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Carbon Leakage through Supply Chain Adjustments

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Abstract

This paper examines carbon leakage through supply chain recalibration in response to European carbon policies. Using input-output data and a high-frequency identification approach for carbon policy shocks, this paper investigates whether stringent carbon regulations in Europe affect the imports of carbon-intensive inputs from major emerging economies lacking similar policies. The findings reveal a temporary increase in the rate of change of imports from emerging countries relative to all inputs in the carbon-intensive sectors following carbon policy shocks, with effects peaking after two years before dissipating. While not directly quantifying emissions transfer, this study suggests some evidence of short-term input substitution patterns consistent with carbon leakage through international supply chains.

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Abbreviations

CBAM	Carbon Border Adjustment Mechanism
CGE	computational general equilibrium
CO_2	carbon dioxide
EEA	European Economic Area
EE MRIO	extended multi-region input-output
EPS	environmental policy stringency
ETS	Emissions Trading System
EU	European Union
EU ETS	European Union Emissions Trading System
GDP	gross domestic product
GMM	generalised method of moments
ICIO	inter-country input-output
IEA	International Energy Agency
IPPC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
NACE	Statistical Classification of Economic Activities in the European Community
OLS	ordinary least squares
PCT	percentage change
PPI	producer price index
R&D	research and development
VAR	vector autoregression
WDI	World Development Indicators (World Bank)
WIOD	World Input-Output Tables

1 Introduction

Climate change represents a global environmental challenge that requires coordinated international action. While governments worldwide have introduced policies to curb carbon emissions, the effectiveness of unilateral regulations remains debated due to potential carbon leakage – where stringent carbon policies in one region lead to increased emissions in less regulated areas (Copeland, Shapiro, & Taylor, 2022).

This concern reflects the broader pollution haven hypothesis from trade theory, which suggests that environmental regulations in developed countries can shift pollution-intensive production towards regions with lower abatement (Levinson & Taylor, 2008). Climate policy is particularly vulnerable to such effects given its global nature and the significant variation in regulatory stringency across countries. The potential for production and emissions to shift to less regulated regions can significantly undermine the effectiveness of unilateral climate policies in reducing global emissions, posing a critical challenge for climate policy design and implementation.

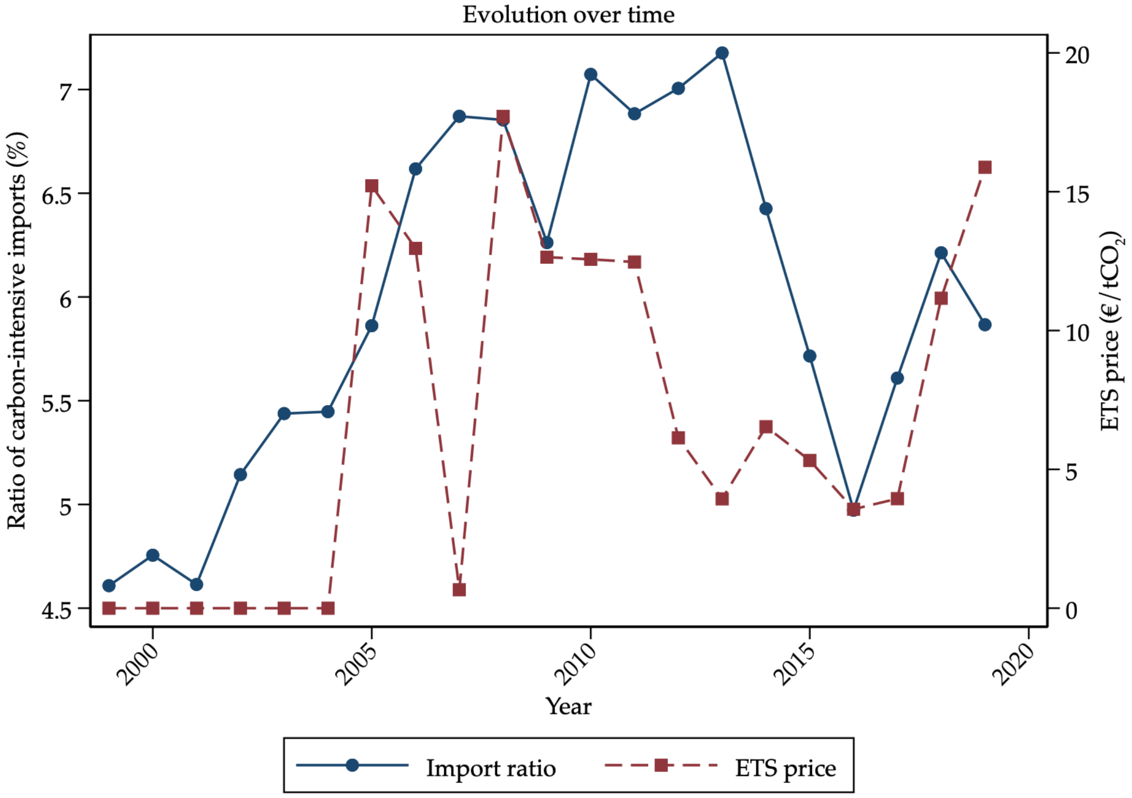
Carbon leakage can occur through three distinct channels (Colmer, Martin, Muûls, & Wagner, 2024). First, firms may shift their supply chains to source more intermediate products from unregulated suppliers, potentially reducing compliance costs while sacrificing some value added. Second, market forces may redistribute production to firms in unregulated sectors, either domestically or abroad, as firms in regulated sectors face higher costs. Third, companies with multiple facilities might reallocate production within their network from regulated to unregulated locations. Each channel represents a pathway through which environmental regulations could lead to unintended increases in emissions in less regulated regions.

While previous studies such as Dechezleprêtre, Gennaioli, Martin, Muûls, and Stoerk (2022) have focused primarily on multinational firms or production relocation and found limited evidence of carbon leakage, this study examines the potentially more responsive supply chain channel. Specifically, this research investigates whether European carbon policies lead to increased sourcing of carbon-intensive inputs from emerging economies, where environmental regulations are typically less stringent.

This focus on input sourcing, rather than complete facility relocation, is motivated by several key insights from the trade and environmental literature. Ederington, Levinson, and Minier (2005) argue that pollution-intensive industries often face significant barriers to relocation due to high transportation costs, substantial plant fixed costs, and benefits from industrial agglomeration. Instead of relocating entirely, these industries might find it more feasible to adjust their input sourcing patterns. Using detailed input-output data, this paper examines how sectors adjust their international sourcing decisions in response to carbon policy changes, focusing particularly on shifts toward suppliers in emerging economies. This approach allows us to identify a potentially important but understudied channel of carbon leakage through supply chain recalibration.

Figure 1 provides suggestive evidence of a supply chain adjustment channel. The ratio of carbon-intensive imports from emerging economies closely tracks the evolution of European Union Emissions Trading System (EU ETS) carbon prices, averaged across Exiobase sectors based on Intergovernmental Panel on Climate Change (IPCC) classifications for Emissions Trading System (ETS) coverage. Import ratios increased from around 4.5 per cent in 2000 to over 6 per cent by 2020, with notable acceleration after the EU ETS introduction in 2005. Particularly sharp increases in import ratios coincided with periods of high ETS prices, such as 2005 to 2006 and 2019 to 2020. This parallel movement between sectoral carbon prices and import patterns, while not establishing causality, suggests that European industries may adjust their sourcing decisions in response to carbon policy changes. While this correlation is consistent with potential carbon leakage through supply chains, establishing causality requires addressing important empirical challenges.

Figure 1: Carbon price and carbon-intensive import ratio trends



Notes: This figure plots average EU ETS carbon prices across covered sectors (dashed red line, right axis, €/tCO_2) and the ratio of carbon-intensive imports from emerging economies to total inputs (solid blue line, left axis, per cent) over the period 1999-2019, averaged across the 29 European countries[1] in our sample.

Source: ETS price data from the World Carbon Pricing Database; import ratios calculated by the author

To identify the causal effect of carbon policies on import patterns, this research addresses two key empirical challenges. First, carbon market regulations and import decisions may be jointly determined by underlying economic conditions, making it difficult to isolate policy impacts from other factors affecting trade patterns. For example, strong economic growth might simultaneously drive stricter environmental policies and changes in import patterns, while adverse economic shocks could lead to both relaxed regulations and altered trade flows. This endogeneity challenge requires careful identification of policy changes that are plausibly exogenous to broader economic conditions. This challenge is addressed by employing the high-frequency identification approach developed by Känzig (2023) to construct exogenous carbon policy shocks, similar to methods used in monetary policy or weather shock analyses.

Second, supply chain adjustments occur gradually as firms modify their sourcing strategies in response to policy changes. These dynamic responses reflect various frictions and constraints in international trade relationships, including existing contracts, search costs for new suppliers, and the time required to establish new business relationships. To capture these dynamic causal effects, this paper employs panel local projections following Jordà (2005), which allows us to estimate impulse response functions at various horizons without imposing the restrictive assumptions inherent in vector autoregression (VAR) models. This approach provides flexibility in modelling the temporal evolution of policy effects while controlling for relevant economic factors and fixed effects.

1 See data section for details.

The empirical specification examines how the identified policy shocks affect three different measures of carbon-intensive input sourcing from emerging economies: the ratio to total imported inputs, the ratio to all inputs (including domestic), and the ratio to total domestic supply. Each measure captures different aspects of potential carbon leakage through supply chains. This comprehensive framework reveals how sectors adjust their international sourcing patterns in response to carbon policy changes over time, while accounting for various economic and policy-related confounding factors.

This paper focuses on imports from major emerging economies with significant carbon emissions: Brazil, China, Indonesia, India, Mexico, Turkey, South Africa, and Russia. These emerging economies were selected based on data availability in the Exiobase input-output database. Changes in European sectors' sourcing patterns following carbon policy shocks are tracked, examining three key measures: the share of carbon-intensive imports from emerging economies relative to total imports, relative to all inputs (both imported and domestic), and relative to domestic supply. Changes in these import shares could indicate carbon leakage through supply chain adjustments, as stricter European carbon policies may incentivise firms to shift from domestic production to imports from less regulated markets. Such shifts could not only undermine global emission reduction efforts but also impact domestic producers through increased competition, affecting industry dynamics and employment.

Analysis of sectoral responses to carbon policy shocks reveals evidence of carbon leakage through supply chain adjustments. While this paper examines three different import share measures, the focus is primarily on the ratio of carbon-intensive inputs from emerging economies to total inputs (both imported and domestic) as our preferred specification. This measure is particularly informative as it captures potential substitution between domestic and foreign carbon-intensive inputs while controlling for overall input demand. The results show a temporary increase in emerging economy imports that peaks at approximately 0.2 percentage points around two years after the shock before gradually returning to zero. This transitory effect suggests that sectors initially respond to stricter carbon policies by increasing their reliance on foreign inputs from less regulated markets, but may later adapt through other channels such as technology upgrades or efficiency improvements. The temporary nature of the response also indicates that supply chain adjustments might serve as a short-term coping strategy rather than a permanent solution to carbon pricing.

This study examines heterogeneous responses across different dimensions. The effects are more pronounced in European countries with lower gross domestic product (GDP), suggesting that smaller economies might be more vulnerable to carbon leakage pressures. Countries without national carbon taxes (beyond the EU ETS) also show larger increases in carbon-intensive imports from emerging economies. However, this paper finds similar responses across sectors regardless of their carbon intensity, suggesting that supply chain network effects may propagate adjustments throughout the industrial structure rather than being confined to carbon-intensive sectors (Wang, 2024). This interconnectedness could explain why the broad-based changes in sourcing patterns regardless of sectoral carbon intensity are observed.

While these findings provide evidence of temporary supply chain recalibration in response to carbon policies, they also suggest that such adjustments may not lead to permanent shifts in input sourcing. This pattern of temporary adjustment informs climate policy design by highlighting the importance of considering short-term leakage risks while suggesting that long-term transformation of production processes may ultimately prevail. The stronger effects in smaller economies and countries without supplementary carbon taxes also point to the potential benefits of coordinated policy implementation and support for technological adaptation, particularly for more vulnerable economies.

Related literature

This study departs from previous research on business relocation and multinational firm behaviour by focusing on industry-wide supply chain adjustments. Consequently, this study captures broader economic adjustments beyond the internal decisions of multinational corporations, providing a more comprehensive view of potential carbon leakage mechanisms through trade channels.

The analysis expands the literature by investigating how European carbon policies affect import patterns from emerging economies, with a focus on potential leakage through supply chain recalibration. Despite the inherent challenges in measuring carbon leakage (Fowlie & Reguant, 2018) researchers have employed various methodologies to examine this phenomenon. However, empirical evidence on carbon leakage remains limited. Computational general equilibrium (CGE) models have been widely used to estimate carbon leakage magnitude (e.g., Carbone & Rivers, 2017; Fowlie & Reguant, 2022). However, this approach often relies on numerous assumptions, yielding mixed results. Empirical studies have also explored carbon leakage through international trade channels, often focusing on the carbon content embodied in trade flows (Aichele & Felbermayr, 2015; Aldy & Pizer, 2015; Naegele & Zaklan, 2019). While these studies provide valuable insights into macro-level trade patterns, they face challenges in accurately imputing the carbon content of diverse goods and services. In a related study, Sato and Dechezleprêtre (2015) found that changes in relative energy prices significantly increase imports, albeit with a very small magnitude of effect.

Recent firm-level studies on multinationals and business relocation have yielded mixed evidence on carbon leakage. Using French manufacturing data, Colmer et al. (2024) found that the EU ETS significantly reduced regulated firms' emissions without evidence of outsourcing to unregulated markets. Similarly, Dechezleprêtre, Gennaioli, Martin, Muûls, & Stoerk (2022) found no evidence of EU ETS-induced leakage to regions with laxer regulations. However, other studies have identified leakage through different mechanisms. Chen, Chen, Liu, Serrato, and Xu (2021) demonstrated conglomerate spillovers, where regulated firms shifted production to unregulated affiliates. Cui, Wang, Wang, Zhang, and Zheng (2023) provided evidence of carbon leakage within ownership networks in China's regional ETS pilots. The availability of firm-level carbon emissions data from sources like Urgentum or the Carbon Disclosure Project has enabled more detailed research. Ben-David, Jang, Kleimeier, and Viehs (2021) found that firms in countries with stricter environmental regulations produce lower domestic CO_2 emissions. However, these firm-level studies often suffer from small sample sizes, typically representing only large public firms.

A significant challenge in empirical studies of carbon leakage has been comparing the relative stringency of carbon policies and establishing causal relationships (Aldy & Pizer, 2014; Sato, Singer, Dussaux, & Lovo, 2015). This study addresses these issues by leveraging recent advancements in carbon policy shock identification. This study utilises the carbon policy shocks constructed by Känzig (2023), which provide a novel measure of unexpected changes in policy stringency. This approach employs a high-frequency identification method similar to studies using monetary policy shocks (Gürkaynak, Sack, & Swanson, 2004; Gertler & Karadi, 2015; Nakamura & Steinsson, 2018). Derived from high-frequency changes in carbon prices around policy announcements, these shocks offer more precise policy impact identification than traditional measures and enable analysis of both immediate and longer-term supply chain responses. Recent studies have employed similar shocks to examine various economic outcomes. Hengge, Panizza, and Varghese (2023) studied carbon policies' impact on stock returns, while Ciccarelli and Marotta (2024) found that climate change and associated mitigation policies have significant, though modest, macroeconomic effects.

This study leverages these carbon policy shocks to analyse their impact on import patterns, capturing potential leakage effects without relying on carbon content calculations or complex modelling assumptions. By focusing on imports from emerging economies to European countries, this paper provides empirical evidence on how carbon policies influence global supply chains and potentially lead to carbon leakage. This study examines the ratio of carbon-intensive imports to total inputs, directly observing shifts in input composition that may indicate leakage. This approach reveals how industries adjust their supply chains in response to carbon policies, potentially capturing leakage effects that broader trade flow analyses might miss. The methodology used in this paper complements previous empirical studies by offering a focused examination of carbon leakage through supply chain recalibration, providing new insights into how carbon policies impact international trade patterns and input sourcing decisions.

2 The European carbon market background

Europe has been at the forefront of carbon policy implementation, with the European Union Emissions Trading System (EU ETS) as an example of successful market-based instruments for carbon emission reduction. Launched in 2005, the EU ETS operates on a “cap-and-trade” principle, covering 27 EU member states and extending to Iceland, Liechtenstein, and Norway as part of the European Economic Area (EEA). The system primarily targets large emission-intensive sectors, encompassing approximately 40 per cent of the EU’s greenhouse gas emissions. Since its implementation, it has demonstrably reduced emissions from power and industry by 37 per cent through annually lowering emission caps.

The EU ETS works by setting a cap on the total amount of certain greenhouse gases that can be emitted by the installations covered. Within this cap, companies receive or buy emission allowances, which they can trade with one another as needed. The cap is reduced over time so that total emissions fall. At the end of each year, a company must surrender enough allowances to cover all its emissions, or heavy fines are imposed. The system has evolved through several phases. Phase I (2005-2007) was a “learning by doing” period to prepare for Phase II. Phase II (2008-2012) coincided with the first commitment period of the Kyoto Protocol. Phase III (2013-2020) introduced significant changes, including a single, EU-wide cap on emissions replacing the previous system of national caps, and auctioning as the default method for allocating allowances. Despite initial challenges such as over-allocation of allowances and consequent price volatility, the EU ETS has matured into a cornerstone of EU climate policy. It has driven significant emissions reductions, particularly in the power sector, and has inspired the development of similar systems worldwide. The EU ETS has also been complemented by other policies, such as renewable energy targets and energy efficiency measures, forming a comprehensive approach to climate change mitigation in Europe.

To maintain a consistent analytical framework and avoid these confounding factors, this study confines observations to the years up to and including 2019. The EU ETS prices surged after 2020 due to several factors: the post-Covid economic recovery increased greenhouse gas emissions and the demand for allowances; the conflict in Ukraine led to historically high gas prices; the introduction of the Market Stability Reserve in 2019 reduced allowance oversupply; and Phase IV’s stricter targets and gradual phase-out of free allowances, aligned with the European Green Deal’s goal for 2050 carbon neutrality, all contributed. Speculative trading, driven by the expectation of more stringent climate policies, also played a role.[2]

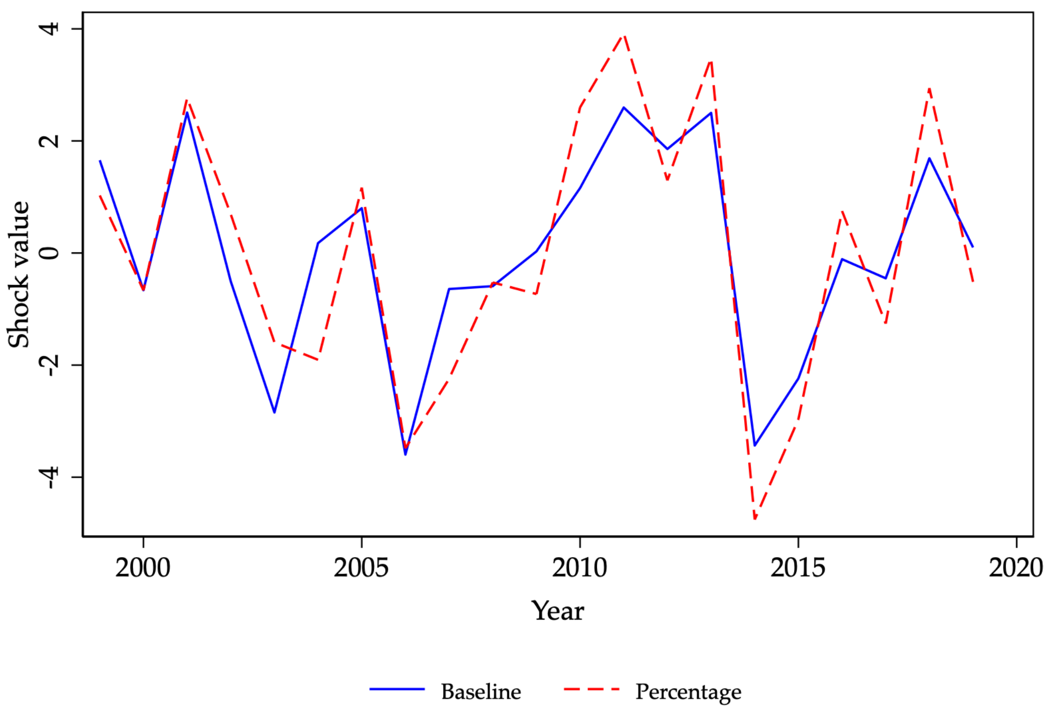
2 See in this connection https://economic-research.bnpparibas.com/html/en-US/European-carbon-price-time-high-3/1/2023,48321.

3 Data

Building on the earlier discussion of the EU ETS, measures of EU carbon policy shocks following Känzig (2023) are utilised, that focus on regulatory news regarding the supply of emission allowances in the EU ETS. These regulatory events include changes to the overall emissions cap, free allocation of allowances, allowance auctions, and the use of international credits, identified through the official journal of the European Union and the European Commission Climate Action news archive. Monthly shocks are aggregated to annual frequency by summing the monthly shocks within each year. These EU ETS carbon policy shocks are identified using the external instruments VAR method, employing the surprise series as an instrument for the energy price residual.

The carbon policy surprise series are measured in two ways: i) "baseline", which represents the euro change in ETS carbon price relative to the prevailing wholesale electricity price, and ii) "pct", which represents the percentage change in the ETS carbon price. This analysis primarily uses the percentage measure as it better captures the relative magnitude of policy changes and allows for more meaningful comparisons across time periods with different baseline carbon price levels. Following Känzig (2023), this study aggregates the monthly carbon policy shocks to annual frequency by summing the shocks within each year, such that the annual shock in year t is calculated as $\mathrm{CPShock_t} = \sum_{m=1}^{12} \mathrm{CPShock_{t,m}}$. Figure 2 plots the resulting annual shock series. While the EU ETS was implemented in 2005, the shock series shows non-zero values in earlier years due to the VAR estimation methodology. The VAR estimates relationships between variables over the entire sample period and uses post-2005 carbon policy surprises to identify structural shocks. Consequently, pre-2005 values reflect these estimated relationships even in the absence of direct carbon policy surprises during that period.

Figure 2: Carbon policy shocks in the European carbon market



Notes: This figure plots the carbon policy shock series at the annual frequency. The shocks are identified using the external instruments VAR method, employing the surprise series as an instrument for the energy price residual. The carbon policy surprise series are measured in two ways: i) "baseline", which represents the euro change in carbon price relative to the prevailing wholesale electricity price, and ii) "pct", which represents the percentage change in the carbon price.

Source: Author, based on carbon policy shock data from Känzig (2023)

3.1 Emerging economy import shares

The measures of carbon-intensive import shares are constructed from Exiobase.[3] Exiobase offers a time series of environmentally extended multi-region input-output (EE MRIO) tables spanning from 1995 to 2022. This dataset covers 44 countries, including all 28 EU members and 16 other major economies, and is organised into 163 industry classifications. Additionally, Exiobase provides data on direct carbon emissions per million euros of output, drawing from emission figures from the International Energy Agency (IEA). This study focuses on import flows from major emerging economies that are also significant global carbon emitters to European countries. Specifically, this study analyses imports originating from Brazil, China, Indonesia, India, Mexico, Turkey, South Africa, and Russia. These emerging economies are selected based on two criteria. First, they are significant global carbon emitters without stringent carbon regulations during our sample period. Second, they are the major emerging economies with detailed sectoral data available in the Exiobase database. This analysis includes a broad set of European destination countries, including both EU member states and select European non-EU countries. These destination countries are Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the United Kingdom.

Exiobase is preferred over the World Input-Output tables (WIOD)[4] and other multi-region input-output tables such as OECD Inter-Country Input-Output (ICIO)[5] Tables because it entails much greater sector details. This granularity is particularly valuable for environmental footprint assessments, as it helps capture the impacts related to specific product categories that might be aggregated in broader International Standard Industrial Classification (ISIC) sectors. Furthermore, given its support from the European Union, Exiobase is particularly adept for studies focusing on European policies. Utilising the yearly input-output tables and the environmental account, import share variables for carbon-intensive sectors are constructed, defined as those in the top 40 per cent of carbon intensity.

3.2 Sectoral-level carbon pricing data

The carbon pricing and coverage data is obtained from the World Carbon Pricing Database (Dolphin & Xiahou, 2022).[6] This database documents carbon pricing policies across 198 national jurisdictions between 1990 and 2020, capturing various policy instruments targeting CO_2 emissions such as carbon taxes and cap-and-trade systems. The database stands out for its comprehensive coverage of carbon pricing policies, particularly in its detailed sectoral disaggregation. Compared to the widely used World Bank Carbon Pricing Dashboard,[7] it offers more granular sectoral-level information. Carbon taxes complement the EU ETS but operate differently: they are implemented at the national level and primarily target sectors not covered by the ETS, such as transportation and construction. Pioneered by Norway and Sweden in the 1990s before the EU ETS existed, carbon taxes have now been adopted by 16 European countries. When the EU ETS was introduced, sectors previously subject to carbon taxes were typically exempted to avoid policy overlap. To account for this dual policy framework, this analysis uses

3 See in this connection https://www.Exiobase.eu/index.php/about-Exiobase.

4 See in this connection https://www.rug.nl/ggdc/valuechain/wiod/.

5 See in this connection https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

6 See in this connection https://github.com/g-dolphin/WorldCarbonPricingDatabase I thank Geoffroy Dolphin for our informative conversations regarding the dataset.

7 See in this connection https://carbonpricingdashboard.worldbank.org.

carbon policy shocks as the key independent variable while controlling for both ETS prices and carbon tax rates to capture the overall carbon pricing landscape.

3.3 Environmental policy stringency (EPS)

The Environmental Policy Stringency (EPS) index is obtained from the OECD. This country-specific measure covers 40 countries from 1990 to 2020 and quantifies the degree to which environmental policies put an explicit or implicit price on pollution behaviour. The index incorporates 13 instruments related to climate and air pollution.[8] As a standardised measure, the EPS index enables cross-country and intertemporal analyses of environmental regulation effects. It uses a scale from 0 (not stringent) to 6 (highest degree of stringency), reflecting the relative stringency of a country's environmental policy instruments in a given year.[9] This EPS index is employed here in the robustness tests to validate the main findings and ensure the consistency of the results across different measures of environmental policy stringency.

3.4 Other variables

This analysis incorporates several control variables to account for various economic and environmental factors. EU ETS prices and carbon tax rates are included from the World Carbon Pricing Database (Dolphin & Xiahou, 2022) to control for the existing policy environment.[10] Carbon intensity data from Exiobase environmental accounts controls for differences in production efficiency across countries and sectors. Country-level GDP from the World Bank's World Development Indicators (WDI) accounts for economic development and market size. Producer price indices (PPI) control for broader cost pressures affecting industrial production decisions. Trade openness (trade-to-GDP ratio) captures countries' integration into global markets and their propensity to trade. Together, these variables help isolate the effects of carbon policy shocks from other factors that might influence import patterns.

4 Summary statistics

The analysis covers 1999 to 2019, ending before potential confounding events: the Covid-19 pandemic, the Ukraine conflict, and the EU ETS Market Stability Reserve introduction. The final sample comprises 76 Exiobase sectors across 21 European countries. Table 1 presents comprehensive statistics for the key variables.

Panel A shows the distribution of carbon-intensive import shares measured three ways. The ratio to total imported inputs ($ImportShare^1$) averages 14.62 per cent, with considerable variation (SD=15.32 per cent). When measured against total inputs ($ImportShare^2$), including both domestic and imported, the average share is lower at 5.97 per cent (SD=10.71 per cent), reflecting the importance of domestic inputs in production. The ratio to total domestic supply ($ImportShare^3$) shows a higher mean of 47.92 per cent but with substantial heterogeneity (SD=253.19 per cent), indicating significant cross-sectional variation in import dependence relative to domestic production capacity.

8 The EPS index does not include water and waste management policies since the data are not available in a large cross-country panel and are also hard to turn into a quantitative cross-country indicator.

9 Scores are assigned according to the distribution of the observations with the respective policy implemented.

10 See in this connection https://github.com/g-dolphin/WorldCarbonPricingDatabase.

Panel B presents the carbon policy shock measure derived from surprises in carbon permit prices. These shocks, constructed as differences between actual and expected price changes, have near-zero means. This aligns with rational expectations theory, as systematic bias in expectations should be arbitraged away. However, the substantial standard deviations reveal significant unexpected policy variations that could influence sourcing decisions. The shock distribution suggests frequent policy surprises in both directions, providing variation for identifying causal effects.

Panel C summarises the control variables capturing various economic and policy dimensions. Carbon intensity exhibits substantial sectoral heterogeneity, reflecting differences in production technologies and energy efficiency. Economic indicators like GDP, PPI, and trade openness show considerable variation across countries and time, highlighting the importance of controlling for different stages of economic development and market integration. Although carbon taxes vary by country due to national policy differences, ETS prices are uniform across all EU countries in any given year. In the summary statistics, both measures are averaged across Exiobase sectors to reflect sectoral coverage of both carbon policies.

Table 1: Summary statistics

	Observations	Mean	SD	P1	P50	P99
Panel A: Outcome variables						
ImportShare[1](over total imported inputs)	28318	14.62	15.32	5.04	9.63	17.89
ImportShare[2](over total inputs)	28319	5.97	10.71	1.02	2.51	5.72
ImportShare[3](over total domestic supply)	28319	47.92	253.1	1.42	4.01	11.88
Panel B: Carbon policy shock						
CPShock(pct)	33516	-1.66e-12	2.32	-1.59	-.51	1.30
Panel C: Control variables						
Log(GDP)	20748	20.00	1.32	19.09	19.77	21.37
Log(carbon intensity)	33516	.45	1.46	.012	.06	.27
ETS price	33516	6.70	11.62	0	0	9.45
Carbon tax rate	33516	2.50	11.43	0	0	0
PPI	25384	85.51	10.14	79.80	87.34	93.14
Trade openness	33516	98.82	40.79	64.54	86.39	127.77

Notes: This table presents the summary statistics for outcome variables of import patterns, carbon policy shock variables, and control variables. The variables are defined in Appendix Table A1.

5 Empirical methods

5.1 Identification challenges

Evaluating the impact of carbon pricing on potential leakage effects ideally requires a study design that isolates the changes induced by these policies. However, several challenges complicate this ideal scenario. First, identifying and isolating the impact of carbon policies is difficult given various factors simultaneously influencing firm and industry behaviour. Second, participation in carbon pricing schemes, such as the EU ETS, is not random, introducing potential selection bias. In practice, a randomised control trial for carbon pricing is politically unfeasible. Researchers use econometric methods, such as difference-in-differences, assuming that carbon policies do not affect unregulated firms or sectors. However, this assumption may be violated as policy effects can be transmitted through supply chains, potentially contaminating control groups. Moreover, when studying potential leakage through import patterns, additional challenges arise. Various factors beyond carbon policies, including global economic trends, trade agreements, and technological changes may influence changes in import ratios. The gradual implementation of carbon policies also makes it difficult to identify clear “before” and “after” periods for analysis.

To address these identification challenges, the high-frequency identification approach developed by Känzig (2023) was utilised to quantify carbon policy shocks. This method builds on techniques originally developed for monetary policy analysis (Gürkaynak et al., 2004; Gertler & Karadi, 2015; Nakamura & Steinsson, 2018), where researchers measure asset price movements in narrow windows around policy announcements to isolate policy impacts. The EU carbon market’s frequent policy updates and active futures trading make it ideal for high-frequency identification. By measuring price changes in tight windows around regulatory events in the carbon market, this approach can plausibly rule out reverse causality since broader economic conditions are already incorporated in pre-event prices and unlikely to change within the narrow event window.

The constructed carbon policy shocks are considered parallel to exogenous shocks such as weather events or monetary policy changes. This method allows for the isolation of the impact of carbon policies from other confounding factors and overcomes the challenges of non-random policy implementation. While initially developed for monetary policy, this identification strategy has proven effective in various policy contexts, including global oil markets and emissions trading schemes.

5.2 Emerging economy import shares

Three measures of import shares from emerging economies are constructed as follows:

$$\mathrm{ImportShare}_{\mathrm{ik,t}}^{\mathrm{m}} = \frac{\mathrm{Carbon{-}intensive\ inputs\ sourced\ from\ emerging\ economies}_{ik,t}}{Carbon{-}intensive\ denominator_m},$$

where $\mathrm{ImportShare}_{\mathrm{ik,t}}^{\mathrm{m}}$ denotes the fraction of carbon-intensive inputs that sector i in country k sources from emerging countries without carbon policies in year t, relative to the total carbon-intensive inputs or supply from all sources. Carbon-intensive sectors are defined as those in the top 40 per cent of carbon intensity across all sectors. The superscript $m \in 1,2,3$ indicates three different measures, each using a different denominator:

- $denominator_1$ = total carbon-intensive imported inputs
- $denominator_2$ = all carbon-intensive inputs (imported and domestic)
- $denominator_3$ = total carbon-intensive domestic supply.

These measures allow for the assessment of the relative importance of carbon-intensive imports from emerging countries that lack carbon policies. The first measure focuses on the composition of the imports. This is useful for directly observing changes in international sourcing patterns. It shows whether carbon-intensive imports from emerging economies are increasing relative to imports from other sources. The second measure includes both imported and domestic inputs. It provides a broader perspective on how the share of carbon-intensive imports from emerging economies changes relative to the total input mix. This measure is particularly important as it indicates a potential input substitution effect, showing whether there is a general shift towards foreign sourcing or just a recomposition of existing imports. As such, it is the primary focus of this paper, offering the most direct evidence of whether firms substitute domestic inputs with imports from emerging economies in response to carbon policies. The third measure compares carbon-intensive imports to the total domestic economic activity in the sector. It can indicate whether imports are growing relative to domestic production, which is particularly relevant for assessing potential domestic industry impacts.

5.3 Dynamic effects of carbon pricing on import patterns from emerging economies

The dynamic causal effects on the three measures of carbon-intensive import shares are estimated using (panel) local projections à la Jordà (2005).

$$\Delta_h y_{ik,t+h}^m = \alpha + \beta^h \text{CPShock}_t + \sum_{p=1}^{P} \theta_p^h x'_{ik,t-p} + \sigma_k^h + \epsilon_{ik,t+h},$$

where h denotes the horizon at which the relative effect is estimated. The dependent variable $\Delta_h y_{ik,t+h}^m \equiv y_{ik,t+h}^m - y_{ik,t-1}^m$ is defined as the cumulative difference of the import share outcome variables ($m \in 1,2,3$) measuring the fraction of carbon-intensive inputs that industry sector k in European country i sources from emerging economies in year t+h, as defined above.

For panel data local projections, one would normally project the outcome variables on the shocks and control variables, including the lag of the outcome variable. However, including the lagged outcome variable with fixed effects creates biases in the estimation that would require more complex generalised method of moments (GMM) methods to address. To avoid this issue while maintaining simple ordinary least squares (OLS) estimation, the approach follows Jordà, Schularick and Taylor (2015) and projects the cumulative difference $y_{ik,t+h}^m - y_{ik,t-1}^m$$ on the righthand side variables, excluding the lagged dependent variable. The independent variable of interest, CPShock_t denotes carbon policy shocks at year t, extracted from a proxy-VAR model from Känzig (2023). Following Känzig and Konradt (2023), lagged shock variables are not included in the specification since the shock series shows no significant serial correlation (Ljung-Box test p-value = 0.88).

Percentage changes rather than baseline (euro) changes in carbon prices are employed as the shock measure, as percentage changes better reflect how sectors evaluate relative costs and make sourcing decisions. The vector $\boldsymbol{x}'_{\boldsymbol{ik,t-p}}$ includes lagged control variables including carbon intensity, GDP, ETS price, and carbon tax rate, with lags up to order P, allowing for richer dynamics in economic factors that might influence import shares. Sector (destination country's) fixed-effects σ_k^h is included to account for time-invariant characteristics. The superscript ^{h} on the coefficients indicates that separate regressions are estimated for each horizon ^{h}, allowing for dynamic effects over time.

5.4 Heterogeneous effects

Heterogeneous effects of carbon policies on import patterns from emerging economies are explored across different sector types, country sizes, and existing carbon pricing regimes.

First, the various effects across importing sectors with different levels of carbon intensity are examined. Importing sectors of the European countries are categorised into low, middle, and high carbon intensity groups (terciles) based on their pre-shock carbon intensity (ton CO_2 per thousand-dollar gross output). By examining heterogeneity across carbon intensity levels, the assessment can determine whether carbon policies disproportionately affect high-emission sectors, potentially leading to greater carbon leakage.

Next, heterogeneity across European importing countries is investigated based on their economic size. Countries are grouped into terciles according to their logged GDP levels (in constant 2015 dollars). In the analysis, these are referred to as low, middle, and high GDP countries, respectively. This approach helps one to understand if the impact of carbon pricing on import patterns varies with the economic size of the importing country, potentially revealing differences in adaptation strategies or vulnerabilities to carbon leakage across economies of different scales.

Finally, heterogeneity based on the presence of national carbon taxes in European importing countries is explored. A distinction is made between countries without additional national carbon taxes and those with national carbon taxes on top of the EU-wide ETS system. This distinction allows for examination of whether the presence of additional national carbon pricing mechanisms influences the effect of broader carbon policy shocks on import patterns from emerging economies.

6 Results

6.1 Main results

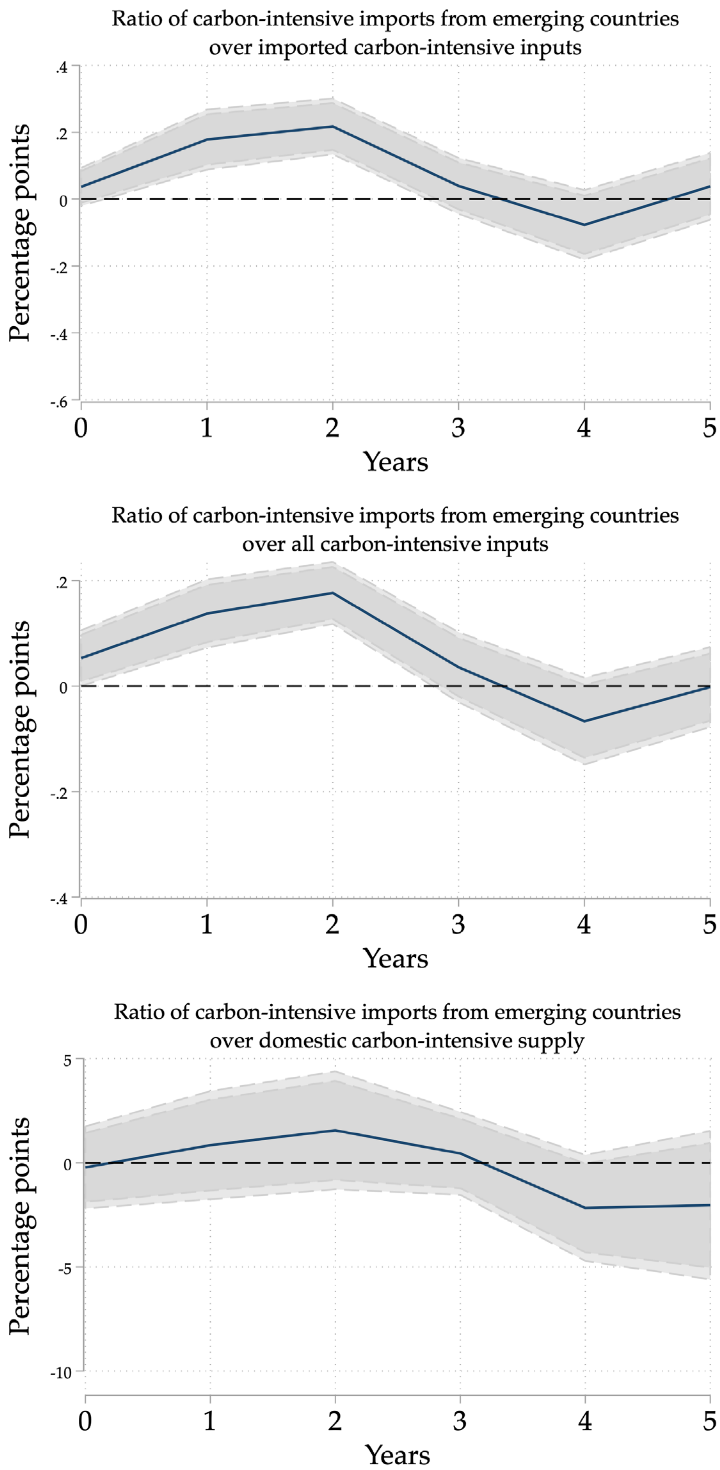
How do carbon policies affect the import patterns of the European countries from the emerging countries? The baseline carbon policy shocks are extracted from surprises in euro-denominated carbon price changes relative to prevailing wholesale electricity prices, as constructed by Känzig (2023) The three outcome variables measuring the fraction of carbon-intensive inputs sourced from emerging economies are examined relative to i) total imported inputs; ii) all inputs (imported and domestic); and iii) total domestic supply.

The results suggest modest evidence of European sectors adjusting their sourcing of carbon-intensive inputs in response to carbon policy shocks. This is examined through three measures, each capturing different aspects of potential carbon leakage. Figure 3 presents impulse responses to an unexpected increase in carbon policies for all three measures.

The middle panel shows the primary measure – the ratio of emerging economy imports to all inputs (both imported and domestic) – which directly captures substitution between domestic and foreign sources. This measure reveals a small but positive cumulative response of approximately 0.2 percentage points that peaks around two years after a one standard deviation increase in carbon policy shock (normalised to increase energy prices by one per cent on impact), before gradually returning to zero. While Känzig (2023), who developed the carbon policy shocks used in this study, found that these shocks lead to a 0.6% reduction in domestic GHG emissions, our findings reveal a significant leakage channel through supply chain adjustments. The increase in carbon-intensive imports indicates that carbon leakage through supply chains may offset some of the domestic emissions gains, though precise quantification of this offset would require additional analysis. This result contrasts with Colmer et al. (2024), who find no statistically significant changes in French firms' importing behaviour under the EU ETS and conclude that supply chain leakage is not a major driver of emissions reductions. This study's findings can be considered alongside earlier work by Sato and Dechezleprêtre (2015), who examined a different time period (1996-2011) and found that a 10 per cent increase in energy price differences between countries leads to a 0.2 per cent increase in overall imports. The transitory nature of this effect suggests initial adjustment through international sourcing, followed by longer-term adaptation through technology upgrades or efficiency improvements. The top panel presents the ratio of emerging economy imports to total imported inputs, showing similar patterns in how import composition shifts. The bottom panel shows the ratio to total domestic supply, where effects become less significant, likely due to broader economic fluctuations affecting this measure of domestic production.

These findings indicate that, while stricter carbon policies may lead European sectors to temporarily increase their reliance on carbon-intensive inputs from emerging economies, the effects dissipate over time rather than resulting in permanent shifts in sourcing patterns. This temporal pattern reveals important dynamics in how firms adapt to environmental regulations. Initially, firms appear to respond through the most flexible available channel – adjusting their international sourcing patterns to maintain competitiveness. However, as firms adapt over the longer term, they likely develop more sustainable solutions such as technology upgrades, efficiency improvements, or process innovations that reduce carbon intensity. This evolution from short-term trade adjustments to longer-term technological adaptation suggests that, while carbon leakage through supply chains may occur initially, firms ultimately find ways to maintain production while complying with stricter environmental regulations. The transitory nature of the effects also indicates that concerns about permanent production relocation or lasting damage to domestic industry competitiveness may be overstated, though short-term adjustment costs remain important considerations for policy design.

Figure 3: Impulse responses of import patterns to carbon policy shock (pct)



Notes: This figure plots the impulse responses of input sourcing from emerging economies following a carbon policy shock, estimated using local projection. The top, middle, and bottom panels show the fraction of inputs that industry sector k in country i sources from emerging economies in year t+h, relative to total imported inputs, all inputs, and total domestic supply in carbon-intensive sectors, respectively. The x-axis represents years after the shock. Carbon policy shocks (pct) are extracted from the carbon policy surprises measured as euro change in carbon price, relative to the prevailing wholesale electricity price (Känzig, 2023). Solid lines represent point estimates, while dark- and light-shaded areas indicate 90 per cent and 95 per cent confidence bands, respectively.

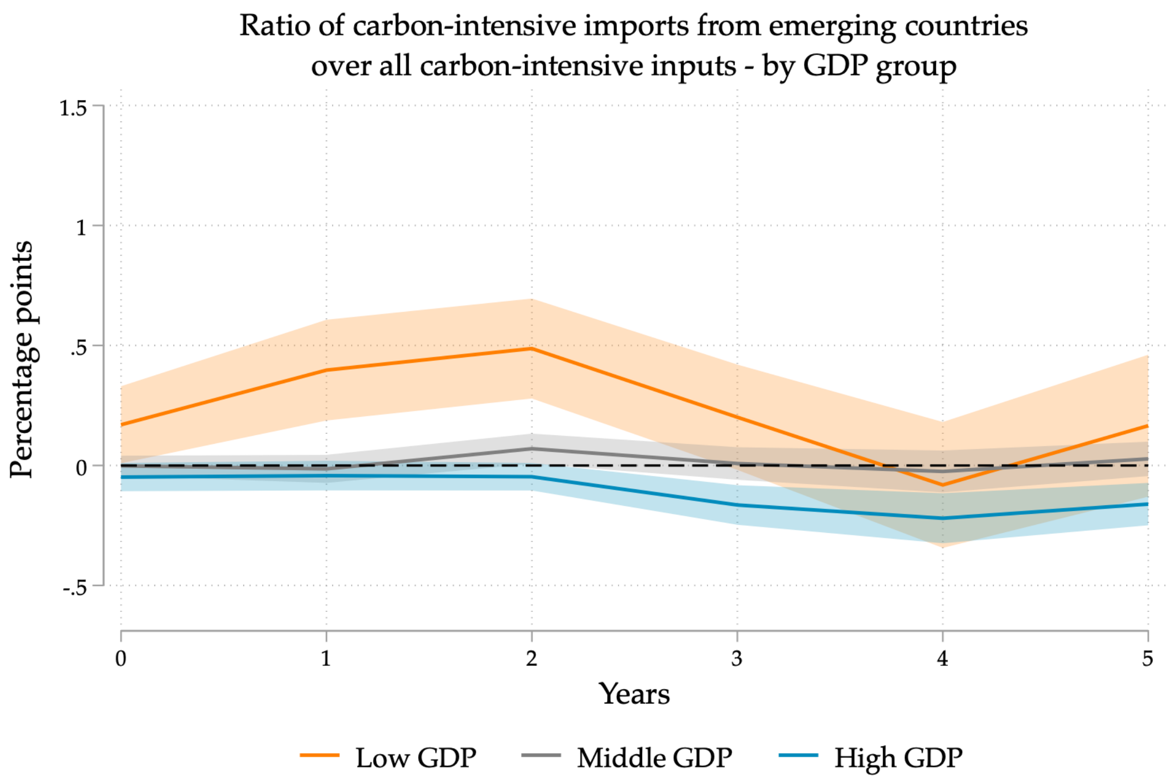
Source: Author’s calculations

6.2 Heterogeneity analysis

The heterogeneity of our results is examined across multiple dimensions, focusing on both sector-specific and country-specific characteristics.

Figure 4 illustrates the heterogeneous effects of carbon policies across European (importing) countries with different GDP levels. Lower-GDP countries (bottom tercile) experience a more pronounced increase in the ratio of carbon-intensive imports from emerging economies to total imported inputs. This cumulative effect peaks at over 0.5 per cent around year two post-shock, before gradually diminishing to zero by year four, suggesting a temporary but significant adjustment in sourcing patterns. In contrast, higher GDP countries (top tercile) show a slight decrease in this ratio, potentially indicating their greater capacity to maintain or even strengthen domestic production despite stricter environmental regulations. The contrast between these groups suggests that countries with lower GDPs are more vulnerable to carbon leakage effects, possibly due to the limited technological and financial resources required to adapt their production processes. This finding implies that economic size may play a crucial role in a country's ability to maintain domestic production in the face of stringent carbon policies, with smaller economies potentially more susceptible to outsourcing carbon-intensive production to emerging economies. The divergent responses also highlight the importance of considering country-specific characteristics when designing carbon policies, as uniform regulations may have uneven distributional consequences across countries with different economic capacities.

Figure 4: Heterogeneity by European (importing) countries' GDP

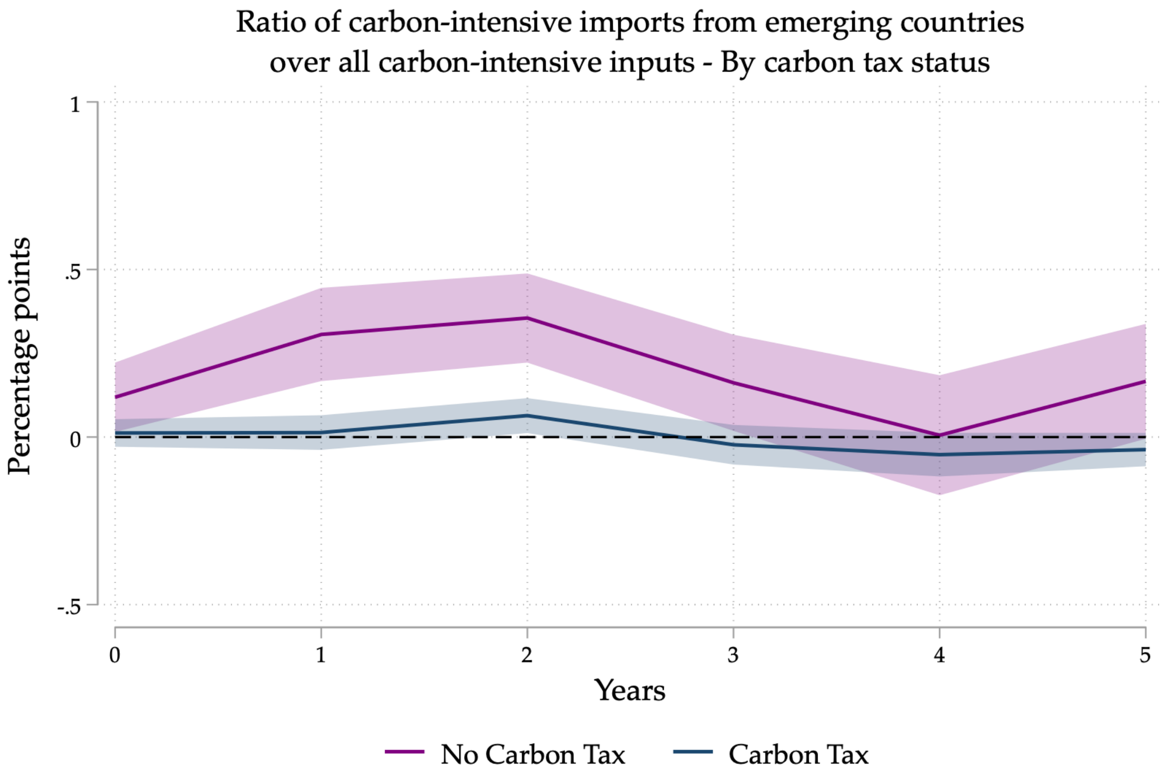


Notes: This figure plots the impulse responses of input sourcing from emerging economies following a carbon policy shock, estimated using local projection, for low GDP countries (orange), middle GDP countries (gray), and high GDP countries (blue). European countries are grouped into terciles based on their logged GDP (2015 constant) levels. The x-axis represents years after the shock. Carbon policy shocks (pct) are extracted from the carbon policy surprises measured as euro change in carbon price, relative to prevailing wholesale electricity price (Känzig, 2023). Shaded areas indicate 95 per cent confidence bands.

Source: Author's calculations

Figure 5 demonstrates heterogeneous effects based on European countries' carbon tax status. Countries without national carbon taxes (in addition to the EU-wide ETS) show a larger increase in carbon-intensive imports from emerging markets compared to those with additional national carbon taxes. This divergence becomes particularly pronounced two years after the shock, suggesting a delayed but significant adjustment in sourcing patterns. This pattern mirrors the results in Figure 4, likely because carbon taxes have been primarily implemented in wealthier Western and Northern European countries, which typically have more resources to invest in cleaner production technologies. These findings indicate that the implementation of national carbon taxes, complementing the EU-wide Emissions Trading System (EU ETS), may enhance efforts to mitigate carbon leakage through multiple policy instruments working in tandem.

Figure 5: Heterogeneity by European (importing) countries' carbon tax status

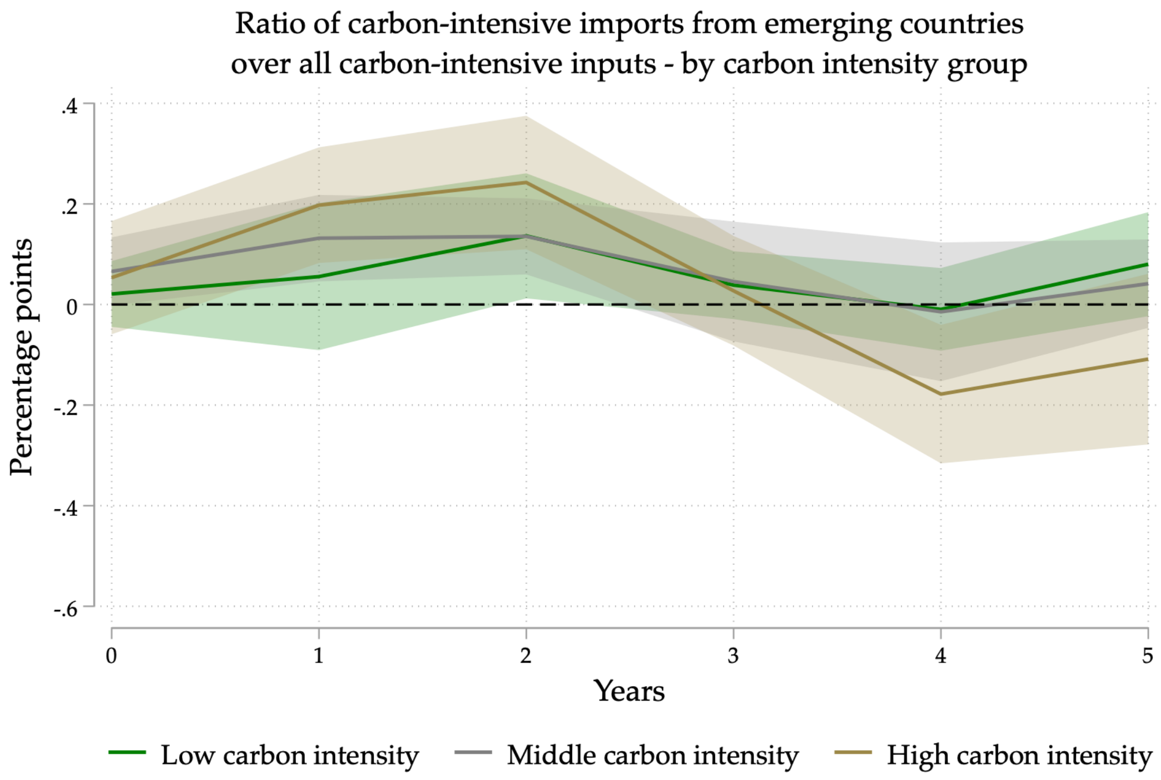


Notes: This figure plots the impulse responses of input sourcing from emerging economies following a carbon policy shock, estimated using local projection, for countries without national carbon taxes (purple), and countries with national carbon taxes (navy) on top of the EU-wide ETS system. The x-axis represents years after the shock. Carbon policy shocks (pct) are extracted from the carbon policy surprises measured as euro change in carbon price, relative to prevailing wholesale electricity price (Känzig, 2023). Shaded areas indicate 95 per cent confidence bands.

Source: Author's calculations

Figure 6 examines whether sectors with different carbon intensities respond differently to carbon policy shocks. This analysis finds that sectors across all carbon intensity levels show similar responses, with high-carbon sectors being slightly more sensitive to carbon pricing. This pattern suggests that European carbon policies lead to broad-based shifts in sourcing patterns towards emerging economies, regardless of sectors' emission intensities. Such homogeneous responses across sectors point to the possibility that supply chain networks transmit policy-induced adjustments throughout the industrial structure, rather than being confined to the most carbon-intensive activities.

Figure 6: Heterogeneity by sectoral carbon intensity



Notes: This figure plots the impulse responses of input sourcing from emerging economies following a carbon policy shock, estimated using local projection, for low carbon intensity (green), middle carbon intensity (gray), and high carbon intensity sectors (brown). The carbon intensity (pre-shock) is measured as CO_2 emissions (in tons) per 2015 thousand-dollar gross output. Sectors are grouped into terciles based on their carbon intensity. The x-axis represents years after the shock. Carbon policy shocks (pct) are extracted from the carbon policy surprises measured as euro change in carbon price, relative to prevailing wholesale electricity price (Känzig, 2023). Shaded areas indicate 95 per cent confidence bands.

Source: Author's calculations

7 Robustness

7.1 Responses to carbon tax

The main identification strategy using carbon policy shocks is complemented with a "control-based" approach following Metcalf and Stock (2020) and Känzig and Konradt (2023). This approach identifies the effects of carbon taxes by controlling for various economic and sectoral factors to isolate plausibly exogenous variations in carbon prices. This complementary analysis serves both as a robustness check and provides insights into how different types of carbon pricing policies might affect supply chain adjustments. The following (panel) local projection is estimated:

$$\Delta_h y_{ik,t+h} = \alpha + \beta^h \mathrm{Ctax}_{ik,t} + \sum_{p=1}^{P} \theta_p^h x'_{ik,t-p} + \sigma_k^h + \epsilon_{ik,t+h},$$

where the independent variable of interest $\mathrm{Ctax}_{ik,t}$ is the carbon tax[11] imposed on country i and sector k. The outcome variable is the fraction of carbon-intensive inputs that industry sector k in country i sources from emerging economies in year t+h, relative to all inputs (m=2). The vector

11 As in the World Carbon Pricing Database: net tax rate (accounting for exemption) in current local currency unit per tonne of CO_2.

$\boldsymbol{x}'_{ik,t-p}$ includes lagged control variables including the country's GDP, sectoral carbon intensity, producer prices, and trade openness. These controls help account for various economic factors that might influence sourcing decisions independently of carbon taxation. Similar to the main regression, sector (destination country's) fixed-effects σ_k^h is included to account for time-invariant characteristics that might affect the propensity to source from emerging economies.

Figure A2 in the Appendix shows small but positive responses to carbon tax changes, with effects becoming significant in year 3. While these results align directionally with the main findings from the policy shock analysis, the effects are notably smaller in magnitude and take longer to materialise. The smaller and less significant effects likely reflect the gradual, anticipated nature of carbon tax changes compared to the unexpected policy shocks in our main specification. This difference in response patterns highlights the importance of the high-frequency identification strategy in capturing market responses to carbon policy changes, as it better isolates the immediate supply chain adjustments to policy innovations. The delayed response to carbon taxes also suggests that firms may have more time to plan and implement alternative adjustment strategies when facing gradual, predictable policy changes compared to sudden policy shocks.

7.2 Alternative environmental policy measure

The environmental policy stringency (EPS) index is also employed as an alternative measure of environmental regulation. Developed by the OECD, this comprehensive index provides a quantitative assessment of environmental policy stringency across 40 countries from 1990 to 2020, capturing the extent to which national policies impose explicit or implicit costs on polluting activities. The index incorporates both market-based instruments (such as environmental taxes and trading schemes) and non-market regulations (including emission limits and research and development (R&D) subsidies), providing a broader perspective on environmental policy than carbon pricing alone. Figure A1 in Appendix shows the cross-sectional and temporal variations of the EPS index in European countries, highlighting substantial heterogeneity in environmental policy stringency across both countries and time. The following OLS regression is estimated:

$$\mathrm{ImportShare}_{ik,t} = \alpha + \beta \mathrm{EPS}_{i,t} + \theta_p x'_{ik,t} + \sigma_k + \epsilon_{ik,t},$$

where $\mathrm{EPS}_{i,t}$ is the environmental policy stringency index for European country i in year t, $\boldsymbol{x}'_{ik,t}$ is a vector of control variables, σ_k represents sector fixed effects, and $\epsilon_{ik,t}$ is the error term.

Table A2 in the Appendix reports the results from this regression. The estimated coefficients on EPS are positive and highly significant for import share variables (m=1, 2), indicating a robust relationship between environmental policy stringency and carbon-intensive imports from emerging countries. This aligns with the main regression results and provides additional evidence that stricter environmental policies may lead to supply chain adjustments through increased sourcing from countries with weaker environmental regulations. Moreover, additional tests are conducted using a 3-year moving average of the EPS index to capture more persistent policy effects. These results (reported in Appendix Table A3) show similar patterns, further supporting the robustness of the main results.

7.3 Sector composition

While the main analysis compares responses across sectors of different carbon intensities, the robustness of the findings is further tested by excluding energy-intensive sectors. These sectors, including mining and quarrying (NACE B05-B08), petroleum products (C19), chemicals (C20), non-metallic minerals (C23), and basic metals (C24), typically show high sensitivity to carbon policies and often receive special regulatory treatment such as free allowance allocations in the

EU ETS. These sectors are particularly important to examine separately, given their strategic economic importance and their historically significant role in European industrial production. By excluding these sectors, the test determines whether the findings represent broader economic patterns rather than being driven by the most carbon-exposed industries. The results in Figure A3 of the Appendix remain consistent with the main findings, showing similar magnitudes and temporal patterns of adjustment. This consistency further supports the conclusion that supply chain adjustments are not driven solely by energy-intensive industries but reflect broader network effects across different sectors.

8 Conclusions and policy implications

This paper has examined carbon leakage from European countries to emerging economies through supply chain adjustments in response to carbon policies. Using high-frequency identification of carbon policy shocks and local projection methods, this analysis has documented significant changes in cross-border sourcing behaviour. The analysis revealed that carbon policy shocks induce European industries to cumulatively increase their carbon-intensive imports from emerging economies by roughly 0.2 per cent, reaching this peak effect after two years before returning to zero. While statistically significant, this measured response suggests that carbon leakage via supply chains deserves attention in policy design. The short-lived nature of these effects indicates that businesses initially seek flexibility through international procurement but subsequently find alternative ways to adapt, such as investing in cleaner technologies or enhancing operational efficiency.

This analysis reveals important heterogeneous effects across both country and sector dimensions. First, the analysis found that lower-GDP countries experience substantially larger increases in carbon-intensive imports, with cumulative effects peaking at over 0.5 per cent around two years after the shock. In contrast, higher-GDP countries showed minimal or even negative responses, suggesting that economic resources play a crucial role in determining countries' ability to maintain domestic production under stricter environmental regulations. Second, countries without national carbon taxes showed larger increases in carbon-intensive imports compared to those with additional national carbon taxes, highlighting the potential benefits of complementary policy instruments in mitigating carbon leakage. Interestingly, this analysis found relatively homogeneous responses across sectors with different carbon intensities, with only slightly stronger effects in high-carbon sectors. This broad-based pattern suggests that carbon policy effects transmit through supply chain networks beyond just the most carbon-intensive activities, pointing to the importance of considering industry interconnections in policy design.

These findings provide several important policy implications. The stronger responses in lower-GDP countries and those without national carbon taxes suggest that policy coordination and support for vulnerable economies are crucial. The finding that countries with both national carbon taxes and EU ETS show smaller leakage effects suggests that using multiple carbon pricing policies together may work better than using the EU ETS alone. The recent introduction of the Carbon Border Adjustment Mechanism (CBAM) suggests that policymakers recognise these leakage concerns, though future research could examine whether such interventions successfully mitigate the temporary effects this paper documents.

References

Aichele, R., & Felbermayr, G. (2015). Kyoto and carbon leakage: An empirical analysis of the carbon content of bilateral trade. *Review of Economics and Statistics*, *97*(1), 104-115.

Aldy, J. E., & Pizer, W. A. (2014). *Comparability of effort in international climate policy architecture* (HKS Working Paper RWP14-006). Harvard Kennedy School.

Aldy, J. E., & Pizer, W. A. (2015). The competitiveness impacts of climate change mitigation policies. *Journal of the Association of Environmental and Resource Economists*, *2*(4), 565-595.

Ben-David, I., Jang, Y., Kleimeier, S., & Viehs, M. (2021). Exporting pollution: Where do multinational firms emit CO2? *Economic Policy*, *36*(107), 377-437.

Carbone, J. C., & Rivers, N. (2017). The impacts of unilateral climate policy on competitiveness: Evidence from computable general equilibrium models. *Review of Environmental Economics and Policy, 11*(1), 24-42.

Chen, Q., Chen, Z., Liu, Z., Suárez Serrato, J. C., & Xu, D. (2021). *Regulating conglomerates in China: Evidence from an energy conservation program* (NBER Working Paper 29066). National Bureau of Economic Research (NBER).

Ciccarelli, M., & Marotta, F. (2024). Demand or supply? An empirical exploration of the effects of climate change on the macroeconomy. *Energy Economics*, *129,* 107163.

Colmer, J., Martin, R., Muûls, M., & Wagner, U. J. (2024). Does pricing carbon mitigate climate change? Firm-level evidence from the European Union emissions trading system. *Review of Economic Studies*, *rdae055*.

Copeland, B. R., Shapiro, J. S., & Taylor, M. S. (2022). Globalization and the environment. In G. Gopinath & K. Rogoff (Eds.), *Handbook of International Economics* (Vol. 5, pp. 61-146). Elsevier. https://doi.org/10.1016/bs.hesint.2022.02.002

Cui, J., Wang, C., Wang, Z., Zhang, J., & Zheng, Y. (2023). *Carbon leakage within firm ownership networks* (SSRN Paper 4514971). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4514971

Dechezleprêtre, A., Gennaioli, C., Martin, R., Muûls, M., & Stoerk, T. (2022). Searching for carbon leaks in multinational companies. *Journal of Environmental Economics and Management*, *112,* 102601.

Dolphin, G., & Xiahou, Q. (2022). World carbon pricing database: Sources and methods. *Scientific Data*, *9*(1), 573.

Ederington, J., Levinson, A. & Minier, J. (2005). Footloose and pollution-free. *Review of Economics and Statistics*, *87*(1), 92-99.

Fowlie, M. L., & Reguant, M. (2018). Challenges in the measurement of leakage risk. *AEA Papers and Proceedings*, *108,* 124-129.

Fowlie, M. L., & Reguant, M. (2022). Mitigating emissions leakage in incomplete carbon markets. *Journal of the Association of Environmental and Resource Economists*, *9*(2), 307-343.

Gertler, M., & Karadi, P. (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, *7*(1), 44-76.

Gürkaynak, R. S., Sack, B. P., & Swanson, E. T. (2004). *Do actions speak louder than words? The response of asset prices to monetary policy actions and statements. The response of asset prices to monetary policy actions and statements* (Finance and Economics Discussion Series (FEDS), Staff Working Paper 2004-66). Divisions of Research & Statistics and Monetary Affairs Federal Reserve Board.

Hengge, M., Panizza, U., & Varghese, R. (2023). *Carbon policy surprises and stock returns: Signals from financial markets* (SSRN Paper 4343984). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4343984

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, *95*(1), 161-182.

Jordà, Ò., Schularick, M., & Taylor, A. M. (2015). Betting the house. *Journal of International Economics*, *96*, 2-18.

Känzig, D. R. (2023). *The unequal economic consequences of carbon pricing* (NBER Working Paper 31221). National Bureau of Economic Research (NBER).

Känzig, D. R., & Konradt, M. (2023). *Climate policy and the economy: Evidence from Europe's carbon pricing initiatives* (NBER Working Paper 31260). National Bureau of Economic Research (NBER).

Levinson, A., & Taylor, M. S. (2008). Unmasking the pollution haven effect. *International Economic Review*, *49*(1), 223-254.

Metcalf, G. E., & Stock, J. H. (2020). Measuring the macroeconomic impact of carbon taxes. *AEA Papers and Proceedings*, *110,* 101-106.

Naegele, H., & Zaklan, A. (2019). Does the EU ETS cause carbon leakage in European manufacturing? *Journal of Environmental Economics and Management*, *93,* 125-147.

Nakamura, E., & Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: The information effect. *The Quarterly Journal of Economics*, *133*(3), 1283-1330.

Sato, M., & Dechezleprêtre, A. (2015). Asymmetric industrial energy prices and international trade. *Energy Economics*, *52,* 130-141.

Sato, M., Singer, G., Dussaux, D., & Lovo, S. (2015). *International and sectoral variation in energy prices 1995-2011: How does it relate to emissions policy stringency?* (Working Paper 212). Grantham Research Institute on Climate Change and the Environment.

Wang, H. (2024). *Beyond borders: The impact of embodied carbon policy costs on industrial firm performance* (SSRN Paper 4936398). https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4936398

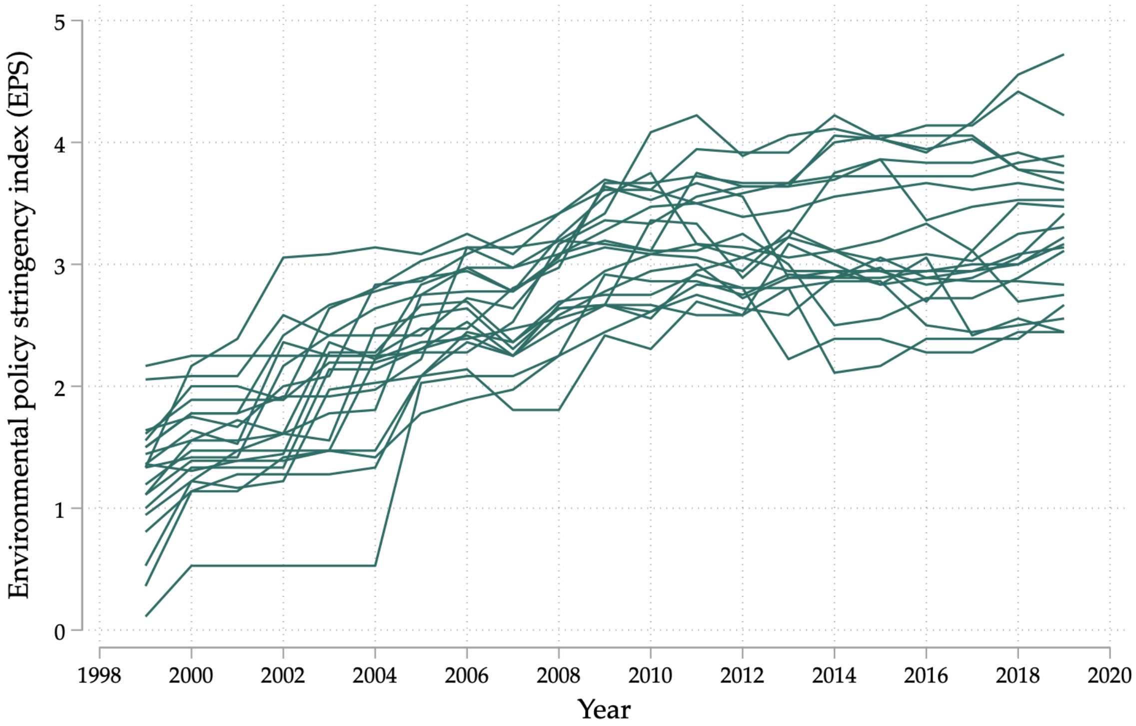
Appendix

Table A1: Variable description

Variable	Description and Unit
ImportShare[1]	Share of imports over total imported inputs (%)
ImportShare[2]	Share of imports over total inputs (%)
ImportShare[3]	Share of imports over total domestic supply (%)
CPShock (baseline)	Carbon policy shock (€/MWh)
CPShock (pct)	Carbon policy shock (percentage change)
Log(GDP)	Log of GDP (2015 US$)
Log(carbon intensity)	Log of CO_2 (2015 US$)
ETS Price	Log of CO_2 emissions per unit of economic output
Carbon tax rate	EU Emissions Trading System carbon price (€/t CO_2)
PPI	Producer prices in industry (index, 2015=100)
Trade openness index	Trade as share of GDP (%)

Notes: This table provides variable definitions. For summary statistics, refer to Table 1 in the main text.

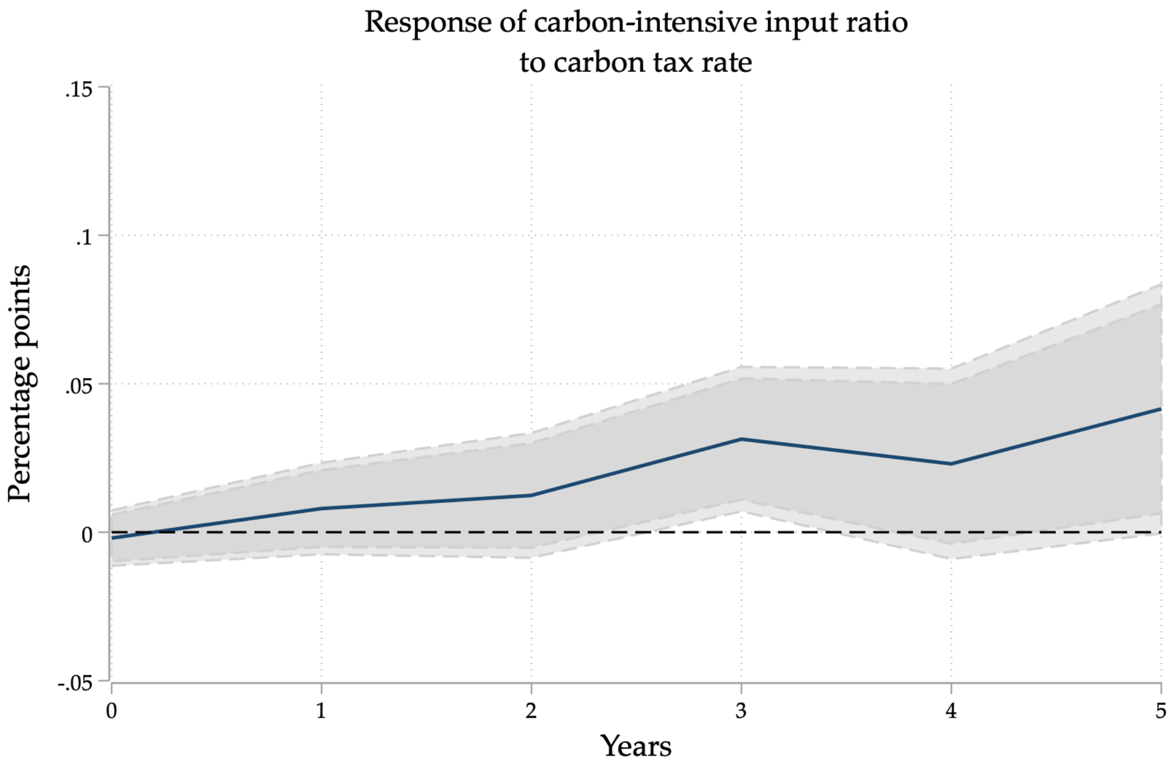
Figure A1: Cross-sectional and temporal variation of EPS index



Notes: This figure shows the temporal evolution of the Environmental Policy Stringency (EPS) index for the 16 European countries (as the sourcing countries) in the data sample. The EPS index serves as a measure of the stringency of environmental policies and regulations in each country over time.

Source: Author, based on EPS data from OECD

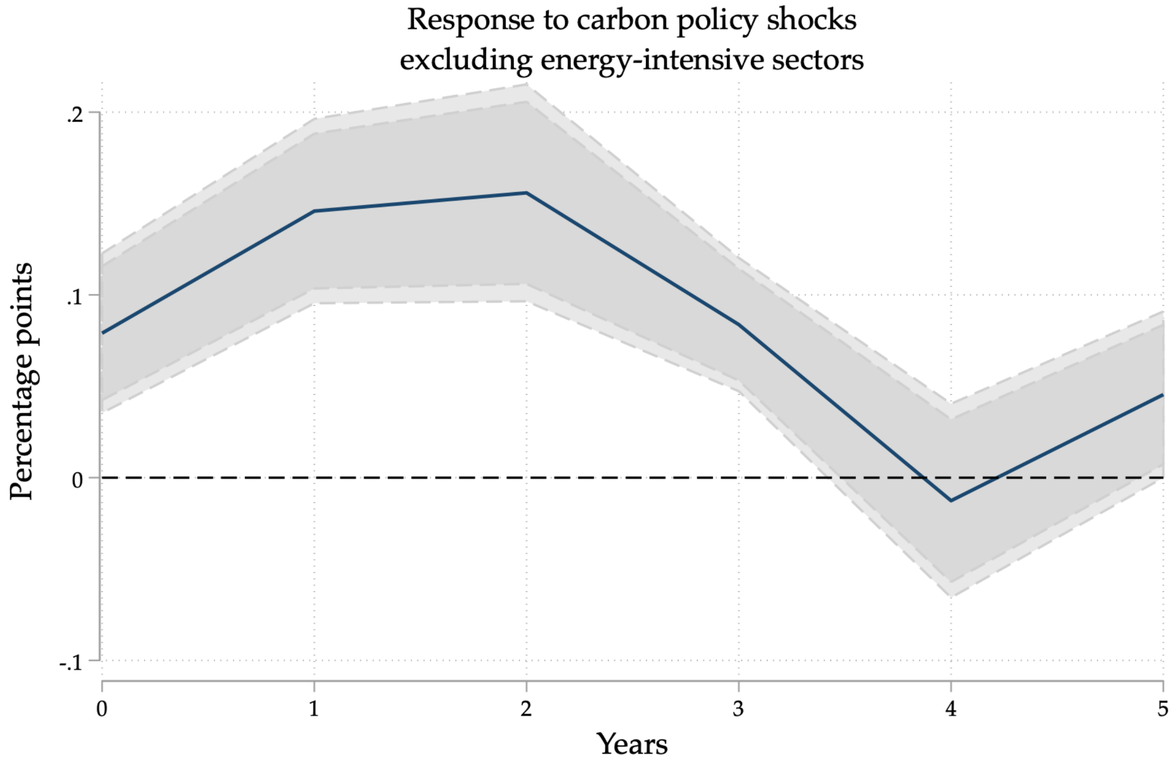
Figure A2: Robustness: impulse responses to carbon tax rate



Notes: This figure plots the impulse responses of input sourcing from emerging economies to carbon taxes, estimated using local projection. The outcome variable of interest is the fraction of inputs that industry sector k in country i sources from emerging economies in year t+h, relative to all inputs in carbon-intensive sectors.

Source: Author’s calculations

Figure A3: Robustness: restricted sample excluding energy-intensive sectors



Notes: This figure plots the impulse responses of input sourcing from emerging economies following a carbon policy shock, estimated using local projection. The sample used in this regression excludes energy-intensive sectors, specifically those with NACE 2-digit codes B05-B08 (Mining and Quarrying), C19 (Manufacture of Coke and Refined Petroleum Products), C20 (Manufacture of Chemicals), C23 (Manufacture of Other Non-metallic Mineral Products), and C24 (Manufacture of Basic Metals). The outcome variable of interest is the fraction of inputs that industry sector k in country i sources from emerging economies in year t+h, relative to all inputs in carbon-intensive sectors. Carbon policy shocks (baseline) are extracted from the carbon policy surprises measured as euro change in carbon price, relative to prevailing wholesale electricity price Känzig (2023). Solid lines represent point estimates, while dark- and light-shaded areas indicate 90 per cent and 95 per cent confidence bands, respectively.

Source: Author’s calculations

Table A2: Environmental policy stringency and import shares from emerging countries

VARIABLES	(1) ImportShare[1]	(2) ImportShare[2]	(3) ImportShare[3]
EPS	2.608***	1.299***	9.203
	(0.361)	(0.251)	(7.417)
Log(GDP)	2.397***	1.179***	8.732
	(-0.918)	(0.190)	(5.398)
Log(carbon intensity)	-0.918	0.190	26.08
	(1.181)	(0.900)	(25.33)
PPI	-0.331***	-0.187***	-0.512
	(0.0388)	(0.0322)	(0.626)
Trade openness	0.239***	0.157***	1.601***
	(0.0249)	(0.0201)	(0.433)
Constant	-22.38***	-5.626	-64.21
	(7.167)	(4.543)	(67.99)
Observations	13950	13951	13950
R-squared	0.290	0.315	0.160
Adjusted R-squared	0.286	0.311	0.155

Notes: ImportShare[1,2,3] represent the share of imports over (1) total imported inputs, (2) total inputs, and (3) total domestic supply, respectively, in carbon-intensive sectors. Robust standard errors are clustered at the sector level. *, **, and *** indicate significance at the 10 per cent, 5 per cent, and 1 per cent levels, respectively.

Source: Author's calculations

Table A3: Environmental policy stringency and import shares from emerging countries

VARIABLES	(1) ImportShare[1]	(2) ImportShare[2]	(3) ImportShare[3]
EPS_3MA	2.419***	1.284***	14.06*
	(0.390)	(0.276)	(7.593)
Log(GDP)	2.497***	1.190***	8.647
	(0.290)	(0.244)	(5.639)
Log(carbon intensity)	-0.879	0.272	31.40
	(1.201)	(0.939)	(26.42)
PPI	-0.387***	-0.215***	-0.708
	(0.0438)	(0.0365)	(0.698)
Trade openness	0.236***	0.155***	1.605***
	(0.0248)	(0.0201)	(0.444)
Constant	-29.42***	-16.56***	-245.3*
	(6.106)	(5.291)	(143.7)
Observations	13147	13148	13147
R-squared	0.295	0.320	0.163
Adjusted R-squared	0.291	0.316	0.158

Notes*:* ImportShare[1,2,3] represent the share of imports over (1) total imported inputs, (2) total inputs, and (3) total domestic supply, respectively, in carbon-intensive sectors. Robust standard errors are clustered at the sector level. *, **, and *** indicate significance at the 10 per cent, 5 per cent, and 1 per cent levels, respectively.

Source: Author's calculations