to the OECD industry list.
Source: Yan et al. (forthcoming).

Conclusion and discussion

Global value chains have become more prevalent in many countries, leading to a surge in CO_2 emissions from international production sharing through both trade and investment (e.g., FDI) channels. The GVC phenomenon, which involves multiple cross-

border flows of intermediate goods, may complicate the implementation of the Paris Agreement, which relies on a patchwork of national policies. A persistent challenge in international climate change negotiations is how to allocate responsibility for global warming among the various participants in GVCs, such as producers, consumers, exporters, importers, investors, and investees.

This chapter presents a consistent GVC accounting framework that allows us to trace the CO_2 emissions responsibility of different country-sector-bilateral combinations through various trading routes. Our results show that the emissions from production processes in developing economies, based on their own responsibility, have accounted for a large share of global emissions growth since 2001 and reached a peak in 2019. This is worrisome because most developing economies have weaker environmental regulations and lower enforcement levels. It is imperative to curb these emissions with more effective tools, including environmental regulation, taxation, and the introduction of carbon trading schemes (ETS) domestically. Taking the PRC as an example (see Tang et al. 2020), if more balanced regulation coverage and equalized financial system for heterogeneous firms (whether they are large-scale firms or SMEs, state-owned, foreign-invested, or private firms), could be introduced, the PRC's 2030 commitment to reduce CO_2 emissions could be achieved more efficiently with less GDP loss (its green investment would be 50% lower, and its energy efficiency 84% higher than in the business-as-usual scenario in 2030). Once the PRC could get "greener" in its domestic production, its exports via GVCs will also be greener.

Although the carbon intensity of GVCs, as measured by emissions per unit of value-added, decreased in both developed and developing economies between 1995 and 2021, generating GDP through international trade is still a more carbon-intensive process than generating GDP through purely domestic value chains. Thus, introducing a Carbon Border Adjustment Mechanism (CBAM) in the context of a trade-investment-environment nexus could promote the formation of green value chains in the GVC and Paris Agreement era. However, a well-designed CBAM at the global level is crucial for getting consensus to increase carbon cost and reduce carbon leakage. For example, applying a GVC-based CGE simulation analysis to the EU's CBAM, Qian et al. (2023) show that several EU countries would experience higher GDP growth, and CO_2 emissions outside EU also would be reduced. However, the EU's CBAM will also trigger a slight increase in total CO_2 emissions within the EU due to the "rebound effects" and carbon leakage across EU countries; most countries especially the non-EU countries will suffer a relatively larger decline in consumer welfare. Therefore, an alternative may be to design the carbon border adjustment along GVCs at the country-sector-bilateral level, based on each country's share of responsibility for CO_2 emissions, rather than a simple one-way imposition like a trade tariff.

In addition to looking at responsibility at the country level, we also examine the roles of MNEs, who are the main actors in GVCs. Based on MNEs' complex production arrangements, global CO_2 emissions are transferred not only between investing countries (home countries) and producing countries (host countries), but also among

other countries (third countries) in the GVC network, which adds to the complexity of global carbon transfer. From a global perspective, about 30%-40% of MNEs' CO_2 emissions are embodied in their exports to third countries, but these shares vary across different economies due to different FDI motivations and GVC production arrangements of MNEs. Nearly 80% of these third-country induced emissions are related to GVC activities, but this share varies considerably by host country (e.g., the share is only 60% in India and over 90% in Australia), and the GVC position of host countries (whether downstream or upstream in the value chain) is an important factor in this difference. At the sector level, in the textile sector, nearly 1/3 of MNEs' emissions are generated in the PRC, and 50% of them are induced by third countries, while this share is only 14% in the U.S. and more than 90% in Viet Nam.

The transnational investment of MNEs also affects the distribution of emission responsibility and economic benefits across countries. Overall, during 2005-2016, the factor income-based accounting (FIBA) value-added and CO_2 emissions of advanced economies are underestimated by 287.2 billion USD to 766.5 billion USD and 415.4 Mt to 489.6 Mt, respectively, while those of emerging markets and developing economies are overestimated. The latter bears some of the emission responsibility of the former, which partly supports the pollution haven hypothesis. From the national perspective, major FDI-outflowing advanced economies receive more factor income and incur less environmental cost, while major FDI-inflowing emerging market and developing economies receive less factor income and incur more environmental cost. As of 2016, the cumulative net carbon transfers from advanced economies to emerging markets and developing economies through MNEs' investment amounted to 1800.8 Mt. If EMDEs were compensated based on an estimation of this environmental cost, an additional 26.61 billion USD would be used to supplement the Green Climate Fund (GCF). Our research provides a useful reference point for future negotiations of carbon responsibility sharing across countries and offers a feasible way for financing the GCF, which will facilitate the achievement of the net-zero emission target consistent with the Paris Agreement.

Although there is a general agreement on the principle of "common but differentiated responsibilities" (CBDR) among the international community, many challenges remain in implementing it effectively. Given the increasing difficulty of limiting global warming to 1.5°C and the fact that most developing economies have no absolute emissions reduction targets and relatively weak environmental regulations, it is crucial to help these countries set appropriate and ambitious targets for reducing emissions and/or achieving carbon neutrality, which could help curb the current rapid rise in global CO_2 emissions. The Paris Agreement allows countries to start from different points and pursue different ambitions toward their own carbon neutrality goal, and uses production-based accounting to measure their emissions (e.g., the original idea of carbon neutrality at the individual country level means taking full responsibility for all direct and indirect emissions), without explicitly considering the responsibility sharing of carbon leakage caused directly and indirectly by international trade and investment.

This implies that a net carbon exporting country and a net FDI inflow country might bear more responsibility in achieving its own carbon neutrality goal, while a net carbon importing country and a net FDI outflow country might bear less responsibility than needed. In this sense, negotiating about responsibility sharing for carbon leakage across countries is inevitable if we want to achieve the global goal of net-zero emissions. Therefore, our GVC-based sharing approach provides a useful reference point for future negotiations.

References

ADB. 2021. Global value chain development report 2021: Beyond production.

Andrew R, Forgie V. 2008. A three-perspective view of greenhouse gas emission responsibilities in New Zealand. Ecological Economics. 68, 194-204.

Antràs P, de Gortari A. 2020. On the geography of global value chains. Econometrica. 88, 1553-1598.

Apple 2022. Environmental Progress Report 2022. https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2022.pdf (Accessed on 30 October 2023)

Avendano R, Tan S, Poquiz JL. 2023. Impact of environmental regulations on carbon intensive FDI in developing Asia, GVC Development Report Background Paper (ADB).

Baldwin R. 2013. Trade and industrialization after globalization's second unbundling: How building and joining a supply chain are different and why it matters. NBER Working Paper. No.17716.

Bastianoni S, Pulselli FM, Tiezzi E. 2004. The problem of assigning responsibility for greenhouse gas emissions. Ecological Economics. 49, 253-257.

Bloom N, Sadun R, Van Reenen J. 2012. Americans do it better: US multinationals and the productivity miracle. American Economic Review. 102, 167-201.

Bohn T, Brakman S, Dietzenbacher E. 2021. From exports to value added to income: Accounting for bilateral income transfers. Journal of International Economics. 131, 103496.

Bu M, Wagner M. 2016. Racing to the bottom and racing to the top: The crucial role of firm characteristics in foreign direct investment choices. Journal of International Business Studies. 47,1032-1057.

Cadarso MÁ, López LA, Gómez N, Tobarra MÁ. 2012. International trade and shared environmental responsibility by sector. An application to the Spanish economy. Ecological Economics. 83, 221-235.

Cadestin C, de Backer K, Desnoyers-James I, Miroudot S, Rigo D, and Ye M. 2018. Multinational enterprises and global value chains: The OECD analytical AMNE database. OECD Trade Policy Papers. No. 211.

Copeland BR, Taylor MS. 1994. North-South trade and the environment. The Quarterly Journal of Economics. 109, 755-787.

Coppola A, Maggiori M, Neiman B, Schreger J. 2021. Redrawing the map of global capital flows: The role of cross-border financing and tax havens. The Quarterly Journal of Economics. 136, 1499-1556.

Dietzenbacher E, Cazcarro I, Arto I. 2020. Towards a more effective climate policy on international trade. Nature Communications. 11, 1130.

Ekholm K, Forslid R, Markusen JR. 2007. Export-platform foreign direct investment. Journal of the European Economic Association. 5, 776-795.

Gereffi G, Fernandez-Stark K. 2016. Global value chain analysis: A primer. The Duke Center on Globalization, Governance & Competitiveness.

GISS-NASA (Goddard Institute for Space Studies, National Aeronautics and Space Administration). 2023. GISS Surface Temperature Analysis version 4 (GISTEMP v4). https://data.giss.nasa.gov/gistemp/

Greenhouse Gas Protocol. 2011. Corporate value chain (Scope 3) accounting and reporting standard. World Resources Institute and World Business Council for Sustainable Development, Washington, DC.

Gütschow J, Jeffery ML, Gieseke R, Gebel R, Stevens D, Krapp M, Rocha M. 2016. The PRIMAP-hist national historical emissions time series. Earth System Science Data. 8, 571-603.

Hoekstra AY, Wiedmann TO. 2014. Humanity's unsustainable environmental footprint. Science. 344, 1114-1117.

Hopkin, M. 2005. Greenhouse-gas levels highest for 650,000 years. Nature.

Ito T. 2013. Export-platform foreign direct investment: Theory and evidence. The World Economy. 36, 563-581.

Johnson RC, Noguera G. 2012. Accounting for intermediates: Production sharing and trade in value added. Journal of International Economics. 86, 224-236.

Kander A, Jiborn M, Moran DD, Wiedmann TO. 2016. Reply to 'consistency of technology-adjusted consumption-based accounting'. Nature Climate Change. 6, 730-730.

Koch N, Basse Mama H. 2019. Does the EU Emissions Trading System induce investment leakage? Evidence from German multinational firms. Energy Economics. 81, 479-492.

Kondo Y, Moriguchi Y, Shimizu H. 1998. CO_2 emissions in Japan: Influences of imports and exports. Applied Energy. 59, 163-174.

Konisky DM. 2007. Regulatory competition and environmental enforcement: Is there a race to the bottom? American Journal of Political Science. 51, 853-872.

Koopman R, Wang Z, Wei S. 2014. Tracing value-added and double counting in gross exports. American Economic Review. 104, 459-494.

Lenzen M, Murray J, Sack F, Wiedmann T. 2007. Shared producer and consumer responsibility — Theory and practice. Ecological Economics. 61, 27-42.

Lüthi D, Le Floch M, Bereiter B, Blunier T, Barnola J-M, Siegenthaler U, Raynaud D, Jouzel J, Fischer H, Kawamura K, Stocker TF. 2008. High-resolution carbon dioxide concentration record 650,000–800,000 years before present. Nature. 453, 379–382.

Melitz MJ, Trefler D. 2012. Gains from trade when firms matter. Journal of Economic Perspectives. 26, 91-118.

Meng B, Gao Y, Ye J, Zhang M, Xing Y. 2022. Trade in factor income and the US-China trade balance. China Economic Review. 73, 101792.

Meng B, Liu Y, Gao Y, Li M, Wang Z, Xue J, Andrew R, Feng K, Qi Y, Sun Y, Sun H, Wang K. 2023. Developing countries' responsibilities for CO_2 emissions in value chains are larger and growing faster than those of developed countries. One Earth. 6, 167-181.

Meng B, Peters GP, Wang Z, Li M. 2018. Tracing CO_2 emissions in global value chains. Energy Economics. 73, 24-42.

Meng B, Ye M. 2022. Smile curves in global value chains: Foreign- vs. domestic-owned firms; the U.S. vs. China. Structural Change and Economic Dynamics. 60, 15-29.

Meng B, Ye M, Wei S. 2020. Measuring smile curves in global value chains. Oxford Bulletin of Economics and Statistics. 82, 988-1016.

Peters GP. 2008. From production-based to consumption-based national emission inventories. Ecological Economics. 65, 13-23.

Peters GP, Weber CL, Guan D, Hubacek K. 2007. China's growing CO_2 emissions -- a race between increasing consumption and efficiency gains. Environmental Science & Technology. 41, 5939-5944.

Pinkse J, Kolk A. 2012. Multinational enterprises and climate change: Exploring institutional failures and embeddedness. Journal of International Business Studies. 43, 332-341.

Qian H, Meng B, Ye J. 2023. How will the EU's carbon border tax redefine global value chains? Considering firm heterogeneity. IDE Discussion Paper.

Rocchi P, Serrano M, Roca J, Arto I. 2018. Border carbon adjustments based on avoided emissions: Addressing the challenge of its design. Ecological Economics. 145, 126-136.

Sapkota P, Bastola U. 2017. Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. Energy Economics. 64, 206-212.

Shahbaz M, Nasir MA, Roubaud D. 2018. Environmental degradation in France: The effects of FDI, financial development, and energy innovations. Energy Economics. 74, 843-857.

Shao Y. 2017. Does FDI affect carbon intensity? New evidence from dynamic panel analysis. International Journal of Climate Change Strategies and Management. 10, 27-42.

Singhania M, Saini N. 2021. Demystifying pollution haven hypothesis: Role of FDI. Journal of Business Research. 123, 516-528.

Tang W, Meng B, Wu L. 2020. The impact of regulatory and financial discrimination on China's low-carbon development: Considering firm heterogeneity. Advances in Climate Change Research. 11, 72-84.

Taylor MS. 2005. Unbundling the pollution haven hypothesis. Advances in Economic Analysis & Policy. 4.

Timmer MP, Erumban AA, Los B, Stehrer R, de Vries GJ. 2014. Slicing up global value chains. Journal of Economic Perspectives. 28, 99-118.

Tukker A, Dietzenbacher E. 2013. Global multiregional input–output frameworks: An introduction and outlook. Economic Systems Research. 25, 1-19.

UNFCCC. 2015. Adoption of the Paris Agreement. Paris: United Nations Framework Convention on Climate Change.

Wang Z, Wei S, Yu X, Zhu K. 2017. Measures of participation in global value chains and global business cycles. NBER Working Paper. No.23222.

Wang Z, Wei S, Yu X, Zhu K. 2021. Tracing value added in the presence of foreign direct investment. NBER Working Paper. No.29335.

Wang Z, Wei S, Zhu K. 2013. Quantifying international production sharing at the bilateral and sector levels. NBER Working Paper. No.19677.

Wiedmann T. 2009. A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecological Economics. 69, 211-222.

World Bank. 2020. World development report 2020: Trading for development in the age of global value chains.

WTO-IDE. 2011. Trade patterns and global value chains in East Asia.

Xing Y, Kolstad CD. 2002. Do lax environmental regulations attract foreign investment? Environmental & Resource Economics. 21, 1-22.

Yan Y, Li X, Wang R, Pan A. 2023a. Global value chain and export-embodied carbon emissions: New evidence from foreign-invested enterprises. Economic Modelling. 127, 106449.

Yan Y, Li X, Wang R, Zhao Z, Jiao A. 2023b. Decomposing the carbon footprints of multinational enterprises along global value chains. Structural Change and Economic Dynamics. 66, 13-28.

Yan Y, Li X, Wang R, Meng B, Zhao Z, Li X. Forthcoming. Visible carbon emissions vs. invisible value added: Re-evaluating the emissions responsibility of multinational enterprises in global value chains. Ecological Economics.

Yan Y, Li X, Wang R, Zhou Y, Zhao Z. 2023d. Is there a “third-country effect” in global carbon emission transfer? New insights from multinational enterprises on the trade-investment nexus. GVC Development Report Background Paper.

Zhang Z, Zhu K, Hewings GJD. 2017. A multi-regional input–output analysis of the pollution haven hypothesis from the perspective of global production fragmentation. Energy Economics. 64, 13-23.

Zhu K, Guo X, Zhang Z. 2022. Reevaluation of the carbon emissions embodied in global value chains based on an inter-country input-output model with multinational enterprises. Applied Energy. 307, 118220.

6

Greening Global Value Chains: A Conceptual Framework for Policy Action

Elisabetta Gentile, Rasmus Lema , Roberta Rabellotti, Dalila Ribaudo

6.1 Introduction

The greening of a global value chain (GVC) is the process that results in the reduction of its ecological footprint, such as the impact on greenhouse gas (GHG) emissions, biodiversity loss, and overexploitation of existing natural resources (De Marchi et al. 2019). Reducing global GHG emissions is fundamental to achieving the Paris Agreement objective of keeping warming below 1.5°C. However, the fact that international production, trade, and investment are increasingly organized in GVCs, with different production stages located across different countries, makes it more challenging to coordinate the multiple actors involved in the chain towards this common goal (ADB forthcoming).

To analyze how greening can occur along the value chain, one must first understand the impact that GVCs have on the environment. There are three main channels through which GVCs affect the environment: a *scale effect*, a *composition effect*, and a *technique effect* (World Bank 2020). The scale effect is described as an increased level of production, leading to increased transport volumes and travels, waste production, and overexploitation of scarce resources, resulting in increased GHG emissions. As GVCs involve multiple cross-border flows of intermediate goods, an increase in economic activity leads to additional emissions from transportation and packaging of intermediate inputs. Indeed, Chapter 5 shows that GVCs have led to a surge in CO_2 emissions from international production-sharing through trade and investment. The international transport sector, in particular, was estimated to account for more than 10% of global emissions in 2018 (OECD 2022), and although overall carbon emissions from international transport dipped during the COVID-19 pandemic,

Note: Chapter contributed by the Asian Development Bank (ADB). The views expressed are those of the authors and do not necessarily reflect the views and policies of ADB or its Board of Governors or the governments they represent.

they are now rebounding to pre-pandemic levels (Crippa et al. 2023). Maritime transport is the type most closely linked to GVCs, since more than 80% of the volume of international trade in goods is carried by sea (UNCTAD 2021). The share of shipping emissions in global emissions is estimated at 2.89% in 2018, and depending on the size of the scale effect, overall GHG emissions from international shipping are projected to increase up to 130% of 2008 levels by 2050 (IMO 2020).[1]

The composition effect reflects changes in the composition of production within a country because of international trade. In the case of GVCs, the production process is broken up into tasks that can be shifted from one location to another. This leads to environmental benefits when production tasks are relocated where it is the most efficient, or environmental costs when carbon-intensive tasks are relocated to jurisdictions where environmental regulation is lax (i.e., ”pollution outsourcing“). The latter scenario also results in environmental inequality, as some countries benefit from shifting economic activity away from carbon-intensive tasks, whereas others pay the cost (ADB forthcoming). Empirical evidence does not support a major reconfiguration of GVCs towards countries with lax climate policies, likely because emission abatement represents a smaller fraction of a firm’s total operating costs compared to capital, labor, and transport costs (Copeland, Shapiro, and Taylor 2021; WTO 2022). It is worth noting that the available empirical evidence may refer to a time when emission permit prices were relatively low. With the increasing diffusion of carbon price initiatives and permit prices increasing, the incentives for carbon leakages are likely to increase (World Bank 2022).

The technique effect refers to firms getting access to production methods that reduce emissions per unit of output through trade. In the case of GVCs, knowledge flows among firms along the value chain to facilitate the development, adoption, and adaptation of ”green” products and processes at different supplier levels (Altenburg and Rodrick 2017). GVC participation can be a powerful incentive for firms to ‘clean up’ their production processes to comply with lead firm requirements, with those who can’t adapt being left out of the value chain.[2]

To sum up, the scale effect results in increased GHG emissions (holding composition and technique constant); the composition effect is negligible; and the technique effect leads to a decrease in emissions per unit of output. Therefore, the technique effect must override the scale effect to reduce the environmental impact of a GVC. Empirical evidence at the macro level shows that the net effect depends on multiple factors, such as the type of pollutant, a country’s development stage, sector composition, and the energy sources used. (WTO 2022).

---

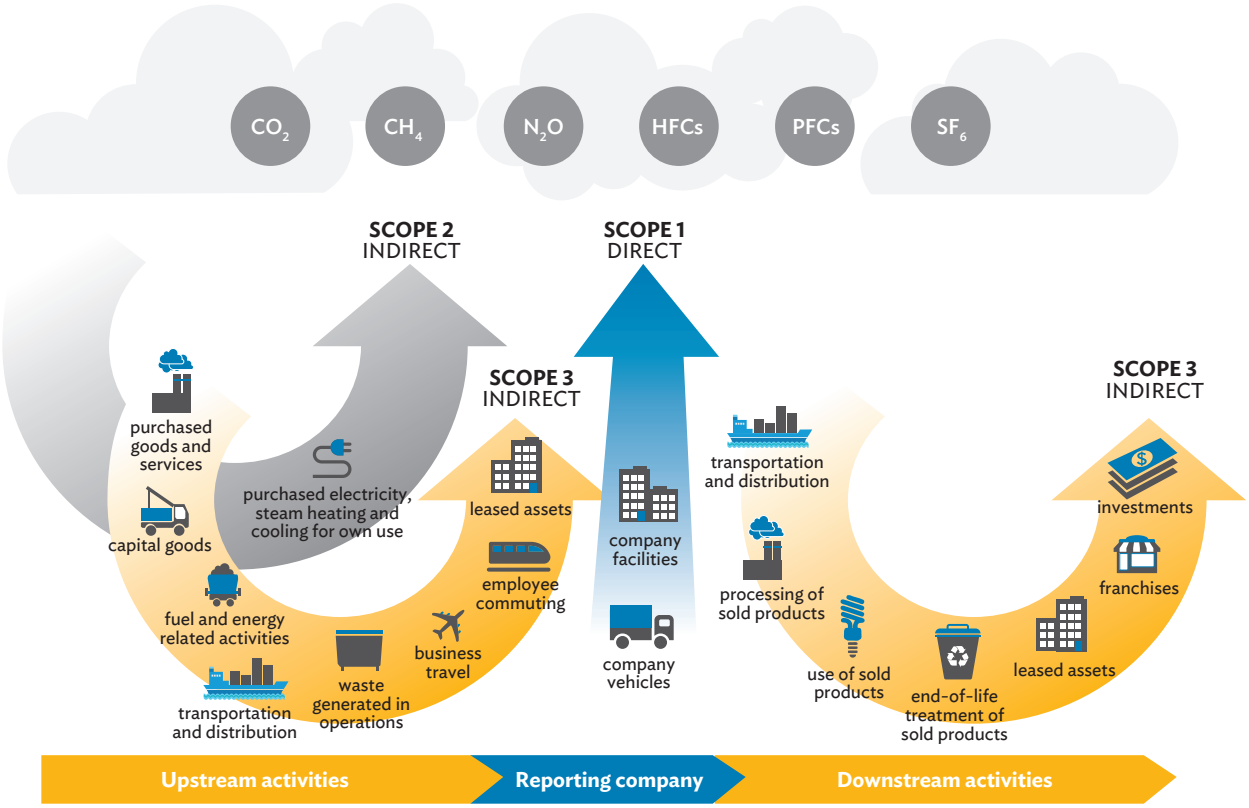
1 At the time the study was conducted, it was too early to assess the impact of the COVID-19 pandemic on emission projections (IMO 2020).

2 Lead firms, such as Toyota, Apple, or Nike arrange their networks of suppliers to produce a given product. They tend to control access to key resources and activities, such as product design, international brands, and access to final consumers. This usually gives them considerable influence over the other suppliers in the production network (Chang, Bayhaqi, and Zhang 2012).

The focus of this chapter is the potential policy levers to incentivize GVC greening at the firm level. A conceptual framework is presented to investigate (i.) why GVC greening occurs, (ii.) the types of environmental innovation undertaken in GVCs, (iii.) the actors involved, (iv.) how the greening occurs in GVCs and the different stages, and (v.) the outcomes of GVC greening. Table 6.1 offers a detailed description of the different elements included in the conceptual framework, which is accompanied by case studies for evidence-based policy implications.

A GVC is a web of independent, yet interconnected enterprises where lead firms tend to specialize in high value-added activities, relying on external suppliers to perform production tasks. The implication for GHG emissions across the value chain is shown in Figure 6.1. Assuming the "reporting company" shown in the figure is a GVC lead firm, the direct emissions from company-owned and controlled resources, known as *scope 1 emissions*, are shown at the center. To the far left, there are the indirect emissions from the generation of purchased electricity, steam, heating, and cooling for the firm's own use, i.e., *scope 2 emissions*. Finally, the indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions, are known as *scope 3 emissions*.

Figure 6.1: Overview of Greenhouse Gas Emissions Across the Value Chain



Source: WRI and WBCSD 2011.

The case of global technology lead firm Apple illustrates the relevance of scope 3 emissions: less than 1% of the firm's CO2 emissions are directly from the corporation itself. No emissions are produced from energy use, since energy is sourced from renewables. However, the products' lifecycle emissions in upstream and downstream production and use are significant: more than 75% of emissions are from products manufacturing in supplier firms, 14% from product use, and 5% from product transport (Apple 2022a). Hence, it is important for lead firms to be accountable for the environmental footprint of their entire value chain.

As shown in Chapter 5, emissions from production tasks are increasingly concentrated in developing economies to produce goods and services for export to high-income economies. Therefore, GVC greening can also help redress the environmental inequality arising from the geographical distribution of tasks along the value chain.

The rest of the chapter is organized as follows: The next five sections examine the five elements of the conceptual framework shown in Table 6.1. This is followed by a three-pronged strategy for policy action based on (i.) creating and amplifying the driving factors, (ii.) leveraging the identified enabling mechanisms, and (iii.) monitoring outcomes and addressing environmental inequality. The chapter concludes by drawing lessons from evidence and findings presented.

6.2 The Driving Factors of Global Value Chain Greening

GVC greening has institutional, market, and technological drivers that have spillover effects on one another. Institutional drivers typically derive indirectly from societal pressures and political decisions to reduce negative externalities in home economies. For example, as of 2022, 46 countries were pricing emissions through carbon taxes or emission trading schemes (Black, Parry, and Zhunussova 2022). Denmark currently has the highest enterprise carbon tax scheme, which will reach USD 160 per ton of carbon dioxide emitted by 2030 (Jacobsen and Skydsgaard 2022). However, as the cost of emissions becomes increasingly expensive in certain countries, there is a risk that firms based in those countries will move carbon-intensive production to countries with less stringent climate policies, a phenomenon known as "carbon leakage."

In order to stem carbon leakage from countries without a carbon price, the European Union is phasing in the Carbon Border Adjustment Mechanism (CBAM), which will take effect in 2026, with reporting starting in 2023. The CBAM is a carbon tariff targeting goods deemed at most significant risk of carbon leakage—cement, iron and steel, aluminum, fertilizers, electricity, and hydrogen—designed to ensure the carbon price of imports is equivalent to the carbon price of domestic production. However, as discussed in Chapter 5, the CBAM is not without criticism from those who see it as further exacerbating global trade tensions and unfairly affecting developing economies with lower historical emissions (ADB forthcoming).

Table 6.1: The Conceptual Framework for Global Value Chain Greening

Key question	Why is GVCs greening occurring?	What type of environmental innovation is involved in GVCs greening?	Who are the actors involved in environmental innovation?	How is environmental innovation implemented in the value chain?	What are the biophysical outcomes?
Description	The main drivers of GVC greening	The main forms of environmental innovation in GVCs	The key actors in GVC greening	The enablers of GVC greening	The outcomes of GVC greening
Main categories	**Institutional drivers** • At national level » Introduction of sustainability standards » Introduction of carbon taxes » Introduction or changes in national environmental legislations • At global level » Environmental provisions in trade agreements » International environmental agreements **Market drivers** • Changes to green preferences among consumers or professional users in existing markets • Shift of market demand to green lead markets **Technology drivers** • New green technology in manufacturing • Digital technologies to minimize waste, energy use, enforce traceability	**Environmental process innovation** • Substitution of energy-sources, energy intensive materials, scarce natural resources, toxic inputs • Reduction of waste from the production process • Reduction of energy consumption • Optimization of the material flow **Environmental product innovation** • New designs replacing environmentally harmful components • Designing of recycled products • Designing for durability • Substitution of complete environmentally harmful product • Recycling • Re-use of waste **Environmental organizational innovation** • Lean production • Green Supply Chain Management	**Chain internal actors** • Lead firms: buyers and producers • Suppliers (different tiers) **Chain external actors** • National/Local governments • NGOs, • Civil society organizations	• **Enabled by lead firms** » Standard-driven » Mentorship driven • **Enabled by suppliers** Autonomous building of internal knowledge • **Collectively enabled** Business associations, consortia • **Enabled by the state** i.e., local, and national governments	• Climate change mitigation • Mitigation of biodiversity loss • Sustainable use of territorial and marine ecosystems • Diffusion of affordable, reliable, and sustainable energies • Diffusion of sustainable consumption and production patterns
Additional questions	• Can the drivers be traced to specific structural changes associated with the green transformation? • Are the drivers mainly national or global?	• Did the innovations involve several types of innovation at once, cross-cutting between product, process and organization? • In which stages of the GVC is the green innovation taking place?	• Is there mainly one driving actor or are several actors jointly responsible for environmental innovation? • How do internal and external actors interact with one another?	• Does learning take place at the collective or individual level? • In which areas have capabilities been built? • Which incentives should be set across the chain to foster the diffusions of environmental innovations?	• Does innovation result in greener GVCs overall? • Have efforts at greening GVCs largely resulted in improved reputations of lead firms rather than improved environmental outcomes? • Are there any trade-offs between positive and negative outcomes? • Who are the beneficiaries of GVC greening? Who are the losers?

Institutional drivers may also arise in multilateral settings. This applies, for example, to trade agreements where detailed environmental provisions are included in the charters with the effect of increasing green exports from developing countries, particularly pronounced in countries with stringent environmental regulations (Brandi et al. 2020).[3] Moreover, private governance mechanisms—whereby environmental concerns become part of a broader multilateral network of cooperation and standardization driven by corporate initiatives—are increasingly becoming relevant. For example, the Carbon Pact agreements that the global shipping company Maersk enters into with its customers form the basis for a value-chain-spanning approach to mitigating the carbon emissions from transport. Through the Carbon Pact, Maersk is provided transparency into the logistical flows of its customers' production network, thus unlocking possibilities for optimization of transport emissions (Salminen et al. 2022).

The market drivers of GVC greening are rooted in changes to green demand preferences amongst consumers or professional users in existing markets or to the shift of market demand to green lead markets, i.e., markets with more stringent environmental protocols. For example, concerns about climate change amongst consumers may lead global buyers to introduce fair trade labels that include a certification process to ensure environmental standards, such as the introduction of the Forest Stewardship Council (FSC) label to wood products to ensure sustainable sourcing or the climate label introduced by the British multinational corporation Tesco in 2007, although this was discontinued in 2012 due to unforeseen costs and lack of take-up by other businesses (Lucas and Clark 2012). British retailer Marks & Spencer's 'Plan A' initiative, discussed in Box 6.1, is an example of consumers successfully driving the lead firm to greening its value chain.

Aggregate demand patterns may shift from locations with lax environmental regimes to green lead-markets (Beise and Rennings 2005). Foreign regulations have stimulated renewable energy innovation in the energy domain due to the foreign demand inducement effect. Foreign climate and environmental policies can thus spur green innovation in other countries. GVCs may act as an important channel whereby foreign environmental regulatory stringency signals are conveyed to induce domestic renewable energy innovations (Herman and Xiang 2022). These are typically diffused through the efforts to meet more environmentally demanding customer requirements. Lead firms may respond to customer and institutional pressure by transferring environmental requirements upstream in the supply chain, either by collaborating or monitoring the suppliers' environmental performance (Laari et al. 2016).

A different demand effect is seen when the final demand for sectoral products shifts from one market to another, where the latter is part of the green economy. For example, when demand for lithium shifted from ceramics and glass to lithium-ion batteries—a

3 For an overview of the environmental provisions included in preferential trade agreements (PTAs), see the TRade and ENvironment Database (TREND) (IDOS 2022).

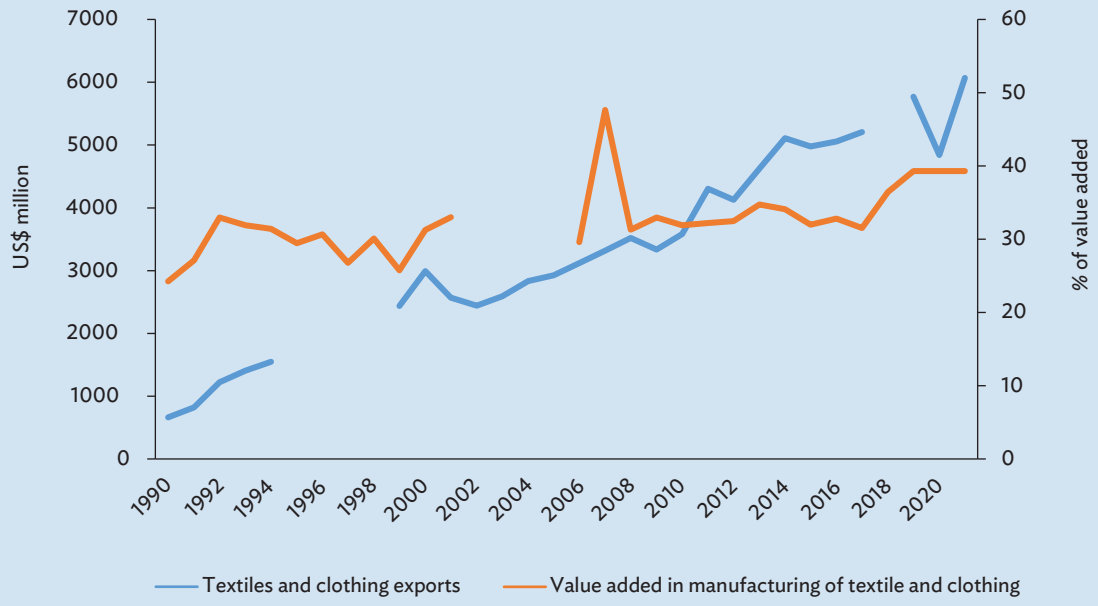
market with significantly higher environmental attention—it induced environmental innovations to reduce mining waste at the source of GVCs (Tabelin et al. 2021).

Box 6.1: The (Un)Willingness to Pay for Green: Textile Suppliers in Sri Lanka

The textile industry has a high environmental impact because of its intensive use of natural resources, energy, and chemicals (European Parliament 2023). It is also one of the "light industries" where the barriers to entry in production are relatively low, serving as a springboard for export-oriented industrialization for developing economies (OECD, WTO, and IDE-JETRO 2013). Figure 6.2 presents the case of Sri Lanka. Between 1990 and 2021, the country saw a steady growth in textiles and clothing exports and an increase in value added in manufacturing, albeit at a slower pace.

Sri Lankan exporters on the textile value chain are typically first-tier suppliers to international apparel brands, exporting finished garments manufactured with imported materials. One of those international brands is British retailer Marks & Spencer (M&S). In 2006, M&S conducted a survey that showed their customers' growing expectations for the company to focus on climate change. However, they did not want to pay a premium for it, and they did not want to know all the details of what the company was doing to fight climate change and how it was doing it (Goger 2013). To align its strategy to the survey findings, in 2007 M&S launched the M&S Plan A, with the tagline: "Plan A because there is no Plan B for the one planet we have" (M&S 2015). Plan A included 100 ethical commitments to be achieved within 5 years, implemented both internally and among roughly 2,500 suppliers around the world, based on the idea that environmental upgrading could enhance supplier competitiveness in the long run.

Figure 6.2: Sri Lanka's Performance in Textile and Clothing Manufacturing, 1990–2021



Source: World Integrated Trade Solution and World Development Indicators (accessed 26 September 2023).

As one of the first Plan A projects in 2007, M&S decided to pilot four model environment-friendly factories for apparel in Sri Lanka, partly because the Sri Lankan suppliers had well-established relations of trust with M&S after 20 years of doing business together (Goger 2013). The pilot projects involved green designs for the plants and work processes such as rainwater catchment, solar power, waste reduction, and an energy-efficient cooling system (Figure 6.3).

Although building the model eco-factories cost approximately 30% more than a conventional factory, M&S contributed a very small share of the overall cost in seed funding. Furthermore, it did not offer a price premium, did not commit to higher orders, and did not offer long-term contracts to its suppliers. It is not surprising, then, that the model eco-factories were built by firms that had substantial financial and managerial resources and were well positioned to benefit from early mover advantages (Goger 2013).

continued on next page

Box 6.1: continued

In a different study, Khattak et al. (2015) interviewed three textile firms in Sri Lanka that had embarked on an environmental upgrading trajectory in one or more of their factories. All firms held the Leadership in Energy and Environmental Design (LEED) certification standard, were International Standards Organization (ISO) 14001 certified, and were signatories of the Global Compact, a policy initiative for businesses committed to aligning their operations and strategies with 10 principles in the areas of human rights, labor, environment, and anticorruption. Compliance with these standards is necessary to get procurement from global buyers, namely European and United States-based retailers.

Figure 6.3: The Plan A Model Eco-Factories

a. Green Uniforms in a Model Eco-Factory

b. Plants on the Shop Floor and Natural Lighting

c. a Green Roof on a Model Eco-Factory

d. Solar Panels and Rainwater Catchment Systems

Source: Goger (2013).

The three firms studied by Khattak et al. (2015) engaged in environmental upgrading through a combination of technological, organizational, and social initiatives. Because of the substitution of fossil energy sources and the shift towards biogas, solar PV, and hydroelectric power for steam production, all firms included in the study were able to reduce their carbon emissions. Some of the factories had also introduced rainwater harvesting facilities and waste recycling systems to divert waste from landfills. The firms transformed their organizational processes by incorporating policies and regulations consistent with the standard of their environmental certifications and implementing monitoring tools. Finally, they organized programs to foster a green culture across all levels of employees.

In all three cases examined by Khattak et al. (2015), lead firms played a key role in the environmental upgrading process. They encouraged their local suppliers to upgrade, set the standards, and offered future contracts in exchange for compliance. They shared knowledge not only on certification standards to help their suppliers upgrade, but also on future industry trends. It is also worth noting that all three factories manufactured and exported high value-added products for which specifications and production processes are not easily codified; hence, frequent interactions between lead firms and suppliers were required to transmit the tacit knowledge required.

For all three local suppliers, lead firms did not provide any low-cost funding nor grants to support environmental innovation, and most of them did not offer higher prices for products manufactured in an environmentally sustainable manner. Because improving the eco-efficiency of production lowered operating costs, the three suppliers stayed competitive by offering lower prices to international buyers.

continued on next page

Box 6.1: continued

In addition to asking suppliers to improve environmental compliance without any financial support, lead firms are known to pressure them for a lower price, a practice known as "squeezing." While already capable and financially sound suppliers can absorb the initial investment in greening their operations, firms facing capacity and financial constraints may be left out of the value chain (Goger 2013; Ponte 2020).

This case study shows that shifts in consumer demand can lead to GVC greening. However, when consumers are unwilling to pay a premium for products from sustainable manufacturing and lead firms are unwilling to reward suppliers for such compliance, only the more advanced firms with considerable financial resources can participate.

References

European Parliament. 2023. *The impact of textile production and waste on the environment (infographics)*.
Goger, Annelies. 2013. "The making of a 'business case' for environmental upgrading: Sri Lanka's eco-factories." *Geoforum* 47, pp. 73-83.
Khattak, Amira and Christina Stringer and Maureen Benson-Rea and Nigel Haworth. 2015. Environmental Upgrading of Apparel Firms in Global Value Chains: Evidence from Sri Lanka. *Competition & Change* 19(4), pp. 317–335.
Marks & Spencer. 2015. *Reflections on plan a progress.* (accessed September 26, 2023).
Organisation for Economic Cooperation and Development (OECD) and World Trade Organization (WTO) and Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO). 2013. *Aid for Trade and Value Chains in Textiles and Apparel.*
Ponte, Stefano. 2020. The Hidden Costs of Environmental Upgrading in Global Value Chains. Review of International Political Economy 29(3), pp. 818–843.

The technology drivers of GVC greening arise when new technologies induce efficiency savings with a greening effect or innovations to meet greener demand requirements. Innovations may spread beyond individual firms through entire value chains, and such diffusion, especially between the Global North and Global South, is key to greening GVCs (Glachant et al. 2013).

The major technological shift that occurred at the turn of the 21st century, known as the Fourth Industrial Revolution (4IR), is characterized by the convergence of a wide range of breakthroughs—not just digital (e.g., artificial intelligence), but also physical (e.g., new materials) and biological (e.g., bioengineering). Particularly relevant to GVC greening are Smart Manufacturing and Service Technologies and Data Processing Technologies (Lema and Rabellotti 2022).

Smart manufacturing and service technologies are involved in automating and decentralizing production tasks. They include advanced robotics, 3D printing, wireless technologies, and sensors (e.g., the Internet of Things [IoT]). Examples of this class of technologies include RFID tags, which can improve logistics efficiency and thereby reduce global trade's overall carbon impact; fixed and mobile sensors in harvesting and logging equipment and satellite data that provide precise information on matters of interest such as tree species, biodiversity counts, or illegal logging and fishing; and wireless sensors and GPS tracking systems that generate data used to optimize logistics and significantly reduce carbon emissions (Caldeira Pedroso et al. 2009, Gale et al. 2017, Mangina et al. 2020). In the case of smart factories that already employ IoT and robots, improvements in the algorithms could result in continuous optimization and increases in energy efficiency. For example, in a case study of a smartphone manufacturer that uses robots, based in the People's Republic of China, algorithm changes to optimize the robot operation increased the productivity of these machines

(Fuoco 2018). Finally, the savings in using 3D printing instead of traditional production methods can be substantial. For example, a study found that additive manufacturing on the production of less flight-critical lightweight aircraft parts could reduce the weight of these parts, thus reducing the weight of an airplane, its fuel consumption, and the related carbon emissions in air travel (Huang et al. 2016).

Data processing technologies enable interconnection and data exchange within and between firms. They include big data, blockchain, cloud computing, and Artificial Intelligence (AI). Blockchain can enhance sustainability both upstream and downstream. In upstream supply chain management, for example, blockchain can track faulty products or components to reduce reproduction, with recalls resulting in decreased resource consumption and reduced GHG emissions; it can also increase traceability to ensure that designated green products are environmentally friendly, such as in the case of the blockchain-based Supply Chain Environmental Analysis Tool (SCEnAT) system to trace the carbon footprint of products or the Programme for the Endorsement of Forest Certification (PEFC) to ensure that wood is sustainably sourced (Saberi et al. 2019). Downstream, blockchain can be used to enhance incentives to recycle, such as with the RecycleToCoin system that enables people to return plastic containers for a financial reward, and to provide information to buyers on the origin of products and guarantees authenticity of the information.

AI is relevant across environmental domains such as energy, production, and natural resource management (Toniolo et al. 2020). For example, to reduce energy consumption in operations, firms are starting to adopt technologies that can optimize green energy use in smart grids. In agriculture, supply chain professionals can draw on AI inputs to plan shipping and the delivery of perishable goods by monitoring and forecasting the state of the cargo. This is often aided by AI that draws on data from sensors and other technologies involved in smart supply chain systems and intelligent food logistics. Measures such as certifications, codes of conduct, supply chain reporting, lifecycle assessments, supplier audits, smart packaging, and eco-efficiency programs may all be aided by AI. In this respect, machine learning and intelligent automation improve environmental management.

Box 6.2 presents the famous case study on the sourcing of tuna from the Eastern Tropical Pacific (ETP) purse seine fishery, which resulted in high dolphin mortality due to entanglement in the nets. The tuna caught in the ETP was then processed, canned, and sold to consumers in the United States. Dolphin mortality was a negative biophysical outcome in the canned tuna value chain that was greatly reduced in the thirty-year period going from the early 1970s to the early 2000 through a convergence of market, institutional, and technology drivers. It is also a case where legislation at the national level resulted in ”leakage” of the environmental cost, with subsequent attempts by the national legislator to address the problem. Finally, it emphasizes the importance of multilateral action to create common rules and standards.

Box 6.2: The "Tuna-Dolphin Problem" and the Drivers of Global Value Chain Greening

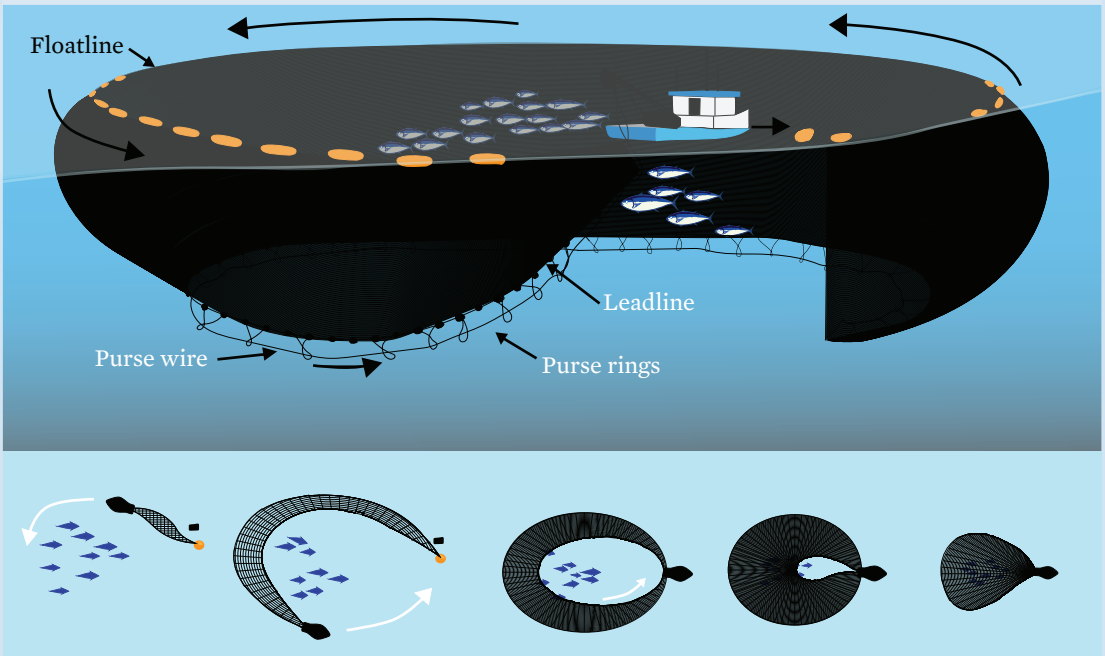
The Eastern Tropical Pacific (ETP), a large swath of the Pacific Ocean extending from Mexico to Peru, is the only region in the world where large pods of dolphins are prevalent above schools of tuna, accompanied by flocks of seabirds. This gathering makes it possible to visually locate large schools of tuna by searching for the seabirds, which closely track the tuna. Once the dolphins are sighted closer to the ocean surface, they are chased and encircled with purse seines to capture the schools of tuna underneath them. A purse seine is a large surrounding net that hangs vertically in the water with its bottom edge held down by weights and its top edge buoyed by floats. Once the school of tuna is encircled, the net is "pursed" at the bottom, capturing the dolphins that follow the tuna (Figure 6.4).

It has been estimated that more than 7 million dolphins were killed by ETP tuna purse seiners since the late 1950s (IMMP 2022), and this is just due to entanglement. Research suggests that chase and encirclement may also have many other negative impacts on dolphins, such as increased fetal and calf mortality, separation of nursing females and their calves, decreased fecundity, increased predation, disruption of mating and other social systems, and ecological disruption (Ballance et al. 2021).

In the mid-1960s, the high dolphin mortality in the ETP tuna purse seine fishery came to widespread public attention in the United States, resulting in calls on the government to take action that ultimately led to the Marine Mammal Protection Act (MMPA) being enacted in 1972 with the goal of reducing dolphin mortality to "insignificant levels approaching zero" (NOAA 2023). Since dolphin mortality continued to be high after the passage of the MMPA, the legislation was tightened in subsequent amendments that led many US vessels to register under flags of other countries or to fish for tuna in other geographic regions, using other methods (Ballance et al. 2021).

Modifications to purse-seine fishing methods were identified relatively early to reduce dolphin mortality from entanglement. They range from simple solutions such as using swimmers and divers to disentangle and release dolphins and using high-intensity floodlights to illuminate dolphins in the nets at night, to more technical solutions. For example, the "backdown," whereby the vessel is run in reverse after the seine has been pursed and approximately two-thirds of the net brought on board the vessel, which releases the dolphins while the tuna tend to remain below the dolphins in a deeper part of the net. Sawing a "dolphin safety" panel of relatively small mesh netting into the purse seine to surround the apex of the backdown area where dolphins are most likely to gather has also proven very effective (Ballance et al. 2021).

Figure 6.4: A Purse Seine Net



Source: Authors based on AFMA 2023.

continued on next page

Box 6.2: continued

As US vessels left the ETP fleet due to the stringent MMPA requirements, vessels from other countries entered in larger numbers, so that the number of vessels using purse seines in the ETP continued to increase. The 1984 amendments to the MMPA introduced embargoes on tuna imports from fleets with dolphin mortality above that of the US fleet, due to concerns that US gains in lowering dolphin mortality were being offset by increased mortality from non-US vessels. In 1988, dolphin mortality requirements on tuna imports were further tightened. At the same time, environmental public opinion pressure led to voluntary action by the three largest US tuna canners to buy only tuna caught using methods other than purse seine fishing.

The US embargo on the sale of tuna caught with purse seine nets was lifted in 1997 after challenges by Mexico and other nations under the General Agreement on Tariffs and Trade (GATT). Meanwhile, a 1990 amendment to the MMPA established the "dolphin-safe" label, which mandated that during the entire trip for which tuna were captured no purse seines were deployed that targeted dolphins at the sea surface, as verified by a certified observer. The labels, combined with environmental activism to pressure major US retailers, effectively excluded tuna caught on dolphins from the large and lucrative US market (Ballance et al. 2021). Mexico challenged the dolphin-safe label multiple times under the WTO non-discrimination rule and the WTO's appellate body ruled against the US in 2012 and 2015, arguing that the label did not take into account the risk to dolphins of other tuna fishing methods. After the US adapted the label, the appellate body upheld the measure in 2019 and ruled that it is fully consistent with WTO rules (WTO 2019).

In the early 1990s, before the embargo on non-MMPA compliant tuna was lifted, the foreign fleets' desire to re-enter the US market formed the basis for a series of multilateral initiatives (Ballance et al. 2021). In 1992, with the La Jolla Agreement, 10 fishing countries (including the US and Mexico) established the International Dolphin Conservation Program with a focus on comparability of dolphin mortality to the US fleet under the MMPA and the dolphin-safe label. The agreement introduced two key features: (i) the non-transferable Dolphin Mortality Limit (DML) per vessel, whereby once a vessel reached its own DML, it was required to cease purse seine fishing targeting dolphins, and a vessel changing flags would still retain its DML; and (ii) an International Review Panel (IRP) tasked with the review of cases of apparent non-compliance with the La Jolla Agreement based on fisheries observer reports. In addition to representatives of the Parties to the Agreement, the IRP included elected industry and NGO representatives, thus increasing transparency and accountability.

In 1995, the Declaration of Panama was signed by 12 nations. It reaffirmed a commitment to reduce dolphin mortality to levels approaching zero, declared the nations' intention to formally establish strict stock-specific DMLs on a per-vessel basis, and agreed to place fisheries observers on every large purse-seine vessel to verify dolphin mortality. Finally, in 1998 features of the La Jolla Agreement and the Declaration of Panama were formally incorporated into the Agreement on the International Dolphin Conservation Program (AIDCP), a legally binding multilateral agreement with three primary objectives: (i.) progressively reduce incidental dolphin mortalities in the tuna purse-seine fishery in the Agreement Area to levels approaching zero, through the setting of annual limits; (ii.) seek ecologically sound means of capturing large yellowfin tunas not in association with dolphins with the goal of eliminating dolphin mortality in this fishery; and (iii.) ensure the long-term sustainability of the tuna stocks in the agreement area, as well as that of the marine resources related to this fishery, taking into consideration the interrelationship among species in the ecosystem (IATTC 2023).The AIDCP also made periodic attendance of informational seminars to educate fishing captains on bycatch mitigation a requirement for certification to engage in purse-seine fishing under the agreement.

Together, these institutional, market, and technological drivers reduced dolphin mortality due to entanglement by more than 99%. However, it is unclear whether and to what degree dolphin populations have recovered. That is because conducting comprehensive repeated surveys to derive rigorous estimates of dolphin populations requires significant funding, not to mention the logistical challenges of such a large and remote area, and the multinational nature of the fishery, which complicate data collection, regulation, and enforcement (Ballance et al. 2021). Multilateral action is needed to monitor the biophysical outcomes of countries' joint action.

References

Ballance, Lisa T. and Tim Gerrodette and Cleridy E. Lennert-Cody and Robert L. Pitman and Dale Squires. 2021. A History of the Tuna-Dolphin Problem: Successes, Failures, and Lessons Learned. *Frontiers in Marine Sciences* 8(754755).

International Marine Mammal Project (IMMP). 2022. The Tuna Dolphin Tragedy.

Inter-American Tropical Tuna Commission (IATTC). 2023. Agreement on the International Dolphin Conservation Program (AIDCP). (Accessed on 6 October 2023).

National Oceanic and Atmospheric Administration (NOAA). 2023. Marine Mammal Protection Act: The full text of the Marine Mammal Protection Act of 1972 as amended. (Accessed on 6 October , 2023).

World Trade Oraganization. 2019. US-Tuna II (MEXICO) (DS381): Summary of Key Findings. (Accessed on 6 October 2023).

6.3 Types of Environmental Innovation

Environmental innovation is defined as a radical or incremental change in processes, products and organizational models that results in a reduction of the chain's ecological footprint – such as its impact on greenhouse gas emissions, biodiversity losses, and natural resources overexploitation (De Marchi et al. 2019). In this section, we distinguish between environmental process innovation, environmental product innovation, and environmental organizational innovation, although in the real world there is a lot of overlap among the three categories. For example, it may be difficult to distinguish between process and product environmental innovations; the two often take place together since a change in the production process is often needed to modify a product. Process and organizational innovations could also overlap because process improvements can be the result of fulfillment of environmental management standards such as ISO 4000 (De Marchi and Di Maria 2019). Nonetheless, the evidence presented in this section is useful to get a more concrete grasp of what type of innovation is making GVC greener.

Environmental process innovation occurs when eco-efficiency increases along the different stages of the value chain through the reorganization of the production process or the use of superior technology. An example of environmental process innovation in the logistics of PET plastic bottle recycling is described by Bjorklund et al. (2012). The large volume of collected PET bottles creates challenges in terms of increasing requirement of storage space and rising emissions from transportation. To tackle these issues, Returpack, a Swedish recycling company, introduced a new equipment to compress the bottles in collecting trucks, reducing the transported volumes throughout the entire flow. This innovation led to a reduction in the number of trips, an increase in the volume of recycled bottles, and a decrease in the company's carbon footprint.

Kunkel et al. (2022) explore the greening of Chinese companies in the electronics industry due to the introduction of Big Data Analytics (BDA) for sustainable supply chain collaboration. The adoption of BDA for tracking suppliers' environmental footprints has made it possible to: (i) track CO2 emissions along the supply chain; (ii) predict whether companies were at risk of not meeting sustainability targets; (iii) calculate carbon footprint along the chain; and (iv) track fleet routes in logistics processes. This has also resulted in more efficient tracking and tracing of containers and reusable packaging material, with a reduction in the amount and cost of packaging.

The tannery district in Arzignano, Italy, is an example of suppliers within GVCs as proactive actors in environmental innovation (Box 6.3). The local government supported creation of the baseline infrastructure to reduce the cluster's ecological footprint; that enabled the firms to leverage funding from the EU for environmental innovation.

Environmental product innovation takes place with the development of environment-friendly products (i.e., designed for durability, using recycling inputs, recycling, reduced

Box 6.3: Environmental Innovation in Industrial Clusters—The Arzignano Tannery District

In the leather production process, several steps to produce the final output entail a high level of water consumption and pollutants that in the final stage produce emissions like dust and organic compounds. Consequently, the leather industry has experienced a growing flow of investments in environmental sustainability.

Arzignano is an industrial town of about 25,000 people in northeastern Italy. Its industrial district specializes in leather production and the local tanneries are suppliers in different value chains, such as IKEA in the furniture industry, LVMH in the fashion industry, and Audi and BMW in the automotive industry. Within the leather GVC, tanneries usually perform low value-added tasks at the production stage (Figure 6.5). The higher value-added tasks in pre-production, such as research and development, are generally performed by chemical firms (including large multinationals such as BASF), whereas lead firms handle higher value-added tasks in post-production, such as marketing and branding (De Marchi and Di Maria 2019).

Figure 6.5: Leather Production in an Arzignano Tannery

Source: Gruppo Mastrotto SpA

In response to environmental pressure and stringent regulation, the cluster has undertaken intense environmental upgrading activities since the early 1970s, acting both at the cluster and firm level, with a gradually more systemic approach. With support from the local government, the consortium built a water treatment plant and an industrial sewage system to collect sludge and water refuse from the tanneries. These investments represent a baseline infrastructure for the improvement of the local environmental situation and the foundation for further cluster development; that is precisely what happened with the GreenLIFE project, funded by the European Commission, which ran from 2014 to 2017. Five local companies developed several process innovations to make the leather production process more sustainable (European Commission 2021). A first innovation introduced in the local tanneries was aimed at reusing water, also leading to a reduction in electricity use. A further area for innovation was the optimization of material flow in the liming process using oxygenated water instead of pollutants, thereby reducing the use of toxic inputs. Finally, the local firms developed a new tanning agent from renewable sources based on natural polymers instead of chrome.

While the creation of the baseline infrastructure was mostly in response to local pressures, the tanneries' participation in GVCs provided a powerful incentive for them to engage in environmental innovation. First, by demonstrating the ability to develop such advanced processes, the tanneries wanted to signal to their international buyers that they are ready to perform higher value-added activities, including co-development of new product lines. Second, large international buyers, especially in the automotive and fashion industries, are demanding increasingly sustainable inputs of their suppliers in response to pressure from consumers and policymakers. Third, when it is not possible to compete on costs with suppliers from emerging markets (e.g., the People's Republic of China), then environmental sustainability is key to maintaining a competitive advantage (De Marchi and Di Maria 2019).

The new processes tested under the GreenLIFE project demonstrated up to 70% less water consumption due to bath recovery; reduced consumption of chemicals (up to 80% of sulfates, 20% of chlorides and complete elimination of chromium and formaldehyde compounds); lower energy consumption (up to 10% less electricity and 10% methane); lower waste production (up to 50% of the waste produced in weight can be recycled); and reduced odorous emissions from the tannery district (European Commission 2021). The achievements of the project have also contributed to a wide range of EU legislation.

The case of the Arzignano leather cluster highlights several aspects of GVC greening. First, is the role suppliers take as drivers of environmental innovation within GVCs as opposed to lead firms, which do not have technical knowledge in the tannery process (De Marchi and Di Maria 2019). Second, it is an example of collectively enabled innovation, which is commonly found in industrial clusters (Giuliani, Pietrobelli, and Rabellotti 2005). Finally, the case highlights the role of the local government as an actor enabling innovation by supporting the creation of the local infrastructure that propelled further cluster development, as well as the role of supranational organizations such as the European Union in supporting environmental innovation.

References

De Marchi, V., and Di Maria, E. (2019). Environmental upgrading and suppliers' agency in the leather global value chain. *Sustainability*, 11(23), 6530.

European Commission. 2021. *GREEN LIFE: GREEN Leather Industry for the Environment.* Reference: LIFE13 ENV/IT/000840. (accessed September 24, 2023).

Giuliani, Elisa and Carlo Pietrobelli and Roberta Rabellotti. 2005. Upgrading in Global Value Chains: Lessons from Latin American Clusters. *World Development* 33(4), pp. 549-573.

packaging, and waste reuse). An example is provided by Aquafil, an Italian company specializing in nylon yarns for carpeted floors (De Marchi et al. 2013b). In addition to investing in energy production and a more efficient energy management through a co-generation plant, the company developed a new yarn named Econyl, made by recycling carpets, which reduces the use of raw materials and waste at the end of the product lifecycle.

Box 6.4 presents the case of Valcucine, an Italian company producing high-end, design-driven kitchens. Because of its continuous research and development efforts, the company introduced several environmental features to differentiate itself from the competition, thus obtaining a premium price (De Marchi et al. 2013a).

Box 6.4: Valcucine: A Mentoring-Driven Approach to Product Innovation

Valcucine is an Italian company in Northeastern Italy that specializes in the production and commercialization of kitchens for high-end markets. Its business model is based on attractive design, technological innovation, and attention to quality and sustainability. The firm does not perform any manufacturing activity except for assembly and relies on a network of roughly 300 suppliers, with first-tier suppliers mostly located in the surrounding area. Design and marketing are the major activities performed in-house, while sales are carried out by specialized retailers worldwide and through a few flagship stores. Valcucine is responsible for the marketing and design of almost all new products and cooperates with suppliers on technical features.

Valcucine's environmental goals of reducing the materials used in the production process, reducing the environmental impacts of furniture disposal, and improving recyclability are achieved through extensive product innovation. Kitchens are designed to be technically and aesthetically durable, and highly recyclable (up to 100%)— attributable to the selection of raw materials (e.g., glass and aluminum), and the use of one-material components that are put together solely by mechanical joints. Accessories, such as lights and appliances, are considered to be among the most environment-friendly available on the market.

The typical supplier In Valcucine's network is a small family-run operation for which the cost of obtaining and maintaining an environmental process certification can be prohibitively high. Therefore, the company typically does not ask for certifications as a prerequisite to do business. Instead, compliance with the environmental features of the product is guaranteed by a tough internal control system based on first-hand knowledge of the processes used by suppliers achieved through frequent on-site visits and by co-developing process innovations. The firm also actively looks for second-tier suppliers that can match its requirements and join the collaboration with first-tier suppliers to develop new products. This is the case, for example, of the air emission and health improvements achieved through the co-development of a new waterborne varnish in close cooperation with its first-tier supplier, a varnish producer, and a machinery company (De Marchi et al. 2013a).

Valcucine fosters the environmental upgrading of its suppliers by sharing knowledge on the product, processes, or organization, and at times through joint investments or other favorable financial conditions. It suggests how to reduce environmentally harmful products and processes and collaborates with suppliers in developing new solutions. In addition, the company works to sensitize its suppliers on why it is important to reduce environmental impacts and how this process can yield important economic benefits for them.

The Valcucine case shows that a mentoring approach based on close collaboration of the lead firm with its suppliers can lead to environmental innovations that go beyond mere compliance with environmental process certification standards. However, this approach is likely facilitated by the physical proximity of the lead firm with many of its key suppliers.

References

De Marchi, Valentina and Eleonora Di Maria and Stefano Ponte. 2013a. The Greening of Global Value Chains: Insights from the Furniture Industry. *Competition & Change* 17 (4), pp. 299–318.

Environmental organizational innovation happens when organizational changes reduce the environmental impact of companies (i.e., introduction of lean production tools). An example of organizational innovation with environmental implications is "lean manufacturing" practices aimed at reducing production costs by avoiding overproduction and excessive inventory, reducing transportation, defects, delays, and overprocessing.

Chiarini (2014) presents a study of five European manufacturers of motorcycle components for customers including Piaggio, Aprilia, BMW, and Honda. All companies share similar assembly lines and do not treat chemical products; their main concerns are energy consumption, oil spillage, and emissions of fumes and dust in production processes. To address environmental concerns, they adopted lean manufacturing. The study shows that an organizational innovation as simple as positioning machines closer to one another reduces handling and transportation of materials within the plant, and introducing new technology to press plastic products reduces the amount of garbage produced. In this case the incentive for these suppliers to adopt lean manufacturing practices was twofold: operating in the EU means that these companies are committed to environmental strategies such as ISO 14001 and publishing their environmental balances and impact yearly; and increasing efficiency and minimizing waste can curb production costs.

Laari et al. (2016) investigate the adoption of customer-driven Green Supply Chain Management (GSCM) in 119 Finnish manufacturing companies. GSCM manages upstream and downstream supply chains for minimizing the overall environmental impact. It is a combination of environmental and supply chain management techniques, involving both the internal dimension of firms (i.e., green transport and green marketing) as well as external transactions with suppliers and customers. The study finds that manufacturers with strong internal GSCM practices combined with arm's length environmental monitoring of suppliers are likely to perform well in environmental issues and that if a firm seeks to improve financial performance, it needs to form more collaborative relationships with customers to achieve environmental goals.

6.4 Actors Involved in Environmental Innovation

The GVC literature stresses the role played by the lead firms in transferring knowledge and introducing innovations along the chain. With respect to GVC greening, lead firms are described as the main driving actors of environmental innovation. As further elaborated in the next section, lead firms can adopt different governing mechanisms to facilitate or impose the greening of suppliers. They can, for example, impose standards on their suppliers and expect them to comply, or they can provide mentorship support, transferring knowledge and reinforcing the learning process needed to become greener (De Marchi et al. 2019). Case 1 on the Sri Lankan textile suppliers provides an example of buyer-driven environmental innovation.

Suppliers may also autonomously introduce environmental innovations contributing to GVC greening. The case study on the Italian leather value chain discussed in Box 6.3 shows that tanneries involved in the automotive and fashion value chains introduced environmental innovations without a specific request by the lead firms, but rather proactively anticipating the introduction of new technical standards in the industry.

Actors external to the chain include policymakers, customers, NGOs, and civil society organizations (CSOs). While the institutional drivers of GVC greening are discussed in section 6.2.1, the Hawassa Eco Park case discussed in Box 6.5 shows how policymakers can go beyond their regulatory role and become direct actors in the GVC greening process, in this case by collaborating with private actors in policy design.

De Marchi et al. (2019) refer to two examples of independent third-party organizations playing a role in sustaining the development of socio-environmental standards: Oxfam's Behind the Brands campaign (2013-2016) followed by the Implementation Initiative (2016-2020) and Greenpeace's Detox campaign in the fashion industry. Oxfam challenged 10 of the largest food and beverage companies to improve their social and environmental policies. The companies introduced a scorecard system measuring the strength of sustainability and human rights policies and commitments, not only at the level the company itself but within its supply chain. Following the Greenpeace campaign, 80 companies, including retailers and suppliers in the fashion industry, pledged to reduce or eliminate toxic chemicals from their products.

Box 6.5: When private actors and government come together: The Hawassa Industrial Park

Hawassa is a city in Ethiopia of about half a million people that hosts a 300-acre industrial EcoPark. The inception of the EcoPark is the result of the synergy between the private and public sector, more specifically, the cooperation between the Government of Ethiopia and the Phillips-Van-Heusen (PVH) company.

Based in New York City, PVH is one of the biggest holdings in the fashion industry, owning brands such as Calvin Klein and Tommy Hilfiger. In its efforts against climate change, PVH pledges to (i.) drive a 30% reduction in its global supply chain (Scope 3) emissions by 2030, (ii.). eliminate single-use plastics by 2030, and (iii.) achieve zero hazardous chemicals and harmful microfibers in textile wastewaters by 2025 (PVH 2019).

The objective of the Government of Ethiopia was to attract investors by establishing a sustainable textile and apparel industry in the country at the supplier level. The government acted through the Industrial Parks Development Corporation (IPDC), an initiative devoted to attract foreign direct investment in key strategic manufacturing industries. Public investments facilitated job creation and technology transfer in areas such as waste management.

When PVH showed interest in Ethiopia, the government built the Hawassa Industrial Park. PVH indicated that all the environmental and safety regulations and the characteristics of the data-driven monitoring system were based on the standards developed within the Sustainable Apparel Coalition (SAC), of which PVH is a member, as conditions for sourcing from Ethiopia. The EcoPark offers infrastructure such as a solid waste management system, 100% renewable energy, and LED lights, which are needed for companies to qualify as certified suppliers.

In 2012, PVH became an early mover in Ethiopia. Currently, the park hosts 18 apparel and textile companies from the US, the People's Republic of China, India, Sri Lanka, and six local manufacturers (Hawassa Industrial Park 2023).

The Hawassa Industrial Park is a case of policymakers going beyond their regulatory role to become direct actors in the GVC greening process (Jensen and Whitfield 2022); thus, it is an example of environmental upgrading enabled by the integration of private actors and government in policy design. The project provides the basic infrastructure for the suppliers located there to meet the standards set by the SAC and hence participate in textile GVCs. However, due to delays, lack of funding, and difficulties in completing and staffing the EcoPark, Jensen and Whitfield (2022) conclude that so far, the main beneficiaries of the public investment in green infrastructure are foreign buyers, whereas the domestic capacity to create new industries through vertical integration using sustainable resources is quite limited.

References

Hawassa Industrial Park. (accessed on 24 September 2023).
Jensen, F., and Whitfield, L. (2022). Leveraging participation in apparel global supply chains through green industrialization strategies: Implications for low-income countries. *Ecological Economics* 194, 107331.
Phillips-Van-Heusen (PVH). 2019. Forward Fashion Targets. (accessed 24 September 2023).

Other third-party institutions playing a key role to ensure that suppliers in the chain correctly implement environmental standards (e.g., ISO 14001) are independent certification bodies, such as the Société Générale de Surveillance (SGS), Intertek, and Bureau Veritas. They verify suppliers' compliance with such standards, and their reports decide whether the supplier can remain in the value chain. Several third-party standards—such as Registration, Evaluation, Authorization and Restriction of Chemicals (REACH); Global Recycle Standard (GRS); Better Cotton Initiative; ISO 14001; and Leadership in Energy and Environmental Design (LEED) —focus primarily on environmental issues. Others, such as the Worldwide Responsible Accredited Production (WRAP), Sedex, and FairTrade focus on social issues and provide environmental guidelines (Khan et al, 2019). However, as sustainability becomes more mainstream and brands are increasingly incentivized to display third-party "green" certifications, consumers should investigate any green certification labels they see on products to ascertain whether or not they are valid (EarthTalk 2016).

6.5 The Enabling Mechanisms of Environmental Innovation

Within GVCs, there are different enabling mechanisms for implementing environmental innovations. How knowledge circulates within the chains and how environmental innovations are developed and introduced could change depending on the actors involved. We document these diverse mechanisms by distinguishing those (i) enabled by lead firms, (ii) enabled by suppliers, (iii) collectively enabled, and (iv) enabled by the government.

Lead firms are the main actors responsible for the introduction of environmental innovations in GVCs. De Marchi et al. (2013b) identify two main approaches adopted for greening GVCs: a standard-driven approach and a mentoring-driven approach.

A standard-driven approach is when the lead firm introduces specific rules and codes of conduct aimed at reducing the chain's environmental impact, which suppliers must satisfy. Standards and certifications can be developed by third-party organizations or by the lead firm itself.

De Marchi et al. (2013a) present the case of IKEA, which requires both kinds of certifications from its suppliers: they must be ISO 4001 certified, use wood certified by the Forest Stewardship Council (FSC), and abide by IKEA's own IWAY supplier code of conduct (IKEA 2019). IKEA's suppliers are also responsible for the environmental conduct of their second-tier suppliers, and the lead firm offers incentives when first-tier suppliers buy from second-tier ones that also respect the IWAY code of conduct. IKEA has a verification and peer learning system in place to ensure the code requirements are fulfilled by its suppliers. It also established formal projects to transfer know-how in eco-efficiency and help suppliers get access to renewable energy and negotiate affordable contracts with renewable electricity providers. Similar programs have been launched by many other companies in different industries; another notable example is Apple, which adopted the Supplier Clean Energy Program (Apple 2022b).

The standard-driven approach works well for large firms that aim at achieving eco-efficiency in the production process together with cost efficiency in a price-sensitive market. With the implementation of standards and a strong control system, IKEA selects suppliers capable of complying with those standards, and both the lead firm and the suppliers have gained from cost reductions in the manufacturing process (De Marchi et al. 2013a).

The limitations of an approach mainly driven by standard compliance are documented by Krishnan et al. (2022), who present evidence on the Kenya-United Kingdom (UK) horticulture value chain. The authors show that UK supermarkets impose very stringent standards on Kenyan exporting firms, which in turn enforce compliance with these conditions on farmers. Farmers then adopt environmental practices such as integrated pest management and soil testing, which are complex and seldom used in that region. Occasionally, the exporting firms provide some training and access to extension services, also in collaboration with training associations and NGOs, but only in a few demonstration farms and a few times a year. Moreover, the contracts signed by farmers are very rigid in terms of standard compliance and quantity purchased, and the price paid does not account for the increased costs of production and the impact on soil and water quality. The study concludes that the Kenyan farmers' biophysical outcomes are negative across all the indicators investigated: quality of soil and water, biodiversity, and sustainable use of resources. The Kenyan exporting firms and UK supermarkets, on the other hand, benefited in terms of "green" reputation and increasing market share for eco-friendly products.

A mentoring-driven approach is when certifications are not available, or suppliers need support, and the lead firm directly transfers knowledge to its suppliers and sustains their greening process. In their study on digitalization in the Chinese electronics supply chain and its implications for its sustainability, Kunkel et al. (2022) find that collaboration between buyers and suppliers has a fundamental role in pushing forward the digitalization for sustainability in the value chain. Continuous interaction between buyers and suppliers is key to building trust, which is essential for allowing mutual access to data about energy use. Case 1 describes how the three Sri Lankan green textile manufacturers interviewed by Khattak et al. (2015) had frequent interactions with their international buyers to acquire the tacit knowledge for environmental innovation in production of complex products. Box 6.4 discusses how Italian kitchen designer Valcucine works in close cooperation with a small number of very committed suppliers to meet environmental goals rather than imposing standards, leading to co-development of environmental innovation.

A crucial factor for the success of a mentor-driven approach is suppliers' competencies and strategic intent in engaging in environmental upgrading (Khattak et al. 2015). Because suppliers that can deliver environmental upgrading are larger in scale and already have higher capabilities, the end result could be consolidation of the supplier base with fewer opportunities for smaller, more marginal suppliers (Khan et al. 2019).

In their study of the Pakistani apparel chains, Khan et al. (2019) highlight a trend of proactive environmental upgrading whereby suppliers anticipate future environmental

requirements to leverage their upgrading initiatives as a competitive factor to access new buyers and markets. More commonly in clusters, innovation is a collective effort given that firms, often characterized by a common specialization, are used to collaborate on innovative activities (Box 6.5). Finally, a key enabling role is played by national or sub-national public actors when they provide the basic infrastructure that contributes to GVC greening (Boxes 6.3 and 6.5).

6.6 The Outcomes of Global Value Chain Greening

While a substantial body of literature exists on the impact of GVCs on workers and society, which is the subject of Chapter 7, the literature on environmental sustainability is much more recent, with only a handful of studies so far conducted, as reviewed in the earlier sections of this paper. This section continues to seek insights from this literature, with the attention now turned to the biophysical outcomes of GVC greening, that is the effect on the environment seen as comprising flora and fauna; land, soil, water, and air; and the atmosphere (Mackie 2021). We start by briefly bringing together the types of greening outcomes identified in the literature, then we discuss the key issues in interpreting these outcomes. This discussion is subject to considerable uncertainty, incomplete knowledge, and lack of robust quantitative evidence because most studies tend to focus more on environmental innovation rather than on biophysical outcomes.

Overall, the biophysical outcomes of GVC greening processes can be divided into the following types:

- GHG emissions: studies focusing on environmental innovation and potential emission reduction from lead-firm schemes (De Marchi et al. 2013a; Jensen and Whitfield 2022; Khattak et al. 2015; Bjorklund et al. 2012).
- Biodiversity: studies about the uptake by companies in deforestation-linked GVCs for environmental monitoring and improvement (Gallemore et al. 2022) and schemes to ensure sustainable wood harvesting (von Geibler et al. 2010).
- Sustainable land use: studies about the introduction of certification and standard schemes to reduce or avoid soil degradation, for example, in cocoa (Fold and Neilson 2016), palm oil (Dermawan and Hospes 2018), and beans and avocado (Krishnan et al. 2022).
- Energy use: renewable energy initiatives such as that of Walmart, which provides education and advice on power purchase agreements to its network of suppliers (Walmart 2022).
- Toxic materials: studies about the reduction or elimination of chemical hazards in products or services or water pollution (e.g., through discharging wastewater without regard to adequate wastewater infrastructure) in response to voluntary standards (Mackie 2021).

Table 6.2 lists the biophysical outcomes that the studies discussed in this chapter investigate. It shows the complexity of accounting and collecting quantitative information for many diverse dimensions, which can have either positive or negative environmental impacts. The greening of the GVCs happens when the net environmental impact is positive.

Table 6.2: Biophysical Outcomes of Global Value Chain greening

Industry	Indicator	Reference
Agriculture	Soil erosion Fresh water availability Leaching (loss of water-soluble nutrients) Wind erosion Number of local flora and fauna Level of pollination Availability of water table Inorganic waste generation Electricity use	Krishnan et al. (2022)
Fisheries	Dolphin stock status	Ballance et al. 2021
Apparel	Carbon footprint (LEED-certification) CO_2 emissions Solid waste landfill Production costs: energy and water High Index Facility Environment Module (FEM) Environmental management systems Energy use and greenhouse gas emissions Water and electricity consumption Wastewater Emissions to air Waste management Chemical management	Khattak et al. (2015) Jensen and Whitfield (2022)
Leather	Electricity use Water recycling Chemical management	De Marchi et al. (2019)
Furniture	Recycling of raw materials CO_2 emissions Water consumption	De Marchi et al. (2013a)
Logistics	Volume of recycled material Number of travels CO_2 emissions Recycling of raw materials	Bjorklund et al. (2012)
Automotive	Waste reduction Reduction of oil leakages Electricity consumption	Chiarini (2014)

A thorough assessment of claims of environmental impact is challenging because systematic measurement efforts are scarce, and the outcomes are highly complex to measure. Many studies are single cases of firm-level or sector-level initiatives where it is difficult to isolate, generalize, and attribute causal factors. Several quantitative studies focus on the potential environmental benefits of GVC participation rather than the process of GVC greening.[4] For example, Batrakova and Davies (2012) find that manufacturers inserted into GVCs adopt more energy-efficient technologies, especially among energy-intensive firms. They measure the effect of exporting, but the environmental innovations that led to emissions reductions is a ”black box” in these studies.

When specific metrics are sometimes defined, they are often firm or GVC metrics (what the firm does, e.g., its sourcing of wood) rather than environmental outcome measures as such (e.g., how biodiversity is affected). In general, “the scarcity or incompleteness of data has thus far limited the ability to accurately assess the impact of environmental upgrading processes on actual outcomes” (Krishnan et al. 2022). In addition, reputational outcomes for individual firms may sometimes outweigh biophysical outcomes. In other words, given the above-mentioned difficulty in specifying environmental impact, firms may exaggerate claims of reduced environmental harm or increased environmental benefit, while receiving a perceived image boost, a phenomenon known as ‘greenwashing.’ Coen et al. (2022) studied 725 corporate sustainability reports with machine-aided textual analysis to test whether climate claims translated into verifiable performance measured by changes in GHG emissions over a 10-year period. They found that while some climate commitments were genuine, most were producing symbolic rather than substantive action.

There are also several important tradeoffs in terms of different green outcomes, such as tradeoffs between the carbon emission effect of bioproducts as petroleum substitutes versus nitrogen pollution or the environmental impact of renewable energies, such as solar or wind, producing large amount of waste for the decommissioning of obsolete systems (Lema et al, 2023). Finally, these biophysical outcomes are also experienced heterogeneously by different GVC actors: certain actors can reap benefits by appropriation, whereas others experience a drainage of their environmental resources (Krishnan et al. 2022).

6.7 A Three-Pronged Strategy for GVC Greening

Table 6.3 presents a three three-pronged strategy to promote and sustain GVC greening derived from the conceptual framework: (i.) policies for creating and augmenting the driving factors; (ii.) policies to strengthen and support environmental innovations acting on the identified enabling mechanisms and (iii.) policies aimed at monitoring outcomes and addressing environmental inequalities.

4 For an overview of the literature on the potential environmental benefits of GVC participation, see Delera (2022).

The first column in Table 6.3 lists policies for creating and augmenting the driving factors of GVC greening. Governments must on the one hand put in place environmental regulation and standards as a measure for incentivizing and supporting environmental innovations, eliminating barriers, and creating new markets; on the other hand, they must use taxation—or more broadly fiscal policy—to modify price signals so that firms internalize externalities and properly value environmental resources. Governments must also promote and sustain the development of green technologies by investing in research and innovative activities. Another critical action at the national and subnational level is increasing awareness among consumers in schools, workplaces, and public spaces to promote environmentally sustainable consumption patterns.

Table 6.3: A Three-Pronged Strategy for GVC greening

Create and amplify the driving factors	Leverage the identified enabling mechanisms	Monitor outcomes and address environmental inequality
National and subnational level • Regulations and standards • Taxation • Consumption patterns • R&D activities **Global level** • Agreements to avoid environmental dumping • Agreement to control transboundary toxic movements • Agreements to lift tariff and non-tariff barriers to trade in environmental goods and services • Global initiatives to support R&D collaborations	**Policies involving lead firms** • Make lead firms responsible for the environmental impact of their suppliers • Provide support to lead firms that contribute to GVC greening • Introduce green procurement policies • Create a green supplier database • Create incentives for cooperation on green innovative activities between lead firms and suppliers • Strengthen sustainable innovation ecosystems **Policies involving domestic suppliers** • Strengthen knowledge infrastructure • Strengthen sustainable innovation ecosystems • Develop local specialized scientific, technological, managerial, and organizational capabilities • Introduce green procurement policies • Provide financial support to environmental innovations **Policies supporting collective initiatives** • Support activities aimed at driving the green agenda in business organizations • Support R&D activities taking place in consortia **Policies aimed at building and strengthening infrastructure** • Provide basic green infrastructure and logistics • In clusters and industrial parks, invest in specific infrastructure for GVC greening in the dominant industry • Encourage investment and linkages in recycling industries	• Introduce measures to address the unequal impact of greening within chains • Introduce appropriate forms of regulation to orchestrate private sustainability initiatives to achieve fair and just environmental protection • Increase knowledge about biophysical outcomes and develop monitoring system to measure complex outcomes • Track the environmental performance of firms within the chains that receive subsidies to adopt environmental innovations

Because the salient feature of GVCs is that they span national boundaries, action at the global level is critical for GVC greening. Environmental agreements are needed, for example, in dissuading arbitrage between jurisdictions and environmental dumping across countries, and in controlling transboundary movements of hazardous waste and its disposal.

Trade agreements are also necessary to lift tariff and nontariff barriers to trade in environmental goods and services. The recent resurgence of protectionism can prevent the spreading of new environmental solutions and thus poses a danger to achieving GHG reduction targets.

Global initiatives to support R&D collaborations across countries and institutions can boost environmental innovation. Furthermore, they can facilitate the adoption and adaptation of frontier technologies in developing economies to foster environmental equality.

The second column in Table 6.3 focuses on actions that leverage the identified enabling mechanisms to strengthen and support environmental innovation. As discussed in Section 6.4, lead firms play the key role in greening the entire value chain, although suppliers are increasingly taking the initiative to increase their involvement in GVCs or in response to public pressure.

Strengthening sustainable innovation ecosystems—by building human capabilities, establishing standard and metrology organizations, developing technical and advisory services, investing in domestic R&D in research centers and universities, and strengthening university-industry linkages—helps both lead firms and suppliers. Similarly, the introduction of green procurement policies that can either add the condition of meeting specific environmental standards to tender for government contracts or exclude firms not certified by certain environmental standards can be a powerful incentive for both lead firms and suppliers. For example, certain green public procurement guidelines require that a firm's products contain a minimum amount of recycled content or achieve specified levels of energy efficiency.

For lead firms, regulation that makes them explicitly responsible for the environmental impact of their suppliers should be paired with support for lead firms that contribute to GVC greening. That would incentivize other foreign and domestic firms to shift toward sustainable practices to gain the same support.

Enabling connections between lead firms and sustainable domestic companies, for example by creating a green supplier database, can boost GVC greening. Beyond traditional information, such as production capacity, goods and services offered, and contact information, the database can offer information regarding the sustainability of operations, such as environmental protection and carbon offset activities, the social impact of the operations, and supply chain management.

Governments can also create incentives for cooperation on green innovative activities between lead firms and domestic suppliers. For example, special categories for green investment and green innovation can be created under policies to incentivize foreign direct investment and knowledge transfers.

Empowering domestic suppliers to drive GVC greening requires strengthening the knowledge infrastructure, enhancing local skills development, and providing information and skills to anticipate the future impacts of environmental legislation, carbon taxes, and new standards. A forward-looking approach would also include developing local specialized scientific, technological, managerial, and organizational capabilities to absorb, adapt, and eventually develop the relevant knowledge for facilitating environmental innovation.

Financial incentives are perhaps the most powerful for suppliers: it can be difficult to persuade firms and financial intermediaries to invest in green innovation when there is limited business evidence on the return on investment. Therefore, innovation and technology funds financed by the public sector, international donors, and development banks are key to piloting new approaches.

Governments can also support collective initiatives for GVC greening. Industry associations can be important allies in driving a green agenda. Consortia aggregating firms specializing in similar and complementary stages along the value chain can also implement environmental innovation with government support.

A crucial enabling mechanism for GVC greening is the provision of basic infrastructure and logistics, such as renewable energy sources and waste management systems, that can serve as a platform for further innovation. In the case of clusters and industrial parks, specific infrastructure may be needed to enable GVC greening in the dominant industry. Facilitating investments in the recycling industry and the creation of linkages to other industries (i.e., chemicals) is also part of building this infrastructure.

Finally, the third column in Table 6.3 focuses on policies aimed at monitoring outcomes and addressing environmental inequality. Inequality along value chains is a product of the power asymmetries intrinsic to actors within the GVC. Addressing these inequalities requires the full spectrum of policies discussed in Table 6.3, from strengthening national and multilateral institutions, to providing core infrastructure, to building capacity.

Monitoring should be iterative and integrated into any greening initiative from the start. It helps to identify any potential issues, track progress, and measure outcomes. The increased transparency also leads to better accountability. This is particularly relevant for firms within the chains that receive subsidies to engage in environmental practices. A regulatory framework that fosters environmental accountability is also conducive to private sustainability initiatives to achieve fair and just environmental protection.

Conclusion

In this chapter, we introduce a framework addressing five related questions: (i) Why is GVC greening occurring? (ii) What type of environmental innovation is undertaken in GVCs? (iii) Who are the actors involved? (iv) How is environmental innovation taking place? And (v) What are the outcomes? The evidence collected on the five dimensions of the framework provides three main findings that point to challenges for both policy action and future research.

First, while GVC greening has institutional, market, and technological drivers, institutional drivers play a major role because of the public good nature of the green transition. New policies and legislation related to domestic or global sustainability transformation agendas are central to GVC greening. Market and technological drivers are also essential, but they ultimately tend to be driven by institutional drivers. Therefore, GVC greening is characterized by endogeneity, complementarity, and interaction effects among the different drivers.

Promoting such drivers may require a shared effort among institutional actors at national and global levels. However, as advanced and emerging economies are increasingly competing to gain competitive advantage in new green technologies, domestic policies play a greater role than global concerns (Aklin and Mildenberger 2020). The Inflation Reduction Act that the US enacted in 2022 is a good example of a climate policy that aims to address both domestic competitiveness and sustainability issues.

Multilateral policies acting as driving factors, such as multilateral climate agreements, have been pivotal in the last decades (i.e., the United Nations Framework Convention on Climate Change [UNFCCC] in 1992, the Kyoto Protocol in 1997, and most recently the Paris Agreement in 2015). The notion that the public will support expensive climate policies more if other nations adopt them is one of the reasons for securing cooperation among multiple states. This is true both because it increases the likelihood that important sustainability goals will be achieved and because such efforts are consistent with widely shared fairness norms. Research suggests that multilateralism increases public acceptance of costly climate action, and it makes it more appealing and ’fair” (Bechtel et al. 2022). However, multilateral negotiations appeared to be stalled after the 2022 UN Conference of the Parties (COP27) because of geopolitical tensions arising from the energy crisis and sparring between the Global South and high-income economies (Masood et al. 2022).

Governments turning sharply away from multilateral cooperation may pose a major challenge to GVC greening. A way forward to safeguard multilateralism and global institutional drivers sustaining GVC greening is to invest in initiatives developed among smaller groups of like-minded economies such as the Breakthrough Agenda, involving 45 economies and the private sector to accelerate the shift to green technologies in industries such as agriculture, transport, steel, cement, and energy (Dworking and Engström 2022). Coordination at the global level might also help promote the energy transition towards the net-zero goal (e.g., a single international carbon tax rate).

The second key message is that several actors, not only lead firms but also suppliers, national and local governments, and often a combination of them, contribute to GVC greening. There is evidence showing that suppliers, proactively anticipating the introduction of new technical standards in the industry, introduce environmental innovations as a competitive factor to access new buyers and markets.

However, the greening opportunities within the chain may not unroll evenly among the suppliers. Several studies show that lead firms do not always provide enough financial, managerial, and knowledge resources for their suppliers to implement green strategies, leaving them out of the chain if they are unable to meet such requirements. This risk is particularly high for small firms in developing countries and in developed ones because implementing environmental standards in own operations and monitoring sustainability in suppliers has economies of scale—that is, the cost of sustainability per unit of output reduces with increasing size of operations (Görg et al, 2021).

The uneven distribution of costs, benefits, and rewards for greening the value chain poses a challenge for policymakers to address this supplier-squeeze (Krishnan et al., 2022). Actors external to the GVC, such as national or local governments, NGOs, and independent certification bodies, can provide technical and financial support to suppliers in GVCs to implement environmental innovations. National or subnational public actors can provide the basic infrastructure that contributes to GVC greening. Effective support of actors with more limited capacities will need further investigation about how GVC greening affects various actors operating in and beyond GVCs, the damage and benefits caused, and the possible tradeoffs between different types of environmental and socioeconomic outcomes.

Finally, there is very limited evidence on the biophysical outcomes (De Marchi and Gereffi 2023). Among the indicators considered in the literature are CO2 emissions, biodiversity, sustainable land use, energy use, and use of toxic materials. However, firms may exaggerate claims of reduced environmental harm or increased environmental benefit to receive an image boost, sometimes concealing greenwashing practices. Moreover, there are important tradeoffs between environmental and socioeconomic outcomes, and therefore the final assessment of whether GVC greening happens generally remains a research gap in most of the existing studies.

Therefore, accounting, monitoring, and disclosing the environmental outcomes and the possible tradeoffs with socioeconomic outcomes are not only challenging but are also essential dimensions to investigate along the entire value chain. Firms in different business sectors implement different organizational capabilities to track their greening progress. Yet, raising knowledge about biophysical outcomes and the several tradeoffs and developing monitoring systems to measure them is key. For instance, the US clothing company, Levi Strauss & Co., publishes on its website a detailed description of its environmental life cycle assessment (LCA), a quantitative method for evaluating the impact of a product along the value chain and at various stages. It is a tool used to assess

the stages and impact of a product's entire life, from raw material extraction (cradle) to waste treatment (grave), and it informs consumers and actors involved in the chain about their environmental impact. However, the LCA does not account for economic or social impacts.

A GVC perspective on monitoring activities is also being implemented by policymakers as in the case of the Extended Producer Responsibility (EPR) laws introduced by many countries to make producers responsible for the post-consumer stage of a product's life cycle or in presence of due diligence rules in case of commodities associated with deforestation (De Marchi and Gereffi 2023). However, multilateral efforts to orchestrate and harmonize private and national initiatives are strongly needed to make environmental-outcome tracking systems more effective, again pointing at the inevitability of a multilateral approach in GVC greening due to its intrinsic global, transboundary nature.

References

Aklin, Michaël, and Matto Mildenberger. 2020. Prisoners of the wrong dilemma: Why distributive conflict, not collective action, characterizes the politics of climate change. *Global Environmental Politics*. 20 (4). pp. 4–27.

Altenburg, Tilman, and Dani Rodrik. 2017. Green industrial policy: Accelerating structural change towards wealthy green economies. In Tilman Altenburg and Claudia Assmann, eds. *Green industrial policy: Concepts, policies, country experiences*. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE). pp. 1–20.

Apple. 2022a. *Environmental Progress Report 2022*.

Apple. 2022b. *Supplier Clean Energy 2022 Program Update*.

Asian Development Bank (ADB). Forthcoming. Decarbonizing Global Value Chains. In *Asian Economic Integration Report 2024: Decarbonizing Global Value Chains*. Manila.

Australian Fisheries Management Authority (AFMA). 2023. *Methods and Gear – Purse Seine*.

Ballance, Lisa T., Tim Gerrodette, Cleridy E. Lennert-Cody, Robert L. Pitman, and Dale Squires. 2021. A History of the Tuna-Dolphin Problem: Successes, Failures, and Lessons Learned. *Frontiers in Marine Sciences*. 8 (754755).

Batrakova, Svetlana, and Ronald B. Davies. 2012. Is There an Environmental Benefit to Being an Exporter? Evidence from Firm-Level Data. *Review of World Economics*. 148 (3). pp. 449–474.

Beise, Marian, and Klaus Rennings. 2005. Lead Markets and Regulation: A Framework for Analyzing the International Diffusion of Environmental Innovations. *Ecological Economics*. 52 (1). pp. 5–17.

Bechtel, Michael M., Kenneth F. Scheve, and Elisabeth van Lieshout. 2022. Improving Public Support for Climate Action through Multilateralism. *Nature Communications*. 13 (1). 6441.

Björklund, Maria, Uni Martinsen, and Mats Abrahamsson. 2012. Performance Measurements in the Greening of Supply Chains. *Supply Chain Management*. 17 (1). pp. 29–39.

Black, Simon, Ian Parry, and Karlygash Zhunussova. 2022. More Countries Are Pricing Carbon, but Emissions Are Still Too Cheap. *International Monetary Fund (IMF) Blog*.

Brandi, Clara, Jakob Schwab, Axel Berger, and Jean-Frédéric Morin. 2020. Do Environmental Provisions in Trade Agreements Make Exports from Developing Countries Greener? *World Development*. 129 (104899).

Caldeira Pedroso, Marcelo, Ronaldo Zwicker, and Cesar Alexandre de Souza. 2009. RFID Adoption: Framework and Survey in Large Brazilian Companies. *Industrial Management & Data Systems*. 109 (7). pp. 877–897.

Chang, Philip and Akhmad Bayhaqi and Bernadine Zhang Yuhua. 2012. Concepts and Trends in Global Supply, Global Value and Global Production Chains. Asia-Pacific Economic Cooperation Issues Paper No. 1.

Chiarini, Andrea. 2014. Sustainable Manufacturing-Greening Processes Using Specific Lean Production Tools: An Empirical Observation from European Motorcycle Component Manufacturers. *Journal of Cleaner Production*. 85. pp. 226–233.

Coen, David, Kyle Herman, and Tom Pegram. 2022. Are Corporate Climate Efforts Genuine? An Empirical Analysis of the Climate 'Talk–Walk' Hypothesis. *Business Strategy and the Environment*. 31 (7). pp. 3040–3059.

Copeland, Brian R., Joseph S. Shapiro, and M. Scott Taylor. 2021. Globalization and the Environment. *NBER Research Working Paper*. No. 28797. Cambridge, MA: National Bureau of Economic Research.

Crippa, Monica et al. 2023. *GHG Emissions of All World Countries*. Luxembourg: Publications Office of the European Union.

Delera, Michele. 2022. Is Production in Global Value Chains (GVCs) Sustainable? A Review of the Empirical Evidence on Social and Environmental Sustainability in GVCs. *Sustainable Global Supply Chains Discussion Papers*, No. 1. Research Network Sustainable Global Supply Chains, Bonn.

De Marchi, Valentina, Eleonora Di Maria, Stefano Ponte. 2013a. The Greening of Global Value Chains: Insights from the Furniture Industry. *Competition & Change*. 17 (4). pp. 299–318.

De Marchi, Valentina, Eleonora Di Maria, and Stefano Micelli. 2013b. Environmental Strategies, Upgrading, and Competitive Advantage in Global Value Chains. *Business Strategy and the Environment*. 22 (1). pp. 62–72.

De Marchi, Valentina, and Eleonora Di Maria. 2019. Environmental Upgrading and Suppliers' Agency in the Leather Global Value Chain. *Sustainability*. 11 (23). 6530.

De Marchi, Valentina, Eleonora Di Maria, Aarti Krishnan, and Stefano Ponte. 2019. Environmental Upgrading in Global Value Chains. In Stefano Ponte, Gary Gereffi, and Gale Raj-Reichert, eds. *Handbook on Global Value Chains*, pp. 310–323. Cheltenham: Edward Elgar Publishing.

De Marchi, Valentina, and Gary Gereffi. 2023. Using the Global Value Chain Framework to Analyse and Tackle Global Environmental Crises. *Journal of Industrial and Business Economics*. 50. pp. 149–159.

Dermawan, Ahmad, and Otto Hospes. 2018. When the State Brings Itself Back into GVC: The Case of the Indonesian Palm Oil Pledge. *Global Policy*. 9 (S2). pp. 21–28.

Dworking, Anthony, and Mats Engström. 2022. We'll Always Have Paris: How to Adapt Multilateral Climate Cooperation to New Realities. *Policy Brief*. No. 469. European Council on Foreign Relations.

EarthTalk. 2016. Are Green Labels Legitimate or Just Greenwashing? *Scientific American*. 18 April.

European Commission. 2021. *GREEN LIFE: GREEN Leather Industry for the Environment*. Reference: LIFE13 ENV/IT/000840.

European Parliament. The impact of textile production and waste on the environment (infographics) (accessed 27 September 2023).

Fold, Niens, and Jeff Neilson. 2016. Sustaining Supplies in Smallholder-Dominated Value Chains. In Mara P. Squicciarini and Johan Swinnen, eds. *The Economics of Chocolate*. pp. 195–212. Oxford University Press.

Fuoco, Davide. 2018. The Paradox of Smart Manufacturing. Automate. 22 June.
Gale, Fred, Francisco Ascui, and Heather Lovel. 2017. Sensing Reality? New Monitoring Technologies for Global Sustainability Standards. *Global Environmental Politics*. 17 (11). pp. 65–83.
Gallemore, Caleb, Izabela Delabre, Kristjan Jespersen, and Ting Liu. 2022. To See and Be Seen: Technological Change and Power in Deforestation Driving Global Value Chains. *Global Networks*. 22 (4). pp. 615–630.
Giuliani, Elisa, Carlo Pietrobelli, and Roberta Rabellotti. 2005. Upgrading in Global Value Chains: Lessons from Latin American Clusters. *World Development*. 33 (4). pp. 549–573.
Glachant, Matthieu, Damien Dussaux, Yann Ménière, and Antoine Dechezleprêtre. 2013. Greening Global Value Chains: Innovation and the International Diffusion of Technologies and Knowledge. *World Bank Policy Research Working Paper*. No. 6467. Washington, DC: World Bank.
Goger, Annelies. 2013. "The making of a 'business case' for environmental upgrading: Sri Lanka's eco-factories." *Geoforum*. 47. pp. 73–83.
Görg, Holger, Jann Layand Stefan Pahl, Adnan Seric, and Frauke Steglichand Liubov Yaroshenko. 2021. Multilateral Coordination and Exchange for Sustainable Global Value Chains. *Policy Brief*. T20 Italy.
Hawassa Industrial Park (accessed 24 September 2023).
Herman, Kyle S., and Jun Xiang. 2022. Channeled Through Trade: How Foreign Environmental Regulations Induce Domestic Renewable Energy Innovation. *Energy Research & Social Science*. 89 (102629).
Huang, Runze, Matthew Riddle, Diane Graziano, Joshua Warren, Sujit Das, Sachin Nimbalkar, Joe Cresko, and Eric Masanet. 2016. Energy and Emissions Saving Potential of Additive Manufacturing: The Case of Lightweight Aircraft Components. *Journal of Cleaner Production*. 135. pp. 1559–1570.
IDOS. TREND Analytics (accessed 31 May 2023).
IKEA. 2019. IWAY Standard. Edition 6.0.
Inter-American Tropical Tuna Commission (IATTC). 2023. Agreement on the International Dolphin Conservation Program (AIDCP).
International Marine Mammal Project (IMMP). 2022. The Tuna Dolphin Tragedy.
International Maritime Organization (IMO). 2020. *Fourth IMO Greenhouse Gas Study 2020*. London: International Maritime Organization.
Jacobsen, Stine, and Nikolaj Skydsgaard. 2022. Denmark agrees corporate carbon tax. *Reuters*. 24 June.
Jensen, Federico, and Lindsay Whitfield. 2022. Leveraging Participation in Apparel Global Supply Chains Through Green Industrialization Strategies: Implications for Low-Income Countries. *Ecological Economics*. 194 (107331).
Khan, Mahwish J., Stefano Ponte, and Peter Lund-Thomsen. 2019. The 'factory manager dilemma': Purchasing practices and environmental upgrading in apparel global value chains. *Environment and Planning A: Economy and Space*. 52 (4). pp. 766–789.

Khattak, Amira, Christina Stringer, Maureen Benson-Rea, and Nigel Haworth. 2015. Environmental Upgrading of Apparel Firms in Global Value Chains: Evidence from Sri Lanka. *Competition & Change*. 19 (4). pp. 317–335.

Krishnan, Aarti, Valentina De Marchi, and Stefano Ponte. 2022. Environmental Upgrading and Downgrading in Global Value Chains: A Framework for Analysis. *Economic Geography*. 99. pp. 25–50.

Kunkel, Stefanie, Marcel Matthess, Bing Xue, and Grischa Beier. 2022. Industry 4.0 in Sustainable Supply Chain Collaboration: Insights from an Interview Study with International Buying Firms and Chinese Suppliers in the Electronics Industry. *Resources, Conservation, and Recycling*. 182 (106274).

Laari, Sini, Juuso Töyli, Tomi Solakivi, and Lauri Ojala. 2016. Firm performance and customer-driven green supply chain management. *Journal of Cleaner Production*. 112 (3). pp. 1960–1970.

Lema, Rasmus, and Roberta Rabellotti. 2022, The Green and Digital Transition in Manufacturing Global Value Chains in Latecomer Countries. *Background Document to the Technology and Innovation Report 2023*. Geneva: United Nations Conference on Trade and Development.

Lema, Rasmus, Elisabetta Gentile, and Roberta Rabellotti. 2022. Green Tech Global Value Chains: Are There Upgrading Opportunities for Developing Countries? Mimeo. Manila: Asian Development Bank.

Lucas, Louise, and Pilita Clark. 2012. Tesco steps back on carbon footprint labelling. *Financial Times*. 1 February.

Mackie, Colin. 2021. Due Diligence in Global Value Chains: Conceptualizing 'Adverse Environmental Impact.' *Review of European, Comparative & International Environmental Law*. 30 (3). pp. 297–312.

Mangina, Eleni, Pranav Kashyap Narasimhan, Mohammad Saffari, and Ilias Vlachos. 2020. Data analytics for sustainable global supply chains. *Journal of Cleaner Production*. 255 (120300).

Marks & Spencer. 2015. *Reflections on Plan A Progress*.

Masood, Ehsan, Jeff Tollefson, and Aisling Irwin. 2022. COP27 Climate Talks: What Succeeded, What Failed and What's Next. *Nature*. 612 (7938). pp. 16–17.

National Oceanic and Atmospheric Administration (NOAA). Marine Mammal Protection Act. The full text of the Marine Mammal Protection Act of 1972 as amended (accessed 6 October 2023).

Organisation for Economic Co-operation and Development (OECD). 2020. Trade Policy Implications of Global Value Chains. *Trade Policy Brief*. February. Paris.

OECD. 2022. *Trade in Embodied CO_2 ($TECO_2$) Database*. Paris.

OECD, World Trade Organization (WTO), and Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO). 2013. *Aid for Trade and Value Chains in Textiles and Apparel*.

Phillips-Van-Heusen (PVH). 2019. *Forward Fashion Targets*.

Ponte, Stefano. 2020. The Hidden Costs of Environmental Upgrading in Global Value Chains. *Review of International Political Economy*. 29 (3). pp. 818–843.

Saberi, Sara, Mahtab Kouhizadeh, Joseph Sarkis, and Lejia Shen. 2019. Blockchain Technology and its Relationships to Sustainable Supply Chain Management. *International Journal of Production Research*. 57 (7). pp. 2117–2135.

Salminen, Jaakko, Mikko Rajavuori, Mika Viljanen, and Agnes Hellner. 2022. Greenhouse Gas Emissions in Global Value Chains: Governance, Regulation and Liability. *Copenhagen Business School Law Research Paper Series* No. 22-05. Copenhagen.

Tabelin, Carlito Baltazar, Jessica Dallas, Sophia Casanova, Timothy Pelech, Ghislain Bournival, Serkan Saydam, and Ismet Canbulat. 2021. Towards a Low-Carbon Society: A Review of Lithium Resource Availability, Challenges and Innovations in Mining, Extraction and Recycling, and Future Perspectives. *Minerals Engineering*. 163 (106743).

Toniolo, Korinzia, Eleonora Masiero, Maurizio Massaro, and Carlo Bagnoli. 2020. Sustainable Business Models and Artificial Intelligence: Opportunities and Challenges. In Florinda Matos, Valter Vairinhos, Isabel Salavisa, Leif Edvinsson, Maurizio Massaro, eds. *Knowledge, People, and Digital Transformation: Approaches for a Sustainable Future*, pp. 103–117. Springer.

von Geibler, Justus, Kora Kristof, and Katrin Bienge. 2010. Sustainability Assessment of Entire Forest Value Chains: Integrating Stakeholder Perspectives and Indicators in Decision Support Tools. *Ecological Modelling*. 221 (18). pp. 2206–2214.

United Nations Conference on Trade and Development (UNCTAD). 2021. *Review of Maritime Transport 2021*. New York: United Nations.

Walmart. 2022. Energy. Walmart Sustainability Hub.

World Bank. 2020. *World Development Report 2020: Trading for Development in the Age of Global Value Chains*. Washington, DC.

World Bank. 2022. *State and Trends of Carbon Pricing 2022*. Washington, DC.

World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI). 2011. *Corporate Value Chain (Scope 3) Accounting and Reporting Standard*.

World Trade Organization. 2019. US-Tuna II (MEXICO) (DS381): Summary of Key Findings.

World Trade Organization (WTO). 2022. *World Trade Report 2022*. Geneva.

7

Global Value Chains for Inclusive Development

Sang Hyun Park, Kathryn Lundquist, Victor Stolzenburg[1]

7.1 Introduction

This chapter examines the inclusiveness of GVCs[2] to identify which trade-related policies can support inclusive development. GVCs account for a major share of international trade, impacting people in developing and developed economies alike. The rise of GVCs contributed to higher growth and income levels in many developing economies, leading to a remarkable acceleration of cross-country income convergence. However, the gains from trade in GVCs are not always fairly distributed. The relationship between GVC integration and within-country inequality, or inclusiveness, is complex. GVCs have promoted opportunities for economic and social upgrading through job creation, knowledge and technology spillovers, and improved working conditions. In some instances, these positive effects have accrued especially to workers and firms that face larger barriers in accessing foreign markets, such as informally employed workers, women, or micro, small, and medium-sized enterprises (MSMEs), thereby closing existing labour market gaps. But GVC integration can also widen pre-existing disparities by raising the demand for skills or by strengthening agglomeration forces that widen the rural-urban divide.

---

1 World Trade Organization. sanghyun.park@wto.org; kathryn.lundquist@wto.org; victor.stolzenburg@wto.org (corresponding author). The opinions expressed in this paper are those of the authors. They do not represent the positions or opinions of the WTO or its Members and are without prejudice to Members' rights and obligations under the WTO. The chapter benefitted substantially from background papers authored by Kathryn Lundquist, Marcelo Olarreaga, Gady Saiovici, Cristian Ugarte, Lu Wang, Xiaolong Xu, Xiuna Yang, and Jiantuo Yu. The authors would also like to thank Weidi Yuan who provided valuable inputs, Marc Bacchetta, Aya Okada, Mari Tanaka and Jiantuo Yu for helpful comments, and William Shaw for excellent editing. Any errors are attributable to the authors.

2 In contrast to the country level, there are no established definitions for GVC integration at the firm- or worker-level, which is the focus of this chapter. For the purposes of the chapter, GVC integration is defined for firms as either directly or indirectly importing inputs, exporting, or selling domestically to a multinational company. For workers, GVC integration refers to working for a firm that is defined as integrated into GVCs. The effects of related concepts, such as import competition, are for the most part not considered.

Importantly in the context of this report, inclusiveness is a key aspect of resilient and sustainable GVCs. On resilience, as the backlash against globalization in advanced economies has shown, rising inequality can lower political support for trade and increase barriers to GVC integration. Moreover, since the impacts of shocks tend to be unevenly distributed within economies, it is important that all parts of society are able to recover quickly for the economy as a whole to be resilient. For instance, certain sectors were more severely impacted during the COVID-19 pandemic, including the labour-intensive garment industry in developing economies. This had a disproportionate effect on women, as female employees are overrepresented in low-wage textile and apparel production. The potential consequences of prolonged unemployment among female garment workers include adverse effects on the health and education of the next generation, especially girls, reversing much of the progress on SDG goals that the international community has struggled to build up for the past decades.

On sustainability and the increasingly urgent need of a green transition, it is crucial to adopt low-carbon technologies on an economy-wide scale to achieve rapid and effective results. GVCs can be an important tool in this regard, as they link countless firms within economies from large to small. This means that GVCs can accelerate technology diffusion from technological leaders to less innovative firms if the GVC environment is such that barriers to entry for smaller firms can be overcome. Therefore, by prioritizing inclusiveness, GVCs can play a pivotal role in building sustainable and resilient economies for the benefit of all stakeholders.

This chapter reviews the evidence of how GVCs have impacted inclusiveness within developing economies.[3] It addresses several important questions. Can developing economy firms, many of which are MSMEs, upgrade their position within the global production process through GVC participation, or will they remain stuck in low-value-added stages? Has GVC participation adversely affected workers in developing economies, or has it led to improvements in welfare and labour standards? Can GVCs effectively address social concerns such as gender inequality and child labour? Answering these questions requires to look at the conditions in GVCs but also at the broader impact on the affected economies. After all, inclusive GVCs only support inclusive development if they are accessible to the broader economy.

The topic of this chapter is more crucial than ever for two reasons. First, the negative shocks prompted by the COVID-19 pandemic, geopolitical tensions, and the environmental crisis have been shown to hurt some groups, such as low-skilled workers, female employees and MSMEs in developing economies, more than others (WTO, 2020; ILO, 2020a). Second, consumers are increasingly aware of the spillover effects of their choices on workers in developing economies. This has triggered

3 The literature on GVC integration and inclusiveness is extensive. We focus on developing economies and the more recent empirical evidence since we consider this to be the most relevant angle for current policy discussions surrounding inclusiveness in GVCs.

renewed efforts by policymakers and investors to address inclusiveness in supply chains. Ensuring that the resulting policy responses are grounded in solid evidence is important for them to lead to lasting improvements.

The chapter finds that on average GVCs deliver meaningful benefits to workers and firms in developing economies. Firms connected to GVCs benefit in terms of productivity and quality through a multitude of channels, including the transfer of tacit knowledge and technologies, access to finance, information and higher quality inputs, and more demand. For workers, GVCs generate job opportunities in formal sectors and increase wages, particularly for lower-skilled workers. While GVCs may contribute to wage inequalities, they can also improve working conditions through demand-side pressures and voluntary upgrading efforts by MNCs. This can also lead to social upgrading as GVCs are linked to female empowerment and reduced child labour. Digital technologies have played a crucial role in enhancing the inclusiveness of GVCs by reducing trade costs but imply risks related to automation and market power.

More generally, market failures, such as oligopolies, and non-trade barriers limit the inclusiveness of GVCs. Concentrated product and labour markets cut into the profits of producers and workers in developing economies. A varied set of restrictions holds women back from benefitting from firm upgrading in GVCs. This implies that policy should focus on facilitating access to GVCs and address market imperfections and barriers. Social provisions in trade agreements and due diligence requirements, the dominant approaches currently, may in many instances not be the ideal tools. In any case, they should be accompanied by continuous cooperation between developing and advanced economies to promote positive outcomes and take into account the economic literature highlighting possible negative side effects.

The chapter is organized as follows. Section 2 examines the impact of GVC integration on firm performance in developing economies, especially MSMEs, and Section 3 reviews the impact on labour markets and social concerns. Sections 4 and 5 look ahead by discussing the future of inclusive GVCs with growing automation and artificial intelligence (AI) and the policy implications before Section 6 concludes.

7.2 GVCs can Improve the Performance of MSMEs in Developing Economies

This section examines the recent evidence on GVC participation and firm performance in developing economies. The key message is that firms, many of which are MSMEs, tend to enjoy substantial benefits from GVC integration. The literature suggests that there are five main channels through which MSMEs benefit from GVC participation: improved access to international markets, enhanced access to tacit knowledge and good management practices, technology spillovers and innovation, quality upgrading,

and improved access to trade finance. However, despite these advantages, MSMEs encounter challenges due to limited capacity and institutional barriers, setting them apart from larger multinational firms. The benefits of GVC participation tend to favour companies that are sizable, technologically advanced, professionally managed, and possess diversified trade networks (Gereffi and Luo, 2015). Moreover, the limited bargaining power compared to larger firms, can prevent MSMEs from receiving a fair share of the profits generated within GVCs.

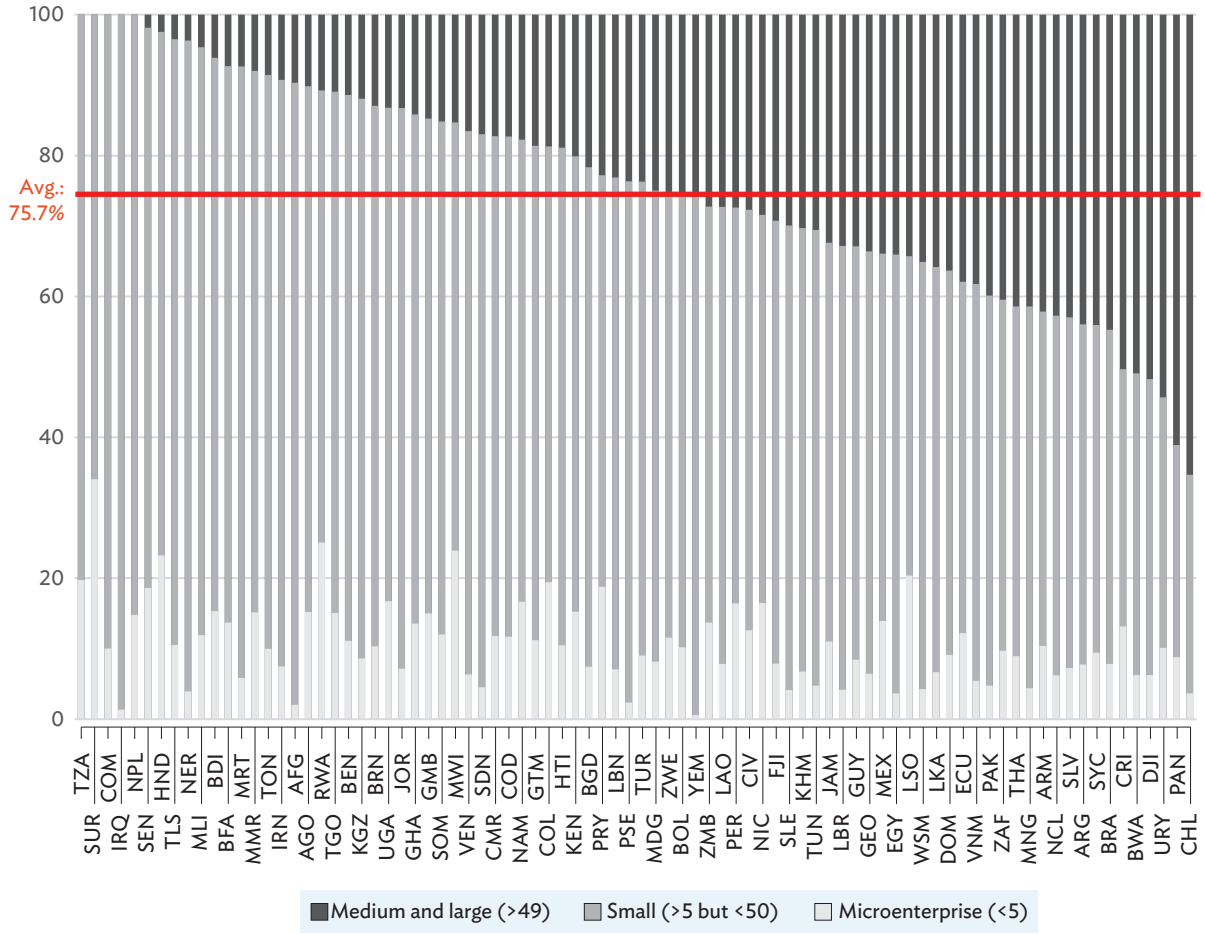
The Context: MSMEs' Role in Developing Economies and Trends in their GVC Participation

MSMEs are the primary source of employment in developing economies. Statistics across 84 developing economies reveal that, on average, firms with less than 50 employees hire approximately 75.7% of the total workforce (Figure 7.1). Particularly in low-income developing economies, the proportion of workers employed by MSMEs is very high, comprising often informal work or non-standard employment arrangements (OECD, 2023a). These workers are at most partially covered by labour regulations, making them particularly susceptible to economic shocks. Consequently, fostering the resilient participation of MSMEs in GVCs is vital in fostering overall inclusiveness in GVCs. A recent study in South Africa also underscores the role of small, innovative firms in job creation when joining GVCs. As smaller and younger firms enter GVCs and improve productivity through resource reallocation, they are more likely to create jobs, compared to large firms continuously operating within GVCs (Ndubuisi and Owusu, 2023).

However, MSMEs' GVC participation is hampered by several factors, including financial constraints and a lack of operational capabilities. These factors also explain why, even when MSMEs are integrated in GVCs, their participation often exhibits two specific characteristics. Firstly, MSMEs in developing economies tend to specialize in low-value-added, labour-intensive segments of the production process, as they rely on leveraging cheap labour. Secondly, most of the GVC participation of MSMEs occurs through indirect linkages, rather than direct exports or imports. MSME GVC participation, especially in developing economies, typically occurs by supplying intermediate inputs to lead firms with local presence. These lead firms are typically large firms (Lundquist, 2023), as "going global" can be particularly challenging for small firms (Buciuni et al., 2022). If MSMEs trade directly, it is often in sectors with low entry costs and capital requirements.

That said, even indirect linkages to foreign markets through GVCs can generate large benefits. The interdependence of firms within GVCs provides opportunities for sharing knowledge, technology and even credit, which can have a particularly strong impact on MSMEs given the numerous constraints they tend to face. A foreign firm and a local supplier interact and coordinate to maintain the smooth functioning of the supply chain. This interaction facilitates the transfer of tacit knowledge, which has the potential to enhance domestic innovative capabilities (Gentile et al, 2021). Benefits tend to be stronger when so-called *superstar* firms – firms that dominate their market – are involved

Figure 7.1: Share of Employment by Firm Size in Developing Economies (%)

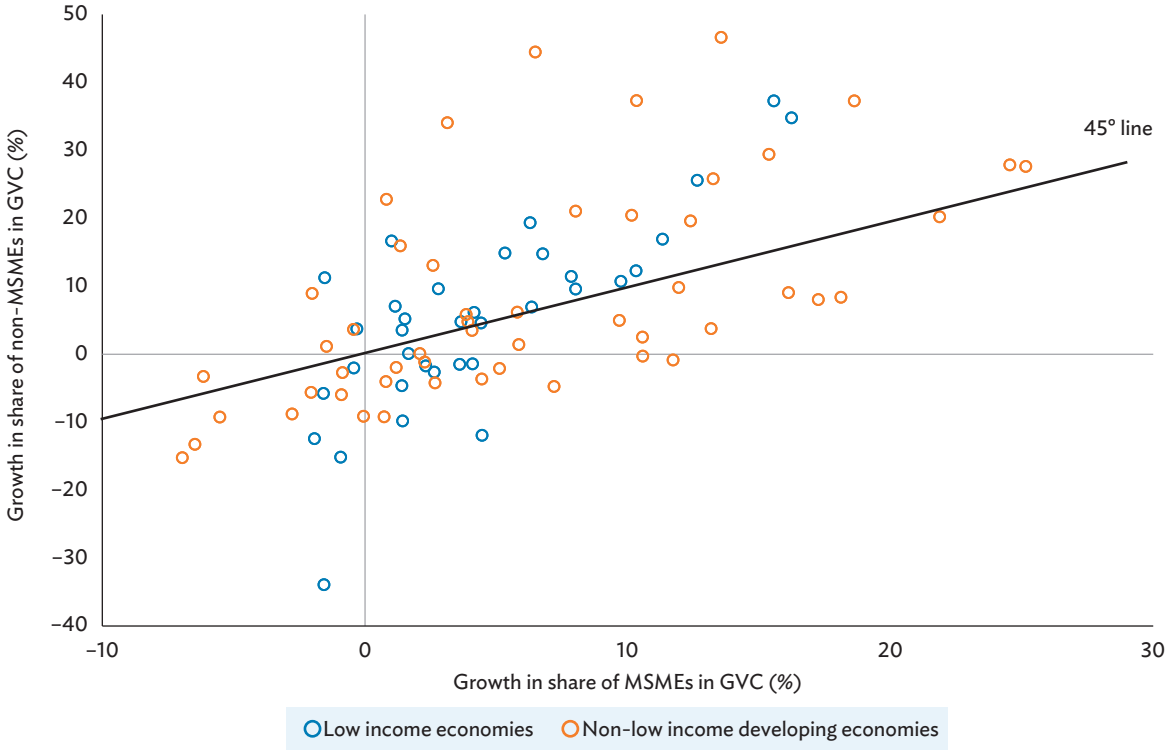


Source: Generated by the authors using ILOSTAT (2023). The figures for each country represent the latest available year among the 84 developing economies included. Employment includes both formal and informal employment.

due to their established supply and demand network, which helps their local suppliers to gain access to international markets themselves (Cusolito et al., 2016). Irrespective of whether superstar firms are domestic or foreign firms, they prioritize investments in R&D, ICT, and human capital, leading to more potent spillover effects (Amiti et al., 2023).

Data from developing economies suggests that MSMEs have improved their direct participation in GVCs. Figure 7.2 illustrates that, for most economies, the share of MSMEs directly engaged in GVCs has increased over the last decade, indicated by all points to the right of the perpendicular line. Large firms ("non-MSMEs") have enjoyed even faster growth in GVC participation in a significant number of developing economies, as indicated by points positioned above the 45-degree line. This trend is particularly prominent in low-income economies. Nevertheless, the increased participation of MSMEs is a positive sign for the inclusiveness of GVCs.

Figure 7.2: Growth in the Share of Firms Participating in GVC in the Recent Decades (2006–2022)



Source: Authors' calculation based on the World Bank Enterprise Survey (WBES) of 86 developing economies, applying statistical weights in each data set. The GVC participation rate is defined as the proportion of firms engaged in both exporting and importing and is computed separately for MSMEs (defined as enterprises with fewer than 100 employees) and non-MSME firms (including firms with 100 or more employees, state-owned enterprises, subsidiaries of large firms, or foreign firms) within each developing economy. The growth rate is determined by comparing GVC participation rates for a given year in the period 2006-2013 with the participation rate for a given year in the period 2014-2022. As countries are surveyed infrequently, the exact years used for the comparison differ from country to country based on data availability. The classification of low-income economies is applicable to those with an income per capita below 1,000 USD.

GVCs Facilitate Access to International Markets

MSMEs face greater information frictions when accessing foreign markets, from finding buyers and suppliers to understanding foreign standards and changing trade regulations. For example, searching and matching between buyers and sellers can be very costly. Startz (2021), using transaction data in Nigeria, finds that traders often incur huge travel costs when searching for new suppliers as it requires face-to-face meetings to learn reliably about supplier quality. In the Philippines, Allen (2014) finds that producers incur substantial costs to learn about prices in other locations and that roughly half of the observed regional price dispersion is due to information frictions.

Participating in GVCs with lead firms presents a significant opportunity for MSMEs to overcome such information frictions and trade barriers. Lead firms have established networks of buyers and suppliers which each supplier may be able to access on its own (Amiti et al., 2023). This often results in an increase in the number of buyers due to reduced information frictions or the credibility gained from contracting with top-tier

firms. Additionally, MNC affiliates and suppliers demonstrate a greater propensity to export and import, engage with diverse economies, and achieve higher values of trade (Conconi et al., 2022). As domestic firms enter MNCs' supply chains and start selling to foreign companies, they acquire essential knowledge and skills for exporting and often start exporting to economies where the respective MNC is headquartered or has an affiliate. These experiences further lead to significant productivity gains driven by an improved ability to acquire new buyers (Alfaro-Urena et al., 2022b; Carballo et al., 2019).

Improved access to foreign inputs has also been shown to increase firm productivity (Amiti and Konings, 2007; Kasahara and Rodriguez, 2008; Topalova and Khandelwal, 2011, Halpern et al., 2015). In a recent study, Bisztray et al. (2018) find that Hungarian firms can learn about better access to inputs through peers in spatial and managerial networks through knowledge spillovers. Spillovers are stronger when firms or peers are larger and more productive. From a GVC perspective, this implies that the networks with lead firms, which tend to be more productive, will generate a greater knowledge spillover to local MSMEs, giving them advantages in accessing cheaper, higher quality inputs and capital goods.

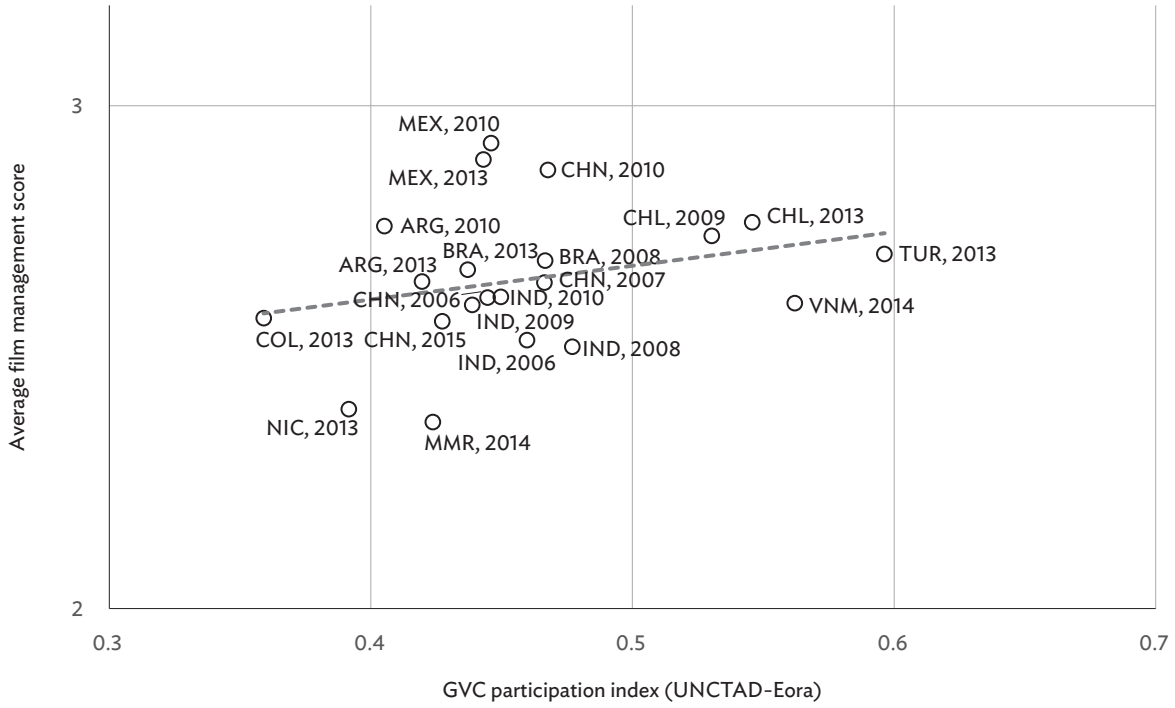
Employee spinoffs and labour mobility more generally are another avenue to overcome information frictions. When employees of MNCs or other firms participating in GVCs establish spinoffs, their knowledge of foreign markets can substantially accelerate export market entry. This contributes to the superior performance of spinoffs relative to other start-ups (Muendler and Rauch, 2018). Similarly, when highly skilled workers move from an MNC to a domestic employer, they transfer information leading to higher wages in their new firms (Poole, 2013).

GVCs Facilitate the Transfer of Good Management Practices

Lack of non-codifiable knowledge, such as managerial capacity, is a common constraint for MSMEs, especially in developing economies (Sok et al., 2020; Bloom et al., 2012). These businesses face limitations in their managerial resources due to time constraints and information frictions, and, most importantly, a shortage of specialized professionals (Manaresi et al., 2022). Despite these challenges, participation in GVCs can facilitate the dissemination of good management practices.

Management quality is a crucial factor in determining firm performance (Bloom and van Reenen, 2007; Caliendo et al., 2020). Effective organizational management is, for instance, closely associated with the adoption of new production technologies (Juhász et al., 2020; Atkin et al., 2017a). Good management practices have also been shown to improve working conditions, demonstrating the complementary relationship between management practices and working conditions (Distelhorst et al., 2017). For example, evidence from garment factories in Bangladesh suggests that the promotion of occupational safety and health compliance by MNCs has the greatest impact in factories with better managerial practices (Boudreau, 2022).

Figure 7.3: Quality of Management Practices and GVC Participation



Source: Authors' calculation based on UNCTAD-Eora for GVC participation index, and World Management Survey (Bloom et al., 2021) for average firm management score of each country. The GVC participation index is calculated as (Indirect Value Added (DVX) + Foreign Value Added (FVA)) divided by the gross export of each country.

Management practices can improve through forward participation in GVCs, or "learning by exporting". Exporting firms enhance their productivity and competitiveness by acquiring efficient management knowledge, driven by the intense competition they face in foreign markets in advanced economies (Urata and Baek, 2021). In the case of Myanmar, as garment manufacturing firms increase exports, they improve not only performance and size, but also management practices (Tanaka, 2020). In general, cross-country comparisons, as depicted in Figure 7.3, align with this mechanism, showing that developing economies with a higher degree of GVC participation tend to have a higher average firm management score.

MSMEs can acquire management know-how especially through long-term relationships with lead firms (Antràs and Yeaple, 2014). Repeated interactions enable a greater flow of information between lead firms and their MSME suppliers, leading to improvements in these smaller firms' management practices, technology, and skill levels (ADBI and ADB, 2016). This mechanism contributes to higher productivity and innovativeness in MSMEs (MacGarvie, 2006; Abbey et al., 2017; Anh and Dang, 2020). Moreover, foreign ownership can provide better networks with foreign partners, access to technology and management experiences, and learning opportunities from exporting through parent companies (Hing et al., 2020). Joint ventures with foreign capital, for example, can be an important channel as they bring in newer and more advanced skills in processing, technology, funding, marketing, and other management knowledge that expand the company's participation in the global value chain (Sok et al., 2020).

Management practices can diffuse because MNCs may voluntarily transfer valuable knowledge assets to their local suppliers in order to enhance their efficiency and competitiveness. These transfers can take the form of training programs, or knowledge-sharing initiatives (Saliola and Zanfei, 2009). A recent case study by Sudan (2021) on India's automotive industry illustrates how MSMEs benefit from direct knowledge transfers. The study demonstrates how a lead firm in India's automotive industry facilitated process upgrading among MSMEs through various channels, leading to the adoption of just-in-time, total quality management, and total productivity management practices. These initiatives resulted in new learning and demonstration effects on the lead firm's subsidiaries and associated component firms, illustrating how the lead firm enabled the integration of Indian SMEs into the global value chain by initially equipping them with the capacity to leverage their participation. Similar mechanisms have been observed in other sectors, such as the aeronautic and coffee GVCs. MNCs disseminate company knowledge by training employees of MSMEs or smallholder farmers, monitoring technical production, and promoting learning processes, since the MNCs rely on their suppliers to meet quality standards (Cafaggi et al., 2012).

The superior management practices of MNCs can also be disseminated through indirect channels, such as employment turnover. When domestic managers work at MNCs and gain exposure to high-quality management practices, they can transfer this knowledge to new workplaces when switching jobs (Poole, 2013; Bloom et al., 2020; UNCTAD, 2021)

However, the mere presence or connections to MNCs may not guarantee the spillover of tacit knowledge. Management knowledge, being tacit, non-routine, and sometimes non-codifiable in nature, poses challenges for its dissemination outside of firms. While significant spillovers of management knowledge often occur within firms, improvements in management practices can be short-lived and easily reversed when managerial turnover takes place (Bloom et al., 2020). Moreover, language barriers can be a critical obstacle to the spread of foreign managerial practices to domestic managers. Using randomized controlled trials in firms in Myanmar, one study found that reducing language barriers through subsidized English lessons can enhance the transfer of management knowledge (Guillouet et al., 2022; see also Box 7.1).

GVCs Facilitate Quality Upgrading

GVCs play a crucial role in promoting quality upgrading for MSMEs and smallholder farmers in developing economies. Quality upgrading, for instance to meet standards, is often a precondition for GVC integration (Macchiavello and Miquel-Florensa, 2019; Rifin and Nauly, 2020). This is supported by extensive empirical evidence (Rodriguez-Clare, 1996; Newman et al., 2015; Alfaro-Urena et al., 2022b). Improving quality can benefit MSMEs through export and input channels, and the positive impacts can be maximized through quality improvement programs or quality certifications.

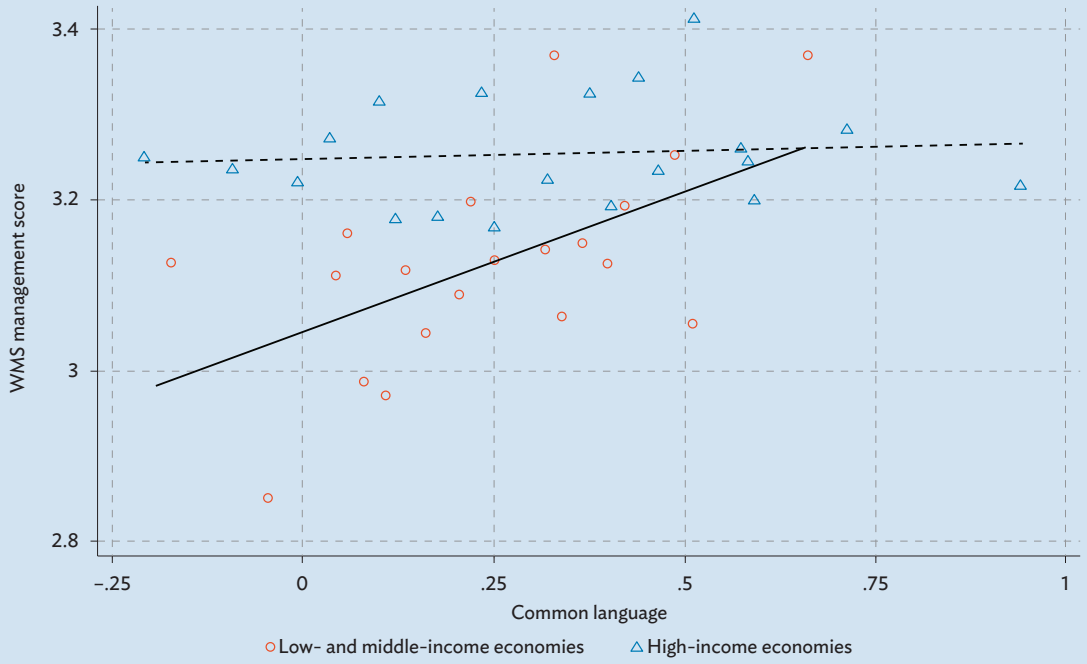
Box 7.1: The Importance of Language Skills for Knowledge Diffusion

Language differences are an important barrier to knowledge diffusion because they influence FDI and outsourcing decisions of MNCs, which are key drivers of knowledge and technology spillovers (Kim et al., 2015). The effect of language differences is also visible in knowledge-intensive strategic alliances such as collaborative R&D activities among firms. A study on semiconductor design observed an inverted U-shaped relationship between partners' language differences and the likelihood of forming cross-border R&D alliances (Joshi and Lahiri, 2015). This finding indicates that language differences serve as a noticeable source of friction for establishing such alliances.

Furthermore, easier access to English education has been demonstrated to play a key role in mitigating inequality in the context of globalization. For instance, in India, districts where the incentives to learn English were larger, primarily due to regional languages being highly dissimilar to Hindi, the alternative official language, saw greater benefits from globalization. These benefits manifested as significant growth in knowledge-intensive sectors like IT, and an increase in school enrolments. This increased engagement in education and technology, in turn, limited the rise in wage premiums for skilled labour, thus decreasing inequality (Shastry, 2012).

Language friction can also have an impact on various types of strategic interactions and organizational processes. As discovered by Guillouet et al. (2022), language differences can impede the spillovers of management skills and tacit knowledge within MNCs. Effective communication and knowledge sharing within MNCs can be hindered when language barriers exist, potentially limiting the transfer of valuable skills and knowledge among employees within the organization.

Figure 7.4: Management Quality and Language Similarities between Host and HQ Country



Note: Guillouet et al. (2022) use a gravity specification to generate the binned scatter plot, wherein they regress the WMS management score of a subsidiary on the common language indicator, the distance between the host and origin country, the number of employees, and both host and origin country fixed effects.

Figure 4 from Guillouet et al. (2022) demonstrates a positive correlation between the management scores of MNC subsidiaries and language similarities between the host country and the headquarters' country of origin, presenting a stark difference between low- and middle-income economies (represented by a solid line) and high-income economies (dashed line). The authors highlight that this correlation is markedly flatter for subsidiaries in high-income economies compared to those in middle and low-income economies. This suggests that language barriers could impede the effective transfer of knowledge from MNCs to employees in developing economies, potentially restricting the advantages gained from such knowledge transfers.

As foreign language skills are considered as general skills in the labour market of developing economies, firms may underinvest in language training. Such underinvestment in skills calls for the need for policy interventions, either through foreign language training programs or formal education. For instance, the Trinidad government has taken a step in this direction by passing a bill in 2005, making Spanish a mandatory subject in schools and requiring basic Spanish proficiency for all civil servants. Davies (2005) explains that one of the motivations behind this policy was to align its language with Venezuela, the largest oil producer in the hemisphere, in order to strengthen Trinidad's own oil and natural gas industries. This example shows the importance of sharing a common language to promote business linkages, and further, knowledge transfers.

Similar to management practices, quality upgrading within GVCs can be facilitated through "learning by exporting" (Clerides et al., 1998; De Loecker, 2007; Harrison and Rodriguez-Clare, 2010). Pressure from conducting business in highly competitive foreign markets forces exporting firms to improve their performance. GVC integration as a seller requires a reliable and timely production of quality inputs, leading to upgrading by raising incentives to invest in input and output quality (Stolzenburg et al., 2019). A major driving force in this mechanism is a demand-side factor - notably, higher demand for quality - in markets in advanced economies. This demand pressure forces firms to upgrade their quality standards to meet the requirements of high-income foreign buyers. In a unique research study focusing on Egyptian rug producers gaining access to foreign markets, Atkin et al. (2017b) discovered a notable increase in the overall quality levels of rugs.

Importantly for MSMEs in developing economies, the positive effects of supply chain trade also arise through indirect exporting. Recent studies show that the positive effects of export opportunities for larger firms spill over to the domestic economy through large firms' linkages with domestic suppliers. As the exporting firms require higher quality inputs to compete on foreign markets, their suppliers increase their skill intensity and sourcing from abroad to upgrade the quality of their products. This can lead to positive wage effects that are up to 9 times larger than in models not accounting for domestic linkages (Demir et al., forthcoming; Fieler et al. 2018).

Sourcing strategies imposed by lead firms play also a crucial role in the quality upgrading efforts of exporting firms in developing economies (Cajal-Grossi et al., 2023; Gereffi, 1999; Egan and Mody, 1992). MNCs that source from abroad often encounter quality issues. To address this, firms can adopt relational sourcing methods. Relational sourcing constitutes a strategy employed by buyers, wherein orders are assigned to a limited pool of suppliers. Buyers engage in long-lasting relationships with suppliers and pay higher prices to incentivize and enable suppliers to deliver high-quality inputs. This contrasts with spot-sourcing strategies, where transactions take place without long-term, recurring relationships. By paying additional markups, MNCs aim to improve relationship dimensions that are difficult to contract and observe, such as input quality (Macchiavello, 2022; Cajal-Grossi et al., 2023).

Quality improvement programs offered to MSMEs and smallholder farmers are another way for buyers to ensure required quality (Cafaggi et al., 2012; Sudan, 2021; Sok et al., 2020; Macchiavello and Miquel-Florensa, 2019). A study on the Sustainable Quality Program implemented in Colombia's coffee value chain finds that such programs can reduce the gap between prices farmers receive and final consumer prices, increasing quality upgrading incentives (Macchiavello and Miquel-Florensa; 2019). Quality certification programs can play a similar role (Rifin and Nauly, 2020). Dragusanu et al. (2022) and Zavala (2022) find that Fair Trade Certification decreases inequality in the coffee sectors of Costa Rica and Ecuador, as rents are transferred from the intermediaries to the farm owners.

Importing is also important for quality upgrading as it provides firms in developing economies with access to cheaper and higher quality inputs and capital goods (Goldberg et al. 2010, Sudan, 2021). The economic literature consistently highlights that more successful exporters use higher-quality manufactured inputs and employ more skilled workers to produce superior outputs that command higher prices (Verhoogen, 2008; Kugler and Verhoogen, 2012; Khandelwal, 2010; Manova and Zhang, 2012; Bastos et al., 2018). Furthermore, local MSMEs can achieve enhanced quality by combining domestic and foreign intermediate inputs (Sudan, 2021). This finding aligns with the observation made by Halpern et al. (2015), who discovered that imported inputs are not perfect substitutes for domestic inputs and are generally of higher quality.

GVCs Facilitate Technology Transfers and Innovation

GVCs facilitate the transfer of technology and innovation from lead firms to their suppliers. As discussed previously, lead firms in GVCs have an incentive to transfer technology and know-how as they rely on high-quality inputs from their suppliers (Baldwin and Lopez-Gonzalez, 2015; Piermartini and Rubinova, 2021). The flow of knowledge between firms within GVCs is stronger for long-term firm-to-firm relationships that are characteristic of some value chains, making them highly effective in transferring technology (Antras, 2020; World Bank, 2020). The technology transfer in relationships between foreign customers and local suppliers has proven to be highly effective in raising supplier productivity (Javorcik, 2004; Alvarez and Lopez, 2008). MSMEs can also sometimes reap the benefits of technology transfers even if they are not directly exporting or importing as long as they are part of domestic production networks that benefit from trade (Iyoha, 2022).

In this regard, the heterogeneity among local suppliers in developing economies, specifically in their capacity to absorb, assimilate, and adapt knowledge and skills transferred by lead firms, is a crucial factor. While GVCs have been empirically shown to stimulate innovation, as measured by the number of patent applications, the presence of strong absorptive capacity is crucial in this process (Piermartini and Rubinova, 2021). A study conducted by De Marchi et al. (2015) examined 50 GVCs in developing economies and categorized them into different groups. They found that just under a fifth of the cases fell into the "GVC-led innovators group," indicating that these firms effectively used GVC knowledge to drive innovation. However, more than half of the cases analyzed belonged to the "Marginal Innovators group," characterized by a lack of in-house R&D activities and a weak local innovation system that limited their reliance on local learning sources. This evidence underscores the importance of addressing the absorptive capacity constraints faced by MSMEs in developing economies for local innovation.

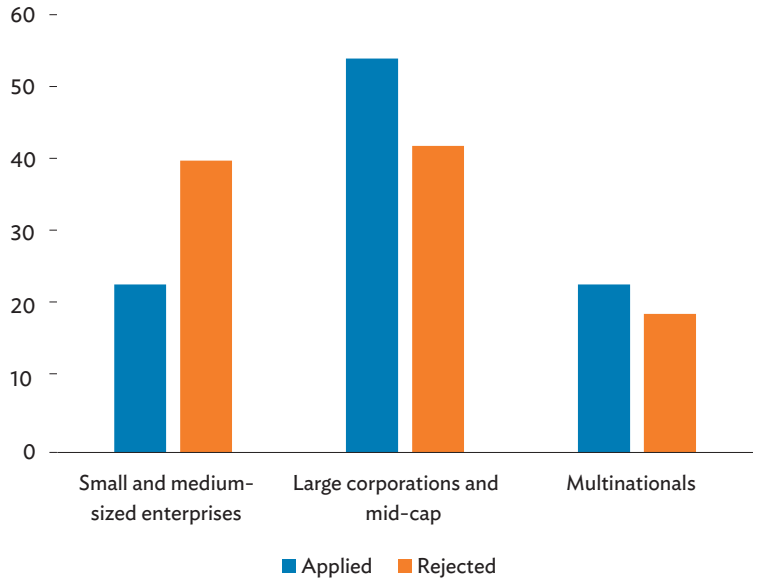
Similarly, not all GVC relationships are equally conducive to transfers or innovation (Saliola and Zanfei, 2009). The relationships of MSMEs with global lead firms are often confined to mere purchase-supply relationships, where the lead firms provide only limited information. This leaves little room for innovation, particularly in the areas of

marketing, human resources, and finance (Kumar and Subrahmanya, 2010). In such "captive relationships," significant bargaining power imbalances can trap suppliers in repetitive and non-innovative tasks, instead of fostering learning and innovation processes that are typical of relational GVCs. For instance, recent research in the mining industry has demonstrated that the hierarchical governance prevalent in this sector often hinders learning and innovation, due to power and information asymmetry between lead firms and local suppliers (Pietrobelli et al., 2018).

GVCs Facilitate Access to Trade Finance for MSMEs

Smaller businesses, especially from developing economies, have limited access to trade finance. As trade finance is used in approximately 80% of global trade transactions (WTO and IFC, 2022), this acts as a substantial non-tariff trade barrier (WTO, 2016). According to a recent figure (Figure 7.5) from the Asian Development Bank, small businesses are significantly more likely to have their trade finance requests rejected compared to large firms (ADB, 2021). Trade credit is commonly used by financially constrained firms to finance input purchases or extend financing to their customers (Fabbri and Klapper, 2009). This is particularly prevalent among small firms (Marotta, 2001; McMillan and Woodruff, 1999). Working capital plays a critical role in bridging the timing gap between costs and cash flows, and GVCs necessitate substantial short-term financing to meet their non-linearly increasing working capital requirements throughout the production chains (Kim and Shin, 2023).

Figure 7.5: Trade Finance Rejections



Source: ADB (2021)

Firms in developing economies encounter added obstacles in obtaining affordable and adequate trade finance due to the financial challenges typically found in these economies. For instance, in West African economies, trade finance only supports a quarter of goods trade, which is lower than the African average of 40 percent and the global average of 60-80 percent (WTO and IFC, 2022). MSMEs face even greater obstacles. In a joint 2013 survey by the OECD and the WTO on Aid for Trade, the lack of access to finance, particularly trade finance, was identified as the primary obstacle for suppliers from low-income economies to enter, establish, or move up in value chains. Approximately 65 percent of suppliers from low-income economies expressed concerns about inadequate access to finance, while only 6 percent of lead firms in the production chains considered it an issue.

Participation in GVCs can significantly alleviate financial constraints by providing access to credit, particularly for MSMEs. To overcome credit limitations, firms within GVCs often use firm-to-firm credit arrangements and trade credit as a means of obtaining working capital. This approach is strongly tied to GVCs' high dependency on finance, where accounts payable and receivable play a key role in short-term financing for firms (Kim and Shin, 2023). The interconnected nature of GVCs, underscored by repeated transactions and long-term relationships, ensures that financial decisions made by upstream companies can directly and indirectly influence the financial performance of downstream suppliers, even in arm's length relationships (IMF, 2017). Such interdependencies encourage larger, less financially constrained firms to borrow at lower foreign currency rates and channel these funds domestically to their smaller suppliers, albeit with a reduction in profits (Hardy et al., 2023).

Within GVCs, trade credit often materializes as a result of enduring contractual relationships, fortified by reputation dynamics (Bocola and Bornstein, 2023). This creates a strong motivation to repay suppliers to avoid damaging these critical connections, as both buyers and sellers benefit from maintaining these relationships (Bocola and Bornstein, 2023; Macchiavello, 2022). Empirical evidence further emphasizes the critical role GVCs play in enhancing credit access for MSMEs, with firms engaged in GVCs more likely to receive and extend trade credit to their suppliers and customers, especially if they're financially constrained (IMF, 2017; Thang and Ha, 2022). This advantage is particularly pronounced when these firms establish long-term trade relationships with large international partners, an invaluable benefit in scenarios with limited access to bank credit or weaker banking relationships (Minetti et al., 2019).

Furthermore, the role of GVCs as financial intermediaries can also have macroeconomic implications, contributing to the stabilization of emerging market economies. Trade credit has the capacity to absorb external shocks, thereby assisting in the smoothing of firms' output (Garcia-Appendini and Montoriol-Garriga, 2013). Moreover, firms can use trade credit to manage liquidity (Amberg et al., 2021), stabilize their trade partners (Ersahin et al., 2023), manage currency shocks, and enhance overall economic stability (Hardy et al., 2023). However, while firm-to-firm financing allows for greater output

support on average, it can sometimes increase vulnerability to financial shocks. For instance, the presence of trade credit amplified the financial impact on firms during the Great Recession (Bocola and Bornstein, 2023).

7.3 GVCs Can Help Workers in Developing Economies

This section examines the recent evidence concerning labour market impacts of GVC participation. The key message is that engaging in GVCs leads to substantial benefits. GVCs create job opportunities in formal sectors with higher wages and better working conditions, particularly for lower-skilled workers. For example, the US-Viet Nam Trade Agreement led to a reallocation of labour from the informal sector to formal employers, resulting in significant wage adjustments (McCaig and Pavcnik, 2018). Import channels can lower production costs and enhance productivity for domestic firms, thereby leading to growth and increases in manufacturing employment (Topalova, 2007; Goldberg et al., 2010; Amiti and Konings, 2007; Bas and Bombarda, 2023). In Ethiopia, employment in manufacturing increased when a surge in Chinese imports led to productivity gains and increased capacity utilization driven by better quality inputs (Ngoma, 2023).

However, several issues remain regarding the impact of GVC integration on wage inequality, informal labour, and labour standards. The benefits of GVC participation may not be equally distributed among workers of different skill levels or between regions. At the macro-level, the conclusions regarding the effects of GVCs on inequality are complex, and the impacts of a particular trade shock may evolve dynamically over time, making the effects of trade exposure time-horizon specific (Dix-Carneiro and Kovak, 2023). That said, a background paper to this chapter finds that GVC integration tends to reduce aggregate income inequality in developing economies (Yu et al., 2023).

The section also finds that GVC integration can address social concerns, with a focus on female empowerment and child labour. Cross-country evidence demonstrates that participation in GVCs can have a pivotal role in both economic and social upgrading (UNCTAD, 2013; Stolzenburg et al., 2019). GVCs not only directly contribute to economic prosperity that benefits disadvantaged groups but also provide an opportunity for lead firms to leverage their corporate resources in driving social upgrading initiatives. Specifically, lead firms can play an important role in enhancing social standards among lower-tier suppliers, thereby creating positive spillover effects that extend upstream within the value chain (Narula, 2020). In line with this, the section finds that GVCs have increased female empowerment and tend to reduce child labour. However, underlying barriers, for instance regarding access to education or finance, prevent GVCs from contributing further to closing gender inequalities.

GVCs Can Support a Shift to Formal Employment

GVC integration tends to reduce informal employment as it raises the demand for formal labour. Informal employment is prevalent in many developing economies. Informal workers typically have lower job security, income, and fewer benefits and opportunities compared to formal workers. Informal workers are often excluded from formal labour regulations, which limits their access to social protections and benefits, including health care and retirement plans. They tend to earn lower wages and have limited opportunities for education and training, which constrains their ability to acquire new skills, participate in international trade and advance their careers (Bacchetta et al., 2009; McCaig and Pavcnik, 2018).[4]

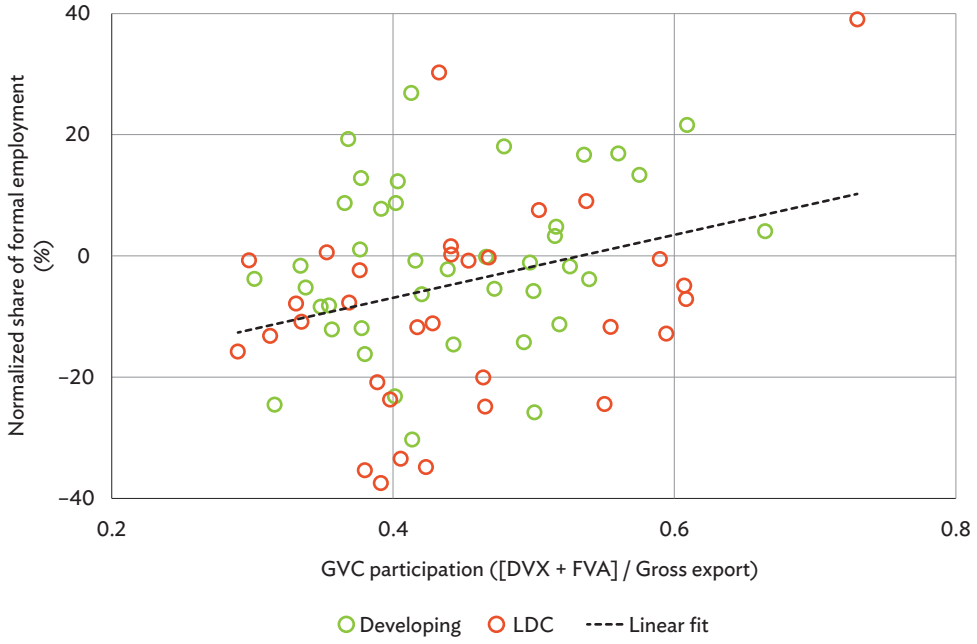
In general, the integration in GVCs, particularly through increased export opportunities, has led to a significant shift of workers from the informal sector to formal employment (Maertens and Swinnen, 2009). This view is consistent with the conventional perspective of the informal sector, which posits that the informal sector primarily serves as a holding ground for workers who are unable to secure formal sector jobs (Chandra and Khan 1993). According to this view, as an economy develops and the pool of formal sector jobs expands, the growing number of formal sector opportunities will naturally crowd out informality. Cross-country comparisons also indicate that GVC participation is positively associated with the share of formal employment, particularly among developing economies (Figure 7.6).

Multiple examples from recent GVC integration episodes show that increased access to advanced economy markets through GVCs has led to a shift away from more informal sectors, such as agriculture, in economies like the People's Republic of China (PRC) (Erten and Leight, 2021). A notable example is the United States-Viet Nam Bilateral Trade Agreement, which resulted in a sharp reduction of US tariffs on Vietnamese exports and induced the reallocation of labour from informal microenterprises to formal employers (McCaig and Pavcnik, 2018). During this adjustment, the influx of new entrants following the tariff reductions was critical in generating formal manufacturing, with foreign firms playing an important role (McCaig et al., 2022). In Bangladesh, where the growth in GVC-integrated garment sector exports has been a major driving force in economic growth in the past decades, trade exposure has increased formal labour force participation, especially for women (Goutam et al., 2017). In Cambodia, a surge in garment exports to the EU induced a 16-22 percent increase in employment at formal establishments (Tanaka, 2022).

---

4 That said, recent literature has also highlighted several useful aspects of informal labour markets. Studies show that the informal sector plays a role as an "unemployment buffer" when a country is facing negative shocks induced by trade exposure (Dix-Carneiro et al., 2021; Ponczek and Ulyssea, 2022). In addition, the existence of an informal sector may mitigate the monopsony power of firms by providing an outside option to workers (Amodio et al., 2022).

Figure 7.6: GVC Participation and Formal Share of Employment



Source: Authors' calculation based on ILOSTAT for (in)formal share of employment, and UNCTAD-Eora for GVC participation The graph controls for year fixed effects and GDP per capita and plots the latest observations of each country in ILOSTAT. The GVC participation index is calculated as (Indirect Value Added (DVX) + Foreign Value Added (FVA)) divided by the Gross Export of each country.

Formalization of employment can also occur through input channels, as access to cheaper inputs or more advanced foreign technology becomes easier. When Mexico initiated the North American Free Trade Agreement (NAFTA) in 1994, improved access to foreign-technology-embedded inputs prompted firms to upgrade production technologies. This upgrade resulted in an increase in the demand for skilled workers, leading to the reallocation of high-skilled workers from the informal sector to formal firms (Bas and Bombarda, 2023). However, the effect on informality through the input channel might be limited. This is the case if the domestic enterprises which previously produced the now imported inputs, react to the fall in demand by reducing their formal workforce (OECD, 2023b).

Another significant mechanism that can help developing economies increase formal employment are responsible business conduct (RBC) efforts of MNCs. Informal sector engagement in GVCs has fallen in line with the demands of MNC investors or stakeholders who are increasingly concerned about reputational issues. For example, in the aftermath of the 2013 Rana Plaza tragedy, MNCs enforced the use of exclusively formal workers more strictly at garment suppliers in Bangladesh (Narula, 2020).

While export-led GVC integration offers the potential for growth in the formal sector of developing economies, further GVC integration may not necessarily displace informal sector jobs due to several factors. First, the informal sector provides opportunities for entrepreneurship and flexible work arrangements, and can also serve as a supply chain

link to the formal sector (Fajnzylber et al. 2006, Bennett and Estrin 2007). This may explain the persistent presence of informal employment in some developing economies despite their increasing participation in GVCs. For example, in Bangladesh, exports more than doubled in real terms between 2002 and 2010, boosting formal employment. Yet, the formal share of employment remained nearly constant at around 15 percent during the same period as informal employment also expanded. This may be because of the indirect demand generated through domestic supply chain linkages and through higher incomes raising the consumption of local services (Goutam et al., 2017).

Furthermore, in cases where governments' enforcement capacity is weak and reputational pressures are small, the costs associated with complying with higher employment standards imposed by legislations in foreign markets and MNCs' standards may result in more informal labour demand to cut labour costs (Standing, 1999). In South Africa, for example, Barrientos and Kritzinger (2004) note that fruit growers that have had to contend with rising standards imposed by supermarket GVCs and increasing government regulations for higher labour standards, made greater use of informal contract labour, especially as falling international market prices hurt their competitiveness.

In summary, export-led GVC integration in the manufacturing sector has generally led to growth in formal employment in many economies. Backward GVC integration also helps the growth of formal sector employment, although the effect could be mitigated if domestic firms face increased competition from imported inputs. Whether at the same time informal employment will decrease in the economy depends largely on other factors, including the enforcement capacity of governments.

GVCs Can Improve Job Quality

A race-to-the-bottom in working conditions of firms in developing economies due to cost pressures in GVCs is a frequent concern surrounding supply chains (Im and McLaren, 2023). Workers may be exposed to unsafe working conditions in order to keep production costs competitive in the global marketplace (Rossi, Luinstra, and Pickles, 2014). GVCs can lead to labour standards being defined by the demands of flexibility, resulting in easier hiring and firing, more short-term contracts, fewer benefits, and longer periods of overtime. Firms may also underestimate the value of non-pecuniary aspects of jobs, such as pay transparency, occupational safety and health measures, and emotional well-being (Adler et al., 2017). While low non-pecuniary rewards may bring short-term trade advantages to firms, they carry long-term costs to society (ILO, 2008).

However, GVC participation can also increase job quality in developing economies. GVC integration can increase the resources available to invest in job quality, as the gains stemming from GVC integration increases income levels within host countries. Given the correlation between income and improved working conditions, this "income effect" can consequently drive better workplace environments (UNCTAD, 2021).

Furthermore, MNCs typically apply higher labour standards. Empirical evidence underscores the feasibility of transferring enhanced labour practices and norms from MNCs' home countries to their host nations (Ali and Seric, 2014). MNCs tend to standardize business operations across different subsidiaries, thereby minimizing fixed operational costs (Helpman et al., 2004). Moreover, MNCs tend to maintain better labour standards compared to domestic peers because MNCs may want to attract highly skilled individuals within competitive labour markets (Mosely, 2011) and maintain a stable workforce (Mendez and van Patten, 2022).

MNCs' high labour standards can also be indirectly diffused into the economy through local spillovers. HR practices at MNCs can be acquired by workers who were previously employed, subsequently disseminating them to local economies through job turnovers (Poole, 2013).

Diffusion also takes place as GVC integration creates reputational pressure from demand-side actors, such as customers or NGOs. Lead firms that are concerned about reputational risks will voluntarily choose to impose stricter regulation through monitoring, or through alternative sourcing strategies. This is particularly relevant in economies where governments lack the capacity to enforce regulations or monitoring mechanisms. MNCs might choose to enforce regulations on their own if they perceive that the cost of implementing better labour standards is outweighed by the risk of negative publicity. This mechanism is theoretically supported by Krautheim and Verdier (2016) who present a model where the possibility of NGO scrutiny increases the incentive for the firm to choose a better production technology, improving its reputation in the eyes of consumers and thus increasing demand.

MNCs may use so-called relational sourcing strategies which serve as an effective mechanism to support compliance by suppliers in cases where monitoring is difficult. Relational sourcing - which is typically characterized by long-term, repeated transactions where buyers pay higher mark-ups - can motivate suppliers to deliver on aspects that are difficult to monitor or contract, such as labour standards. This strategy can serve as an enforcement mechanism because sellers typically want to avoid situations where long-term relationships are terminated due to non-compliance. These long-term relationships hold greater value for sellers compared to what they would gain in spot-sourcing, where short-term orders are awarded to the lowest bidders (and consequently mark-ups are squeezed due to competition). In other words, relational sourcing can incentivize suppliers to comply with labour standards by subjecting them to the threat of relationship termination in case of non-compliance, while also increasing the resources to invest in better job quality (Macchiavello, 2022). For instance, a change in sourcing strategy by Gap Inc, a global apparel retailer, brought a significant improvement in job quality at suppliers by making a continuous business relationship dependent on compliance with labour standards (Amengual and Distelhorst, 2020).

There is evidence that MNCs' voluntary intervention to address labour standard issues in developing economies can be highly effective. For example, Tanaka (2020) finds that exporting to high-income economies among Myanmar's export-oriented garment firms positively and substantially affects working conditions, especially in the areas of fire safety, health management, and worker-firm negotiation. Boudreau (2022) finds that stronger occupational safety and health committees improved objective measures of safety, based on randomized controlled trials on 84 suppliers in Bangladesh, selling to multinational apparel buyers. In her findings, the largest effects on compliance, safety, and voice were seen in factories with better managerial practices. Following the Rana Plaza tragedy in 2013, reputational shocks caused a spatial reorganization of apparel supply chains. French companies named as responsible for the scandal pulled out part of their production from Bangladesh and shifted their sourcing to economies that are closer to France, such as Türkiye, Morocco, Poland and Portugal (Koenig and Poncet, 2022).

However, there are caveats to mechanisms relying on MNCs' voluntary interventions. This is because NGO activities and awareness channels may have geographic limits, and their impact may not be as strong in upstream production stages that are not directly visible to consumers. NGO supervision of companies is often bounded by a strong "home bias" (Hatte and Koenig, 2020; Koenig et al., 2021), as the supervision weakens for firms that operate at arms' length. One study finds a significant link between the costs of ethical production and the likelihood for transactions occurring at arms' length rather than within the firm (Herkenhoff and Krautheim, 2022). In addition, in upstream industries, in which brands are less visible to final consumers, corporate social responsibility (CSR) investments are typically low (Herkenhoff et al., 2021). The impact of awareness channels may also be short-lived. For example, Ang et al. (2012) find that the rate of compliance with regulations slowed after the elimination of public disclosure at the factory level.

GVCs Tend to Widen Wage Inequality

GVC integration raises labour demand in developing economies, which leads to higher wages (Adao et al., 2022). This effect is driven by different channels. Foreign lead firms typically pay higher wages than domestic firms as they are more productive (Javorcik, 2015). In addition, MNCs improve workers' outside options, including for unskilled labour (Fukase, 2014). This causes upward pressure on wages in the domestic labour market (Alfaro-Urena et al., 2021). Recent evidence also finds that standardized wage setting procedures anchor firm-wide wages to headquarter wage levels in MNCs, leading to substantial wage premia for MNC employees in developing economies (Hjort et al., 2022).

While the effect of GVCs on average wages is relatively clear, the distribution of wages within GVC jobs and, hence, the impact of GVCs on wage inequality is more complex. International trade shifts demand for domestic production factors through both export and import channels. First, foreign consumers and firms may demand products

that require different types of skills than domestic consumers and firms. Second, the availability of foreign inputs might cause shifts in the skill demands of domestic consumers and firms. As GVC integration typically operates through both channels, the direction of the effect of GVC participation on inequality, particularly between low-skilled and high-skilled workers, depends on which labour input demand will grow, or which channel (import or export) holds more dominance (Adao et al., 2022). Due to a multitude of factors that can affect these channels, as well as local labour market frictions and policies, the effect of GVC on wage inequality is context-specific.

GVC integration can contribute to an increase in wage inequalities, as exporting or global sourcing from foreign markets through GVCs can increase the demand for high-skilled labour in GVC industries. Traditional economic theory predicts that the integration of richer, skilled-labour abundant economies with poorer, unskilled-labour abundant economies should lead to an increase in the skill premium in richer economies and a decrease in poorer economies. However, in practice, trade and GVC participation has been shown to be associated with increasing skill premiums in many developing economies that underwent trade liberalization in the 1980s and 1990s (Goldberg and Pavcnik, 2007). This is because offshored tasks to developing economies from developed ones are typically considered highly skilled in developing economies. Quality dimensions of exported goods can also contribute to a growing demand for high-skilled workers. Not only do exported goods from developing economies serve quality-sensitive developed economies, inducing a larger demand for higher skilled labour to meet these quality standards, but high complementarities along production stages across borders lead disproportionately to even greater demand for skilled labour (Farole et al., 2018; Shepherd and Stone, 2012; Crinò, 2012; Hollweg, 2019).

Similar mechanisms can occur through the import channel. In a recent study on Ecuador, Adao et al. (2022) show that the importation of intermediates tends to reduce the demand for the factor services of poor individuals as many intermediate goods are imported by firms employing high-skill workers. The import channel also relates to capital-skill complementarities. As economies reduce tariffs and trade costs decline, the price of capital decreases, especially in lower-income economies that tend to import a large share of their capital equipment. If capital complements skilled labour but substitutes unskilled labour, then increased openness can lead to increases in the skill premium, even in economies that have an abundance of unskilled labour. Dix-Carneiro and Traiberman (2023) demonstrate that capital-skill complementarity can provide a plausible explanation for the increase in the skill premium in many Latin American economies following their trade reforms. Similar effects were observed in Mexico's manufacturing sector, where input tariff reductions disproportionately benefited high skilled workers through input-skill biased channels (Bas and Bombarda, 2023).

However, many of these effects ignore the dynamic nature of human capital. Increased demand for skills raises incentives to obtain skills. In a study on services liberalization, Nano et al. (2021) find that the expansion of services employment after a liberalization

period can explain a significant share of increased educational attainment in India in the 1990s. As services, especially those central to GVCs like telecommunications or finance, offer higher wages and demand higher skills, GVC integration makes schooling more affordable and increases the returns to schooling. Both channels increase educational attainment. In line with this, Yu et al. (2023) find that investments in education can help GVC integration reduce income inequality in developing economies.

GVC exposure can also contribute to regional wage disparities. Unfavourable effects through trade are associated with growing spatial inequality within developing economies, exacerbated by mobility frictions (Topalova, 2010; Dix-Carneiro and Kovak, 2017). As employment, wages, and non-labour market effects are not adjusted, a lack of labour mobility across space can lead to a large and persistent effect on regional inequality following trade shocks. GVC integration is strongly associated with greater concentration in cities, as well as border regions for economies neighbouring GVC partners. For instance, in Mexico and Viet Nam, economic integration across national borders is associated with greater spatial concentration within national borders (World Bank, 2020). Inclusion in services GVCs can also worsen regional wage inequalities in developing nations (Nano and Stolzenburg, 2021), as highly traded services sectors tend to be more clustered than manufacturing or agriculture. This is related to the spatial agglomeration mechanism, where the interaction of skill-sharing is particularly important for these services (Diodato et al. 2018). McCaig (2011) also finds that gains from GVC participation in Viet Nam are not evenly distributed across unskilled workers in different regions, due to low levels of inter-provincial migration, especially for unskilled workers.

The benefits of export-led growth from GVC integration may not necessarily reach low-wage workers due to firms' labour market power. In Brazil, for example, the strong oligopsony power in the labour market that existed prior to trade liberalization became even greater as employment was reallocated to higher-paying exporting firms. The result was little to no improvement in the overall wage level (Felix, 2021). Similarly, in Colombia, despite hiring more workers and paying higher wages in the face of export shocks, firms with oligopsonistic labour market power kept wages much lower than the respective marginal productivity (Amodio and De Roux, forthcoming). Amodio et al. (2022) also provide similar insights from the Peruvian labour market, showing how employer concentration can determine labour market outcomes across local labour markets.

A study on a major agricultural firm in Costa Rica highlights that labour mobility is an important counterweight to monopsony power. Labour mobility increases the outside option of workers so that firms are required to offer better remuneration in order to retain the local workforce, despite their monopsonistic presence in the local labour market. This could result in an improvement in the welfare of low-wage workers. However, the study shows that by offering remuneration in the form of local amenities partly in place of higher wages, firms can subsequently reduce labour mobility and shift market power away from workers (Mendez and van Patten, 2022).

GVCs Can Support Gender Equality

GVCs, especially in industries such as apparel, footwear, and electronics, have presented opportunities for women in developing economies to benefit from international trade through job creation and higher wages (Kumar, 2017). Recent examples of GVC-led growth, such as in Viet Nam and the PRC, demonstrate the positive effects of reallocating the female workforce from informal agricultural sectors to manufacturing or services industries (Pham and Jinjarak, 2023). Firms involved in GVCs, particularly foreign-owned firms, tend to have a higher proportion of female workers (World Bank and WTO, 2020). This trend holds across various manufacturing and agricultural sectors. For instance, the export-led growth by the garment manufacturing sector in Bangladesh provided jobs predominantly for the female labour force (ILO, 2020a). Similarly, in West Africa, the shea butter industry, which is dominated by women, experienced higher incomes as it integrated into GVCs (Chen, 2017).

These improvements in economic opportunities have far-reaching effects, as they contribute to the overall well-being of women. Women's outside options can influence marriage, fertility decisions, and intra-household gender dynamics. In Bangladesh, young females exposed to export-processing garment industry jobs tend to delay marriage and childbirth (Heath and Mobarak, 2015). For unmarried women, decisions regarding marriage or fertility, such as whether or when to marry or have children, are affected by their educational attainment or training decisions (Jensen, 2012). For married women, regardless of their labour market participation while married, having greater or better outside options can enhance their bargaining power within households (Majlesi, 2016). Improved bargaining power for women has also been shown to reduce domestic violence (Aizer, 2010). Moreover, as women often have greater decision-making power over household expenditures, there is an increase in spending on public goods, such as children's health and medicine. The effects can induce more gender-equal outcomes for children, as higher bargaining power can also lead to relatively better health outcomes for female children compared to male children (Majlesi, 2016).

Importantly, the effects are not limited to women employed within GVCs. In Myanmar, a study by Molina and Tanaka (2023) documented a reduction in domestic violence in households located near exporting factories. Following its political reform in 2011, Myanmar's garment industry experienced significant growth between 2012 and 2020, primarily driven by exports to the EU, USA, and Japan (Eurocham, 2022). The expansion of exporting opportunities not only created employment and higher wages for women, but also led to substantial improvements in working conditions within exporting garment firms. The main driving force behind these improvements was the pressure exerted by foreign buyers on supplier factories to enhance their working conditions, as foreign buyers were concerned about reputational risks associated with sweatshop production (Tanaka, 2020). Aligned with the outside option mechanism, women who considered a

garment factory job as a viable alternative, even if they were not directly employed in such factories, benefitted from the existence of export opportunities. The positive effects extended beyond the immediate workforce, indicating the spillover benefits associated with the presence of exporting industries in the region.

The growth of services GVCs has played a pivotal role in driving significant changes in terms of gender equality and women's empowerment (Lan and Shepherd, 2019). Services have created numerous job opportunities with higher salaries, resulting in a notable increase in female employment and contributing to closing the gender wage gap (WTO, 2019, Nano et al., 2021). This improvement is linked to women's comparative advantage in the services sector, where physical strength is less important than in agriculture and manufacturing (Galor and Weil, 1996; Juhn et al., 2014). A study by Ouyang et al. (2022) highlights how greater export opportunities to the US led in the PRC to a reallocation of women from agriculture towards the services sector where wages were higher. The improved economic status of women in these regions brought about significant social changes including delayed marriages and a decrease in fertility rates.

Notably, success stories from economies like India and the Philippines highlight the impact of IT and Business Process Outsourcing (BPO) services exports on women's workforce participation. More than 50% of BPO workers in the Philippines and 34% of IT workers in India are women, which are significantly higher rates than their respective national averages. Women also gained greater opportunities for managerial roles and skills upgrading in the IT sector (Nano and Stolzenburg, 2021). Previous evidence from rural villages in India supports this mechanism, particularly in the context of career opportunities for women in BPO services. These opportunities have been found to contribute to female empowerment by reducing the likelihood of early marriage and childbirth. Instead, women choose to enter the labour market or pursue further education and training. Furthermore, they indicate an increased aspiration for a career (Jensen, 2012).

MNCs play an important role in the link between GVCs and gender equality. They usually follow more equal management practices, and they can propagate these practices in host economies directly, by employing local workers, or indirectly, through spillovers (UNCTAD, 2021). MNCs typically offer more equal opportunities for women (Sharma, 2020), especially by hiring more female workers in production and administrative occupations (Tang and Zhang, 2021). For instance, in Chile, Delgado (2020) shows that foreign ownership increases the share of female workers within firms. In addition, large MNCs tend to have more gender equal corporate cultures, as shown by having a higher share of female top managers compared to domestic firms across economies (UNCTAD, 2021).

In terms of indirect impacts, there is evidence that domestic firms operating in close proximity to, or within the same industry as, MNCs may be more inclined to adopt

gender-equal practices. For example, in Costa Rica, Monge-Gonzalez et al. (2021) observe that the increase in the female labour share in domestic firms was driven by the presence of MNCs. Similarly, in the PRC, Tang and Zhang (2021) find that the female labour share in domestic firms increases in correlation with the prevalence of foreign affiliates in the same city or industry. These findings highlight the potential for positive spillover effects on gender equality from MNCs to domestic firms through proximity and industry influence.

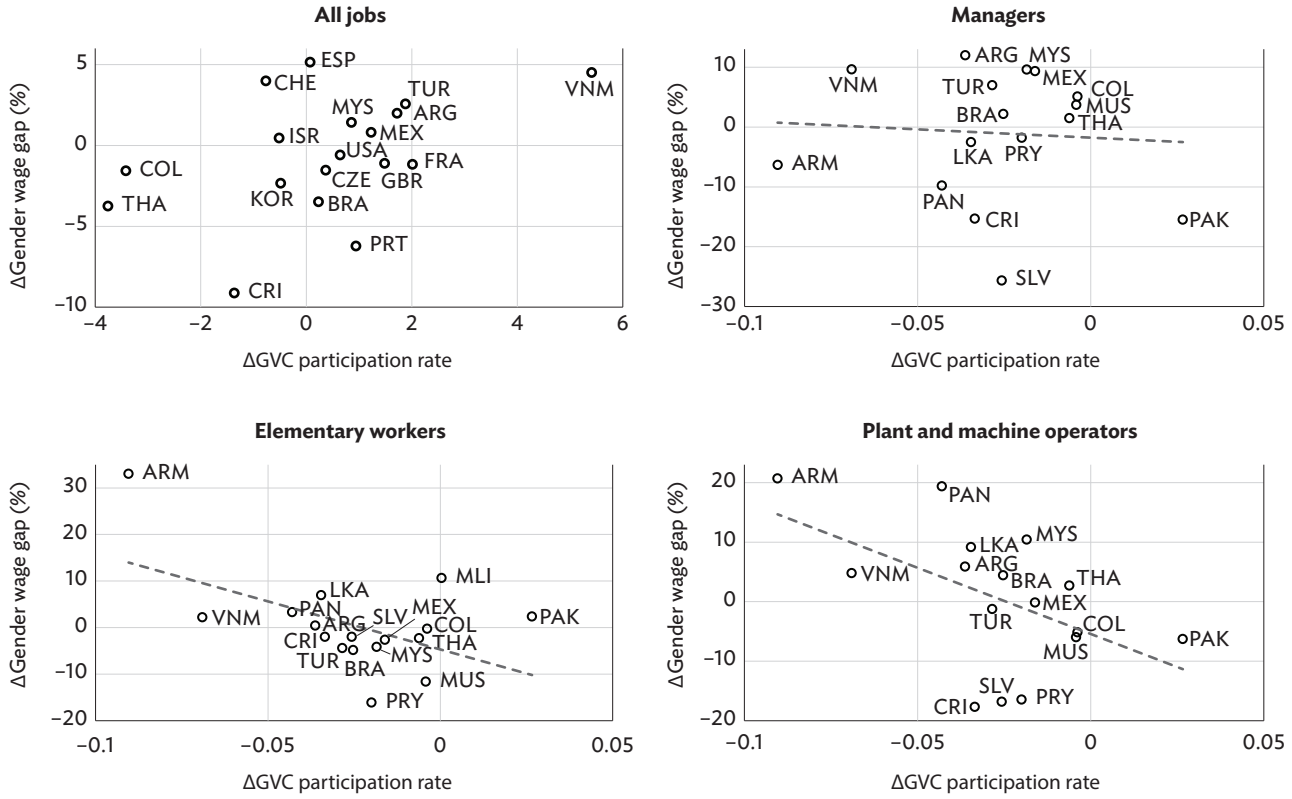
This effect can operate through multiple channels. First, the practices can spread through local labour mobility. Workers who have previously worked at MNCs can apply the skills and gender practices they have acquired in their previous work experience when they move to domestic workplaces (Monge-Gonzalez et al., 2021). Second, domestic firms, upon witnessing the success and productivity of more gender-equal peer FDI firms that generate higher profits, may be motivated to imitate the social norms and values of MNCs (Monge-Gonzalez et al., 2021; Tang and Zhang, 2021). Lastly, as the presence of FDI firms leads to higher competition in the domestic market, gender discrimination can become costly (Tang and Zhang, 2021). This relates to the "costly discrimination" argument that trade opening and the presence of MNCs will increase competition in the domestic market, making it economically disadvantageous to discriminate against females in the labour market (Becker, 1957; Black and Brainerd, 2004; Ederington et al., 2009).

While GVC participation has created jobs in developing economies for women, women tend to take a larger share of jobs in labour-intensive GVCs than do men (Hollweg, 2019). While this does benefit women in the lower end of the income distribution and helps narrow the gender wage gap in low-wage, low-skilled jobs, there is little evidence to suggest that it has a similar effect on high-skilled jobs in the economy. Due to a variety of often trade-unrelated barriers, women often find themselves concentrated in lower value-added segments of the value chains, limiting their access to higher-skilled and higher-paying positions. This can hinder the positive effects of GVC participation and limit the welfare gains associated with GVCs (World Bank and WTO, 2020).

To gain a more nuanced understanding of the relationship between the gender wage gap and GVC integration, cross-country patterns are examined in Figure 7.7. The figure reveals no correlation when plotting the change in the gender wage gap against the change in the degree of GVC integration (top left), but important differences emerge, particularly between low-skilled and high-skilled jobs. In low-skilled jobs, such as elementary occupations[5] or plant machine operators, a negative correlation between the gender wage gap and GVC integration is observed. This means that the gender wage gap tends to decrease as the country becomes more integrated into GVCs. However, in high-skilled jobs such as corporate managerial positions, this negative correlation is nearly non-existent and statistically insignificant.

5 This is defined by ILO's ISCO (International Standard Classification of Occupations), as "simple and routine tasks which mainly require the use of hand-held tools and often some physical effort".

Figure 7.7: Gender Wage Gap and GVC Participation



Source: Authors' calculations are derived from ILOSTAT and the UNCTAD-Eora database. The rate of increase (between 2014 and 2018) in the GVC participation index is calculated using UNCTAD-Eora data, while the rate of increase in the gender wage gap (between 2014 and 2018) is computed from ILOSTAT data. All figures control for GDP per capita and year fixed effects. For both GVC participation and the gender wage gap, the most recent year's figures are used.

Existing literature also finds that a higher degree of GVC integration may not necessarily lead to a lower gender wage gap, especially among high-skilled occupations. There are multiple reasons for this. Firstly, the presence of MNCs or exporting firms may result in a larger gender wage gap within their own organizations compared to domestic firms (Stolzenburg et al., 2020). This effect is particularly pronounced in high-skilled jobs like managers, professionals, and technicians, as exporting firms may prefer highly flexible employees who can work non-standard hours, respond to late-night calls, and engage in international travel at short notice. These preferences may potentially lead to discrimination against women who are perceived as less flexible (Bøler et al., 2018). This mechanism is supported by previous research by Yahmed (2023), which indicates that trade gains, such as improved access to inputs and markets, can perpetuate discriminatory practices within firms and hinder progress towards gender equality.

Furthermore, the spillover effects from MNCs to upstream industries may be limited. Fernandes and Kee (2020) found that gender-related policies and practices implemented by MNCs in Bangladesh's apparel sector often do not effectively transmit to domestic suppliers. Similarly, researchers have often found no significant

relationship between MNCs' backward linkages and the share of female labour (Monge-Gonzalez et al., 2021). This limitation can be attributed to a weaker awareness in upstream sectors, as upstream firms may have lower visibility for downstream firms and customers (Herkenhoff et al., 2021). Consequently, there may be less pressure for gender-equal practices within firms in the upstream sectors.

In summary, the consequences of GVC participation for gender inequality are complex. Empirical findings highlight several key points. Firstly, GVC integration and export-led growth provide increased job opportunities in the formal sector, decreasing gender inequality and promoting female empowerment, although the effect is mostly concentrated in low skilled jobs. Secondly, despite this success, the impact of GVCs and trade is shaped by existing gender discriminatory practices and social norms. Factors

Box 7.2: GVCs and Returns to Education

Exporting or the adoption of new technology can generate employment opportunities and increase the rewards to education when new jobs require higher levels of education. This can lead to an overall increase in educational attainment. It is important to consider the gender dimension as well, since the impact of skill-biased technical change can vary depending on differences in educational attainment and skill types between genders (Juhn et al., 2014).

GVC integration can result in higher returns to education in developing economies. For example, in Indonesia, the growth of manufacturing employment at the district level has been positively correlated with increased enrolments in schools and decreased youth labour force participation (Federman and Levine, 2005). Similarly, in India, the business process outsourcing industry, which requires advanced IT skills, has contributed to increased school enrolment rates, as the industry rewards individuals with higher levels of education (Oster and Steinberg, 2013). More broadly, the growth of business services has led to higher educational attainment in India due to both higher incomes and higher returns to education (Nano et al., 2021). These examples illustrate how GVC integration can stimulate educational attainment by providing economic incentives for individuals to invest in their education.

Importantly, globalization, particularly the job opportunities created through globalization, can have a positive impact on female education attainment. In India, girls, who traditionally faced disadvantages in education, have surpassed boys in terms of schooling attainment and improved their employment outcomes. GVCs, and especially services GVCs, played a relevant role for this. In rural Indian villages, recruiting services that facilitate young women's entry into the business process outsourcing industry have been associated with a higher likelihood of obtaining more schooling or post-school training (Jensen, 2012). In Bangladesh, proximity to export-processing ready-made garment industries has led to increased schooling for young females, as these industries value numeracy and literacy skills (Heath and Mobarak, 2015). Furthermore, as MNCs tend to employ highly skilled women (UNCTAD, 2021; Stolzenburg et al., 2020), the presence of MNCs can incentivize women to acquire more skills. Nano et al. (2021) find that services liberalization, facilitating entry of foreign firms, helped substantially closing the gender education gap in India. These studies share the common feature that GVCs offer higher quality jobs that typically reward women's educational attainment.

However, it is important to note that the relationship between GVC participation and education attainment is not always straightforward. While GVCs can offer job opportunities with higher wages, they may not necessarily reward higher levels of education, leading to an increase in the opportunity cost of education. This can be particularly true in contexts where the returns to education are low and there is a higher demand for youth labour in factories, resulting in youth being drawn out of school (Federman and Levine, 2005; Atkin, 2016).

Empirical evidence highlights the importance of the types of jobs created through GVCs in shaping educational outcomes. In PRC, the increase in exports following its accession to the WTO in 2001 had heterogeneous effects based on the skills demanded by the export sectors. High-skill export shocks were found to increase both high school and college enrolments, while low-skill export shocks led to a decrease in both. This contributed to divergence in educational attainment across regions (Li, 2018). Similarly, cross-country evidence by Blanchard and Olney (2017) indicates that educational attainment decreases with agricultural exports and unskilled manufactured exports but increases with skilled manufactured exports.

In summary, while GVC participation has the potential to improve education attainment by providing higher quality jobs, the actual impact can vary depending on factors such as the skills demanded by the export sectors and the availability of alternative employment opportunities. The types of jobs created through GVCs play a crucial role in shaping the relationship between GVC integration and education attainment.

such as family mandates (Bøler et al., 2018), limited access to credit, education, skills, and social capital (Hollweg and Lopez, 2020), and structural gender discrimination through sectoral or occupational segregation and gender norms can hinder the mobility of female workers both horizontally, across industry sectors (Mansour et al., 2022) and vertically, into higher managerial roles (Reyes, 2023). This typically deters the closing of gender wage gaps among high skilled workers in corporations.

Expanding industries through GVCs may not necessarily increase the demand for female workers either because of occupational gender segregation or imperfect substitutability between male and female workers (Do et al., 2016; Gaddis and Pieters, 2017; Mansour et al., 2022). The flip side of this argument would be that, specializing in industries with a high concentration of female workers enhances women's economic prospects, thus implying that liberalizing trade benefits women's labour market conditions in economies that excel in female-intensive industries (Gaddis and Pieters, 2017). These findings underscore the importance of identifying gender-specific labour market frictions and addressing existing gender discriminatory norms to maximize the opportunities that GVCs provide for gender equality.

GVCs Can Reduce the Incidence of Child Labour

Work practices in less-developed economies may fail to meet international standards and can encompass violations of core labour standards. For instance, sourcing through GVCs has been linked to scandals involving child labour. This has given rise to a number of studies examining whether greater GVC integration will lead to less or more child labour. In line with the broader literature on child labour, the discussion has focused on whether the income effect dominates the substitution effect in child labour supply.

The substitution effect states that an increase in demand for exports from sectors that employ child labour will lead to a corresponding increase in child labour, especially in developing economies with an abundance of cheap labour (Kruger, 2007; Atkin, 2016). This effect explains the unintended consequence of including clauses on child labour in trade agreements. Abman et al. (2023) find that such inclusion of child labour prohibitions in RTAs can, in fact, increase child labour rather than decrease it, especially among slightly older children not covered by the ban due to substitution effects. This finding is in line with previous evidence that shows a legal framework fining businesses that use child labour upon inspection by governments may simply decrease the marginal wage paid to children, leading to an increase in labour supply since they have to work longer hours to meet the minimum subsistence level (Basu, 2005).

On the other hand, if GVC participation increases household income, this can lead to a decrease in child labour (Edmonds and Pavcnik, 2005). This argument is in line with the view that child labour is typically linked to poverty (Edmonds, 2007). In poor families, as children need to provide labour to meet the minimum subsistence level, increased income will naturally lead to a decrease in the labour supply of children. In

addition, the literature on civil society pressure discussed above also applies here. GVC integration might provide firms with both the resources and incentives to reduce child labour in order to be able to supply MNCs and foreign markets.

Much empirical evidence shows that the income and awareness effects are the dominating channels. Exporting increases the general level of income in developing economies, decreasing poverty, thus putting downward pressure on child labour (Edmonds and Pavcnik, 2005 and 2006). In such circumstances, as exports of even heavily child-labour intensive products increase, it will result in a reduction in child labour. Ugarte et al. (2023) find that forward linkages in GVCs effectively decrease child labour, but not gross exports or backward linkages. Importantly, the study reveals that the child labour reduction effect of forward linkages is driven by linkages with economies that strongly respect labour rights, which aligns with the 'awareness' effect.

In summary, the evidence suggests that GVC integration tends to reduce child labour. While economic theory raises concerns about increased demand for products involving child labour, empirical findings indicate that increased income and awareness through international trade can actually lead to a reduction in child labour. While prohibitions or inspections may not be effective in decreasing child labour, participation in GVCs can provide solutions for addressing child labour, particularly when engaging with economies that prioritize labour rights. This underscores the significance of the awareness channel, in addition to the income channel, in driving child labour reduction efforts.

7.4 The Future of Inclusive GVCs

The increasing prevalence of large platform firms, artificial intelligence (AI), and automation carries significant implications for the inclusiveness of GVCs. These technological advancements are reshaping the organization and governance of GVCs with important distributional effects. On the one hand, technological progress is lowering the costs of participating in GVCs, particularly for groups that were previously excluded due to high trade costs. The rise of GVCs, facilitated by advancements in communication technologies in recent decades, has already expanded the range of participants in global trade. Moreover, the further adoption of digital technologies and platforms holds great potential to unlock opportunities for MSMEs and women. On the other hand, large digital platforms, AI, and automation can have negative impacts on MSMEs and workers, particularly those in developing economies, as they lower the importance of labour cost differentials and increase market power asymmetries. Automation technologies can lead to reshoring. The market power wielded by digital platforms, which rely on the vast amount of data they collect, can create imbalances in power relations within GVCs. Recent advancements in generative AI and large language suggest that even highly educated workers with analytical skills may not be immune to automation.

Digital Platforms and GVCs

Digital platforms play a central role in promoting inclusiveness within GVCs. They facilitate the connection between buyers and sellers, thereby reducing the initial fixed costs associated with participating in GVCs. This is particularly significant in developing economies where matching frictions are large (Startz, 2021). Additionally, digital platforms help overcome geographical barriers that exist between trade partners. According to Lendle et al. (2016), the impact of distance on cross-border trade flows is approximately 65 percent smaller for eBay transactions compared to total international trade.

Digital platforms offer distinct advantages for MSMEs, especially in specialized manufacturing and services, which are areas where small firms possess comparative advantages (Cusolito et al., 2016). The digitalization of the services sector also can contribute to a worldwide decrease in gender wage gaps by boosting trade of previously less-tradeable services. The digitization process results in greater cost reductions for the services sector, which tends to have a higher concentration of female workers. As a result, labour demand shifts towards women and gender wage gaps decrease (Bekkers et al., 2023).

However, digital platforms can also hurt inclusiveness. Firstly, they can alter the nature of relationships between firms in GVCs. Goods sold through platforms, such as e-commerce marketplaces, often involve one-time transactions with limited ongoing commitments, and the use of digital technology has the potential to replace the need for implicit contract enforcement, which may undermine the "stickiness" of GVC relationships (Antras, 2020). As already discussed, the relational nature of GVCs has served as the main mechanism for the transfer of technology, management practices and other benefits to firms and workers in developing economies (Macchiavello, 2022; Antras, 2020). In the absence of such characteristics, the opportunities for mutual learning and technology transfers along GVCs may be limited, thereby reducing the potential for quality improvement. Sancak (2022) explores the use of online supplier portals by lead firms in the global automotive value chains for auto parts. She finds that online portals primarily function within arm's length relationships that involve minimal formalized exchange. This suggests that digital technologies could undermine opportunities for upgrading in GVCs.

Digital platforms also have adverse distributional consequences for producers in developing economies. These platforms enable large buyers in developed economies to access information about a larger pool of potential suppliers, thereby making suppliers compete with each other. This can result in improved terms of trade for lead firms, while reducing the share of gains from GVCs accruing to producers in less developed economies (Antras, 2020). Furthermore, concerns arise regarding the market power wielded by digital platforms. Dominant platforms may eliminate competition, posing a threat to inclusive participation, especially in developing economies (Lundquist and Kang, 2021).

In this context, policies should focus on redistributing the gains from platforms to enhance the participation of disadvantaged groups, thereby promoting inclusiveness and fairness. Facilitating the unrestricted transmission of data for business efficiency can significantly benefit MSMEs (Lundquist and Kang, 2021), which often lack access to sufficient information resources. For example, providing data-driven analytical tools to MSMEs within digital platforms can greatly enhance their revenues, creating mutually beneficial outcomes for both participants and the digital platforms (Bar-Gill et al., 2023). Lastly, it is crucial to consider the trade-off between efficiency and fairness to achieve more equitable outcomes on online platforms among participants. Online platforms can exacerbate existing disparities between participants, making it even more essential to address fairness concerns (Athey et al., 2022). Striking a balance between efficiency and fairness is crucial to ensure that the benefits of digital platforms are distributed more equitably among all participants.

Automation and Outsourcing

The advancements in technology over the past decades have shaped the current geographic distribution of the global production system (Baldwin, 2006). In turn, integration into GVCs through forward and backward linkages can also foster adoption of automation technology positively through a learning and competition effect (Du and Nduka, 2020). However, automation technologies could lead to a shift in production closer to consumers, as automation provides an alternative to offshoring for firms in developed economies aiming to reduce labour costs. If automation and offshoring are considered substitutes, advancements in automation would lead to a growing trend of reshoring over time (Antras, 2020).

However, progress in logistics and networking technologies can simultaneously deepen global fragmentation (Butollo et al, 2022). Additionally, catch-up automation in emerging economies can enhance firms' competitiveness in developing nations (Butollo and Lüthje, 2017; Krzywdzinski, 2017). Therefore, it is important to consider not only the potential for reshoring due to automation but also the complex interplay of various factors that shape the dynamics of the global production system.

The relationship between automation and offshoring is far from clear-cut in empirical evidence. On the one hand, the use of robots in developed economies has been associated with reduced offshoring and declining exports from developing economies (Kinkel et al. 2015; Artuc et al., 2018; Artuc et al., 2019), as well as negative labour market outcomes, particularly for low-skilled workers (Pedemonte et al., 2019). Early evidence from developing economies documents potential risk for export-oriented industrialisation through global value chains, as automation will change the geographical distribution of production locations (Azmeh et al., 2022).

On the other hand, automation by firms in developed economies can lower costs, improve productivity, and consequently increase the demand for intermediate inputs, many of which are sourced from less developed economies (Antras, 2020). In the manufacturing sectors, empirical evidence suggests that automation by downstream firms in developed economies may not have a significant negative impact, or even a positive impact, on FDI and sourcing from developing economies. For example, Stapleton and Webb (2020) found that the adoption of robots in Spain led to an increase in imports and the establishment of affiliates in lower-income economies by the same firms. This is because the use of robots stimulates production expansion, enhances productivity (Graetz and Michaels, 2018), and increases the likelihood of firms importing from or establishing affiliates in developing economies.

Recent studies provide support that automation will not necessarily lead to reshoring of production stages to developed economies. One explanation is the sequencing of automation and importing decisions (Stapleton and Webb, 2020), which leads to heterogeneous effects on offshoring. Firms that have already engaged in offshoring to lower-income economies before adopting robots showed no significant change in imports from those economies. On the other hand, firms that had not previously engaged in offshoring were more likely to start doing so after adopting robots. This means that the displacement effect of offshore labour only affects the former group, while the productivity effect of automation on offshoring applies to both types of firms, leading to heterogeneous effects of robot adoption. Alternatively, the adoption of automation technologies can also encourage upstream forward integration, as robots lead to specialisation away from the final step of production and assembly. This is because robots are more complementary to tasks in upstream activities rather than downstream assembly tasks (Fontagné et al., 2023).

In summary, these findings suggest that the relationship between automation and offshoring is influenced by various factors. It highlights the need for a nuanced understanding of the interplay between automation, offshoring, and the complexities of global economic relationships. Assuming that automation will hurt firms and workers in developing economies is certainly premature.

AI and Services GVC

The emergence of new AI tools, including generative AI technologies like ChatGPT, has significant implications for services GVCs in developing economies and represents opportunities for quality upgrading and increased labour productivity in developing economies. Recent empirical evidence by Brynjolfsson et al. (2023) shows that generative AI tools can augment human agents, embodying the best practices of high-skilled workers that were previously difficult to disseminate due to tacit knowledge. Their research shows that AI assistance leads to significant improvements in problem resolution and customer satisfaction for newer and less-skilled workers. For instance, AI recommendations can help low-skilled workers to communicate more like high-skill

workers. This evidence suggests that the use of AI may offer a chance to catch up with advanced knowledge from developed economies.

However, the potential displacement effect of AI can pose a threat to the development strategies adopted by developing economies, specifically those focused on upgrading through services GVCs. This is because the new AI tools have the potential to perform complex tasks that previously required relatively high-skilled labour for non-routine and analytical service sectors that developing economies have been striving to create through upgrading in GVCs. Nano and Stolzenburg (2021) report that AI has reduced the labour intensity of call centres in the PRC. Eisfeldt et al. (2023) find that investors expect firms with a higher proportion of occupations exposed to generative AI to experience greater profits, as AI technology will result in lower input costs through job displacement. Copestake et al. (2023) highlight significant adverse effects of AI on job postings for high-skilled, non-routine, analytical work within the urban, white-collar service sector. However, they also observe the growth of AI-related job opportunities at the district level. This finding suggests that to counter the potential consequences of AI-driven displacement, policy efforts should prioritize fostering innovation, enhancing skills, and adapting to the evolving labour market demands.

7.5 Main Messages and Lessons for Policymakers

Two main messages emerge from this chapter:

1. GVC integration leads, on average, to better outcomes for firms and workers in developing economies. The evidence consistently shows that local suppliers to MNCs and firms exporting intermediates perform better than other firms in developing economies across a broad range of indicators from productivity to quality to innovation. This performance premium spills over to workers. Being employed at MNCs or their suppliers generally leads to higher wages and better working conditions, including a higher likelihood of formal employment.

2. Where GVC integration fails to deliver or underdelivers on benefits, it tends to be caused by underlying market failures and policy barriers rather than GVC integration itself. An important example is market power. Both monopolistic/oligopolistic and monopsonistic/oligopsonistic behaviour of firms on product and labour markets can severely skew the distribution of profits in value chains and put undue pressure on local suppliers to cut costs with negative implications for workers. Another example is gender-based differences in access to education or finance, which prevent women from participating in the gains from upgrading in GVCs. Other key factors are firms' and workers' limited adaptive capacity due to incomplete financial or labour markets in developing economies.

These two findings entail in turn two lessons for policymakers that want to maximize the positive impact of GVCs for inclusive development:

1. Since GVC integration tends to benefit firms and workers, the focus should be on facilitating entry into GVCs and spillovers to the domestic economy to ensure that GVCs are truly inclusive. For example, many regulations and legitimate non-tariff measures raise the costs for firms in developing economies that intend to supply MNCs or importers in advanced economies. Ensuring that these costs remain limited and that MSMEs receive support in covering them is crucial for inclusive development. Similarly, addressing information and matching frictions is important, as they tend to be particularly high in developing economies. At the worker-level, investing in skills remains the most important policy for inclusive development. Better-educated workers have the skills demanded by MNCs, facilitate upgrading and can more readily benefit from new technologies. Skills are also positively associated with geographical mobility, another area that policymakers should focus on.

2. The second focus should be on addressing the underlying market failures and barriers that lead to an uneven distribution of the gains from GVCs. Market power repeatedly features as one of the primary reasons preventing firm and workers in developing economies from obtaining their fair share of profits. Four firms hold two-thirds of the global smartphone market.[6] Three firms account for 80% of the fast fashion market in the United States.[7] Addressing this requires tweaks to traditional competition policy tools that take labour market impacts into account. More creative solutions can also help. One study discussed shows that requiring firms to remunerate workers in wages rather than amenities, such as housing, limits their oligopsony power (Mendez and van Patten, 2022). Others highlight the value of fair trade certifications (Dragusanu et al., 2022). In addition, several studies find positive effect of NGOs and awareness channels which could benefit from increased transparency and reporting requirements. Established long-term relationships between firms also lead to fairer outcomes and should be supported, for instance, through targeted support for firms during crises that prevent firm exit. Beyond market power, addressing barriers and discrimination, be it based on gender, ethnicity, or any other reason, is an important avenue to fully exploit the potential of GVCs to drive inclusive development.

While these lessons emerge from the literature, current policies and policy debates tend to focus more on non-trade provisions (NTPs) in regional trade agreements,

---

6 Counterpoint. 2023. *Global Smartphone Shipments Market Data.* [Accessed on: 23 August 2023]. URL: https://www.counterpointresearch.com/global-smartphone-share/

7 Perri, J. 2023. *Shein Holds Largest U.S. Fast Fashion Market Share.* Bloomberg Second Measure. [Accessed: 23 Aug 2023], URL: https://secondmeasure.com/datapoints/fast-fashion-market-share-us-consumer-spending-data-shein-hm-zara/

import bans and restrictions, and due diligence requirements (DDRs)[8]. For instance, regional trade agreements more frequently include provisions focused on inclusive growth, covering labour standards, gender equality, or sustainability (Mattoo et al., 2020). However, these policies often focus on improving working conditions exclusively within GVCs even though the evidence suggests that workers and firms within GVCs already enjoy better outcomes. As a result, they might aggravate existing differences between those inside and those outside GVCs.

Moreover, many of these policies have been shown to have adverse effects. The inclusion of NTPs in trade agreements can potentially hinder country-level inclusion in GVCs by raising costs and uncertainty, as advanced economies could use these provisions to withdraw trade concessions in the event of non-compliance. Additionally, stronger provisions in low-income economies could lead to a decline in their comparative advantage, resulting in reduced market access to developed economies (Bhagwati, 1995). Recent evidence finds that NTPs are associated with increased exports of environmentally and labour-intensive goods from developed economies while imposing higher trade costs on developing economies, leading to a reduction in labour-intensive exports from the developing economies (Hoekman et al., 2023).

DDRs appear to be based on the assumption that firms willingly underpay workers or refuse to improve working conditions, but this is not in line with the evidence. Many firms invest in labour standards and pay higher markups to ensure reliable, high-quality inputs, as studies on relational sourcing and awareness channels show. MNC employees in developing economies consistently earn higher wages are more likely to be formally employed. In cases where firms do exploit their market power and put strong cost pressure on suppliers and workers, it is unlikely to achieve results when the burden of improving working conditions is shifted to the firms because they can simply increase the distance between themselves and suppliers by reorganizing production and using arms' length rather than intra-firm transactions (Herkenhoff and Krautheim, 2022). Similarly, unintended consequences can arise when seeking to improve labour conditions in developing countries through DDRs. The experience of Costa Rica highlights a case where such policies did indeed benefit low-wage workers employed at affected suppliers, but they had adverse effects on other workers in the economy as they reduced employment and raised domestic prices (Alfaro-Urena et al., 2022a).

Such policies can help ensure that imports of advanced economies are produced under better conditions, but the presence of substitution effects implies that "dirty production" may simply shift to other locations as the evidence on child labour highlights. When children from low-income families engage in child labour to meet minimum subsistence levels, incomplete enforcement of child labour prohibitions may

[8] Supply chain DDRs require firms to identify, prevent, mitigate and account for how they address their actual and potential adverse impacts on sustainability and human rights along their supply chain. A number of laws have been passed or are in preparation that move due diligence from voluntary standard to legal requirement, including in Germany, France, the UK and at the EU-wide level.

result in a decrease in child labour wages, which, in turn, can paradoxically lead to an increase in the overall level of child labour. The net effect on developing economies could even be negative. As a result, these policies may fail to deliver on inclusive development, especially where firms can increase the degrees of separation between themselves and non-compliant suppliers without addressing the root causes. Similarly, shifting the costs of compliance to small firms in developing economies will widen the exclusivity of GVCs and achieve the opposite of inclusiveness.

This is not to say that NTPs and DDRs could not be useful instruments for inclusive GVCs. But for this they must be based on continuous cooperation between advanced and developing economies and they must account for the potential harmful effects identified in the literature. Developing economies are best placed to identify potential negative impacts of NTPs for inclusiveness and their competitiveness. Moreover, the increased demand for coordination among governments in GVCs, manifested by the proliferation of deep trade agreements, naturally facilitates joint efforts to address cross-border policy spillovers and time-consistency issues (Lawrence, 1996; Baldwin, 2011; Laget et al., 2020). Thus, this environment provides an ideal opportunity for cooperation on the aspects of inclusiveness. Therefore, instead of focusing solely on incorporation of such provisions or emphasizing enforceability, cooperation with local governments, firms, and stakeholders to build capacities facilitating compliance with NTPs and DDRs should be an integral part.[9]

There is evidence suggesting that NTPs can have positive effects on trade flows (Brown et al., 2013; Klymak, 2023), especially when combined with cooperation and support from developed economies. Carrère et al. (2022) find a significant and positive effect on exports from low-income economies when labour provisions are implemented. Importantly, the impact is strongest when provisions are accompanied by strong cooperation, rather than enforcement mechanisms. Evidence also shows that if policymakers aim to combat child labour, labour clauses in trade agreements should encourage active education and income support policies, such as providing direct payments to households for school attendance, rather than merely imposing a ban on child labour (Fernandes et al., 2023). This ensures that the desired standards are achieved without jeopardizing inclusiveness and widening inequalities. The external enforcement of minimum standards in trade agreements can also help domestic policy makers make credible commitments vis-à-vis domestic constituents (Maggi and Rodriguez-Clare, 2007).

[9] While among advanced economies, a recent joint stakeholder dialogue series initiated by the EU-US Trade and Technology Council could serve as example. It aims to obtain diverse views on how to cultivate resilience and sustainability along supply chains by establishing a due diligence framework that enhances supply chain transparency and traceability. Moreover, this initiative includes coordination on due diligence legislation across countries, representing a meaningful step toward strengthening due diligence practices (Trade and Technology Dialogue, 2023).

Nevertheless, the ambiguous effects of NTPs, import restrictions and DDRs call for a cautious approach when using them as tools to achieve social or environmental outcomes (Winters, 2023). This holds, in particular, as alternative policy instruments may be available that can more efficiently support inclusive development (Hoekman, 2021). In light of this, such provisions should be developed carefully considering the economic mechanisms at play. It is important to acknowledge that not all social concerns can be effectively addressed solely through the inclusion of NTPs in trade agreements or due diligence requirements due to underlying differences in their root causes.

Finally, support from developed economies in the form of aid, targeted support for NGOs, or technical assistance can likewise enhance the resulting outcomes. With this in mind, soft law provisions that are not subject to dispute settlement are more likely to yield favourable results, provided they entail a support process and cooperation between governments and stakeholder groups. This is particularly true if these provisions are accompanied by programs aimed at addressing specific non-trade objectives (Hoekman et al., 2022; Yildirim et al., 2021).

Conclusion

GVCs account for a major share of international trade and are, therefore, central for the inclusive development agenda. In line with this, GVCs face extensive scrutiny from civil society, especially in the context of scandals and tragedies such as the Rana Plaza collapse. However, these highly visible events can distort the picture and mask more positive facts, such that workers in GVCs tend to earn higher wages. Therefore, this chapter explores the economic mechanisms and empirical evidence regarding whether GVCs have served as engines of inclusive growth in developing economies.

The chapter finds consistent evidence that workers and firms in developing economies enjoy on average substantial benefits from GVC participation. While it is true that the majority of MSMEs in developing economies may not directly participate in GVCs, GVCs still present opportunities for economic upgrading. GVCs facilitate the transfer of tacit knowledge and technologies, allowing MSMEs to enhance their capabilities. Additionally, GVCs contribute to the upgrading of product qualities by enabling MSMEs to access higher quality inputs through backward linkages. Moreover, through forward linkages, MSMEs can meet the higher quality demands of foreign markets when exporting their products. Furthermore, GVCs play a role in financial smoothing by fostering interdependence among firms along the supply chains.

In terms of the labour market in developing economies, GVCs have generated job opportunities in formal sectors and led to higher wages, particularly for lower-skilled workers, as these economies engage in labour-intensive activities through both forward and backward linkages. While GVCs may contribute to wage inequalities across multiple dimensions, they can also raise overall labour standards in developing

economies. This is achieved through demand-side pressures and voluntary upgrading efforts by MNCs. In line with this, GVCs offer opportunities for social upgrading. The chapter focuses on two prominent issues: gender inequality and child labour. GVCs offer jobs and higher wages for women, and this can have a far-reaching impact. MNCs can improve external options for women and contribute to indirect spillovers that promote gender equality. Empirical evidence suggests that better economic opportunities contribute to the empowerment of women. GVCs can contribute to the reduction of child labour by addressing poverty in developing economies and through the awareness channel.

Market failures, such as oligopolies, and barriers not related to trade, such as gender-biased access to education, can severely limit the inclusiveness of GVCs. The chapter finds substantial evidence showing that concentrated product markets divert profits to large trade intermediaries and away from producers in developing economies. Similarly, market power of large employers can prevent workers from receiving a fair wage. A varied set of restrictions holds women back from benefitting when firm upgrade in GVCs as higher-skilled and managerial positions tend to go to men.

Digital technologies have played a crucial role in enhancing the inclusiveness of GVCs by reducing trade costs for MSMEs and women. However, the emergence of digital platforms may alter the relational dynamics that were beneficial for MSMEs in developing economies. Moreover, the immense market power held by large platform firms in the digital space has the potential to exacerbate distributional outcomes. Therefore, policy interventions are necessary to ensure that the gains from digital platforms are redistributed to disadvantaged groups. Subsequently, we examine how automation technologies are shaping the future of GVCs in both manufacturing and services. While there is evidence suggesting that AI and automation technologies could have negative impacts on developing economies, these advanced technologies also present opportunities for economic upgrading and knowledge sharing.

The chapter concludes by arguing that policy makers should focus on facilitating access to GVCs and removing market imperfections and barriers. Current policy approaches based on social provisions in trade agreements or due diligence requirements should be accompanied by more cooperation and take into account the lessons from the academic literature. Evidence suggests that cooperation among advanced and developing economies holds greater significance than mere inclusion of social clauses. Several studies illustrate the economic mechanisms underlying social provisions with important insights on negative side effects. More generally, to maximize the potential of GVCs to contribute to inclusive development, other policy tools should be used to complement current approaches.

References

Abbey, E. N., A. Gyeke-Dako, A. D. Oduro, F. E. Turkson, and P. T. Baffour. 2017. The Employment Generating Effects of Exporting: Firm Level Evidence of Micro, Small and Medium Enterprises (MSMEs) in Ghana. *R4D Working Paper.* No. 2017/02. World Trade Institute of the University of Bern.

Abman, R. M., C. C. Lundberg, J. McLaren, and M. Ruta. 2023. Child Labor Standards in Regional Trade Agreements: Theory and Evidence. *NBER Working Paper*. No. 30908. Cambridge, MA: National Bureau of Economic Research.

Adao, R., P. Carrillo, A. Costinot, D. Donaldson, and D. Pomeranz. 2022. Imports, Exports, and Earnings Inequality: Measures of Exposure and Estimates of Incidence. *The Quarterly Journal of Economics*. 137(3). pp. 1553-1614.

ADB (Asian Development Bank). 2021. ADB Briefs: 2021 Trade Finance Gaps, Growth, and Jobs Survey. Manila.

ADBI (Asian Development Bank Institute), and ADB (Asian Development Bank). 2016. Integrating SMEs Into Global Value Chains: Challenges and Policy Actions in Asia. Brookings Institution Press.

Aizer, A. 2010. The Gender Wage Gap and Domestic Violence. *American Economic Review*. 100(4). pp. 1847-1859.

Adler, P., D. Brown, R. Dehejia, G. Domat, and R. Robertson. 2017. Do Factory Managers Know What Workers Want? Manager–Worker Information Asymmetries and Pareto Optimal Human Resource Management Policies. *Asian Development Review*. 34(1). pp. 65-87.

Alfaro-Ureña, A., B. Faber, C. Gaubert, I. Manelici, and J. P. Vasquez. 2022a. Responsible Sourcing? *NBER Working Paper*. No. 30683. Cambridge, MA: National Bureau of Economic Research.

Alfaro-Ureña, A., I. Manelici, and J. P. Vasquez. 2022b. The Effects of Joining Multinational Supply Chains: New Evidence from Firm-to-Firm Linkages. *The Quarterly Journal of Economics*. 137(3). pp. 1495-1552.

Alfaro-Ureña, A., I. Manelici, and J. P. Vasquez. 2021. The Effects of Multinationals on Workers: Evidence from Costa Rican Microdata. Unpublished.

Ali, M., and A. Seric. 2014. Diffusion of Labor Standards from Origin to Host Countries: Cross County Evidence from Multinational Companies in Africa. *Robert Schuman Centre for Advanced Studies Research Paper*. No. 2014/22.

Allen, T. 2014. Information Frictions in Trade. *Econometrica*. 82(6). pp. 2041-2083.

Alvarez, R., and R. A. López. 2008. Is Exporting a Source of Productivity Spillovers? *Review of World Economics*. 144. pp. 723-749.

Amberg, N., T. Jacobson, E. von Schedvin, and R. Townsend. 2021. Curbing Shocks to Corporate Liquidity: The Role of Trade Credit. *Journal of Political Economy*. 129(1). pp. 182-242.

Amengual, M., and G. Distelhorst. 2020. Cooperation and Punishment in Regulating Labor Standards: Evidence from the Gap Inc Supply Chain. SSRN Papers. https://papers.ssrn. com/sol3/papers.cfm?abstract_id=3466936.

Amiti, M., C. Duprez, J. Konings, and J. van Reenen. 2023. FDI and Superstar Spillovers: Evidence from Firm-to-Firm Transactions. *NBER Working Paper*. No. 31128. Cambridge, MA: National Bureau of Economic Research.

Amiti, M., and J. Konings. 2007. Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia. *American Economic Review*. 97(5). pp. 1611-1638.

Amodio, F., and N. D. Roux. Forthcoming. Measuring Labor Market Power in Developing Countries: Evidence from Colombian Plants. *Journal of Labor Economics*.

Amodio, F., P. Medina, and M. Morlacco. 2022. Labor Market Power, Self-Employment, and Development. Unpublished.

Ang, D., D. Brown, R. Dehejia, and R. Robertson. 2012. Public Disclosure, Reputation Sensitivity, and Labor Law Compliance: Evidence from Better Factories Cambodia. *Review of Development Economics*. 16(4). pp. 594-607.

Anh, D. D., and V. A. Dang. 2020. Global Value Chain Participation and Firms' Innovations: Evidence from Small and Medium-Sized Enterprises in Viet Nam. *ADBI Working Paper*. No.1138. Asian Development Bank Institute.

Antràs, P. 2020. Conceptual Aspects of Global Value Chains. *The World Bank Economic Review*. 34(3). pp. 551-574.

Antràs, P., and S. R. Yeaple. 2014. Multinational Firms and the Structure of International Trade. In *Handbook of International Economics*. 4. pp. 55-130.

Artuc, E., P. Bastos, and B. Rijkers. 2018. Robots, Tasks and Trade. *World Bank Policy Research Working Paper*. No. 8674.

Artuc, E., L. Christiansen, and H. Winkler. 2019. Does Automation in Rich Countries Hurt Developing Ones? Evidence from the US and Mexico. World Bank Policy Research Working Paper. No. 8741.

Athey, S., D. Karlan, E. Palikot, and Y. Yuan. 2022. Smiles in Profiles: Improving Fairness and Efficiency Using Estimates of User Preferences in Online Marketplaces. *NBER Working Paper* No. 30633. Cambridge, MA: National Bureau of Economic Research.

Atkin, D. 2016. Endogenous Skill Acquisition and Export Manufacturing in Mexico. *American Economic Review*. 106(8). pp. 2046-2085.

Atkin, D., A. Chaudhry, S. Chaudry, A. K. Khandelwal, and E. Verhoogen. 2017a. Organizational Barriers to Technology Adoption: Evidence from Soccer-Ball Producers in Pakistan. *The Quarterly Journal of Economics*. 132(3). pp. 1101-1164.

Atkin, D., A. K. Khandelwal, and A. Osman. 2017b. Exporting and Firm Performance: Evidence from a Randomized Experiment. *The Quarterly Journal of Economics*. 132(2). pp. 551-615.

Azmeh, S., H. Nguyen, and M. Kuhn. 2022. Automation and Industrialisation Through Global Value Chains: North Africa in the German Automotive Wiring Harness Industry. *Structural Change and Economic Dynamics*. 63. pp. 125-138.

Bacchetta, M., E. Ernst, and J. Bustamante. 2009. Globalisation and Informal Jobs in Developing Countries. A Joint Study of the International Labour Office and the Secretariat of the World Trade Organization. WTO-ILO, Geneva.

Baldwin, R. 2006. Globalisation: The Great Unbundling(s). In Globalisation Challenges for Europe. Secretariat of the Economic Council, Finnish Prime Minister's Office. Helsinki.

Baldwin, R. 2011. 21st Century Regionalism: Filling the Gap Between 21st Century Trade and 20th Century Trade Rules. *CEPR Policy Insight*. No.56.

Baldwin, R., and J. Lopez-Gonzalez. 2015. Supply-Chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses. *The World Economy*. 38(11). pp. 1682-1721.

Bar-Gill, S., E. Brynjolfsson, and N. Hak. 2023. Helping Small Businesses Become More Data-Driven: A Field Experiment on eBay. *NBER Working Paper*. No. 31089. Cambridge, MA: National Bureau of Economic Research.

Barrientos, S., and A. Kritzinger. 2004. Squaring the Circle: Global Production and the Informalization of Work in South African Fruit Exports. *Journal of International Development*. 16(1). pp. 81-92.

Bas, M., and P. Bombarda. 2023. Input-Trade Liberalization and Formal Employment: Evidence from Mexico. *Working Paper*. Documents de Travail du Centre d'Économie de la Sorbonne.

Bastos, P., J. Silva, and E. Verhoogen. 2018. Export Destinations and Input Prices. *American Economic Review*. 108(2). pp. 353-392.

Basu, K. 2005. Child Labor and the Law: Notes on Possible Pathologies. *Economics Letters*. 87(2). pp. 169-174.

Becker, G. 1957. The Economics of Discrimination. University of Chicago Press.

Bekkers, E., K. Jhunjhunwala, J. Metivier, V. Stolzenburg, and A. N. Yilmaz. 2023. Global Trade Policy Reform and Gender Inequality in the Labour Market. GTAP Resource. No. 6905.

Bennett, J., and S. Estrin. 2007. Modelling Interactions Between Formal and Informal Sectors in a Developing Economy. In *IZA/WB conference in Bonn*. IZA Institute of Labor Economics.

Bhagwati, J. 1995. Trade Liberalisation and 'Fair Trade' Demands: Addressing the Environmental and Labour Standards Issues. *World Economy*. 18(6). pp. 745-759.

Bisztray, M., M. Koren, and A. Szeidl. 2018. Learning to import from your peers. *Journal of International Economics*. 115. pp.242-258.

Black, S. E., and E. Brainerd. 2004. Importing Equality? The Impact of Globalization on Gender Discrimination. *ILR Review*. *57*(4). pp. 540-559.

Blanchard, E. J., and W. W. Olney. 2017. Globalization and Human Capital Investment: Export Composition Drives Educational Attainment. *Journal of International Economics*. 106. pp. 165-183.

Bloom, N., R. Lemos, R. Sadun, D. Scur, J. Van Reenen 2021. World Management Survey – Manufacturing. Harvard Dataverse. V1. UNF:6:k5xYE9W6U534XDiWu3RjrA== [fileUNF].

Bloom, N., A. Mahajan, D. McKenzie, and J. Roberts. 2020. Do management interventions last? Evidence from India. *American Economic Journal: Applied Economics*. 12(2), pp. 198-219.

Bloom, N., C. Genakos, R. Sadun, and J. Van Reenen. 2012. Management Practices Across Firms and Countries. *Academy of Management Perspectives*. 26(1), pp.12-33.

Bloom, N., and J. Van Reenen, J. 2007. Measuring and Explaining Management Practices across Firms and Countries. *The Quarterly Journal of Economics*. 122(4). pp.1351-1408.

Bocola, L., and G. Bornstein. 2023. The Macroeconomics of Trade Credit. *NBER Working Paper*. No. 31026. Cambridge, MA: National Bureau of Economic Research.

Bøler, E. A., B. Javorcik, and K. H. Ulltveit-Moe. 2018. Working across time zones: Exporters and the gender wage gap. *Journal of International Economics*. *111*. pp. 122-133.

Boudreau, L.E. 2022. Multinational enforcement of labor law: Experimental evidence on strengthening occupational safety and health (OSH) committees. *CEPR Discussion Papers*. No. 17579.

Brown, D., R. Dehejia, and R. Robertson. 2013. Is There a Business Case for Improving Labor Standards?: Some Evidence from Better Factories Cambodia. In *Workers' Rights and Labor Compliance in Global Supply Chains*. pp. 69-87. Routledge.

Brynjolfsson, E., D. Li, and L. R. Raymond. 2023. Generative AI at Work. *NBER Working Paper*. No. 31161. Cambridge, MA: National Bureau of Economic Research.

Buciuni, G., J. Canello, and G. Gereffi. 2022. Microfoundations of Global Value Chain Research: Big Decisions by Small Firms. *Environment and Planning A: Economy and Space*. 54(6). pp. 1086-1111.

Butollo, F., G. Gereffi, C. Yang, and M. Krzywdzinski. 2022. Digital Transformation and Value Chains: Introduction. *Global Networks*. 22(4). pp. 585-594.

Butollo, F., and B. Lüthje. 2017. Made in China 2025': Intelligent Manufacturing and Work. In *The New Digital Workplace: How New Technologies Revolutionise Work*. pp. 42-61.

Cafaggi, F., R. P. Macedo, T. Andreotti, C. Gross, L. de Almeida, and T. A. Ribeiro. 2012. Accessing the Global Value Chain in a Changing Institutional Environment: Comparing Aeronautics and Coffee. *IDB Working Paper Series*. No. IDB-WP-370

Cajal-Grossi, J., R. Macchiavello, and G. Noguera. (2023). Buyers' Sourcing Strategies and Suppliers' Markups in Bangladeshi Garments. *The Quarterly Journal of Economics*. qjad026.

Caliendo, M., M. Goethner, and M. Weißenberger. 2020. Entrepreneurial Persistence Beyond Survival: Measurement and Determinants. Journal of Small Business Management. 58(3), pp. 617-647.

Carballo, J., I. Marra de Artiñano, and C. Martincus. 2019. Linkages with Multinationals and Domestic Firms' Performance. *IADB Integration and Trade Sector*. IDB-TN-01746.

Càrrere, C., M. Olarreaga, and D. Raess. 2022. Labor Clauses in Trade Agreements: Hidden Protectionism? *The Review of International Organizations*. 1-31.

Chandra, V., and M. A. Khan. 1993. Foreign Investment in the Presence of an Informal Sector. *Economica*. pp. 79-103.

Chen, T. 2017. The Impact of the Shea Nut Industry on Women's Empowerment in Burkina Faso. *Social Protection and Forestry Working Paper*. No. 3. Food and Agriculture Organization of the United Nations.

Clerides, S. K., S. Lach, and J. R. Tybout. 1998. Is Learning by Exporting Important? Micro-Dynamic Evidence from Colombia, Mexico, and Morocco. *The Quarterly Journal of Economics*. 113(3). pp. 903-947.

Conconi, P., F. Leone, G. Magerman, and C. Thomas. 2022. Multinational Ownership and Trade Participation. *ECARES, CEPR, CESifo and CEP Working Paper*. 1-59.

Copestake, A., M. Marczinek, A. Pople, and K. Stapleton. 2023. AI and Services-Led Growth: Evidence from Indian Job Adverts. *STEG Working Paper*. WP060.

Crinò, R. 2012. Service Offshoring and the Skill Composition of Labour Demand. *Oxford Bulletin of Economics and Statistics*. 74(1). pp. 20-57.

Cusolito, A. P., R. Safadi, and D. Taglioni. 2016. Inclusive Global Value Chains: Policy Options for Small and Medium Enterprises and Low-Income Countries. OECD and World Bank Publications. Washington, DC.

Davies, E. 2005. Hola! Trinidad Drops English and Learns to Speak Spanish. The Independent, September 1. Available at https://www.independent.co.uk/news/world/americas/hola-trinidad-drops-english-and-learns-to-speak-spanish-5347553.html. (Accessed: 5 May, 2023)

De Loecker, J. 2007. Do Exports Generate Higher Productivity? Evidence from Slovenia. *Journal of International Economics*. 73(1). pp. 69-98.

De Marchi, V., E. Giuliani, and R. Rabellotti. 2015. Local Innovation and Global Value Chains in Developing Countries. *UNU-MERIT Working Papers*. 2015-022.

Delgado, K. F. 2020. Foreign Acquisitions and Female Employment in Manufacturing Firms: An Empirical Analysis for Chile. *Transnational Corporations*. 27(3).

Demir, B., A. C. Fieler, D. Y. Xu, and K. K. Yang. Forthcoming. O-Ring Production Networks. *Journal of Political Economy*.

Diodato, D., F. Neffke, and N. O'Clery. 2018. Why Do Industries Coagglomerate? How Marshallian Externalities Differ by Industry and Have Evolved Over Time. *Journal of Urban Economics*. 106. pp. 1-26.

Distelhorst, G., J. Hainmueller, and R. M. Locke. 2017. Does Lean Improve Labor Standards? Management and Social Performance in the Nike Supply Chain. *Management Science*. 63(3). pp. 707-728.

Dix-Carneiro, R., and B. K. Kovak. 2017. Trade Liberalization and Regional Dynamics. *American Economic Review*. 107(10). pp. 2908-2946.

Dix-Carneiro, R., and S. Traiberman. 2023. Globalization, Trade Imbalances, and Inequality. *Journal of Monetary Economics*. 133. pp. 48-72.

Dix-Carneiro, R., P. K. Goldberg, C. Meghir, and G. Ulyssea. 2021. Trade and Informality in the Presence of Labor Market Frictions and Regulations. *NBER Working Paper*. No. 28391. Cambridge, MA: National Bureau of Economic Research.

Dix-Carneiro, R., and B. Kovak. 2023. "Globalization and Inequality in Latin America." *IZA Discussion Papers*. 16363. Institute of Labor Economics (IZA).

Do, Q. T., A. A. Levchenko, and C. Raddatz. 2016. Comparative Advantage, International Trade, and Fertility. *Journal of Development Economics*. 119. pp. 48-66.

Dragusanu, R., E. Montero, and N. Nunn. 2022. The Effects of Fair Trade Certification: Evidence from Coffee Producers in Costa Rica. *Journal of the European Economic Association*. 20(4). pp. 1743-1790.

Du, J., and U. Nduka. 2020. Global Value Chains and the Adoption of Automation Technology. In *Academy of Management Proceedings*. Vol. 2020, No. 1. pp. 18610. Briarcliff Manor, NY: Academy of Management.

Ederington, J., J. Minier, and K. Troske. 2009. Where the Girls Are: Trade and Labor Market Segregation in Colombia. *IZA Discussion Papers*. 4131. Institute of Labor Economics (IZA).

Edmonds, E. V. 2007. Child Labor. *NBER Working Paper*. No. 12926. Cambridge, MA: National Bureau of Economic Research.

Edmonds, E. V., and N. Pavcnik. 2005. The Effect of Trade Liberalization on Child Labor. *Journal of International Economics*. 65(2). pp. 401-419.

Edmonds, E. V., and N. Pavcnik. 2006. International Trade and Child Labor: Cross-Country Evidence. *Journal of International Economics*. 68(1). pp. 115-140.

Egan, M. L., and A. Mody. 1992. Buyer-Seller Links in Export Development. *World Development*. 20(3). pp. 321-334.

Eisfeldt, A. L., G. Schubert, and M. B. Zhang. 2023. Generative AI and Firm. *NBER Working Paper*. No. 31222. Cambridge, MA: National Bureau of Economic Research.

Ersahin, N., M. Giannetti, and R. Huang. 2023. Trade Credit and the Stability of Supply Chains. *SMU Cox School of Business Research Paper*. (21-09). pp. 21-13.

Erten, B., and J. Leight. 2021. Exporting Out of Agriculture: The Impact of WTO Accession on Structural Transformation in China. *Review of Economics and Statistics*. 103(2). pp. 364-380.

Eurocham. 2022. Myanmar Garment Sector FACTSHEET, EuroCham Myanmar's Garment Advocacy Group.

Fabbri, D., and L. Klapper. 2009. Trade Credit and the Supply Chain. *Working paper*. Amsterdam Business School Research Institute.

Fajnzylber, P., W. Maloney, and G. M. Rojas. 2006. Microenterprise Dynamics in Developing Countries: How Similar Are They to Those in the Industrialized World? Evidence from Mexico. *The World Bank Economic Review*. *20*(3). pp. 389-419.

Farole, T., C. Hollweg, and D. Winkler. 2018. Trade in Global Value Chains: An Assessment of Labor Market Implications. *Jobs Working Paper*. No. 18. World Bank Group.

Federman, M., and D. I. Levine. 2005. The Effects of Industrialization on Education and Youth Labor in Indonesia. *The B.E. Journal of Macroeconomics* 5(1), Art.: 20121004.

Felix, M. 2021. Trade, Labor Market Concentration, and Wages. *Working Paper*. Yale University.

Fernandes, A., N. Rocha, and M. Ruta. 2023. Beyond Trade: How Deep Trade Agreements Shape Non-Trade Outcomes. CEPR Press.

Fernandes, A., and H. L. Kee. 2020. Gender Empowerment, Supply Chain Linkages, and Foreign Direct Investment. *World Bank Policy Research Working Paper*. No. 9340.

Fieler, A. C., M. Eslava, and D. Y. Xu. 2018. Trade, Quality Upgrading, and Input Linkages: Theory and Evidence from Colombia. American Economic Review, 108(1), pp. 109-146.

Fontagné, L., A. Reshef, G. Santoni, and G. Vannelli. 2023. Automation, Global Value Chains, and Functional Specialization. *Working Paper*. 2023-05, CEPII Research Center.

Fukase, E. 2014. Foreign Wage Premium, Gender, and Education: Insights from Vietnam Household Surveys. *The World Economy*. 37(6). pp. 834-855.

Gaddis, I., and J. Pieters. 2017. The Gendered Labor Market Impacts of Trade Liberalization: Evidence from Brazil. *Journal of Human Resources*. 52(2). pp. 457-490.

Galor, O., and N. Weil. 1996. The Gender Gap, Fertility, and Growth. *American Economic Review*. 86. pp. 374-387.

Garcia-Appendini, E., and J. Montoriol-Garriga. 2013. Firms as Liquidity Providers: Evidence from the 2007–2008 Financial Crisis. *Journal of Financial Economics*. 109(1). pp. 272-291.

Gentile, E., Y. Xing, S. Rubínová, and S. Huang. 2021. Productivity Growth, Innovation, and Upgrading Along Global Value Chains. In Asian Development Bank, University of International Business and Economics, World Trade Organization, IDE-JETRO, *Global Value Chain Development Report 2021: Beyond Production*. pp. 72-104.

Gereffi, G., and X. Luo. 2015. Risks and Opportunities of Participation in Global Value Chains. *Journal of Banking and Financial Economics*. 2(4). pp. 51-63.

Gereffi, G. 1999. International Trade and Industrial Upgrading in the Apparel Commodity Chain. *Journal of International Economics*. 48(1). pp. 37-70.

Goldberg, P. K., and N. Pavcnik. 2007. Distributional Effects of Globalization in Developing Countries. *Journal of Economic Literature*. 45(1). pp. 39-82.

Goldberg, P. K., A. K. Khandelwal, N. Pavcnik, and P. Topalova. 2010. Imported Intermediate Inputs and Domestic Product Growth: Evidence from India. *The Quarterly Journal of Economics*. 125(4). pp. 1727-1767.

Goutam, P., I. Gutierrez, K. B. Kumar, and S. Nataraj. 2017. Does Informal Employment Respond to Growth Opportunities? Trade-based Evidence from Bangladesh. *Working Paper*. No. WR-1198. RAND Corporation.

Graetz, G., and G. Michaels. 2018. Robots at Work. *Review of Economics and Statistics*. 100(5). pp. 753-768.

Guillouet, L., A. Khandelwal, R. Macchiavello, and M. Teachout. 2022. Language Barriers in Multinationals and Knowledge Transfers. *NBER Working Paper*. No. 28807. Cambridge, MA: National Bureau of Economic Research.

Halpern, L., M. Koren, and A. Szeidl. 2015. Imported Inputs and Productivity. *American Economic Review*. 105(12). pp. 3660-3703.

Hardy, B., F. E. Saffie, and I. Simonovska. 2023. Trade Credit and Exchange Rate Risk Pass Through. *NBER Working Paper*. No. 31078. Cambridge, MA: National Bureau of Economic Research.

Harrison, A., and A. Rodríguez-Clare. 2010. Trade, Foreign Investment, and Industrial Policy for Developing Countries. *Handbook of Development Economics*. 5. pp. 4039-4214.

Hatte, S., and P. Koenig. 2020. The Geography of NGO Activism Against Multinational Corporations. *The World Bank Economic Review*, 34(1), pp. 143-163.

Heath, R., and A. M. Mobarak. 2015. Manufacturing Growth and the Lives of Bangladeshi Women. *Journal of Development Economics*. 115. pp. 1-15.

Helpman, E., M. Melitz, and S. R. Yeaple. 2004. Export versus FDI with Heterogeneous Firms. *American Economic Review*. 94(1). pp. 300-316.

Herkenhoff, P., S. Krautheim, F. O. Semrau, and F. Steglich. 2021. Corporate Social Responsibility along the Global Value Chain. *CESifo Working Paper Series*. 9498, CESifo.

Herkenhoff, P., and S. Krautheim. 2022. The International Organization of Production in the Regulatory Void. *Journal of International Economics*. 137. 103572.

Hing, V., S. M. Thangavelu, and D. Narjoko. 2020. Human Capital and Participation in Global Value Chains: Evidence from Small and Medium-Sized Enterprises in Indonesia. *ADBI Working Paper.* No. 1142. Asian Development Bank Institute.

Hjort, J., X. Li and H. Sarsons. 2022. Across-Country Wage Compression in Multinationals. *American Economic Review. Forthcoming*.

Hoekman, B. 2021. Realizing European Soft Power in External Cooperation and Trade. RESPECT Policy Brief.

Hoekman, B., J. F. Francois, F. Santi, and M. Manchin. 2022. Pursuing Environmental and Social Objectives through Trade Agreements. *Robert Schuman Centre for Advanced Studies Research Paper No. RSC_73*.

Hoekman, B., F. Santi, and A. Shingal. 2023. Trade Effects of Non-Economic Provisions in Trade Agreements. *Economics Letters*. 226. 111081.

Hollweg, C., and A. O. Lopez. 2020. Exporting and Female Labor Market Outcomes in Georgia. *World Bank Policy Research Working Paper*. No. 9432.

Hollweg, C. 2019. Global Value Chains and Employment in Developing Economies. In World Trade Organization, IDE-JETRO, Organization for Economic Co-operation and Development, University of International Business and Economics, World Bank Group, *Global Value Chain Development Report 2019: Technological Innovation, Supply Chain Trade and Workers in a Globalized World*. pp. 72-104.

ILO (International Labour Organization). 2008. Promotion of Rural Employment for Poverty Reduction. International Labour Conference, 97th Session. Geneva: ILO.

ILO (International Labour Organization). 2020a. Understanding the Gender Composition and Experience of Ready-Made Garment (RMG) Workers in Bangladesh, Issue Brief. Geneva: ILO.

ILO (International Labour Organization). 2020b. Gendered Impacts of COVID-19 on the Garment Sector. Geneva: ILO.

Im, H., and J. McLaren. 2023. Foreign Direct Investment, Global Value Chains, and Labor Rights: No Race-to-the-Bottom? *NBER Working Paper*. No. 31363. Cambridge, MA: National Bureau of Economic Research.

IMF (2017). Fintechs and the Financial Side of Global Value Chains— The Changing Trade-Financing Environment. *Thirtieth Meeting of the IMF Committee on Balance of Payments Statistics*. BOPCOM—17/21

Iyoha, E. 2022. Estimating Productivity in the Presence of Spillovers: Firm-level Evidence from the US Production Network. Unpublished.

Javorcik, B. S. 2004. Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages. *American Economic Review*. 94(3). pp. 605-627.

Javorcik, B. S. 2015. Does FDI Bring Good Jobs to Host Countries? *The World Bank Research Observer*. 30(1). pp. 74-94.

Jensen, R. 2012. Do Labor Market Opportunities Affect Young Women's Work and Family Decisions? Experimental Evidence from India. *The Quarterly Journal of Economics*. 127(2). pp. 753-792.

Juhász, R., M. P. Squicciarini, and N. Voigtländer. 2020. Technology Adoption and Productivity Growth: Evidence from Industrialization in France. *NBER Working Paper*. No. 27503. Cambridge, MA: National Bureau of Economic Research.

Juhn, C., G. Ujhelyi, and C. Villegas-Sanchez. 2014. Men, Women, and Machines: How Trade Impacts Gender Inequality. *Journal of Development Economics*. 106. pp. 179-193.

Kasahara, H., and J. Rodriguez. 2008. Does the Use of Imported Intermediates Increase Productivity? Plant-level Evidence. *Journal of Development Economics*. 87(1). pp. 106-118.

Khandelwal, A. 2010. The Long and Short (of) Quality Ladders. *The Review of Economic Studies*. 77(4). pp. 1450-1476.

Kim, M., A. H. Liu, K. L. Tuxhorn, D. S. Brown, and D. Leblang. 2015. Lingua Mercatoria: Language and Foreign Direct Investment. *International Studies Quarterly*. 59(2). pp. 330-343.

Kim, S. J., and H. S. Shin. 2023. Theory of Supply Chains: A Working Capital Approach. *BIS Working Papers*. No. 1070.

Kinkel, S., A. Jager, and C. Zanker. 2015. The Effects of Robot Use in European Manufacturing Companies on Production Off-shoring Outside the EU. In *Proceedings of the 22nd International Annual EurOMA Conference*. Neuchâtel, Switzerland.

Klymak, M. 2023. The Trade Effects of Information Provision about Forced and Child Labor. *World Development*. 167. pp. 106217.

Koenig, P., and S. Poncet. 2022. The Effects of the Rana Plaza Collapse on the Sourcing Choices of French Importers. *Journal of International Economics*. 137. pp. 103576.

Koenig, P., S. Krautheim, C. Löhnert, and T. Verdier. 2021. Local Global Watchdogs: Trade, Sourcing, and the Internationalization of Social Activism. CESifo Working Paper Series No. 9068.

Krautheim, S., and T. Verdier. 2016. Offshoring with Endogenous NGO Activism. *Journal of International Economics*. 101. pp. 22-41.

Kruger, D. I. 2007. Coffee Production Effects on Child Labor and Schooling in Rural Brazil. *Journal of Development Economics*. 82(2). pp. 448-463.

Krzywdzinski, M. 2017. Automation, Skill Requirements, and Labour-Use Strategies: High-Wage and Low-Wage Approaches to High-Tech Manufacturing in the Automotive Industry. *New Technology, Work and Employment*. 32(3). pp. 247–267.

Kugler, M., and E. Verhoogen. 2012. Prices, Plant Size, and Product Quality. *The Review of Economic Studies*. 79(1). pp. 307-339.

Kumar, R. 2017. Global Value Chains: A Way to Create More, Better, and Inclusive Jobs. *Jobs Development Blog*, World Bank, Washington, DC.

Kumar, R. S., and M. B. Subrahmanya. 2010. Influence of Subcontracting on Innovation and Economic Performance of SMEs in Indian Automobile Industry. *Technovation*. 30(11-12). pp. 558-569.

Laget, E., A. Osnago, N. Rocha, and M. Ruta. 2020. Deep Trade Agreements and Global Value Chains. *Review of Industrial Organization*. 57. pp. 379-410.

Lan, J., and B. Shepherd. 2019. Women and the Services Sector. In *Leveraging Services for Development: Prospects and Policies*. Asian Development Bank.

Lawrence, Z. 1996. Regionalism, Multilateralism, and Deeper Integration. Washington, DC: Brookings Institution Press.

Lendle, A., M. Olarreaga, S. Schropp, and P. L. Vézina, 2016. There goes gravity: eBay and the Death of Distance. Economic Journal. *Royal Economic Society*. 126(591). pp. 406–441.

Li, B. 2018. Export Expansion, Skill Acquisition, and Industry Specialization: Evidence from China. *Journal of International Economics*. 114. pp. 346-361.

Lundquist, K. 2023. MNC Supplier Transparency. GVC Development Report Background Paper.

Lundquist, K., and J. W. Kang. 2021. Digital Platforms and Global Value Chains. In *Global Value Chain Development Report 2021: Beyond Production*. Asian Development Bank, University of International Business and Economics, World Trade Organization, IDE-JETRO.

Joshi, A., and N. Lahiri. 2015. Language Friction and Partner Selection in Cross-border RandD Alliance Formation. *Journal of International Business Studies*. 46. pp. 123-152.

Macchiavello, R. 2022. Relational Contracts and Development. *Annual Review of Economics*. 14. pp. 337-362.

Macchiavello, R., and J. Miquel-Florensa. 2019. Buyer-driven Upgrading in GVCs: The Sustainable Quality Program in Colombia. *CEPR Discussion Papers*. No. 13935.

MacGarvie, M. 2006. Do Firms Learn from International Trade? *Review of Economics and Statistics*. 88(1). pp. 46-60.

Maertens, M., and J. F. Swinnen. 2009. Trade, Standards, and Poverty: Evidence from Senegal. *World Development*. 37(1). pp. 161-178.

Maggi, G., and A. Rodriguez-Clare. 2007. A Political-Economy Theory of Trade Agreements. *American Economic Review*. *97*(4). pp. 1374-1406.

Majlesi, K. 2016. Labor Market Opportunities and Women's Decision Making Power within Households. *Journal of Development Economics*. 119. pp. 34-47.

Manaresi, F., A. Palma, L. Salvatici, and V. Scrutinio. 2022. Managerial Input and Firm Performance: Evidence from a Policy Experiment. Unpublished.

Manova, K., and Z. Zhang. 2012. Export Prices across Firms and Destinations. *The Quarterly Journal of Economics*. 127(1). pp. 379-436.

Mansour, H., P. Medina, and A. Velasquez. 2022. Import Competition and Gender Differences in Labor Reallocation. *Labour Economics*. 76. pp. 102149.

Marotta, G. 2001. Is Trade Credit More Expensive than Bank Loans? Evidence from Italian Firm-level Data. Evidence from Italian Firm-level Data. *Working Paper.* UNIMORE.

Mattoo, A., N. Rocha, and M. Ruta. 2020. The Evolution of Deep Trade Agreements. Washington, DC: World Bank.

McCaig, B., N. Pavcnik, and W. F. Wong. 2022. FDI Inflows and Domestic Firms: Adjustments to New Export Opportunities. *NBER Working Paper*. No. 30729. Cambridge, MA: National Bureau of Economic Research.

McCaig, B., and N. Pavcnik. 2018. Export Markets and Labor Allocation in a Low-Income Country. *American Economic Review*. 108(7). pp. 1899-1941.

McCaig, B. 2011. Exporting out of Poverty: Provincial Poverty in Vietnam and US Market Access. *Journal of International Economics*. 85(1). pp. 102-113.

McMillan, J., and C. Woodruff. 1999. Interfirm Relationships and Informal Credit in Vietnam. *The Quarterly Journal of Economics*. 114(4). pp. 1285-1320.

Méndez, E., and D. Van Patten. 2022. Multinationals, Monopsony, and Local Development: Evidence from the United Fruit Company. *Econometrica*. 90(6). pp. 2685-2721.

Minetti, R., P. Murro, Z. Rotondi, and S. C. Zhu. 2019. Financial Constraints, Firms' Supply Chains, and Internationalization. *Journal of the European Economic Association*. 17(2). pp. 327-375.

Molina, T., and M. Tanaka. 2023. Globalization and Female Empowerment: Evidence from Myanmar. *Economic Development and Cultural Change*. 71(2). pp. 519-565.

Monge-González, R., L. Rivera, and N. Mulder. 2021. Cultural Spillovers from Multinational to Domestic Firms: Evidence on Female Employment in Costa Rica. *Transnational Corporations Journal*. 28(1).

Mosley, L. 2011. Labor Rights and Multinational Production. New York: Cambridge University Press.

Muendler, M. A., and J. E. Rauch. 2018. Do Employee Spinoffs Learn Markets from Their Parents? Evidence from International Trade. *European Economic Review*. 105. pp. 159-173.

Munshi, K., and M. Rosenzweig. 2006. Traditional Institutions Meet the Modern World: Caste, Gender, and Schooling Choice in a Globalizing Economy. *American Economic Review*. 96(4). pp. 1225-1252.

Nano, E., and V. Stolzenburg. 2021. The Role of Global Services Value Chains for Services-led Development. In *Global Value Chain Development Report 2021: Beyond Production*. Asian Development Bank, University of International Business and Economics, World Trade Organization, IDE-JETRO.

Nano, E., G. Nayyar, S. Rubinova, and V. Stolzenburg. 2021. Services Liberalization and Educational Attainment: Evidence from India. *WTO Staff Working Paper*. ERSD-2021-10.

Narula, R. 2020. Policy Opportunities and Challenges from the COVID-19 Pandemic for Economies with Large Informal Sectors. *Journal of International Business Policy*. 3. pp. 302-310.

Ndubuisi, G., and S. Owusu. 2023. Global Value Chains, Job Creation, and Job Destruction among Firms in South Africa. *STEG Working Paper*. WP073.

Newman, C., J. Rand, T. Talbot, and F. Tarp. 2015. Technology Transfers, Foreign Investment and Productivity Spillovers. *European Economic Review*. 76. 168-187.

Ngoma, M. M. 2023. Chinese Imports and Industrialization in Africa: Evidence from Ethiopia. Unpublished.

OECD (Organisation for Economic Co-operation and Development). 2023a. SME and Entrepreneurship Outlook 2023. OECD Publishing, Paris.

OECD (Organisation for Economic Co-operation and Development). 2023b. Informality and Globalisation: In Search of a New Social Contract. OECD Publishing, Paris.

Oster, E., and B. M. Steinberg. 2013. Do IT Service Centers Promote School Enrollment? Evidence from India. *Journal of Development Economics*. 104. pp. 123-135.

Ouyang, D., W. Yuan, and Y. Zi. 2022. Empowered Young Women: Trade Liberalization and Women's Family Decisions in China. *Working Paper.* Centre for Economic Policy Research.

Pedemonte, M., T. Vishwanath, and R. D. Zarate. 2019. Trade, Robots and Automation: The Impact of US Robots on Labor Outcomes in Developing Countries. Unpublished.

Pham, L. T., and Y. Jinjarak. 2023. Global Value Chains and Female Employment: Evidence from Vietnam. *The World Economy*. 46(3). pp. 726-757.

Piermartini, R., and S. Rubínová. 2021. How Much Do Global Value Chains Boost Innovation?. *Canadian Journal of Economics/Revue canadienne d'économique*. 54(2). pp. 892-922.

Pietrobelli, C., A. Marin, and J. Olivari. 2018. Innovation in Mining Value Chains: New Evidence from Latin America. *Resources Policy*. 58. pp. 1-10.

Ponczek, V., and G. Ulyssea. 2022. Enforcement of Labour Regulation and the Labour Market Effects of Trade: Evidence from Brazil. *The Economic Journal*. 132(641). pp. 361-390.

Poole, J. P. 2013. Knowledge Transfers from Multinational to Domestic Firms: Evidence from Worker Mobility. *Review of Economics and Statistics*. 95(2). pp. 393-406.

Reyes, M. I. 2023. Did Competing with China Affect Chilean Manufacturing Jobs? Evaluating Gender Differences in Employment During 1995–2006. *Feminist Economics*. 1-25.

Rifin, A., and D. Nauly. 2020. The Impact of Involvement in the Global Value Chain on Coffee Farmers in Indonesia: Case Study of Margamulya Coffee Producer Cooperative and Mitra Malabar Cooperative, Bandung, Indonesia. *ADBI Working Paper.* No. 1143. Asian Development Bank Institute.

Rodriguez-Clare, A. 1996. Multinationals, Linkages, and Economic Development. *The American Economic Review*. 852-873.

Rossi, A., A. Luinstra, and J. Pickles (Eds.). 2014. Towards Better Work: Understanding Labour in Apparel Global Value Chains. Springer.

Saliola, F., and A. Zanfei. 2009. Multinational Firms, Global Value Chains, and the Organization of Knowledge Transfer. *Research Policy*. 38(2). pp. 369-381.

Sancak, M. 2022. The Varying Use of Online Supplier Portals in Auto Parts-Automotive Value Chains and Its Implications for Learning and Upgrading: The Case for Mexican and Turkish Suppliers. *Global Networks*. 22(4). pp. 701-715.

Sharma, S. 2020. The Impact of Foreign Direct Investment on Gender Inequality in India. *Transnational Corporations*. 27(3).

Shastry, G. K. 2012. Human Capital Response to Globalization: Education and Information Technology in India. *Journal of Human Resources*. 47(2). pp. 287-330.

Shepherd, B., and S. Stone. 2012. Global Production Networks and Employment: A Developing Country Perspective. *Working Paper*. TAD/TC/WP(2012)29, Trade and Agriculture Directorate, Organisation for Economic Co-operation and Development, Paris.

Sok, K., R. Phim, S. Keo, and V. Kim. 2020. Connecting Cambodia's SMEs to Regional Value Chains: The "Bridging Gap" and "Missing Link". *ADBI Working Paper*. No. 1150. Asian Development Bank Institute.

Standing, G. 1999. Global Feminization through Flexible Labor: A Theme Revisited. *World Development*. 27(3). pp. 583-602.

Stapleton, K., and M. Webb. 2020. Automation, Trade, and Multinational Activity: Micro Evidence from Spain. SSRN Papers. https://papers.ssrn. com/sol3/papers. cfm?abstract_id=3681143.

Startz, M. 2021. The Value of Face-to-Face: Search and Contracting Problems in Nigerian Trade. Unpublished.

Stolzenburg, V., M. Matthee, C. Janse van Rensburg, and C. Bezuidenhout. 2020. Foreign Direct Investment and Gender Inequality: Evidence from South Africa. *Transnational Corporations Journal*. 27(3).

Stolzenburg, V., D. Taglioni, D. Winkler, S. Ponte, G. Gereffi, and G. Raj-Reichert. 2019. Economic Upgrading through Global Value Chain Participation: Which Policies Increase the Value-Added Gains? In *Handbook on Global Value Chains*. pp. 483-505.

Sudan, F. K. 2021. Leveraging the Participation of SMEs in Global Value Chains of the Automotive Industry: Insights from Maruti Suzuki India Limited. In *Enhancing SME Participation in Global Value Chains*. 398. Asian Development Bank Institute.

Tanaka, K. 2022. The European Union's Withdrawal of Trade Preferences for Cambodia. *The World Economy*. 45(11). pp. 3398-3419.

Tanaka, M. 2020. Exporting Sweatshops? Evidence from Myanmar. *Review of Economics and Statistics*. 102(3). pp. 442-456.

Tang, H., and Y. Zhang. 2021. Do Multinationals Transfer Culture? Evidence on Female Employment in China. *Journal of International Economics*. 133. 103518.

Thang, D. N., and L. T. Ha. 2022. Trade Credit and Global Value Chain: Evidence from Cross-Country Firm-level Data. *International Economics*. 171. pp. 110-129.

Topalova, P. 2007. Trade Liberalization, Poverty, and Inequality: Evidence from Indian Districts. In *Globalization and Poverty*. pp. 291-336. University of Chicago Press.

Topalova, P. 2010. Factor Immobility and Regional Impacts of Trade Liberalization: Evidence on Poverty from India. *American Economic Journal: Applied Economics*. 2(4). pp. 1-41.

Topalova, P., and A. Khandelwal. 2011. Trade Liberalization and Firm Productivity: The Case of India. *Review of Economics and Statistics*. 93(3). pp. 995-1009.

Trade and Technology Dialogue. 2023. Working Group 10 – Global Trade Challenges Roundtable on Due Diligence Report. EU-US Trade and Technology Council.

Ugarte, C., M. Olarreaga, and G. Saiovici. 2023. Child Labour and Global Value Chains. *The World Economy*. 46(4). pp. 941-968.

UNCTAD (United Nations Conference on Trade and Development). 2013. World Investment Report 2013: Global Value Chains: Investment and Trade for Development. Geneva: UNCTAD.

UNCTAD (United Nations Conference on Trade and Development). 2021. Multinational Enterprises and the International Transmission of Gender Policies and Practices. Geneva: UNCTAD.

Urata, S., and Y. Baek. 2021. Does GVC Participation Improve Firm Productivity? A Study of Three Developing Asian Countries. *ADBI Working Paper*. No. 1245. Asian Development Bank Institute.

Verhoogen, E. A. 2008. Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector. *The Quarterly Journal of Economics*. 123(2). pp. 489-530.

Winters, L. A. 2023. Trade Agreements and Non-Trade Objectives: A Cautionary Note. In *Beyond Trade: How Deep Trade Agreements Shape Non-Trade Outcomes*. CEPR Press.

World Bank. 2020. World Development Report 2020: Trading for Development in the Age of Global Value Chains. Washington, D.C: World Bank.

World Bank and WTO. 2020. Women and Trade: The Role of Trade in Promoting Gender Equality. Washington, D.C: World Bank.

WTO (World Trade Organization). 2016. World Trade Report 2016: Levelling the Trading Field for SMEs. Geneva: WTO.

WTO (World Trade Organization). 2019. World Trade Report 2019: The Future of Services Trade. Geneva: WTO.

WTO (World Trade Organization). 2020. World Trade Report 2020: Government Policies to Promote Innovation in the Digital Age. Geneva: WTO.

WTO (World Trade Organization) and IFC (International Finance Corporation). 2022. Trade Finance in West Africa: A Study of Cote D'Ivoire, Ghana, Nigeria, and Senegal.

Yahmed, S. B. 2023. Gender Wage Discrimination with Employer Prejudice and Trade Openness. *World Development*. 170. pp. 106-319.

Yildirim, A., R. Basedow, M. Fiorini, and B. Hoekman. 2021. EU Trade and Nontrade Objectives: New Survey Evidence on Policy Design and Effectiveness. *Journal of Common Market Studies*. 59(3). pp. 556–568.

Yu, Jiantuo, X. Xu, L. Wang, and X. Yang. 2023. The Impact of Global Value Chain Participation on Income Distribution. China Development Research Foundation.

Zavala, L. 2022. Unfair Trade? Monopsony Power in Agricultural Value Chains. Unpublished. https://doi.org/10.1787/c945c24f-en

APPENDIX

Background Paper and Chapter Authors' Workshop for the Global Value Chain Development Report 2023

Global Value Chain Development Report 2023: Resilient and Sustainable GVCs in Turbulent Times

Background Paper Workshop

November 7- 11, 2022

Hybrid conference hosted by WTO, All times in UTC+1 (Central European Time)

Day One: Nov. 7, 2022, Monday

Chairperson: **Victor Stolzenburg**, WTO

Opening remarks

8:30-8:35 **Alexander Keck**, Advisory Committee representative, WTO

8:35-8:45 **Yuqing Xing**, Chair of the Editorial Committee, National Graduate Institute for Policy

Session 1: Measuring GVC participation

8:45-9:15 **Gabriele Suder**, Federation University; Bo Meng, IDE-JETRO; Yuning Gao, Tsinghua University; Jiabai Ye, Hunan University ; Wenyin Cheng, IDE-JETRO

Making Global Value Chains Visible: A Network Analysis Based on Trade in Factor Income

Discussant: **Zhi Wang**, UIBE
Q&A

9:15-9:45 **Jules Hugot**, Reizle Platitas, ADB

Cross-border value chains in developing Asia survive trade tensions and the global pandemic

Discussant: **Simon Neumueller**, WTO
Q&A

9:45-10:15 Miro Frances Capili, Ma. Charmaine Crisostomo, Christian Regie Jabagat, Angelo Jose Lumba, **Mahinthan Joseph Mariasingham**, ADB

Developments in Global Value Chains Amid a Period of Overlapping Crises

Discussant: **Xin Yang**, MD, China International Corporation Q&A
Q&A

10:15-10:45 Bo Meng, **Wenyin Cheng**, Kyoji Fukao, IDE-JETRO; Yuning Gao, Tsinghua University; Shang-Jin Wei, Columbia University

Made in the World': Measuring the Productivity of Global Value Chains

Discussant: **Angelo Jose Lumba**, ADB
Q&A

10:45-11:00 Break

11:00-11:30 **Yuqing Xing**, National Graduate Institute for Policy Studies

Heterogeneity and the domestic value added of PRC's exports

Discussant: **Cai Kun**, UIBE
Q&A

11:30-12:00 **Satoshi Inomata**, IDE-JETRO & OECD; Tesshu Hanaka, Kyushu University

A Risk Analysis on the Network Concentration of Global Supply Chains

Discussant: **Victor Stolzenburg**, WTO
Q&A

12:00-12:30 **Socrates Majune**, Victor Stolzenburg, WTO

Mapping potential supply chain bottlenecks

Discussant: **Satoshi Inomata**, IDE-JETRO & OECD
Q&A

----------End of Day One----------
--

Day Two: Nov. 8, 2022, Tuesday

Chairperson: **Yuqing Xing**, National Graduate Institute for Policy Studies

Session 2: GVCs and Climate Change I

8:30-9:00 **Roberta Rabellotti**, University of Pavia; Elisabetta Gentile, ADB; Rasmus Lema, UNU-MERIT; Dalila Ribaudo, Aston Business School

The greening of GVCs: a conceptualframeworkforpolicy implications

Discussant: **Karsten Steinfatt**, WTO
Q&A

9:00-9:30 Roberta Rabellotti, University of Pavia; Elisabetta Gentile, ADB; **Rasmus Lema**, UNU-MERIT

Green GVCs: are there upgrading opportunities for developing countries?

Discussant: **Rainer Lanz**, WTO
Q&A

9:30-10:00 **Ali Absar**, José-Antonio Monteiro, Ankai Xu, WTO

Global Value Chain resilience in a warming world

Discussant: **Elisabetta Gentile**, ADB
Q&A

10:00-10:15 Break

Session 3: GVCs , Geopolitics and Pandemics I

10:15-10:45 Areef Suleman, **Mustafa Yagci**, IsDB

The Governance of Global Value Chains: The Rising Role of the State

Discussant: **Etel Solingen**, University of California Irvine
Q&A

10:45-11:15 **Yuning Gao**, Tao Zhang, Jiabai Ye, Tsinghua University; Bo Meng, IDE-JETRO

The Impact of COVID-19 Pandemic on Global Value Chains: Considering Firm Ownership and Digital Gap

Discussant: **Kathryn Lundquist**, WTO
Q&A

11:15-11:45 **Yves Renouf**, WTO

The legal impact of geopolitics and geoeconomics on GVCs

Discussant: **Gabrielle Marceau**, WTO
Q&A

11:45-12:15 **Shaopeng Huang**, University of International Business and Economics

The Rise of Techno-nationalism and its Impacts on the Semiconductor GVC

Discussant: **Mahinthan Joseph Mariasingham**, ADB
Q&A

12:15-12:45 **Henry W. Yeung**, National University of Singapore

Explaining geographic shifts of chip making toward East Asia and market dynamics in semiconductor global production networks

Discussant: **Roberta Piermartini**, WTO
Q&A

----------End of Day Two----------

Day Three: Nov. 9, 2022, Wednesday

Chairperson: **Etel Solingen**, University of California Irvine

Session 4: GVCs and Trade Policy

8:30-9:00 **Enxhi Tresa**, WTO

Spillover Effect of Tariffs in Global Value Chains

Discussant: **Yuning Gao,** Tsinghua University
Q&A

9:00-9:30 **Cai Kun**, University of International Business and Economics

Local Content Requirement Policies in the PRC and Their Impacts on Domestic Value-Added in Exports

Discussant: **Nguyen T. Xuan**, Deakin University
Q&A

Session 5: GVCs and Climate Change II

9:30-10:00 **Haoqi Qian**, Fudan University; Bo Meng, IDE-JETRO

How Will the EU's Carbon Border Adjustment Tax Redefine Global Value Chains? Considering Firm Heterogeneity and Trade in Factor- Income

Discussant: **Eddy Bekkers**, WTO
Q&A

10:00-10:15 Break

10:15-10:45 **Angella Faith Montfaucon**, World Bank; Socrates Majune, WTO; Natnael Simachew Nigatu, World Bank

Greening Trade through Global Value Chains in Africa

Discussant: **Jules Hugot**, ADB
Q&A

10:45-11:15 Yue Lu, University of International Business and Economics; **Jinjun Xue**, Nagoya University; Bin Su, National University of Singapore; Haotian Zhang, Tsinghua University

Firm's position in global value chains and its impact on pollutant emissions: evidence from PRC's manufacturing firms

Discussant: **Ankai Xu**, WTO
Q&A

11:15-11:45 **Meng Li**, Shanghai Jiao Tong University; Bo Meng, IDE-JETRO; Yuning Gao, Tsinghua University; Zhi Wang, George Mason University; Yaxiong Zhang, National Development and Reform Commission; Yongping Sun, Hubei University

Tracing CO_2 Emissions in Global Value Chains: Multinationals vs. Domestically-owned Firms

Discussant: **Enxhi Tresa**, WTO
Q&A

11:45- 12:15 **Ran Wang**, University of International Business and Economics

The Carbon emission of multinational enterprises in the global value chains: new insights on the trade-investment nexus

Discussant: **Bo Meng**, IDE-JETRO
Q&A

----------End of Day Three----------

Day Four: Nov. 10, 2022, Thursday

Chairperson: **Mahinthan Joseph Mariasingham**, ADB

Session 6: GVCs , Geopolitics and Pandemics II

8:30-9:00 Christina Georgieva, Kyoto University

The US-PRC trade war and its impacts on the supply chains of the American Auto Industry

Discussant: **Zhongzhong Hu**, UIBE
Q&A

9:00-9:30 **Jingshu Liang**, Jiantuo Yu, China Development Research Foundation

Geopolitical conflicts, Technological Decoupling: Implications for GVC Participation

Discussant: **Shaopeng Huang**, UIBE
Q&A

9:30-10:00 **Etel Solingen**, University of California Irvine; Linde Götz, Leibniz Institute of Agricultural Development in Transition Economies

Snarled in the Gray Zone: GVCs in the Emerging Geopolitical Context

Discussant: **John Hancock**, WTO
Q&A

10:00-10:30 Areef Suleman, **Mustafa Yagci**, IsDB

The Impact of Sanctions on Global Value Chains

Discussant: **Cosimo Beverelli**, WTO
Q&A

10:30-10:45 Break

Session 7: Inclusive GVCs

10:45-11:15 **Socrates Majune**, WTO; Angella Faith Montfaucon, Natnael Simachew Nigatu, World Bank

A Macro and Micro Analysis of Value Chain Trade in Africa

Discussant: **Sifan Jiang**, China International Capital Corporation
Q&A

11:15–11:45 **Kathryn Lundquist**, WTO

MNC Supplier Transparency: A Review of MSME and Developing Economy Participation in GVCs

Discussant: **Federica Maggi**, WTO
Q&A

11:45–12:15 Marcelo Olarreaga, University of Geneva; **Cristian Ugarte**, WTO

Child Labour and Global Value Chains

Discussant: **Yuan Zi**, Graduate Institute Geneva
Q&A

12:15–12:45 **Jiantuo Yu**, Xiuna Yang, Lu Wang, Xiaolong Xu, China Development Research Foundation

Global Value Chain Participation and Income Inequality

Discussant: **Meichen Zhang**, UIBE
Q&A

----------End of Day Four----------

Day Five: Nov. 11, 2022, Wednesday

Chairperson: **Victor Stolzenburg**, WTO

Session 8: GVCs and Climate Change III

8:30-9:00 **Eddy Bekkers**, Jeanne Métivier, Enxhi Tresa, WTO

The impact of intermediates trade on emissions through diffusion of ideas

Discussant: **Angella Faith Montfaucon**, World Bank
Q&A

9:00-9:30 Shawn Tan, **Mara Tayag**, Kevin Quizon, ADB

Asia's Exposure and Vulnerability to European Union's Carbon Border Adjustment Mechanism

Discussant: **José-Antonio Monteiro**, WTO
Q&A

9:30-10:00 **Bo Meng**, IDE-JETRO; Yu Liu, Chinese Academy of Sciences; Yuning Gao, Tsinghua University; Meng Li, Shanghai Jiao Tong University; Zhi Wang, George Mason University; Jinjun Xue, Nagoya University; Robbie Andrew, Center for International Climate Research; Kuishuang Feng, University of Maryland; Yongping Sun, Hubei University

Self- and Shared Responsibilities of CO2 Emissions along Global Value Chains

Discussant: **Marc Bacchetta**, WTO
Q&A

10:00-10:30 **Rolando Avendano**, ADB; **John Poquiz**, King's College London; Shawn Tan, ADB

Impact of environmental regulations on carbon intensive FDI in developing Asia

Discussant: **Ran Wang**, UIBE
Q&A

10:30-10:45 Break

Session 9: GVCs , Geopolitics and Pandemics III

10:45- 11:15 **Massimiliano Calì**, Devaki Ghose, Angella Faith Montfaucon, World Bank; Michele Ruta, IMF

Trade Policy and Exporters' Resilience: Evidence from Indonesia

Discussant: **Socrates Majune**, WTO
Q&A

11:15- 11:45 Devaki Ghose, **Angella Faith Montfaucon**, World Bank

Covid-19, Firms in Global Value Chains and Non-Tariff Measures

Discussant: **Stela Rubínová**, WTO
Q&A

11:45- 12:15 **Xue Jinjun**, Nagoya University; Yuqing Xing, National Graduate Institute for Policy Studies and University of International Business and Economics; Yuyi Deng, University of International Business and Economics

The Impact of Russian-Ukrainian War on Energy Supply Chains and Geopolitics

Discussant: **Yue Lu**, UIBE
Q&A

Closing Remarks:

12:15- 12:25 **Albert S. Park**, Chief Economist and Advisory Committee representative, ADB
12:25- 12:30 **Victor Stolzenburg**, WTO

Global Value Chain Development Report 2023: Resilient and Sustainable GVCs in Turbulent Times

Chapter Authors' Workshop Agenda (Tokyo Time, hybrid-type)

June 5- 6, 2023

IDE-JETRO (#C21 meeting room, second floor), Chiba, Japan

5 June, 2023 (Mon.)

Registration: 09:15-09:40 (C21 meeting room)

Opening remarks

Chairperson: **Bo Meng**, IDE-JETRO

09:45-09:50 Kyoji Fukao, President, IDE-JETRO

09:50-09:55 Albert Park, Chief Economist, ADB (virtual) (8:50 AM, Manila)

09:55-10:00 Yuqing Xing, Chair of the Editorial Committee, Professor of GRIPS

Session 1: Geopolitics and future trajectory of GVCs (Chapter 3)

Chairperson: **Ran Wang**, UIBE

10:00-10:30 Presenter: Jinjun Xue, Nagoya University

10:30-10:45 Discussant: Michele Ruta, IMF (virtual) (4 June, 9:30 PM, Washington DC)

10:45-11:00 Discussant: Etel Solingen, University of California at Irvine

11:00-11:15 Q&A

Coffee break

11:15-11:30

Session 2: GVCs and inclusive development (Chapter 7)

Chairperson: **Shaopeng Huang**, UIBE

11:30-12:00 Presenter: Victor Stolzenburg, WTO

12:00-12:15 Discussant: Aya Okada (virtual), Nagoya University

12:15-12:30 Discussant: Mari Tanaka, Hitotsubashi University

12:30-12:45 Discussant: Jiantuo Yu, CDRF

12:45-13:00 Q&A

Lunch break (C23, C24 meeting rooms)

13:00-14:30

Session 3: GVC Trends and geographic concentration (Chapter 1)

Chairperson: **Victor Stolzenburg**, WTO

14:30-15:00 Presenter: Mahinthan J. Mariasingham, ADB

15:00-15:15 Discussant: Daria Taglioni, World Bank

15:15-15:30 Discussant: Sébastien Miroudot, OECD (virtual) (8:15 AM, Paris)

15:30-15:45: Q&A

Coffee break

15:45-16:00

Session 4: **From fabless to fabs everywhere? (Chapter 4)**
Chairperson: **Etel Solingen**, University of California at Irvine
16:00-16:30 Presenter: Shaopeng Huang, UIBE
16:30-16:45 Discussant: Seamus Grimes, National University of Ireland (virtual) (8:30 AM, Ireland)
16:45-17:00 Discussant: Chan-Yuan Wong, National Tsing Hua University
17:00-17:15 Discussant: XiaopengYin, UIBE
17:15-17:30 Q&A

Reception
18:00-19:30 at IDE Cafeteria (first floor) (Group photo)

6 June, 2023 (Tues.)

Registration 10:00-10:15 (C21 meeting room)

Session 5: Tracing carbon dioxin emissions along GVCs (Chapter 5)
Chairperson: **Mahinthan. J. Mariasingham**, ADB
10:15-10:45 Presenter: Bo Meng (IDE-JETRO) and Ran Wang (UIBE)
10:45- 11:00 Discussant: Joaquim J.M. Guilhoto, IMF (virtual) (5 June, 9:45 PM Washington DC)
11:00-11:15 Discussant: Jong Woo Kang, ADB (virtual) (10:00 AM, Manila)
11:15-11:30 Q&A

Coffee break
11:30-11:45

Session 6: Assessing impacts of the trade-war and COVID-19 on GVCs (Chapter 2)
Chairperson: **Elisabetta Gentile**, ADB
11:45-12:15 Presenter: Yuning Gao, Tsinghua University
12:15-12:30 Discussant: Jules Hugot ADB
12:30-12:45 Discussant: Angella Faith Montfaucon, World Bank
12:45-13:00 Discussant: Satoshi Inomata, IDE-JERO and OECD
13:00-13:15 Q&A

Lunch break (C23, C24 meeting rooms)
13:15-14:30

Session 7: Greening GVCs (Chapter 6)
Chairperson: **Jinjun Xue**, Nagoya University
14:30-15:00 Presenter: Elisabetta Gentile, ADB
15:00-15:15 Discussant: Ran Wang, UIBE
15:15-15:30 Discussant: Rainer Lanz, WTO (virtual) (8:15 AM, Geneva)
15:30-15:45 Q&A

Closing Remarks:
Chairperson: **Yuqing Xing**, Chair of the Editorial Committee, Professor of GRIPS 15:45-15:50
Ralph Ossa, Chief Economist, WTO (virtual) (8:45 AM, Geneva)
15:50-15:55 Xiaopeng Yin, Dean of the RCGVC, UIBE
15:55-16:00 Bo Meng, IDE-JETRO

GLOBAL VALUE CHAIN DEVELOPMENT REPORT 2023

RESILIENT AND SUSTAINABLE GVCS IN TURBULENT TIMES

The Global Value Chain Development Report 2023, the fourth in this biennial series, is released at a critical juncture in the evolution of Global Value Chains (GVCs). In response to the diverse shocks of recent years, this report explores approaches to build resilient and sustainable GVCs. It provides an overview of the most recent trends in GVCs, assesses the effects of the trade tensions and the COVID-19 pandemic on GVCs, and illustrates particular changes of energy and semiconductor supply chains. It also analyzes the challenges of climate change to GVCs and proposes a framework of greening value chains and policy options for enhancing inclusive development through GVC participation.