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Towards Greener and Inclusive Global Value Chains – Insights From Environmental Policy

Bo Meng, Ankai Xu, Meng Li, and Sunghun Lim

4.1 Introduction

The proliferation of global value chains (GVCs) over the past two decades has been propelled by declining cross-border transportation and communication costs – driven by technological advances and the progressive reduction of tariff and non-tariff barriers under the World Trade Organization (WTO) and various regional trade agreements. Despite the recent shocks and uncertainties to GVCs caused by escalating geopolitical tensions, the nature of GVCs – characterized by geographically fragmented production enabled by the expansion of international trade and foreign direct investment (FDI) – continues to play a fundamental role in enabling countries to leverage their comparative advantages and gain value added (WTO, 2023, also see Chapter 1). However, the globalization of production has also been accompanied by a marked increase in greenhouse gas (GHG) emissions (e.g., carbon dioxide, or CO_2, emissions) embodied in cross-border supply chains, as production processes span multiple borders with varying emission intensities (Meng et al., 2023). In response – and aligned with the global community's climate goals of carbon neutrality and reducing carbon leakage (IPCC, 2021) – policymakers are increasingly engaging both upstream suppliers and downstream customers to advance green transition strategies. Table 4.1 provides an illustrative list of climate mitigation policy instruments. These initiatives aim not only to improve environmental performance across value chains, but also to generate economic value, enhance corporate reputation and build long-term environmental competitiveness.

Note: This chapter was led by the Institute of Developing Economies – Japan External Trade Organization (IDE-JETRO). The views expressed are those of the authors and do not necessarily reflect the views of IDE-JETRO.

Table 4.1: Climate Mitigation Policy Instruments

Category	Examples of Policy Instruments
Explicit carbon pricing	– Carbon taxes – Emissions trading systems
Implicit carbon pricing	– Fuel excise taxes – Fuel subsidies (negative carbon prices) – Value-added tax differential for fuels
Mitigation crediting	– Carbon crediting mechanisms – Voluntary carbon markets
Incentive-based policies for technologies, efficiency, and other mitigation-related activities	– Vehicle feebates – Tradable fuel efficiency standards – Feed-in tariffs – Electricity excise taxes and subsidies – Emissions-based vehicle taxes – Tradable renewable portfolio standards – Tradable renewable fuel standards – Technological deployment subsidies – Electric vehicle incentives – Energy efficiency tax credits – Certain industrial and agricultural subsidies
Standards (non-tradable) and other regulations	– Air pollution standards – Greenhouse gas emissions intensity standards – Clean energy standards – Technology mandates or polluting product bans – Fertilizer regulations – Energy efficiency building codes – Fuel efficiency regulations – Energy market reform – (Non-tradable) renewable share mandates
Investment and other policies	– Public investment (e.g., public transportation, enabling infrastructure for innovation) – Information policies (product labelling/rating, certification, information disclosure) – Other electric vehicle policies – Research and development policies

Note: Emissions trading systems (ETSs) take two main forms: mass-based systems, such as cap-and-trade programs that differ in how allowances are allocated; and rate-based systems, such as tradable emission performance standards, output-based pricing systems, and low-carbon fuel standards. Rate-based ETSs limit the intensity but not total amount of emissions; trading results in a price for incremental emissions but benchmark allocations limit the average pricing of emissions, much as with output-based allocation in cap-and-trade regimes or output-based rebating of emission taxes. Under rate-based systems, total emissions fluctuate with economic activity, but to a lesser extent than with carbon taxes. Flexibility mechanisms under cap-and-trade systems also allow emissions to vary but help promote price stability. Thus, subtle but important distinctions exist among the policies that can be blurred in practice. Not all international organizations categorize rate-based ETSs as explicit carbon pricing. When all trading occurs bilaterally or on secondary markets, the resulting emissions price may not be observable.

Source: WTO, OECD, IMF, UN, World Bank (2024)

Given the structural complexity and international interdependence embedded in GVCs, and the reality that climate policies are primarily designed and implemented at the national level – shaped by domestic priorities, institutional capacities and economic structures – there is a pressing need for both domestically effective and globally coherent environmental governance.[1]

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[1] Fragmentation of climate change mitigation policies is costly and could lead to the introduction of complementary policies which could come with trade frictions (Bekkers et al., 2024).

This chapter aims to explore why, how and to what extent well-designed and internationally balanced environmental policies can contribute to the decarbonization of GVCs. A necessary foundation for this analysis is the development of a consistent accounting framework that enables the systematic tracing of both value added and GHG emissions (here proxied by CO_2 emissions) along GVCs. This chapter first introduces a novel GVC-based emissions accounting system capable of capturing both production- and consumption-based emissions at multiple levels of resolution – by country, sector, production stage – through the channels of both trade and FDI.

Drawing from this accounting framework, this chapter demonstrates that emissions reductions must occur across both domestic and international segments of GVCs. GVCs are deeply rooted in domestic production systems yet operate through cross-border production sharing; hence, effective climate mitigation requires action across all nodes of the chain. To illustrate this point, the subsequent section takes China's emissions trading system (ETS) as an example to first show how a carefully designed place-based carbon pricing mechanism, considering balanced regulatory coverage and firm-ownership heterogeneity, can support China to peak CO_2 emissions, lower emissions intensity and green its export structure. Using the WTO Environmental Database (EDB), section 4.3 demonstrates that trade-related environmental policies can shape green GVCs (trade of environment-friendly products and reshape of comparative advantage) through their impact on innovation and technological change. In addition, this chapter also explores how the carbon border adjustment mechanism (CBAM) may influence GVC decarbonization and reshape trade and investment activities undertaken across different types of firm ownership, particularly for countries without robust domestic carbon mitigation policies. While various environmental policies exist, they represent one facet of the broader environmental externalities associated with GVC expansion. Some negative impacts – such as biodiversity loss, occupational heat exposure, pollution, waste etc. – have also intensified alongside the rise of globalized production, yet are less amenable to market mechanisms, which is discussed at the end of the chapter. Our analytical results show that:

(1) GVCs are firmly embedded in domestic production systems while simultaneously operating through cross-border production sharing. This duality implies that effective emissions reduction must address both domestic and international segments of GVCs: meaningful climate mitigation requires action across all nodes of the chain.

(2) National ETSs can play a pivotal role in GVC decarbonization if they are in an appropriately designed manner. Evidence from China's case study suggests that expanding carbon pricing to achieve broader firm coverage and more equitable green financial access can enhance emissions efficiency while minimizing gross domestic product (GDP) losses.

(3) Trade-related environmental policies also influence GVCs by shaping green innovation and technological change. Measures that stimulate green innovation – such as research and development (R&D) subsidies, intellectual property

reforms and market-based instruments that reward low-emission technologies – can accelerate firms and sectors towards the green technological frontier. Over time, such policies may induce structural shifts in competitiveness, enabling some countries to capture higher value added segments of environmental goods production.

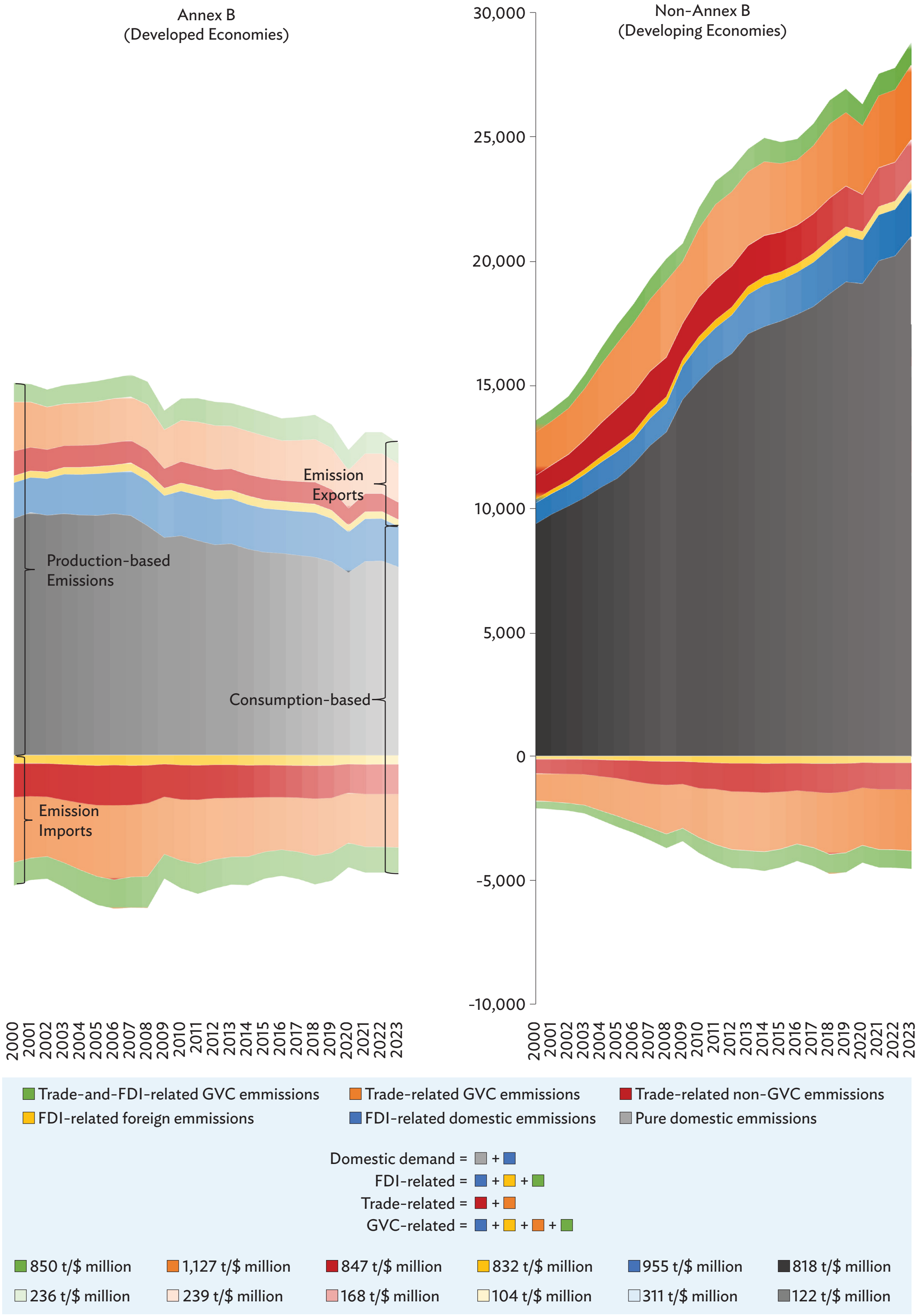
(4) CBAMs – such as the EU's CBAM – when implemented with sufficient sectoral coverage and transparency, can mitigate carbon leakage and create positive spillovers by encouraging trading partners to adopt or strengthen domestic carbon pricing. However, they also generate uneven impacts across countries and different types of firm ownership.

(5) Beyond carbon, this chapter also highlights the broader structural environmental externalities embedded in GVCs. These externalities are rarely reflected in product prices and remain inadequately governed under existing trade and climate frameworks. Internalizing non-carbon externalities in GVCs requires complementary regulatory approaches, internationally recognized standards and stronger cooperative governance mechanisms.

4.2 Tracing CO_2 Emissions along GVCs

Regarding the connection between GVCs and carbon emissions, Meng et al. (2018) integrate the trade in value added (TiVA) and carbon emissions footprint in a unified GVC accounting (Koopman et al., 2014), thus enabling both value added and emissions to be systematically traced at the country, sector and bilateral levels through various trading routes in GVCs. Building upon those pioneering works, Li et al. (2022) update the conventional GVC-based approach following Wang et al. (2021) with explicit consideration of both cross-border production sharing and multinational enterprises' (MNEs) FDI activities in GVCs, and show clearly which (country, sector, firm) emits CO_2 emissions for whom via which type of route in GVCs (see Annex 4.1 for technical details).

Figure 4.1: Tracing CO_2 Emissions of Annex B and Non-Annex B Economy Groups, 2000-2023



Source: Authors' estimation based on Li et al. (2022).

Note: Data for 2000-2020 is sourced from OECD-activity of multinational enterprises (AMNE) and OECD's carbon dioxide (CO2) emissions embodied in international trade (TECO2) database; Emissions for 2021-2023 are imputed based on IEA CO_2 emissions and World Bank GDP data; CO_2 emission intensities (emissions per unit of value-added) are estimated in constant 2015 prices; The Annex B economy group as defined in Kyoto Protocol.

Figure 4.1 presents a comparative overview of production- and consumption-based CO_2 emissions, emission exports and emission imports for developed (defined here as economies listed in Annex B of the Kyoto Protocol) and developing (defined here as economies not listed in Annex B) economy groups, disaggregated by GVC linkages. The figure reveals a pronounced divergence in emissions trajectories between the two groups over the past two decades.

For developed economies, both production- and consumption-based CO_2 emissions have declined steadily. Production-based emissions increased slightly between 2002 and 2007, peaking in 2007, before falling to 12.5 gigatons (Gt) in 2023 – below their 2000 level of 15.0 Gt. Consumption-based emissions followed a similar pattern, decreasing from 16.2 Gt in 2000 to 13.9 Gt in 2023. These declines were primarily driven by reductions in domestic emissions (-20.4%), alongside notable declines in trade-related non-GVC emissions[2] (-30.2%) and trade-related GVC emissions (-20.9%). In contrast, FDI-related domestic and FDI-and-trade-related emissions increased by 13.2% and 8.2%, respectively. The decrease in consumption-based emissions was also supported by an 11.4% reduction in non-GVC trade emissions and an 18.4% reduction in GVC-related trade emissions.

In contrast, developing economies experienced a substantial increase in emissions over the same period. Production-based emissions rose from 13.6 Gt in 2000 to 28.8 Gt in 2023. Between 2000 and 2023, pure domestic emissions and FDI-related domestic emissions increased by 123.6% and 131.2%, respectively. Consumption-based emissions also surged, from 12.3 Gt in 2000 to 27.5 Gt in 2023 – an increase of 104.1%. The scale of this growth far exceeds the emissions reductions observed in developed economies and has become the dominant driver of the net increase in global CO_2 emissions.

In terms of emissions composition in 2023, domestic value chains accounted for 73.4% of total production-based emissions in developed economies and 79.5% in developing ones. Within these shares, pure domestic and FDI-related domestic emissions represented 60.4% and 13.0% for developed economies, and 72.8% and 6.7% for developing economies. The remaining production-based emissions were attributable to cross-border flows: in developed economies, FDI-related foreign emissions accounted for 2.1%, trade-related non-GVC emissions for 5.5%, trade-related GVC emissions 12.5%, and trade-and-FDI-related emissions 6.5%. In developing economies, these shares were 1.2%, 5.6%, 10.5%, and 3.2%, respectively. Emissions linked to GVC-related activities – including FDI-related domestic and foreign emissions, trade-related GVC emissions and trade-and-FDI-related emissions – comprised 34.1% of total production-based emissions in developed economies, compared to 21.6% in developing economies. This indicates a higher degree of GVC integration in developed economies but also suggests a growing trend of emissions relocation and GVC-driven environmental interdependence across both economy groups.

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[2] Non-GVC emissions refer to trade-related emissions that are not linked to trade in intermediate goods or foreign direct investment (FDI). For technical details, see Annex 4.1.

In short, developed economies have demonstrated a clear downward trend in both production-based and consumption-based CO_2 emissions across most segments of GVCs. These reductions are observed not only in emissions for final demands but also for exports, reflecting broad-based decarbonization. Notably, this decline has occurred even as these economies operate at already relatively low carbon intensity levels, with continued improvements in emissions efficiency – i.e., a significantly lower volume of emissions per $1 of value added (as indicated by the colour intensity). By contrast, the trajectory in developing economies has been markedly different. Not only has the decline in carbon intensity been modest – their pace of decline between 2000 and 2023 was only about 60% of that of developed economies – but this limited progress has been accompanied by substantial absolute increases in emissions across all channels. Particularly concerning is the carbon cost of GVC participation: for every additional $1 of value added generated through GVCs, developing economies emit roughly 3.6-4.7 times more CO_2 than their developed counterparts. This gap largely reflects the rapid growth of South-South trade in energy-intensive intermediates and the structural position of developing economies in GVCs, where they are concentrated in upstream, manufacturing-heavy and carbon-intensive activities[3]. This widening disparity in emissions performance also raises serious concerns for both the achievement of the United Nations (UN) Sustainable Development Goals (SDGs) and the feasibility of meeting the Intergovernmental Panel on Climate Change (IPCC) target of limiting global warming to 1.5°C. Without more ambitious and inclusive climate policy responses that address the structural asymmetries embedded in global production systems, both environmental sustainability and equitable development may be at risk.

4.3 How an Emissions Trading System Can Help Decarbonize the Domestic Segments of GVCs

As shown in the previous section, almost all emissions embodied in GVCs ultimately originate from domestic production processes[4]. In other words, unless upstream domestic emissions are effectively mitigated, it will not be possible to substantially reduce the embodied carbon content of downstream exports. This challenge is particularly pronounced in developing economies, where the scale and growth rate of emissions embedded in internationally traded goods are exceptionally high. These economies often exhibit relatively weaker environmental regulatory frameworks and limited adoption of explicit carbon pricing mechanisms. Against this backdrop,

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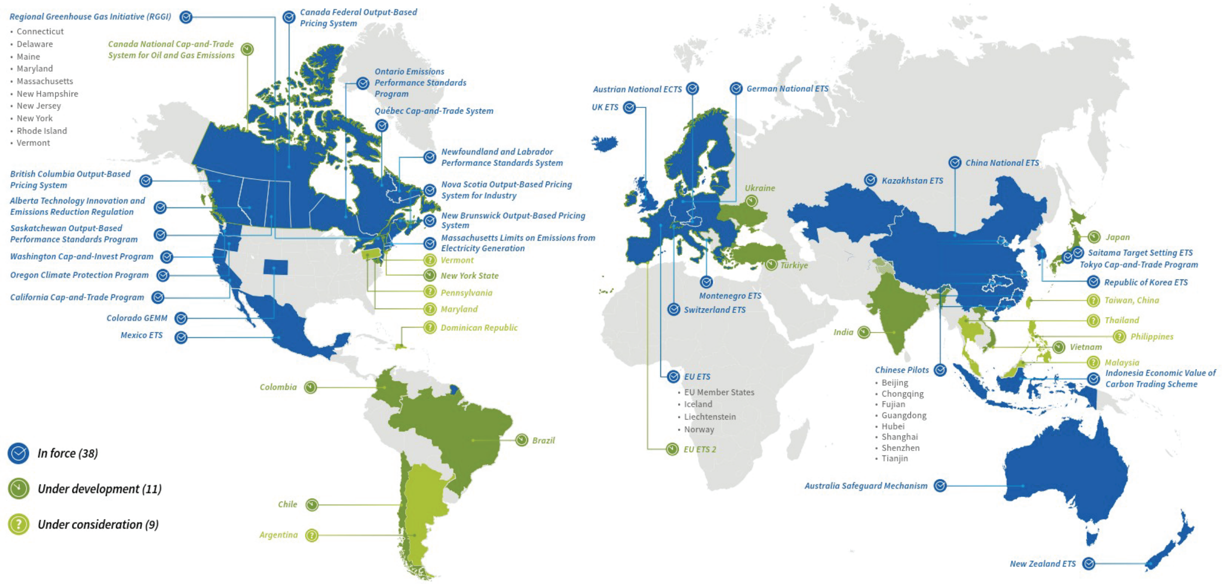
[3] Over the past three decades, trade liberalization has played a critical role in fostering the expansion of GVCs. However, it has also contributed to the increased cross-border movement of carbon-intensive intermediate goods – particularly in the form of rising South-South trade flows in recent years (Meng et al., 2018). These developments highlight the need to incorporate environmental considerations into the design of trade policies. For instance, recent studies suggest that trade liberalization in energy-related environmental goods (EREGs) and environmentally preferable products (EPPs) has the potential to yield dual benefits: reducing carbon emissions while simultaneously enhancing GDP (Bacchetta et al., 2023).

[4] Whether emissions embodied in international transportation services (e.g., cargo shipping) are attributed to domestic production could depend on whether those services are operated by domestic or foreign entities.

achieving global climate targets – such as the 1.5°C or 2°C goals outlined by the IPCC, which calls for cutting emissions by one-quarter to one half in this decade (Parry et al., 2021) – requires urgent policy interventions. Among the available instruments, the introduction of a well-designed, locally tailored ETS stands out as a key market-based solution.

Figure 4.2: The Current State of Play in Emissions Trading



Note: The above ETS world map depicts emissions trading systems currently in force, under development or under consideration. As of January 2025, there are 38 ETSs in force. Another 11 are under development and expected to be in operation in the next few years. These include ETSs in Colombia, Türkiye and Vietnam. Nine jurisdictions are also considering the role an ETS can play in their climate change policy mix. If a jurisdiction has multiple systems in force, it is depicted in blue, with the borders of the jurisdiction representing the layered systems (e.g. Germany and Guangdong). If, however, it has a system in force while an additional one is under development, it is depicted in blue but also features a green border (e.g. the EU).

Source: ICAP (International Carbon Action Partnership) ETS Map.

Over the past two decades, ETSs have become a widely implemented approach to reducing greenhouse gas (GHG) emissions in a cost-effective and flexible manner (see Figure 4.2 for the detailed ETS country coverage). By assigning a price to carbon and allowing regulated firms to trade emissions allowances, ETSs create economic incentives for cleaner production and technological upgrading (Ellerman et al., 2010; Teixidó et al., 2019; Evro et al., 2024; Shobande et al., 2024).

The EU ETS, launched in 2005, is the most mature and institutionally developed carbon market globally. It covers approximately 45% of EU emissions, spanning energy-intensive sectors such as power generation, industry and aviation. In recent years, the EU ETS exhibits some of the highest carbon prices, reaching up to about \$87.8 per metric ton of CO_2 emissions (tCO_2e) in February 2025. Through a series of regulatory reforms – such as the introduction of the Market Stability Reserve, a progressively tightening emissions cap and expanded sectoral coverage – the EU ETS has demonstrated tangible progress in emissions mitigation while preserving economic competitiveness (Joltreau and Sommerfeld, 2018; Verde, 2020; Pahle et al., 2025).

In contrast, the United States (US) has not adopted a federal-level ETS, but subnational initiatives like California's Cap-and-Trade Program and the Regional Greenhouse Gas Initiative (RGGI) provide valuable policy experimentation. These systems have delivered measurable results within their jurisdictions, though their influence on GVC emissions is limited due to their fragmented and localized nature (Caron et al., 2015; Lessmann and Kramer, 2024; Yan, 2021).

China's national ETS, launched in 2021, represents a landmark advancement in climate policy for developing economies. Initially covering the power sector, it applies intensity-based benchmarks rather than absolute emission caps, which may constrain its ability to deliver systemic reductions (Qi and Cheng, 2018; Goulder et al., 2019). Additional concerns include monitoring, reporting and verification (MRV) mechanisms and limited sectoral coverage (Liu et al., 2022a; Huang et al., 2022; Liu et al., 2022b).

In short, while ETSs are not a panacea, they play an increasingly critical role in reducing emissions and supporting the decarbonization of GVCs. Following sections 4.2.1 and 4.2.2 provide an in-depth analysis of China's ETS, demonstrating that the relevant policy should be tailored to local conditions.

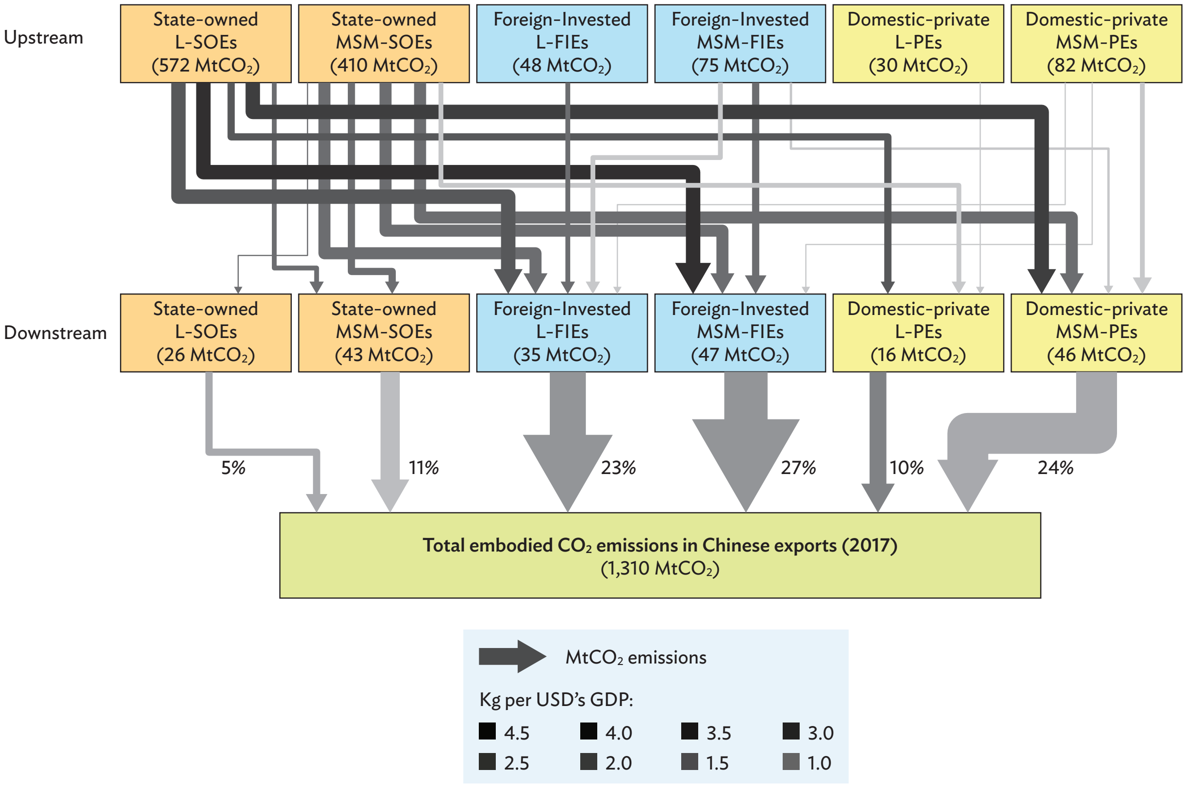
4.3.1 Challenges in Designing Effective Environmental Policies in China

Under market-based instruments, such as an ETS, emitters can follow two basic strategies to meet emission regulations: either adjust their input structure on the production technology frontier or invest in energy technology to shift said frontier.

Whether China's ETS can effectively motivate firms to decarbonize depends critically on two country-specific conditions:

(1) **Comprehensive coverage, including more emitting firms**
For the ETS to function efficiently, it must encompass a broad range of emitting firms –particularly micro, small and medium-sized enterprises (MSMEs). Otherwise, substantial carbon leakage may occur as firms face heterogeneous costs of adjusting their input structures to reduce emissions. Although China's regional ETS pilots have been in operation for over a decade, they have primarily covered a limited number of sectors and large, high-carbon emitters. However, in reality, since 2010 more than half of China's CO_2 emissions have originated from MSMEs. In 2017, MSME exports accounted for approximately 62% of China's total embodied emissions in trade, over 55% of which stemmed from upstream MSMEs (see Figure 4.3). Yet most of these firms remain outside the current ETS framework. Consequently, the "low-hanging fruit" for emission reductions – large, regulated emitters – has largely been exhausted. The

Figure 4.3: Tracing China's Emissions Embodied in Exports from Upstream to Downstream



Note: L: Large sized; MSM: micro, small and medium sized; SOEs: state-owned enterprises; FIEs: foreign-invested enterprises; PEs: private enterprises.

Source: Authors' estimates and Dr. Meichen Zhang (UIBE)'s estimation based on Meng et al. (2018).

marginal effectiveness of existing policy instruments is diminishing, while the costs of further abatement are rising. Without a well-designed mechanism to regulate MSME emissions, achieving both national emission peaking and the decarbonization of China's GVCs will remain a difficult task.

(2) Reducing disparities in green financing and regulatory burdens across firm types

Firms within the same industry but differing in ownership structure and size often face very different costs of green financing. State-owned enterprises (SOEs), typically subject to emission regulation yet enjoying preferential credit access, are more inclined to invest in upgrading production technologies and equipment. In contrast, other regulated emitters – especially large private firms – often rely on substituting energy inputs with other factors due to relatively higher financing costs. Unregulated emitters, mainly MSMEs, are generally disincentivized from cutting emissions because of low energy prices, limited access to affordable credit and weaker enforcement of environmental regulations. This fragmented regulatory landscape generates wide variation in the marginal abatement cost of CO_2 emissions across firms, reducing the overall efficiency of emission reduction. Moreover, the uneven distribution of green investment not only lowers the average efficiency of decarbonization but also crowds out other productive fixed-capital investments, thereby constraining long-term economic growth.

The above two conditions for China are also mutually reinforcing, as gains from green investment (innovation) increase only if such innovation can allow emissions to be more fairly priced (Fischer, 2008). Given the above discussion, this section takes China's ETS as a case study to show that place-based and market-oriented policy design (using national ETS as a proxy here[5]), with more firm coverage and equalized green financial supports for different types of companies, can not only help China peak its emissions around 2030 with less GDP loss but also help Chinese firms become greener participants in GVCs. To do so, this section employs a dynamic computable general equilibrium (CGE) model[6] with explicit consideration of firm heterogeneity (size and ownership) and differential treatments of financing conditions across firms.

4.3.2 Impacts of Place-Based ETS Design on China's Emission Reduction

The dynamic CGE model used accounts for heterogeneous firm types, differentiated policy regulation and endogenous energy-technology investment. The model is calibrated to 2017 as the base year based on a newly estimated Chinese input-output table with 42 sectors and six types of firms in terms of their three ownerships – state-owned, foreign-invested or domestic private – and two sizes (large, non-large: MSMEs) as shown in Table 4.2.

Regarding scenario setting, the total intensity target is set to decrease China's CO2 emissions per unit of GDP by 4% per year beginning in 2017. This target assures that China will meet the commitment made in its intended nationally-determined contributions (INDCs) to decrease the carbon intensity by 60% from 2005 levels and peak China's emissions in 2030. The benchmark for cross-scenario comparison is the business-as-usual (BAU) scenario in which mandatory intensity targets are enforced for certain types of firms to fulfil an exogenously determined total intensity target that meets China's commitment in the INDC. In the BAU scenario, the climate regulations cover only SOEs and large private firms, and only SOEs have much easier access to preferential financial terms. The unbalanced regulatory structure is shown in Table 4.3. In the partial-coverage scenarios, only SOEs and large private firms are regulated by emission constraints and can participate in emission trading; in the full-coverage scenarios, all firms are equally regulated and are able to trade their emissions in an integrated carbon market. In the various financial condition scenarios, the endogenous

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[5] A national ETS is used as a policy proxy; in practice, an ETS combined with a carbon or energy tax should also be considered as an alternative policy option (Zou et al., 2020).

[6] The CGE model used in this section is a recursive dynamic model based on the structure of Rutherford (1995), with modification in the settings for energy technologies following Otto et al. (2008). Future periods are simulated based on the outcomes of the preceding period. The model assumes neo-classical macro closure, that is, it assumes full use and employment of capital and labour.

subsidy (or financial interest) for green investment is provided for SOEs as in the BAU scenario, while in the equalized scenarios, the subsidy is eliminated.

Table 4.2: Firm Size and Ownership

	Firm ownership		
Firm size	State-owned enterprises	Foreign-invested enterprises	Private enterprises
Large enterprises	L-SOE	L-FIE	L-PE
MSMEs	MSM-SOE	MSM-FIE	MSM-PE

Note: Regulated firm types are shaded, with the darker shading indicating access to preferential financial conditions.

Table 4.3: Scenarios under ETS with Different Firm Coverage and Financial Conditions

Financial condition (subsidy as a proxy)	Regulation coverage (ETS as a proxy)	
	Partial coverage	Full coverage
Differentiated	ETS_P_D	ETS_F_D
Equalized	ETS_P_E	ETS_F_E

The main simulation results are presented in Figure 4.4a-d. In the model setting, this section assumes that China fulfils its climate commitment by reducing carbon intensity by at least 60% from 2005 levels and peaking total CO_2 emissions by 2030. Under these assumptions, the model projects that emissions will peak in 2030, corresponding to a 28.5% reduction relative to the counterfactual null scenario, which represents a future without any mitigation policy interventions. Although the emissions trajectories are aligned across policy scenarios, the economic impacts – measured in terms of GDP loss – vary significantly. Compared to the null scenario, average annual GDP growth under the BAU scenario is projected to be 0.15% lower, resulting in a 2.1% GDP loss by 2030. Introducing an ETS with the regulatory design (ETS_P_D) mitigates GDP loss in the early years; however, its economic cost accelerates after 2026 and eventually exceeds that of the BAU scenario. In contrast, scenarios that either expand regulatory coverage to all firm types (ETS_F_D) or eliminate distortions in green finance (e.g., balanced subsidies for green investments in ETS_P_E) result in smaller GDP losses throughout the simulation period. The most favourable outcome is observed under the ETS_F_E scenario, which combines full coverage with a balanced financial structure. This scenario yields a GDP loss approximately 0.8% lower than the null scenario, highlighting the efficiency gains from comprehensive and financially neutral policy design.

Figure 4.4: ETS Scenario Results With Different Firm Coverage and Financial Conditions

Figure 4.4a: GDP loss **Figure 4.4b: Green investment needed**

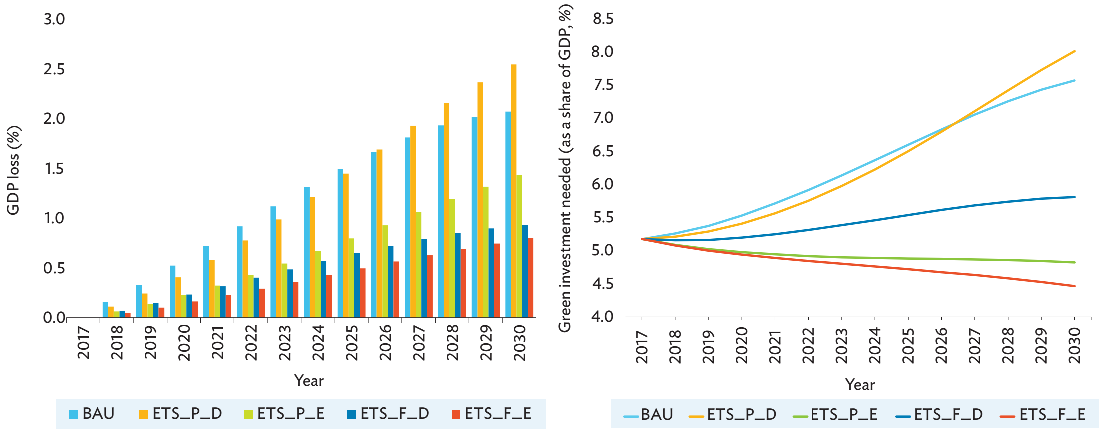
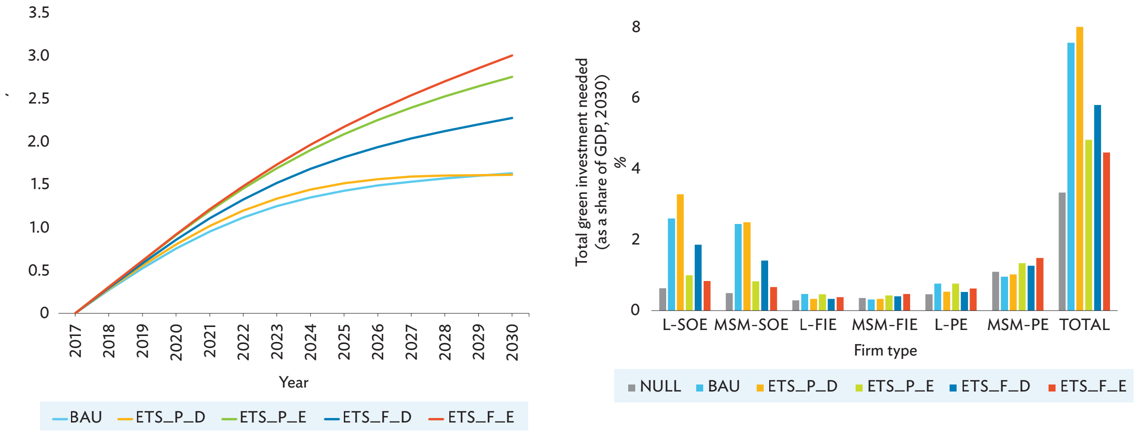


Figure 4.4c: Green investment efficiency **Figure 4.4d: Total green investment needed**



Source: Authors' estimation.

Note: BAU denotes the business-as-usual scenario. ETS_P_D represents an ETS with partial firm coverage under differentiated financial conditions; ETS_P_E indicates partial firm coverage under equalized financial conditions; ETS_F_D refers to full firm coverage under differentiated financial conditions; and ETS_F_E denotes full firm coverage under equalized financial conditions.

Different policy scenarios could impact green investment allocation and efficiency in very different ways. The partial regulation increases the incentives for green investments in regulated firms, and furthermore, the preferential financial conditions further distort green investments towards SOEs. Theoretically, the concentration of green investments in regulated firms, especially subsidized SOEs, leads to unequal marginal revenues across firms and decreases the national average efficiency of green investments. Aside from that, the higher demand for green investments is competing with other fixed capital investments, which will further affect the long-term economic growth. Figure 4.4b-c shows the trajectory of total green investment and its efficiency to illustrate the argument mentioned above. In the BAU and ETS_P_D scenarios, green investment increases quickly as the emission targets tighten. The total amount of accumulated green investment through 2030 for BAU and ETS_P_D accounts for about 7.6% and 8.0% of GDP. However, the efficiency of green investment, defined as the change in emissions intensity from the null scenario divided by the amount of green investment per unit of energy input, decreases dramatically over time. Both expanding the coverage of regulation (ETS_F_D) and elimination of the subsidy for SOE green investment (ETS_P_E) lower the total demand for green investments, while at the same time, its efficiency is significantly increased. In the ETS_P_E scenario, the accumulated green investment accounts for 4.8% of GDP in 2030 and 5.8% in the ETS_F_D scenario, while their efficiency rates in 2030 are 69% and 39% higher than that of BAU. With the full regulation coverage and equalized financial condition (ETS_F_E), total green investment accounts for 4.5% of GDP in 2030, which is the lowest among the various scenarios. At the same time, green investment efficiency under ETS_F_E is the highest among the scenarios considered, which is 84% higher than that for the BAU level.

Figure 4.4d illustrates the distribution of green investment by firm type in 2030 across the different policy scenarios. Under the ETS_F_E scenario – which ensures both comprehensive coverage and the elimination of financial distortions – the total volume of green investment amounts to approximately 4.5% of GDP in 2030. Notably, private MSMEs account for the largest share, comprising nearly one-third of total green investment. This reflects a more efficient and inclusive allocation of capital, where investment decisions are driven by marginal abatement costs rather than regulatory privilege. However, when MSMEs are excluded from emissions regulation, as in scenarios with partial coverage, their incentives to invest in energy-efficient technologies are significantly weakened. At the same time, increased demand for green technologies from regulated firms – particularly large SOEs – drives up technology costs, further crowding out MSMEs from the green investment space. This distortion is clearly observed in the ETS_P_E scenario, where the share of green investment by regulated firms increases, while the share by unregulated MSMEs declines. The situation is even more pronounced under the ETS_P_D scenario, which combines partial coverage with preferential financial treatment for SOEs. In this case, green investment by SOEs increases substantially, while investment from all other non-SOE firms declines. The disproportionate expansion of SOE investment effectively overwhelms the reductions observed in other sectors, leading to resource misallocation. Under both the BAU and ETS_P_D scenarios – characterized by dual distortions in both regulatory coverage and financial support – the total amount of green investment reaches approximately 8% of GDP by 2030. However, more than 67% of this investment is concentrated in SOEs, signalling a highly skewed distribution that undermines overall investment efficiency and reduces the effectiveness of green finance in supporting broad-based industrial transformation.

From GVC perspectives, our model findings carry important implications beyond domestic policy. Since almost all emissions embodied in GVCs ultimately originate from domestic production processes, mitigating upstream emissions is a necessary condition for reducing the embodied carbon in downstream exports. In the absence of effective domestic decarbonization – particularly in intermediate goods and upstream industrial inputs – efforts to green GVCs will remain limited in scope and impact. A place-based national ETS design in China, featuring broader firm coverage and neutral financial treatment across ownership types, can play a pivotal role in addressing this challenge. Such a system would not only enable China to achieve its 2030 emissions peak with reduced macroeconomic costs but also improve the carbon competitiveness of its firms engaged in global production networks. By enhancing incentives for cleaner production across SOEs, private firms and MSMEs alike, a balanced carbon pricing can support a more inclusive transition towards low-carbon industrial upgrading via efficient green investment. In turn, this would strengthen China's position in a future trade environment increasingly shaped by carbon-based regulations, such as the EU's CBAM (which will be discussed later), and contribute meaningfully to the global effort to decarbonize GVCs. The above results indicate that China's case study also can serve as an important reference for other developing economies seeking to establish or strengthen their own carbon pricing, while considering their specific domestic circumstances and constraints in addressing climate change.

4.4 Trade-Related Environmental Policies: Impacts on GVCs and Green Innovation

The previous section focused on how market-oriented domestic policies can help decarbonize GVCs; this section turns to trade-related environmental policies. To better understand the scope and effects of environmental policies, Bellelli and Xu (2024) map trade-related environmental measures using the WTO's Environmental Database (EDB), which compiles more than 13,000 environment-related measures based on notifications submitted by WTO members. Compared with other environmental measures databases, the EDB comprises policy measures that bear direct or indirect implications for trade. It has a wider country coverage, including information from over 160 economies, notified since 2009. Through systematic processing of the notifications, Bellelli and Xu (2024) identify the number of measures in effect, which has been steadily increasing over time (Figure 4.5). Furthermore, the data reveals a correlation between the number of trade-related environmental measures and economies' income levels (Figure 4.6).[7]

4.4.1 Trade-Related Environmental Policies and GVCs

Environmental policies are increasingly shaping the structure and geography of GVCs. As countries pursue climate goals and adopt a wide array of environmental measures, these policies are beginning to influence where, how and by whom goods and services are produced and traded.

The implications for GVCs are multifaceted, reflecting both short-term cost adjustments and longer-term shifts in comparative advantage and technological capabilities. The potential trade and environmental impacts of environmental policies can be conceptualized as follows (see Figure 4.7).

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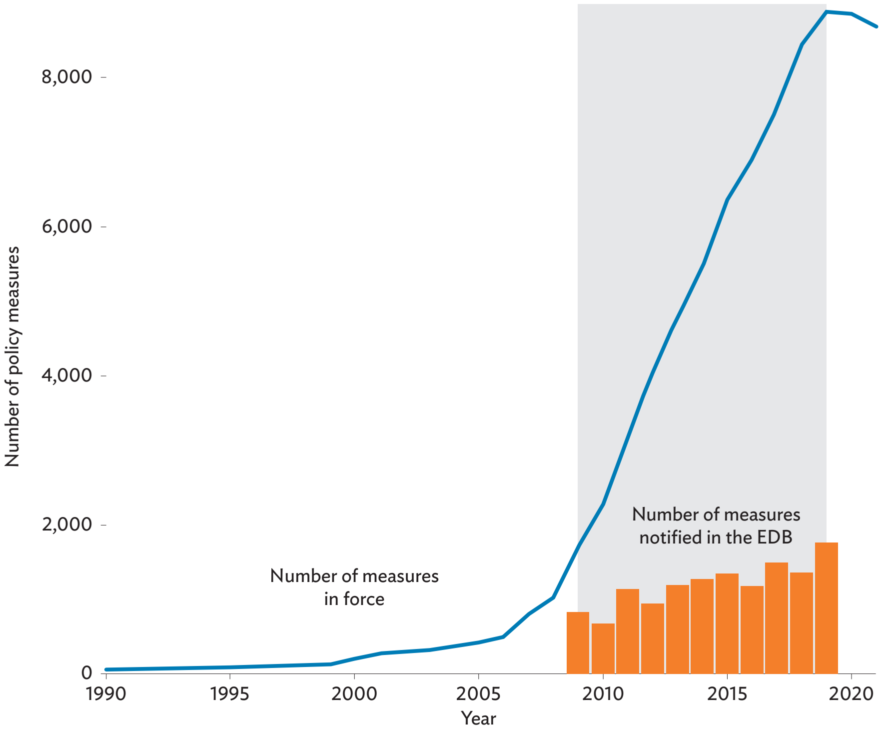
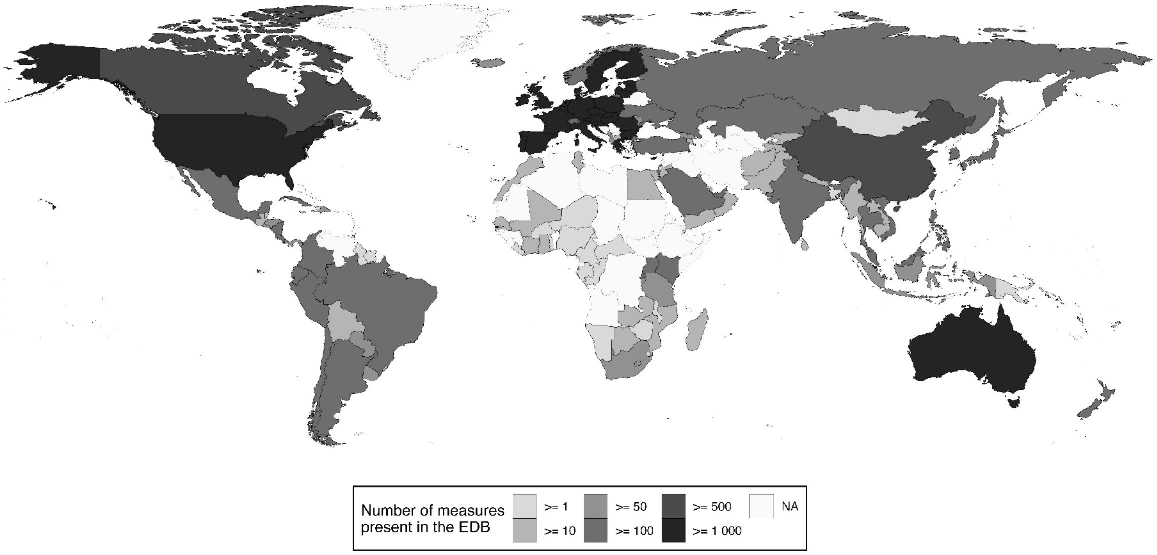
[7] Information based on notifications may be subject to reporting bias. Such as bias may stem from two sources: first, high-income countries are more likely to have the institutional capacity to notify their measures; second, the database records the number of measures rather than their magnitude (e.g., financial value or regulatory stringency), meaning it reflects the presence rather than the intensity of policy activity.

Figure 4.5: Number of Active Environmental Measures in the EDB



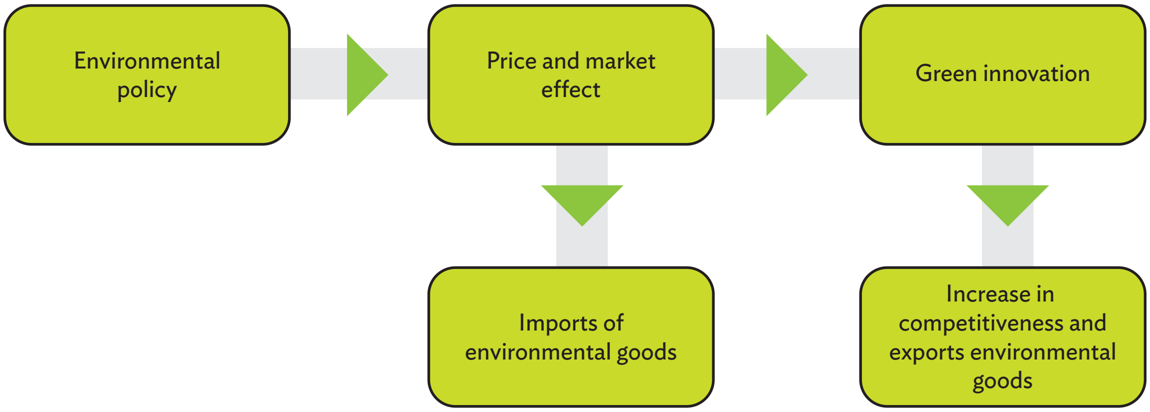
Source: Bellelli and Xu (2024).
Notes: The figure depicts the increase in active environment-related measures notified to the WTO. The line indicates "active measures" based on the implementation periods extracted from the EDB. The bar plot illustrates the number of measures by year of notification. The notification period covered by the EDB is highlighted in grey.

Figure 4.6: Number of Notified Trade-Related Environmental Measures By Economy



Source: Bellelli and Xu (2024).
Notes: The map displays the number of notified measures by economy. A darker filling indicates that a larger number of measures were notified. Economies with white borders are states for which the EDB contains no notified measures.

Figure 4.7: Potential Effects of Environmental Policies



Source: Bellelli and Xu (2024).

One of the most direct ways in which environmental policies impact GVCs is through their effect on relative production costs. Supportive policies such as subsidies, tax credits or preferential procurement can reduce the costs of production for firms engaged in environmental goods and services. When these policies are targeted at specific, environmentally friendly sectors, they can improve the competitiveness of domestic producers in these sectors. This may lead to a repositioning of countries or firms within GVCs, as they gain comparative advantage in cleaner or more innovative segments of the value chain.

In contrast, regulatory measures such as carbon taxes, emissions caps and environmental standards may raise operational costs, especially for carbon-intensive or resource-intensive activities. As compliance costs increase, firms may be incentivized to shift production to jurisdictions with more lenient environmental regulations, or to relocate specific segments of their value chains to optimize cost efficiency. These pressures can alter the global allocation of production stages, with potentially significant implications for the distribution of value added across countries (Koźluk and Timiliotis, 2016; Duan et al., 2021).

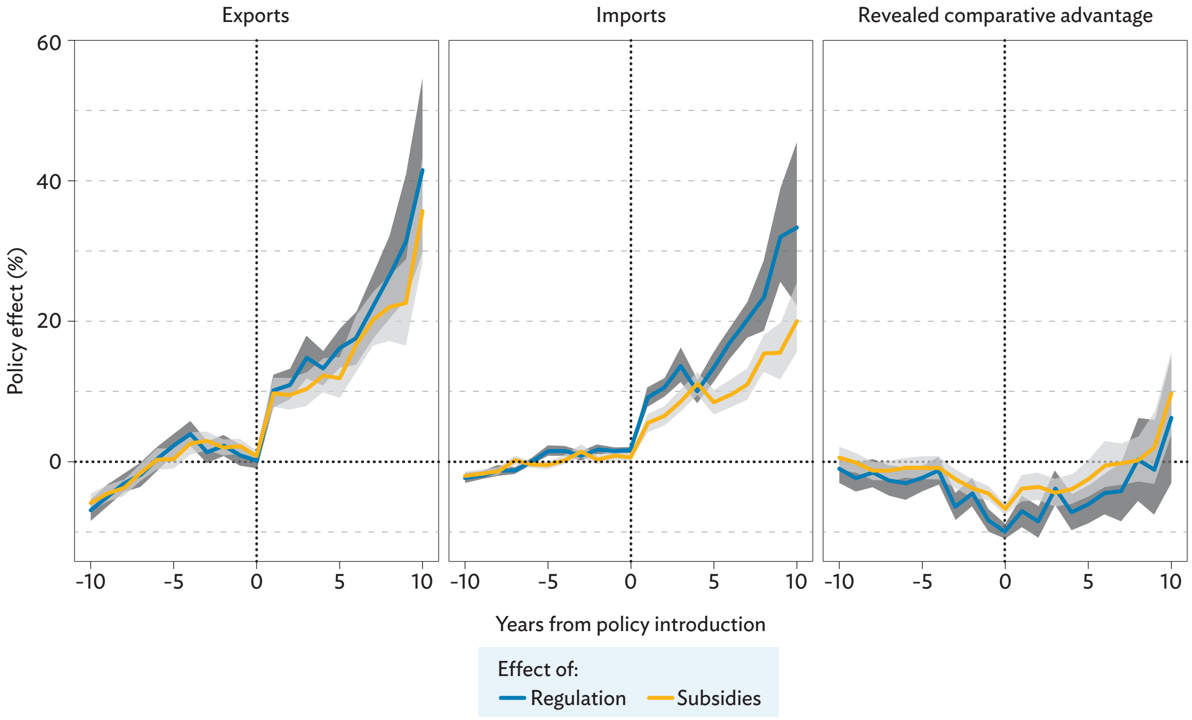
Beyond cost-based effects, environmental policies can also shape GVCs through their impact on innovation and technological change. Policies that encourage green innovation, such as R&D subsidies, intellectual property reforms or market-based instruments designed to reward low-emission technologies, can push firms and sectors up the technological frontier. Over time, this may result in structural shifts in competitiveness, enabling some countries to capture high-value added segments of environmental goods production. In this way, environmental policy not only addresses externalities but also acts as an industrial policy tool, shaping the direction of technical change and the composition of international trade.

This mechanism aligns with the literature of directed technical change first articulated in Acemoglu et al. (2012, 2014). In their model, a final good is produced using either clean or dirty technologies. If clean sectors offer greater profit opportunities, perhaps due to environmental policy incentives, they will attract more innovation, increase productivity and generate comparative advantage in trade.

4.4.2 Empirical Evidence on the Trade and Innovation Effects of Environmental Policies

Understanding the impact of environmental policies, particularly in a globalized world, is essential to facilitate a successful transition to a more sustainable future. Bellelli and Xu (2024) empirically assess these effects using a synthetic counterfactual methodology. Their analysis estimates the average treatment effect of implementing environmental measures on trade flows and innovation outcomes. They distinguish between policies that increase firms' compliance costs ("regulations") and those that lower the cost of production or innovation ("subsidies").

Figure 4.8: Potential Effects of Environmental Policy on Trade



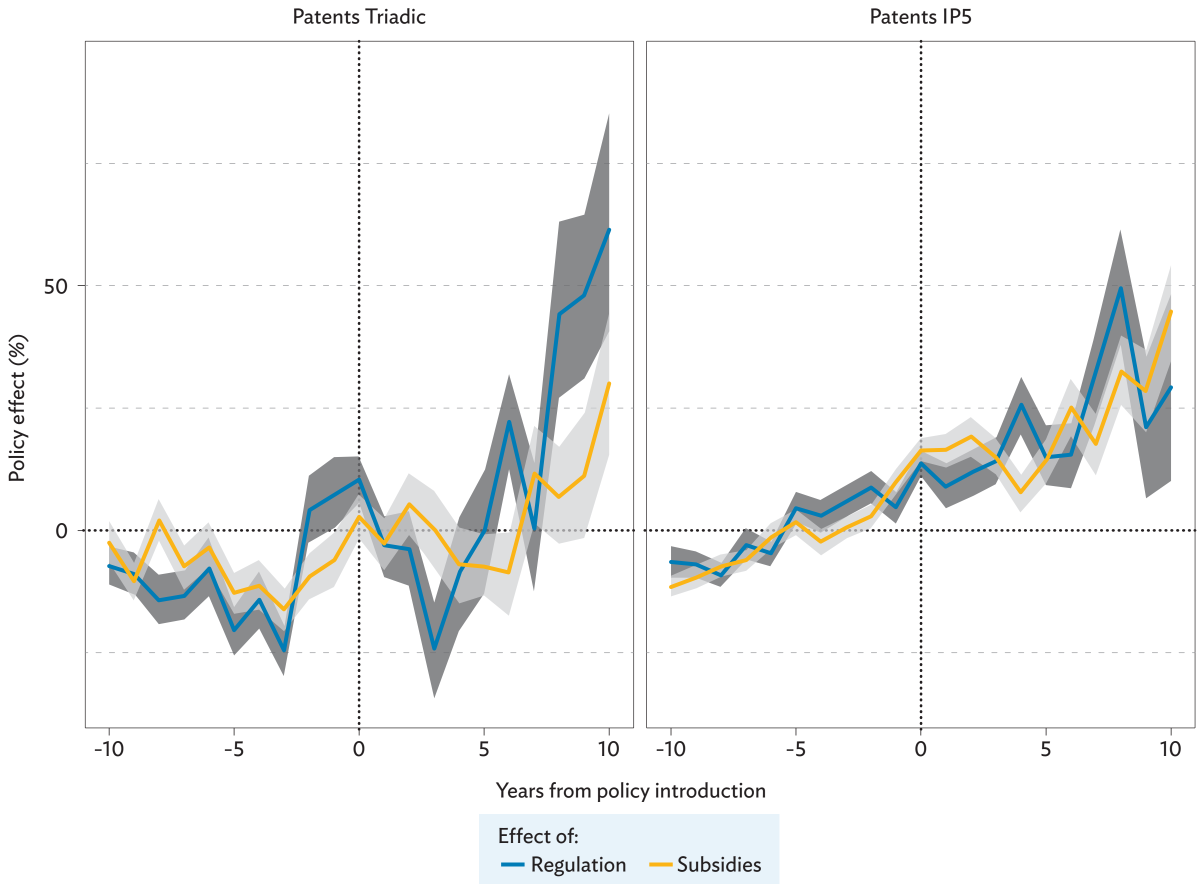
Noted: Shaded area are bootstrapped 95 confidence intervals.

Source: Bellelli and Xu (2024).

Notes: The figure displays the estimation results of a synthetic counterfactual to illustrate the effects of environmental policies on (1) exports of environmental goods, (2) imports of environmental goods and, (3) revealed comparative advantage in environmental goods exports. The horizontal axis represents the years around the implementation of an environmental policy, while the vertical axis indicates the percentage change in the trade in the economy implementing an environmental policy compared with trade in the same sector in the counterfactual countries with no policy. The shaded area represents bootstrapped 95% confidence interval.

As shown in Figure 4.8, the empirical findings show that environmental policies are associated with significant increases in both exports and imports of environmental goods. The effects of these policies gradually increase over time following their implementation, resulting in up to a 40% increase in exports and a 30% increase in imports of environmental goods relative to the synthetic counterfactual approximately 10 years after the environmental measures are enacted. Moreover, regulations and support policies display subtle differences in their trade effects: while both types of policies strongly affect the exports of environmental goods, regulations tend to boost imports slightly more. When measured by the revealed comparative advantage (RCA) of environmental exports, the effects do not appear as pronounced. The implementation of an environmental policy does not seem to be associated with an increase in the comparative advantage of an economy's exports in the initial years of the policy's implementation, and a positive effect on the RCA only becomes visible 8-10 years after a policy is enacted.

Figure 4.9: Potential Effects of Environmental Policy on Green Innovation



Noted: Shaded area are bootstrapped 95 confidence intervals.

Source: Bellelli and Xu (2024).

Notes: The figure displays the estimation results of synthetic counterfactual to illustrate the effects of environmental policies on environmental patents within the triadic family and IP5 family. The horizontal axis represents the years around the implementation of an environmental policy, while the vertical axis indicates the percentage change in patents in the economy implementing an environmental policy compared with patents in the same sector in the counterfactual countries with no policy. The shaded area represents bootstrapped 95% confidence interval.

In terms of green innovation, the analysis shows a statistically significant rise in environmental patent filings following policy implementation. While the patent counts in the triadic family – where patents are filed in different national patent offices – seem to display some fluctuations, the patent counts in the IP5 family – a forum of the world's five largest intellectual property offices – appear to show a steady increase after the implementation of an environmental policy (see Figure 4.9). Both regulatory instruments and subsidy measures contribute to this outcome, though their temporal effects differ. Subsidies appear to have more immediate impacts, while regulations are associated with longer-term innovation responses.

Their work complements a broader literature examining the effects of environmental policies on trade and innovation. A growing body of research highlights the positive impact of environmental policies on innovation. A few sector-specific studies show that well-designed environmental regulations can stimulate clean technology development across a range of industries, including automobiles (Aghion et al., 2016), wind turbines (Dechezleprêtre and Glachant, 2014) and solar photovoltaics (Peters et al., 2011). Firm-level evidence also suggests that the EU ETS has encouraged low-carbon innovation (Calel and Dechezleprêtre, 2016). More broadly, studies find that properly structured environmental regulations can enhance both innovation and firm competitiveness (Ambec et al., 2013; Dechezleprêtre and Sato, 2017). Taking a more holistic view, Pugliese et al. (2019) examine the co-evolution of countries' scientific, technological and productive capabilities, concluding that technological strength is the strongest predictor of industrial and scientific performance.

4.5 Carbon Border Adjustment Mechanisms and Their Impacts on Carbon Leakage in GVCs

If more carbon-intensive countries were to adopt domestic ETSs and, ideally, establish linkages with existing regional or international carbon markets, the risk of carbon leakage through trade and investment could be significantly reduced in theory. In such a harmonized global framework, the differential in carbon pricing between jurisdictions would narrow, thereby weakening incentives for firms to relocate emissions-intensive activities across borders. However, the current global landscape remains fragmented, with substantial variation in carbon pricing coverage, design and stringency across countries (Black et al., 2022). In response to this asymmetry, economies with more ambitious climate policies and lower carbon intensities have either implemented or proposed CBAMs as a mean to level the playing field and prevent leakage. While CBAMs are a second-best solution from a global coordination perspective, they reflect the practical difficulties of achieving synchronized international carbon mitigation policies and may become more prevalent if convergence on such policies remain elusive.

This section builds on the existing literature by first evaluating the potential effectiveness of CBAMs in reducing cross-border carbon leakage. It further examines limitations in current approaches, particularly the limited treatment of GVC structures and firm-level heterogeneity – such as differences in technology adoption, emissions intensity and market exposure between MNEs and local firms. Using a novel GVC-based CGE model, this section analyses the implications of a CBAM similar to the scheme proposed by the EU for emissions, GVCs and economic welfare.

4.5.1 The Potential Effectiveness of CBAMs in Reducing Cross-Border Carbon Leakage

CBAMs are climate policy instruments that can complement existing domestic carbon pricing mechanisms, such as the EU ETS in its early phase. Under the EU's CBAM framework, importers are required to purchase certificates reflecting the embedded emissions in imported products, with prices linked to the ETS[8]. Currently in its transitional phase, the EU CBAM represents the most advanced implementation of cross-border carbon pricing to date. Proposals for CBAM measures in other countries (e.g., Canada, the US) have also been evaluated through CGE models and macroeconomic simulations.

Modelling studies for the EU's CBAM find a substantial drop in leakage rates once import carbon tariffs are applied. For example, Bellora and Fontagné (2023) show that the EU's planned CBAM would curtail leakage compared to a scenario with no border measures. OECD (2025) simulations indicate that, the CBAM effectively prevents carbon leakage by redirecting EU imports from less carbon-efficient countries to more carbon-efficient countries. Further investigation considering supply chains (Dechezleprêtre et al., 2025) shows the CBAM can effectively prevent carbon leakage. However, it only partially mitigates the negative effects of higher carbon prices and free allowances removal on the value added of CBAM-protected industries and negatively affects downstream EU industries.

As pointed out by Fischer and Fox (2012), design choices critically influence leakage outcomes. A key feature is whether CBAMs include export adjustments. Ambec et al. (2024) find that theoretically a CBAM only levels the playing field domestically and may lead to an autarky equilibrium (a no-trade equilibrium occurs when carbon tariffs render foreign firms uncompetitive domestically, and at the same time, domestic firms are unable to compete internationally). To reverse carbon leakage, a CBAM must be complemented with export rebates. In addition, the EU CBAM covers a limited set of

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[8] Under the EU Regulation, CBAM has a transitional (report-only) period from 1 October 2023 to 31 December 2025. The definitive regime applies from 1 January 2026. As amended by Regulation (EU) 2025/2083, Member States sell CBAM certificates in 2027 for emissions embedded in goods imported in 2026, and the first annual surrender for 2026 is due by 30 September 2027. The amendment also introduces a de minimis, single mass-based threshold of 50 tonnes per importer per calendar year; importers at or below this threshold are exempt from CBAM obligations for that year.

emissions-intensive sectors, which constrains its aggregate leakage mitigation effect and may leave competitiveness gaps. A recent study (Qian et al., 2025) shows that EU CBAM with extended emission scope and industry coverage can lower carbon leakage more effectively.

Empirical research suggests that CBAMs can be effective in mitigating carbon leakage, particularly when they are comprehensively designed and embedded within broader cooperative climate strategies. However, important trade-offs remain. Notably, most existing CBAM-related simulations do not explicitly account for GVC linkages or firm-level heterogeneity. In particular, the distinction between MNEs and domestically owned firms is often overlooked, despite their markedly different production structures, emission intensities and exposure to trade policies. This omission risks misestimating the true impact of CBAMs on both carbon leakage and industrial competitiveness. For example, Ortiz et al. (2022) find that MNEs' foreign affiliates disproportionately invest in emission-intensive manufacturing sectors, resulting in greater contributions to host-country CO_2 emissions than to value added. Incorporating firm heterogeneity and GVC structures into future modelling efforts is therefore essential for more accurately capturing the distributional effects of CBAMs – both across firms and between countries.

4.5.2 A GVC-based CGE Analysis for CBAMs Considering Firm Heterogeneity

Thanks to the recent development of GVC accounting for emissions (Meng et al., 2018, 2023) and GVC-based CGE modelling (Koopman et al., 2014; Cai et al., 2015; Meng et al., 2025), as well as the OECD inter-country input-output (ICIO) data with consideration of MNEs' activities via FDI, detailed simulation analysis about how and to what extent a CBAM implemented by the EU impacts emissions and welfare via GVCs becomes available.

This section considers the CBAM scenarios for the EU from two dimensions in our GVC-based CGE model.[9] The first dimension is carbon tax rate, which is set at two levels, one is \$50 per tCO2e and another one is \$100 per tCO_2e. The second dimension is sector coverage and this section also assumes two types of sector coverage: one covers five key sectors (cement, iron and steel, aluminium, fertilizers and electricity) that is proposed in the current EU's CBAM and another one covers all sectors. Table 4.4 provides a summary of four scenarios used in this paper.

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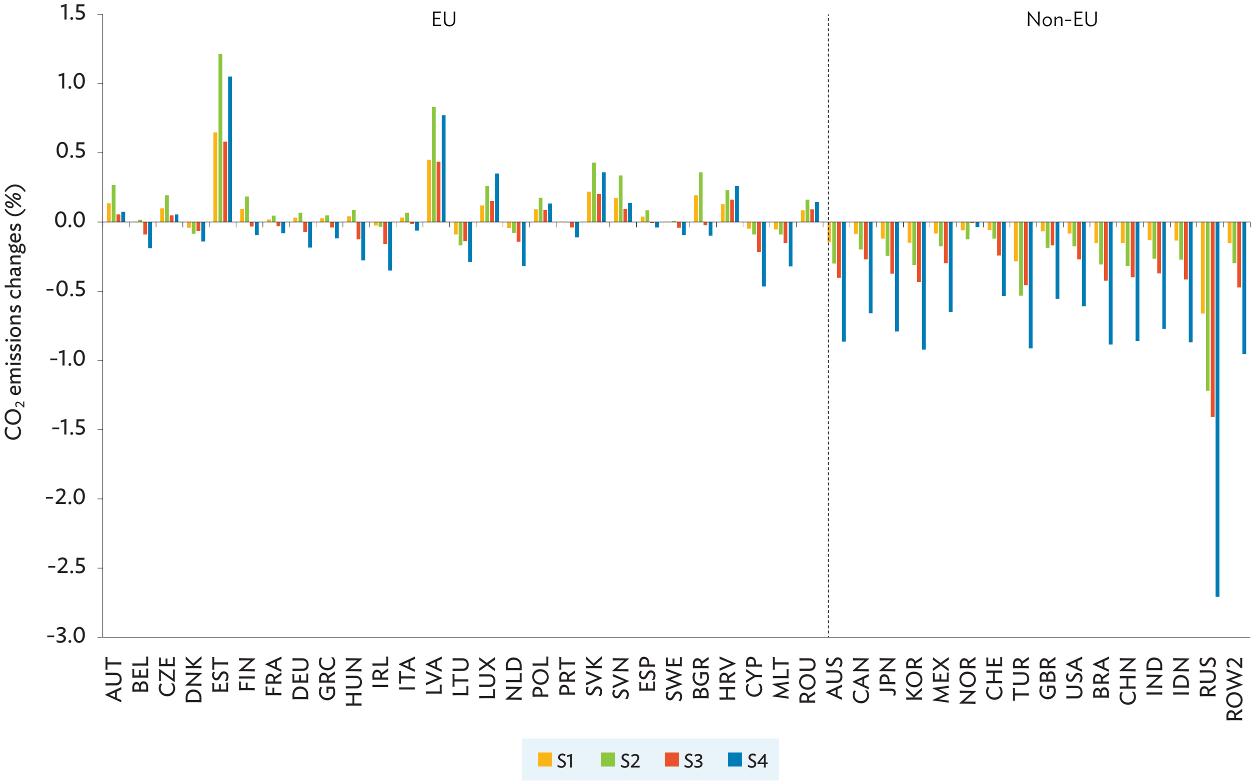
[9] This section uses a revised version of DREAM to study the impacts of CBAM on GVCs. DREAM is originally developed from the GTAP-E model and has been used to study the carbon pricing issues (Qian et al., 2018). Unlike DREAMs used in previous studies that the international trade patterns are modelled indirectly by using the Globe method (McDonald et al., 2007; Wu et al., 2022a, b; Tang et al., 2022). Our model is based on the OECD's Activity of MNEs (AMNE) ICIO table in which MNEs (the main players of GVCs) and local firms are split at the sector level. In addition, the relevant bilateral and sectoral FDI flow and stock data is from Meng et al. (2022)'s estimation which is based on official statistics of several international organizations as well as GTAP database.

Table 4.4: A CBAM CGE Model Scenario Setting

		CBAM tax rate	
		\$50 per tCO_2e	\$100 per tCO_2e
Sector coverage	Key sectors	Scenario 1 (S1)	Scenario 2 (S2)
	All sectors	Scenario 3 (S3)	Scenario 4 (S4)

Figure 4.10: Simulation Results of an EU CBAM's Impact on CO_2 Emissions



Source: Authors' estimation based on Qian et al. (2025).

Figure 4.10 presents the simulated effects of an EU CBAM on global and regional CO_2 emissions across four policy scenarios: S1 (\$50 per tCO_2e applied to key sectors), S2 (\$100 per tCO_2e on key sectors), S3 (\$50 per tCO_2e on all sectors) and S4 (\$100 per tCO_2e on all sectors). At the global level, CO_2 emissions are projected to decline by 0.12%, 0.23%, 0.36%, and 0.69% under scenarios S1 through S4, respectively. Notably, expanding the CBAM's sectoral coverage from a limited set of key industries to the entire economy results in a CO_2 reduction effect approximately 1.5 times larger than that achieved by doubling the carbon price from \$50 to \$100 per tCO2e. This indicates that the breadth of sectoral application has a greater marginal impact on emissions abatement than increasing the carbon price alone.

From a policy implementation perspective, a CBAM limited to key sectors offers clear administrative advantages. It reduces compliance complexity and costs by narrowing the scope to a smaller set of easily identifiable, carbon-intensive intermediate goods.

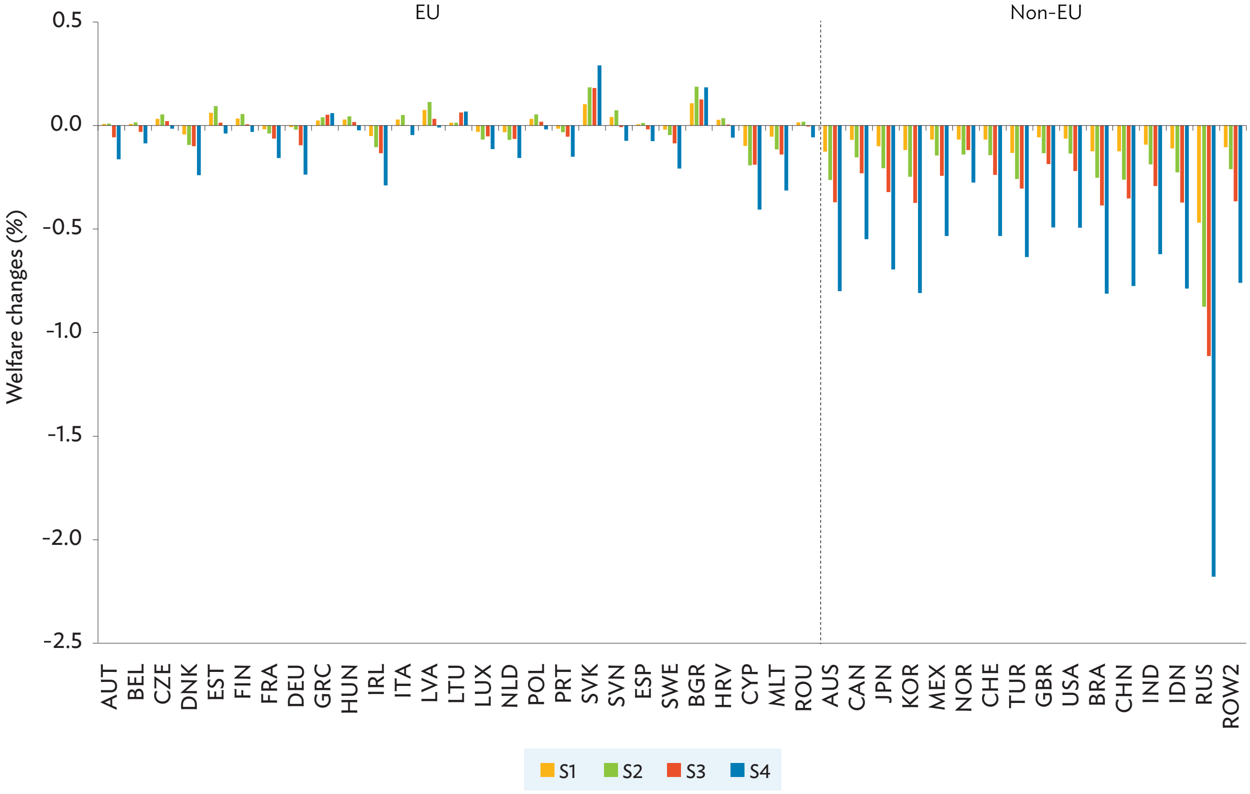
However, this approach may fall short in addressing emissions embodied in complex products with deep and geographically dispersed supply chains. For example, in the case of producing electric vehicles, about half of all emissions (see Chapter 3) occur upstream during the production of power batteries, rather than in final assembly. As such, expanding CBAM coverage across more sectors enhances the policy's effectiveness by allowing carbon price signals to travel further upstream in the value chain, thereby influencing emissions-intensive production stages more comprehensively.

One of CBAMs' central policy objectives is to reduce the risk of carbon leakage – whereby production shifts to countries with laxer climate regulations, undermining the efficacy of domestic climate policy. Simulation results suggest that this goal is largely met, as under scenario S4, CO_2 emissions in non-EU countries decline by nearly 1% on average, reflecting the deterrent effect of a CBAM on emissions outsourcing.

However, the intra-EU impact of a CBAM is far from uniform. While some member states, particularly in Western Europe, experience slight emissions reductions, others – especially in Eastern Europe – record increases. Under scenario S4, more than half of EU countries see emissions rise by an average of 0.7%, whereas certain Western European economies observe modest declines of around 0.2%.

Several structural mechanisms explain this heterogeneity. First of all, by increasing the cost of imported carbon-intensive goods, a CBAM enhances the relative competitiveness of domestically produced alternatives. In Eastern European countries, where industries tend to be more carbon-intensive, this substitution effect leads to increased domestic production – and consequently, higher emissions – even though these products are cleaner than their imported counterparts. Secondly, a CBAM alters intra-EU production dynamics. Facing higher costs for non-EU imports, Western European countries may shift emissions-intensive production to Eastern European member states, where production remains cost-effective and CBAM duties do not apply. This adjustment reduces external leakage but redistributes emissions within the EU. Notably, such reallocation may help Western countries like Germany lower their domestic carbon intensity, contributing to observed emissions reductions, albeit partly through geographic displacement rather than technological improvement. Thirdly, a CBAM indirectly raises energy prices across the EU by increasing the costs of carbon-intensive goods. This elevates the shadow price of carbon and strengthens incentives for firms to adopt cleaner energy sources and invest in energy efficiency. Countries with high energy dependency are particularly responsive to these price signals, driving gradual improvements in energy use and emissions intensity. This mechanism partly accounts for the modest emissions decline observed in some Western European economies under the more stringent CBAM scenarios.

Figure 4.11: Simulation Results of an EU CBAM's Impact on Welfare



Source: Authors' estimation based on Qian et al. (2025).

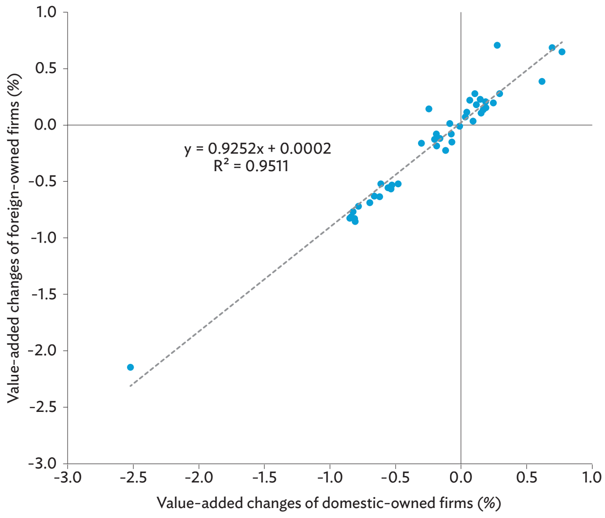
Figure 4.11 provides a detailed estimation of the distributional effects of CBAM by presenting welfare change (based on the equivalent variation) rates across countries and policy scenarios. Consistent with the pattern observed in emissions changes, welfare impacts also exhibit clear regional asymmetries. Non-EU countries generally experience welfare losses, as measured by the income required to restore pre-CBAM levels of well-being, due to reduced competitiveness in the EU market resulting from higher entry barriers on carbon-intensive exports.

Within the EU, the welfare effects are more nuanced. Eastern European countries, whose domestic production is relatively more carbon-intensive, tend to benefit from a CBAM in terms of welfare gains. As imported high-carbon goods become less competitive due to the adjustment mechanism, domestic substitutes – especially those produced within the EU and thus exempt from CBAM – gain market share. This shift enhances production activity and utility levels in these countries, resulting in positive welfare changes.

Conversely, many Western European countries experience welfare losses under a CBAM regime. This is primarily due to increased costs of imported carbon-intensive intermediate inputs, which raise the production costs of final goods across the EU supply chain. Western European economies, characterized by relatively lower carbon intensity in their industrial structure, are less likely to benefit from the substitution effect that favours domestic carbon-intensive production. As a result, they are more exposed to the negative utility effects of higher consumer prices without offsetting gains in production competitiveness. The burden of CBAM-induced price adjustments thus falls more heavily on final consumption in these countries, leading to a net welfare decline.

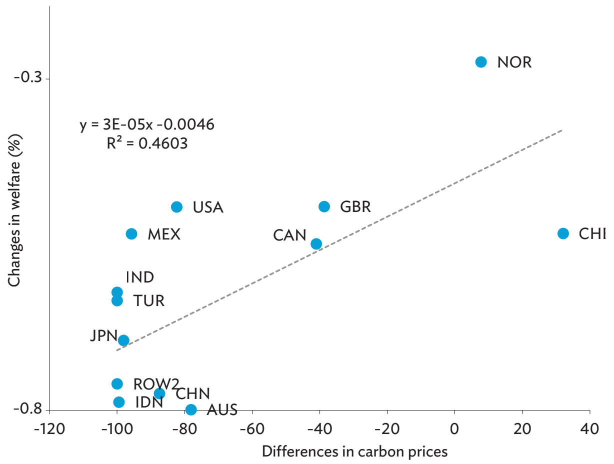
In short, while a CBAM appears effective in reducing global emissions and curbing carbon leakage, it also induces significant structural shifts in production and emissions patterns both within and outside the EU. These heterogeneous effects underscore the need for careful consideration of intra-EU equity and coordination in the design and implementation of carbon border measures. These heterogeneous impacts underscore a critical tension within CBAM frameworks: while the policy effectively reduces global emissions and internalizes carbon costs at the border, its economic burden is unevenly distributed – particularly between EU and non-EU countries, and among EU member states themselves. This highlights the importance of complementary domestic measures and policy coordination mechanisms between the EU and non-EU countries, to ensure a just and politically sustainable transition towards carbon neutrality.

Figure 4.12: Simulation Results of an EU CBAM's Impact on GVCs By Firm Ownership



Note: Based on Scenario 4 (for all sectors and $100 per tCO_2e)
Source: Authors' estimation based on Qian et al. (2025).

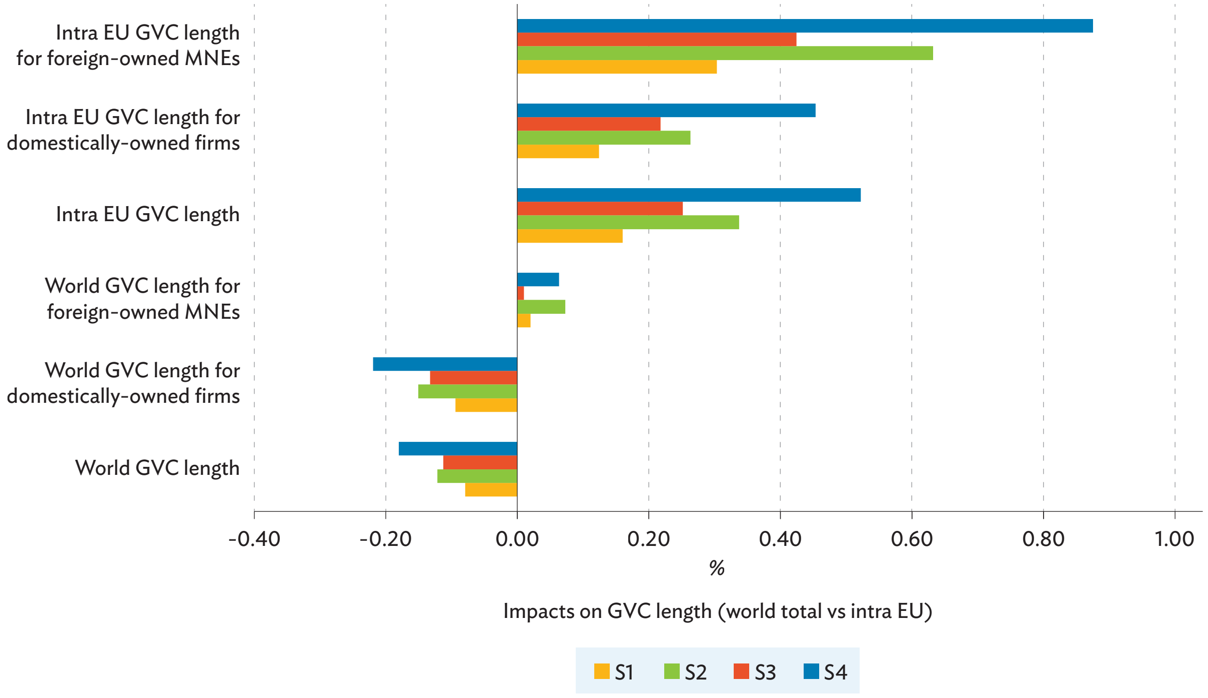
Figure 4.13: The Relationship Between Welfare Changes and the Difference in Carbon Prices for Non-EU Economies



Note: Based on Scenario 4 (for all sectors and $100 per tCO_2e)
Source: Authors' estimation based on Qian et al. (2025).

An important nuance in a CBAM's impact lies in the differential responses between MNEs and domestically owned firms. Figure 4.12 compares GDP changes under Scenario S4 and reveals that MNEs are less adversely affected than domestic firms. This outcome reflects MNEs' greater operational flexibility, broader geographic footprints and experience managing GVCs, which enable them to adapt more effectively to external shocks such as CBAM-induced price shifts. MNEs can reallocate production or adjust sourcing to minimize carbon cost exposure, while also leveraging advanced compliance systems. In contrast, domestically owned firms, often with limited supply chain flexibility and concentrated market operations, are more vulnerable to rising input costs and thus suffer larger output losses.

Figure 4.14: Simulation Results of the EU CBAM's Impact on the Length of GVCs



Source: Authors' estimation based on Qian et al. (2025).

Furthermore, Figure 4.13 shows that non-EU countries with relatively high domestic carbon prices experience smaller welfare losses under an EU CBAM regime. This outcome is intuitive: when exporters offer goods of similar price and quality, those from countries with higher domestic carbon prices are more competitive, as their products are subject to a lower adjustment under a CBAM. This finding aligns with the conclusions of Mehling et al. (2019), suggesting that an EU CBAM may create positive spillover effects by encouraging trade partners to implement or strengthen domestic carbon pricing mechanisms.

The above firm-level implications are further substantiated by changes in GVC length under a CBAM, as illustrated in Figure 4.14. Drawing on the methodology proposed by Wang et al. (2017), this section computes GVC length – proxied by the upstreamness index – for both global and intra-EU production networks. The upstreamness index captures the average number of production stages that a unit of value added in a specific sector passes through before reaching final demand.

The results reveal two contrasting trends. At the global level, CBAM implementation leads to a shortening of GVC length, particularly in segments dominated by domestically owned firms. This suggests a contraction or simplification of international supply chains, likely driven by rising costs associated with carbon-intensive imports and reduced competitiveness of non-EU suppliers. Conversely, intra-EU GVCs become more extended under a CBAM, with the lengthening most pronounced among MNEs. This pattern underscores MNEs' heightened sensitivity to carbon-adjusted import prices and their capacity to restructure production across EU member states. It also reflects their superior capability to maintain complex supply chains by relocating stages of production previously conducted in non-EU regions back within the EU, thereby avoiding CBAM tariffs while preserving operational efficiency.

Together, these findings reinforce the earlier conclusion that while a CBAM similar to the EU's proposed scheme can curb carbon leakage, it may also reinforce structural inequalities between globally integrated firms and domestic producers. Policy measures supporting domestically owned firms' low-carbon transitions are necessary to ensure a more balanced and inclusive adjustment process.

While a CBAM represents a significant innovation in the global carbon pricing landscape, it also faces practical challenges. These include the verification of embedded emissions, administrative complexity, potential inconsistencies with WTO rules and distributional concerns for developing economies. Moreover, interactions with existing carbon pricing mechanisms abroad may lead to overlapping regulation or unintended double taxation, adding to the burden on international trade partners (WTO, 2022). Nordhaus (2015) argues that multilateral "climate clubs" with harmonized carbon pricing and border measures can better address free riding and global emissions. Overland and Huda (2022) emphasize that unilateral CBAMs risk raising trade tensions and achieving only limited global adoption, whereas coordinated efforts enhance legitimacy and impact. Böhringer et al. (2022) note that CBAM can reduce leakage through competitiveness channels but is vulnerable to retaliation and policy gaps. Together, these studies suggest that a CBAM, while useful under fragmented climate governance, is only a partial solution. Greater international coordination through climate clubs or the carbon pricing framework proposed by the WTO (Bekkers et al., 2024), which emphasizes global coverage, equity and fairness, protection for vulnerable groups and flexibility in implementation, is essential for more effective global emissions control.

4.6 Addressing GVC-Driven Environmental Externalities

GVCs have fundamentally reshaped international trade and production, fostering deep economic interdependence among nations. While the expansion of GVCs has generated notable gains in productivity and economic growth, it has also externalized significant environmental costs. The fragmentation and globalization of production have not only redistributed but also often amplified environmental burdens, extending beyond the GHG emissions previously discussed to include various forms of pollution and public health risks. These externalities are frequently shifted towards countries with weaker regulatory capacity or ecologically fragile regions, where enforcement mechanisms are limited and environmental resilience is low. For example, the spatial fragmentation inherent in GVCs enables pollution-intensive production stages to be relocated to jurisdictions with relatively lax environmental standards. This phenomenon, commonly referred to as the "pollution haven" effect, enables high-income economies to import lower-cost goods while displacing pollution, toxic releases and associated health risks to less regulated regions (Copeland et al., 2004; Levinson and Taylor, 2008; Shapiro and Walker, 2018). Consequently, the market prices of traded goods fail to capture their full environmental costs, perpetuating a geographic disconnect between the sites of consumption and pollution generation. Cost competition within GVCs also creates strong incentives for environmental under-regulation, especially in developing and emerging economies. Environmental standards may be under-enforced or circumvented entirely, leading to unchecked pollutant discharges, land degradation and public health risks (Prakash and Potoski, 2006; Kellenberg, 2009). Furthermore, the multi-tiered and opaque nature of GVCs dilutes accountability, making it difficult to trace responsibility or incentivize upstream investment in pollution control technologies.

4.6.1 Environmental Externalities in Manufacturing GVCs

Manufacturing GVCs have dispersed production across borders to exploit cost advantages, while simultaneously externalizing a wide range of environmental burdens. Beyond the well-documented issue of carbon leakage, manufacturing value chains are also major sources of local pollution. Export-oriented industrial zones in East and South Asia release high concentrations of sulphur dioxide (SO_2), nitrogen oxides (NO_x), fine particulates ($PM_{2.5}$) and volatile organic compounds, all of which degrade air quality and threaten public health. In the context of China's export boom, these emissions were linked to increased incidences of respiratory and cardiovascular illnesses (Wang et al., 2017; Bombardini and Li, 2020). In textile manufacturing hubs such as Bangladeshi capital Dhaka and the Indian city of Tiruppur, the discharge of untreated dye effluents has severely contaminated local water bodies, decimating aquatic ecosystems and posing severe risks to human consumption (Al-Tohamy et al., 2022; Subramanian and Baskar, 2022; Masum et al., 2025).

An often-overlooked dimension of manufacturing externalities is the intensification of occupational heat exposure among workers in developing countries. As climate change accelerates, the incidence and severity of extreme heat events have risen. A recent study by Li et al. (2025) shows that between 1995 and 2020, trade-related labour exposure to extreme heat rose by 89%, from 221.5 to 419.0 billion person-hours. Crucially, low- and lower-middle-income countries accounted for 72% of the exposure burden but received only 6.7% of global labour compensation. This discrepancy reveals how trade redistributes climate risk and labour hardship across countries. Workers in heat-prone regions, particularly those integral to global supply chains, require enhanced protection through climate adaptation infrastructure and labour safeguards.

4.6.2 Environmental Externalities in Agricultural GVCs

Agriculture and agribusiness have also become increasingly globalized through value chains (Lim, 2023), generating significant environmental costs, chiefly via land-use change and agrochemical inputs. Rising global demand for commodities such as soy, palm oil, cocoa and beef has driven extensive land use change. In Brazil's Amazon and Cerrado regions, export-oriented expansion of soybean cultivation and cattle ranching has led to accelerated deforestation (Carreira et al., 2024), triggering carbon release, biodiversity loss and hydrological disruption (Lenzen et al., 2012; Chaudhary et al., 2016; Wilting et al., 2021). Empirical evidence suggests that trade liberalization under regional agreements often coincides with forest conversion, as newly profitable cropland replaces native ecosystems (Abman and Lundberg, 2020).

Excessive use of fertilizers and pesticides in export-oriented agriculture represents another major externality. To meet stringent international standards for yield and quality, farmers frequently over-apply agrochemicals, leading to nutrient runoff, groundwater contamination and eutrophication, with an increased load of nutrients. China, for example, consumes nearly one-third of global fertilizer output and continues to experience serious non-point source pollution (Ren et al., 2021; Wang et al., 2023). Similar patterns are observable globally, including the formation of "dead zones" in the Gulf of Mexico due to nutrient loading from export-oriented corn and soybean farming in the Mississippi Basin (Secchi et al., 2011; Rabotyagov et al., 2014). Pesticide overuse contributes further to the degradation of soil quality, pollinator populations and aquatic ecosystems.

Export-oriented agriculture also depletes natural capital. Monoculture production accelerates soil nutrient loss and organic matter depletion, imposing intergenerational costs on local farming communities. Water-intensive exports, such as cotton, almonds and avocados, have caused widespread groundwater over-extraction in arid regions (Cerasoli and Porporato, 2023), echoing historical ecological collapses such as the Aral Sea basin (Micklin, 2007). These "virtual water" exports exacerbate local water stress without internalizing the associated environmental and social costs (Hoekstra and Hung, 2005).

The human cost of agricultural GVCs is equally concerning. Empirical studies document elevated rates of chronic kidney disease among sugarcane workers in Central America and tea labourers in India – linked to recurrent dehydration and prolonged exposure to agrochemicals (García-Trabanino et al., 2015; Venugopal et al., 2021). Pesticide applicators and residents likewise face serious long-term health risks without access to compensation or legal recourse against multinational actors.

Additionally, integration into global food value chains has contributed to dietary transitions in low- and middle-income countries. Drawing on two decades of cross-country data, Hashad et al. (2024) find that deeper backward participation in GVCs is positively correlated with rising obesity rates among women, particularly in urban areas, driven by greater access to processed, energy-dense foods. These findings illustrate how the structure of global food systems not only externalizes environmental harms but also propagates adverse health outcomes. Addressing these multi-dimensional risks calls for integrated policy frameworks that internalize environmental, health and labour externalities across the full length of agricultural GVCs.

4.7 Conclusion and Discussion

This chapter has examined the environmental implications of GVCs through the lens of carbon emissions, the effectiveness of policy instruments and broader ecological externalities. A consistent finding is that while GVCs have enhanced economic integration and efficiency, they have simultaneously externalized significant environmental costs – ranging from embodied carbon leakage to biodiversity loss, ecosystem degradation and occupational health risks. Our analysis shows that environmental burdens are unequally distributed across borders, firm types and social groups. Low-income countries often bear the brunt of upstream emissions, toxic exposure and ecological degradation, while capturing a relatively small share of value-added. Similarly, MSMEs – despite being key contributors to employment and production – are frequently excluded from decarbonization support mechanisms.

These findings collectively reaffirm the need to make GVCs not only greener, but also more inclusive.

To advance greener and more inclusive GVCs, we propose the following policy priorities:

(1) **Broaden and harmonize carbon pricing frameworks or similar policies** in more developing economies, with explicit place-based design to include diverse firm types with equalized green finance treatment. This means extending coverage to more sectors and MSMEs and ensuring that carbon markets provide level playing fields regardless of firm ownership or size. Where possible, ETSs should be linked across borders to facilitate convergence in carbon pricing and reduce arbitrage incentives.

(2) **Coordinate environmental policies internationally.** Fragmented policy landscapes introduce regulatory frictions in GVCs. When countries adopt different environmental regulations (e.g., divergent product standards, carbon pricing mechanisms), this can introduce border adjustment complexities, disrupt economies of scale for firms operating across multiple jurisdictions and

create a need for “regulatory hedging” strategies, where firms adjust production to serve specific regulatory markets.

(3) **Internalize non-carbon externalities in GVCs** by integrating environmental and health criteria into trade and investment rules. This includes binding standards on agrochemical use, land-use change, waste discharge and occupational health – especially in sectors most exposed to ecological harm.

(4) **Promote inclusive climate transitions through multilateral cooperation,** with a focus on strengthening regulatory capacity in developing countries, incentivizing clean technology adoption and embedding equity safeguards in international climate-trade interfaces.

Ultimately, achieving green and inclusive GVCs will require aligning climate ambition with trade openness, industrial competitiveness with social equity and firm-level incentives with collective environmental responsibilities. International cooperation, policy coherence and transparent institutional arrangements will be critical to ensuring that global trade not only sustains prosperity but also safeguards planetary and human health for generations to come.

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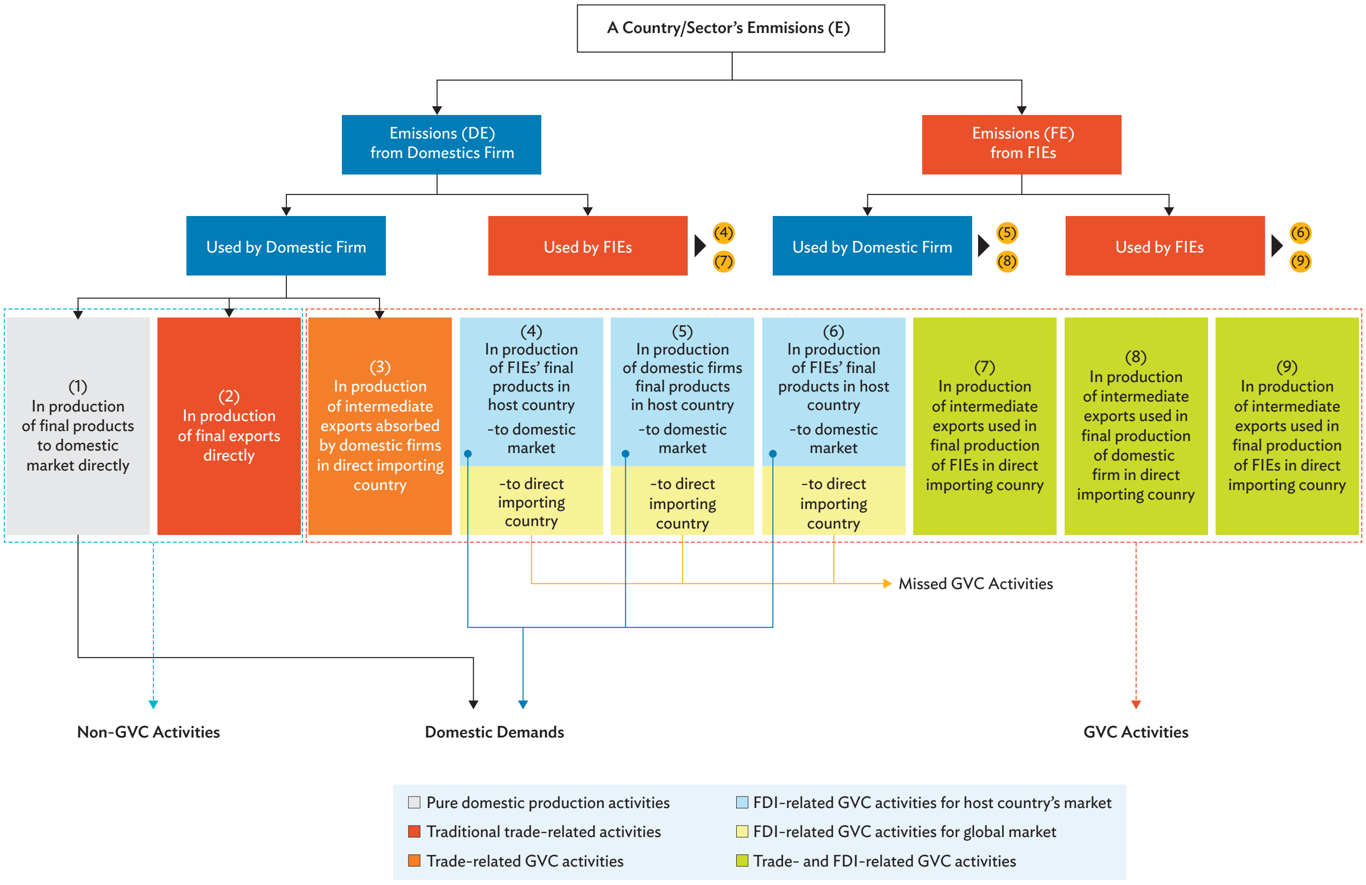
Annex 4.1: Updated Accounting for Tracing CO_2 Emissions along GVCs

Meng et al. (2018) integrate the trade in value added and emissions footprint in a GVC accounting (Koopman et al., 2014), thus enable both value added and emissions to be systematically traced at the country, sector and bilateral levels through various routes in GVCs. However, one problem remains unresolved in Meng et al. (2018): this accounting relies heavily on territory-based measures (the border of the country) rather than the ownership or controlling power of firms. This may lead to misunderstandings in the identification of carbon leakages and emission responsibility sharing at the firm level. For example, numerous MNEs sold considerable amounts of products that were “made” or “assembled” in developing economies through FDI channels, to those economies’ domestic consumers, but conventional accountings do not count such sales and associated emissions as a part of GVCs and GVC related carbon transfer. Therefore, all the responsibility of emissions embodied in those domestic transactions belongs to those developing economies, regardless a production-based or consumption-based approach is followed.

Figure 4.15: Accounting for Tracing Emissions Along GVCs



Source: Li et al. (2022).

Given the above challenges, Li et al. (2022) propose a novel multi-tiered framework to systematically trace a country's sectoral emissions from upstream production stages to downstream final use along GVCs, enabling a more granular understanding of their sources (production-based emissions), transmission (emission transfer or emission export/import) and absorption (consumption-based emissions).

As shown in Figure 4.15, Tier 2 disaggregates these emissions by ownership structure of the producers, distinguishing between domestic enterprises (DEs) and foreign-invested enterprises (FIEs), including affiliates of MNEs. This distinction can help capture the firm heterogeneity in production behaviour, technological capacity and environmental performance. Tier 3 introduces the intermediate-user perspective by classifying emissions according to who uses those goods and services produced by different types of firms. Tier 4 further distinguishes emissions into nine distinct trade and investment routes, which are ultimately grouped into the following six categories based on the final market they serve emissions associated with:

(1) Emissions embodied in purely domestic production
(2) Emissions embodied in traditional trade (Ricardian-type trade of final goods)
(3) Emissions embodied in trade-related GVC activities
(4) Emissions embodied in FDI-related GVC activities serving the host country's domestic market
(5) Emissions embodied in FDI-related GVC activities serving global export markets
(6) Emissions embodied in GVC activities involving both trade and FDI (hybrid routes)

Those emissions could further be linked into two types of firm activities in Tier 5: non-GVC activities, where no cross-border production sharing or FDI is involved, and GVC-related activities involving trade in intermediate goods or FDI-linked production arrangements.

This decomposition enables a detailed characterization of how emissions are embedded and transmitted through various channels in the global production networks, accounting not only for trade but also for investment linkages. It is important to highlight the "missed GVC activities", which are often overlooked in conventional emissions accounting frameworks. These include, for example: 1) final goods produced by FIEs for the domestic or global market (e.g., Tesla (Shanghai) Co., Ltd. manufacturing electric vehicles for both Chinese consumers and export to countries like Japan), and 2) final goods produced by domestic firms using intermediate inputs sourced from FIEs (e.g., Chinese automakers integrating electronic control units produced by Bosch (China) Investment Ltd.). Under traditional accounting systems, such activities are typically classified as either domestic production or Ricardian-type final good trade (i.e., French wine in exchange for English cloth), thereby failing to capture the embedded GVC characteristics. This leads to an underestimation of the emissions footprints and international interdependence of GVCs.

By systematically incorporating these nuanced production and ownership linkages, our framework provides a more accurate and policy-relevant representation of emissions along GVCs, laying the groundwork for more targeted and effective environmental interventions.