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Essays on Environmental Policies, Firm Performance, and Global Supply Chains

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

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by

Hanyi Wang

Committee in charge:

Professor Mark Jacobsen, Chair
Professor Judson Boomhower
Professor Michael Davidson
Professor Joshua Graff-Zivin

2024

The Dissertation of Hanyi Wang is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2024

DEDICATION

To my family.

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ABSTRACT OF THE DISSERTATION

Essays on Environmental Policies, Firm Performance, and Global Supply Chains

by

Hanyi Wang

Doctor of Philosophy in Economics

University of California San Diego, 2024

Professor Mark Jacobsen, Chair

This dissertation investigates the impact of environmental policies on firm performance and global supply chain relationships through three chapters. The first chapter introduces a novel measure of embodied carbon policy costs, incorporating multi-region input-output linkages, to examine the effects of carbon pricing on industrial firm outcomes in Europe. The findings reveal that the inclusion of indirect costs via the global value chain leads to a decrease in firm employment and output and an increase in total factor productivity and investment, with more pronounced impacts for small and capital-intensive firms.

The second chapter explores the transmission mechanism of sustainable investing on firms' financial performance and real outcomes. Focusing on the prevalent portfolio tilting strat-

egy in practice, we delineate the transmission mechanism from investor preference, intermediated by funds, to underlying firms. Leveraging a 2016 natural experiment for identification, we find that firms with greater exposure to low-sustainability fund ownership experience acute downward pressure on their valuation and equity financing. However, no significant impact is observed on firm debt financing, consistent with our observation that the transmission of investors' pressure for sustainability falls short of generating substantial real impacts on firms' investment decisions.

The third paper examines the impact of environmental regulations on global supply chain relationships using a dataset linking customer firms to their suppliers. The study reveals that customers are more likely to terminate supplier relationships in response to more stringent environmental policies in supplier countries, with the effect being less pronounced for manufacturing customer firms and suppliers located in countries with emissions trading systems. Further analysis shows a relatively limited impact of the average supplier country's Environmental Policy Stringency on customer firms' performance, possibly due to low switching costs and competitive supplier markets.

Chapter 1

Beyond Borders: The Impact of Embodied Carbon Policy Costs on Industrial Firm Performance

Abstract: While policymakers generally regard carbon pricing as effective and efficient, the average price of emissions worldwide remains low. A major concern is that unilateral enhancement of carbon policy could negatively impact firms' competitiveness and performance. This paper investigates the impact of carbon policy on industrial firm outcomes in Europe, introducing a novel measure of embodied carbon policy costs that incorporates multi-region input-output linkages. In contrast to prior studies that have found limited effects from direct carbon policy costs, the inclusion of indirect costs via the global value chain leads to findings here that include a decrease in firm employment and output and an increase in total factor productivity and investment. These impacts tend to be more pronounced for small firms and for capital-intensive firms. Finally, a novel test for input substitution in this context estimates the extent to which carbon policy costs drive European industrial sectors to source inputs from countries lacking carbon regulations.

1.1 Introduction

Economists agree that putting a price on carbon emissions is the most effective and efficient tool to mitigate climate change, especially from a public finance perspective. However, only a small group of nations worldwide, predominantly in Europe, have implemented carbon policies. The global average carbon price is only \$6.11 per ton of CO_2[1], while the estimated social costs of carbon (SCC) is updated to be \$185 (Rennert et al., 2022). The major impediment to more stringent carbon policies is the policymakers' belief that implementing them would hinder economic growth.

Unilateral enhancement of carbon policies might impose risks on the international competitiveness of the regulated entities. According to the pollution haven hypothesis, imbalances in environmental policy stringency across regions might cause businesses to shift their operations with laxer environmental policies (Levinson and Taylor, 2008). In the context of climate change and carbon emissions, such disparities might lead to "carbon leakage" — carbon emission reductions in one region might lead to an increase in carbon emissions elsewhere, undermining the overall climate change mitigation goal.

Previous studies that use the event-study approach or difference-in-difference method might yield estimates based on empirical evidence regarding how carbon policies affect the economy. This is because they do not consider the indirect effects on the unregulated sectors from a general equilibrium perspective (Hafstead and Williams III, 2018). Carbon policies usually target the upstream sectors for efficiency concerns. However, the carbon price imposed on one sector could propagate through the global value chain, creating ripple effects that influence production costs, consumer prices, and trade dynamics. This study adds micro-level evidence to the literature focusing on redistributing environmental burdens between industries (Fullerton, 1996). Building upon this foundational work, this paper adopts the framework from Acemoglu et al. (2016a), which delves into the general equilibrium impact of growing Chinese imports on US employment.

Industry input-output linkages can cause both positive and negative shifts in firm operations, resulting in a net effect whose direction remains uncertain. As mentioned by Levinson (2009), understanding the full impact of carbon policies requires considering not only the pollu-

[1] According to the World Banks's State and Trends of Carbon Pricing 2022.

tion embodied in intermediate inputs but also the pollution embodied in the inputs to inputs and beyond. In light of this context, two questions arise: what are the embodied carbon policy costs from each stage of the production process when considering input-output relationships? And, how do those costs influence firm performance and sectoral sourcing patterns?

To answer these questions, this paper constructs a novel measure of embodied carbon policy costs. This measure integrates sectoral linkages using disaggregated carbon policy data from around the world, capturing the ripple effect of rising prices of intermediate goods through production chains. Consider the example of a car manufactured in Germany. Its selling price may increase due to the EU ETS elevating electricity prices from utility companies or because of the rising costs of Swedish steel that is used to produce automotive parts as a result of the Swedish carbon tax. This method builds on the carbon accounting literature, which calculates embodied carbon emissions embodied in the intermediate inputs, and also intermediate inputs to those intermediate inputs, and so on *ad infinitum* (Davis and Caldeira, 2010; Levinson, 2009). I extend this method by not only considering the embodied emissions but also by multiplying these emissions by the corresponding carbon prices imposed at each stage of production. The embodied carbon costs in a sector can then be summed in a way analogous to the aggregation used to derive total embodied carbon emissions. In other words, this method translates physical carbon footprints into economic costs induced by carbon policies.

In Europe, the EU Emissions Trading Systems (EU ETS) and carbon taxes are the two major market-based tools assigning a price to carbon emissions. Yet, it's crucial to note that other carbon policies outside of Europe can also influence the cost of emitting carbon. For example, British Columbia's carbon tax introduced in 2008, and the California Cap-and-Trade Program introduced in 2013. By inverting the input-output tables, I obtain both the direct costs originating from regional carbon policy (such as the EU ETS and carbon taxes) and overall embodied costs, factoring in sectoral linkages that extend beyond EU borders.

I draw from the World Carbon Pricing Database compiled by Resources for the Future (RFF), which provides granular carbon pricing data in 43 countries and 210 IPCC sectors. I further obtain multi-region input-output (MRIO) tables from Exiobase, which covers 44 countries and 163 sectors.[2] Drawing upon these datasets, I then link the embodied carbon policy costs with detailed microdata on industrial firms' balance sheet information obtained from Orbis. The final sample includes one billion firm-year observations from 1998 to 2019, across 16 European countries[3] in 100 unique NACE 3-digit industrial sectors. I choose several firm-level outcome variables of interest: employment, sales, total factor productivity (TFP), and tangible and intangible assets.

Leveraging sector by country by year level variation, I explore how embodied carbon policy costs influence firm competitiveness. The main variation emerges from the disparities in carbon pricing schemes across countries and sectors, which encompass variations in carbon prices as well as the extent of sectoral coverage. My empirical strategy tests the following hypotheses: First, does EU carbon pricing cause industrial firms to downsize their operation? Second, does EU carbon pricing lead to increased firm TFP and investment? At the sector level, is there a tendency for the industrial sector to source input from countries without carbon policies?

The identification strategy in this study centers on estimating the average treatment effect of embodied carbon policy costs on firm-level outcomes. Endogeneity concerns arising from potential correlations between policy decisions and unobserved firm-level variables are addressed through a shift-share instrumental variable framework. This framework utilizes industry-specific carbon costs from foreign carbon policy shifts, weighted by pre-sample 'exposure shares.' These shares are entries in the Leontief inverse matrices, which quantify each sector's susceptibility to foreign carbon policy changes. The approach assumes these foreign policy shifts are uncorrelated with domestic firm performance shocks, thus the 'shock exogeneity' Borusyak et al. (2022). I include firm- and year-fixed effects to control for unobserved heterogeneity and time-varying shocks, respectively, with standard errors clustered at the country-by-sector level. The regressions

[2]Exiobase has its own sector classifications.

[3]These countries are Czech Republic, Germany, Estonia, Spain, France, United Kingdom, Greece, Hungry, Italy, Latvia, Norway, Poland, Portugal, Romania, Sweden, and Slovenia

are weighted by firm size to ensure a balanced representation across different firm sizes.

Firm-level estimation results indicate that direct (i.e. within country) carbon pricing costs do not cause adverse effects on firm competitiveness, consistent with the previous literature. In contrast, overall carbon policy costs, factoring in sectoral linkages, have negative and significant but small impacts on the employment and sales of surviving firms, while potentially encouraging efficiency gains and tangible assets investments. Specifically, a 1% increase in overall carbon pricing costs, everything else being equal, is associated with a 0.0456% decrease in firm employment, a 0.0187% decrease in sales, a 0.00783% increase in total factor productivity (TFP), and a 0.0425% increase in tangible assets investment. There is also a positive effect on intangible assets, although the result is not statistically significant. Compared to the literature that uses energy price variation as a proxy for carbon policy, the magnitude of the employment elasticity attributable to carbon policy estimated in this study is smaller than the employment elasticity of energy prices found in existing research (Marin and Vona, 2021).

These impacts are heterogeneous along a range of dimensions. In particular, smaller or capital-intensive firms are relatively more negatively impacted. Interestingly, firms in highly carbon-intensive sectors face less negative employment impacts. Firms in high-GDP countries exhibit less negative impacts on employment and sales and also show lesser positive impacts on Total Factor Productivity (TFP) and investments compared to their counterparts in mid-GDP countries. Firms in countries that have implemented carbon taxes, in addition to participating in the EU-ETS, have more TFP gains and show more positive impacts on intangible assets.

Sectoral-level regression shows that sectors with higher embodied carbon policy costs tend to source more inputs from countries with laxer carbon policies. This result indicates a potential strategic adaptation by sectors trying to mitigate the challenges of stricter carbon regulations domestically. Such an outsourcing pattern may lead to carbon leakage, where a reduction in emissions in one country is offset by increases in another, undermining the effectiveness of climate policies.

This study's main contribution is to provide a tool for policymakers to evaluate the overall embodied carbon policy costs from various domestic and international climate policies. These costs are linked to a country's economy's input-output structure and patterns of input sourcing from overseas. It is important to note that this study only considers explicit carbon policies such as emissions trading systems and carbon taxes. However, countries often resort to second-best climate policies, implementing various climate policies like technology mandates or subsidies for renewable energy. Thus, it is important to also include those implicit carbon policies in future analysis. Nonetheless, the insights provided by this paper have a series of policy implications, especially relevant when there are increasing cross-border policies such as Europe's Carbon Border Adjustment Mechanism (CBAM). Policies should also be tailored to support more vulnerable firms disproportionately affected by carbon policies while fostering global cooperation to prevent carbon leakage.

Related literature and contribution

This paper contributes to a growing literature studying the effects of carbon pricing and to the literature investigating carbon leakage and trade implications. As highlighted in the review by Martin et al. (2016), discerning the causal impact of carbon pricing is complex since firms' participation in the EU ETS is non-random. Studies such as (Wagner and Petrick, 2014; Naegele and Zaklan, 2019; Dechezleprêtre et al., 2023) find no evidence supporting strong adverse effects of carbon policies like the EU ETS on firm performance. After considering the linkage effects, my paper estimates more negative competitive impacts compared to the existing studies. Past literature often uses energy prices as proxies for carbon prices. However, this may raise concerns as firms could respond differently to carbon pricing compared to shifts in energy prices (Ganapati et al., 2020; Marin and Vona, 2021; Trinks and Hille, 2023; Somers, 2023). This paper contributes to the political debate of to what extent climate policies would hurt firms or producers by directly focusing on the overall costs of carbon policies.

Several papers have already incorporated indirect components of environmental policies. Hassett et al. (2009) finds that the direct component of a carbon tax is significantly more regressive than the indirect component. Naegele and Zaklan (2019) developed measures of carbon policy stringency that incorporate the indirect emission costs stemming from electricity use. However, their scope was primarily confined to the transmission of emission costs within the power sector, and their measures were tailored specifically for individual sectors. This paper generalizes this approach by considering the full carbon policy component of price (costs via the purchase of inputs subject to carbon policies).

This paper is related to the trade and environment literature Grossman and Krueger (1995); Copeland and Taylor (2004); Shapiro and Walker (2018). Moreover, this paper also connects to an expanding body of research on potential "carbon leakage" from environmental regulations (Elliott et al., 2010; Martin et al., 2014; Aichele and Felbermayr, 2015; Fowlie et al., 2016). In contrast to these papers which focus on theoretical frameworks either using computable general equilibrium models or trade models, my approach offers a highly parsimonious reduced-form empirical specification that does not rely on many model assumptions. As Fullerton et al. (2008) highlights, the increased production costs due to domestic environmental taxes might affect the competitive position of domestic firms if foreign producers are not subject to similar environmental taxes. This paper also relates to the literature on international trade and industrial organization that delves into global value chains and international production networks. As highlighted by Fieler et al. (2018), trade effects on importers and exporters can be magnified through domestic input linkages. Building on this these inshgts, this paper extends the discussion to the environmental realm, focusing on the amplified effects of carbon policies through input linkages both domestically and internationally.

This chapter proceeds as follows. Section 1.2 describes the carbon policy background. Section 1.3 presents empirical methods. Section 1.4 describes the data. Section 1.5 presents and discusses the results, and Section 1.6 concludes.

1.2 Carbon Policy Background

1.2.1 Carbon Policies Around the World

The European Union launched its Emissions Trading System (ETS) in 2005 as a pioneering effort for global carbon policies. In 2008, British Columbia became the first North American jurisdiction to implement a revenue-neutral carbon tax. Australia also introduced a Carbon Pricing Mechanism (CPM) in 2012 under the Gillard government. As of 2019, there were 57 carbon pricing initiatives either implemented or slated for introduction worldwide, including 28 emissions trading systems (ETSs) at regional, national, and subnational levels, and 29 carbon taxes, primarily applied at the national level. These carbon pricing initiatives cover about 20 percent of the global GHG emissions (Ramstein et al., 2019). More countries are now pricing carbon, but the average emission prices remain too low. For effective control of global warming, not only does coverage need to expand, but the price must also increase from the current global average of \$6 per ton of CO2 to \$75 by 2023.

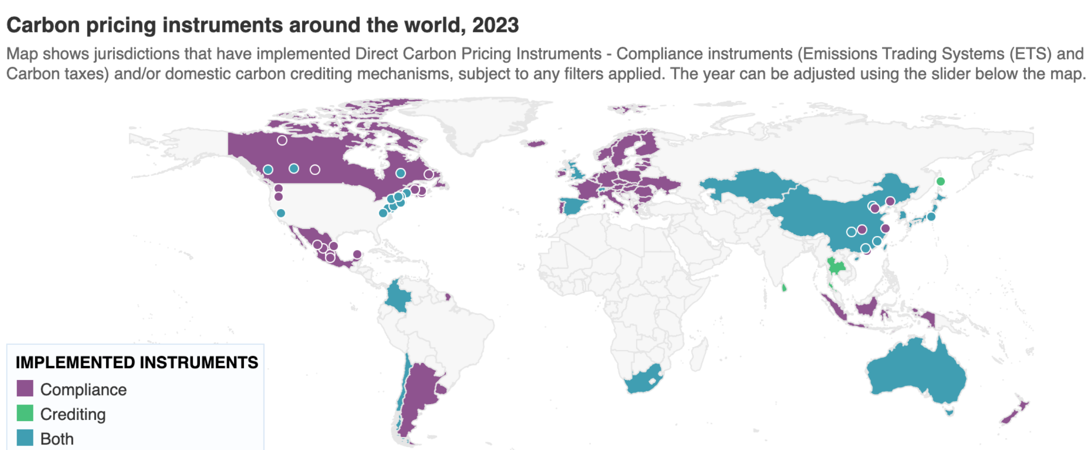


Figure 1.1. Carbon Pricing Instruments Around the World

Notes: This map displays the existing carbon pricing instruments worldwide as of 2023. Data source: World Bank Carbon Pricing dashboard.

1.2.2 Carbon Policies in Europe

Europe has been at the forefront of implementing carbon policies. The EU Emissions Trading System (EU ETS) and carbon taxes are two examples of market-based instruments that put a cost to carbon emissions in Europe. The EU ETS, covering 27 EU member states and also extending to Iceland, Liechtenstein, and Norway as part of the European Economic Area (EEA), primarily targets large emission sectors such as refineries, steel, and chemical industries. This 'cap and trade' system has reduced emissions from power and industry by 37% since 2005 through annually lowering emission caps. 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.[4] To maintain a consistent analytical framework and avoid these confounding factors, this study confines observations to the years up to and including 2019.

Carbon taxes, in contrast with the ETS system, only exist in a subset of European countries. Thoes taxes are determined at the national level and focus on the sectors excluded from the ETS, such as the transportation and the construction sectors[5]. Carbon taxes were firsly implemented in Norway and Sweden in the 1990s, well before the introduction of the EU ETS. To date, sixteen European countries have implemented carbon taxes. To avoid overlapping policies, policy-makers gave exemptions to the sectors originally covered by carbon taxes once they were included in the EU ETS.

Most of the previous studies only focus on a single policy, with exceptions of the studies such as Hassett et al. (2009) and Känzig and Konradt (2023). To assess the overall effects of

[4] See https://economic-research.bnpparibas.com/html/en-US/European-carbon-price-time-high-3/1/2023,48321.
[5] Out of the 31 countries in the EU ETS, 16 have implemented carbon taxes.

carbon pricing, it is crucial to consider both policy schemes, including the carbon taxes and the ETS systems. Moreover, it is also essential to consider carbon policies beyond Europe. Carbon policies in other regions can also influence the prices of the goods imported to Europe, thereby imposing indirect costs on European firms.

1.3 Empirical Methods

1.3.1 Identification Challenges

An ideal evaluation of the competitiveness impact of carbon pricing would create a study design that only credits the policies for the actual changes it induces in those firms. One of the challenges here is identifying and isolating the impact of carbon policies, given that various other factors are simultaneously influencing firm behavior. Moreover, the participation of firms in the EU ETS is not random. In practice, a randomized control trial in carbon pricing is not feasible politically. Researchers typically resort to conventional econometric methods such as the differences-in-differences method with a strong assumption that the carbon policies don't affect unregulated firms. However, the control group might be contaminated since the carbon polciy effect may be transmitted through the supply chain.

1.3.2 A Continuous Measure of Embodied Carbon Policy Costs

Policies imposed on one sector can propagate through the global value chain. For example, an increase in the carbon prices imposed on the energy sector could increase production costs for energy-reliant manufacturers, even if they are not directly subject to carbon pricing. The increased costs could be then passed down to consumers through higher output prices, leading to shifts in demand patterns. The overall embodied carbon pricing costs can be decomposed into (i) direct costs from policies, (ii) indirect costs from domestic linked sectors, and (iii) indirect costs from foreign imports.

Leontief Input-Output Framework

This section utilizes a Leontief Input-Output Framework when calculating the overall embodied costs due to carbon policies. Envision the global economy characterized by S sectors in each of the N countries. Let matrix **A** denote an $NS \times NS$ multi-region input-output (MRIO) table. In this table, each row represents inputs supplied from a specific country$\times$sector, while each column represents outputs demanded by another country sector. The entries from the MRIO table represent the monetary value of inputs from a row's country$\times$sector needed to generate a dollar's worth of output for the column's country$\times$sector.

$$\underset{NS\times NS}{\mathbf{A}} = \begin{pmatrix} a_{11} & a_{12} & & \cdots & \\ a_{21} & a_{22} & & & \\ & & \ddots & & \\ & & & & \\ & & & & \end{pmatrix}.$$

Let **x** be an $N \times S$ matrix representing a specific country$\times$sector's gross output and let **d** by an $N \times S$ matrix of final demand (including the final use of domestic product and imported product). Using an accounting identify: each country$\times$sector's gross output equals the value of its output used for intermediate goods in all industries plus the value of its output used for final demand, we have: $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{d}$. Solving the equation for **x** we get: $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{d}$. The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix **L**. Each entry l_{ijsk} of the Leontief inverse matrix represents the dollars of output from sector s in the country i required to produce one dollar of output from sector k in the country j at year t, including the entire global value chain (inputs, inputs to inputs, etc.).

Embodied Carbon Policy Costs With Input-Output Linkages

The impact of carbon prices on a particular industry can have ripple effects throughout the economy, leading to changes in other prices. The consumer might end up paying more for a good that is not subject to carbon prices. I measure the effective carbon price by inverting MRIO tables, accounting for indirect carbon prices embodied in imported inputs. I constructed a measure of overall embodied carbon policy stringency that includes both direct and indirect effects (through domestically linked industries and trade from foreign policies). Assuming that the market is perfectly competitive[6], I derive sector k's embodied carbon price costs in country j at year t to be :

$$g_{jk,t} = \sum_{i,s} l_{ijsk,t} E_{is,t} \tau_{is,t}, \tag{1.1}$$

where l_{ijsk} denotes the entries of Leontief inverse $\mathbf{L}$, E_{is} represents the direct emissions from producing \$1000 of output from country i in sector s at year t, i.e., the CO_2 emitted from burning coal, oil, and natural gas used directly in this country x sector. $\tau_{is,t}$ is the effective carbon price in the country i sector s at year t (sum of carbon market permit price and carbon tax, if available). I constructed a yearly series of carbon policy costs[7] for industries in European countries. I use the input-output tables which changes over the years, assuming that the input substitutions could happen over time. This method slightly relaxes the assumption made in Fullerton (1996) that input coefficients are fixed and that when one input price rises, producers cannot switch or source cheaper inputs from countries with laxer carbon regulations. Thus, this measure creates snapshots of the costs faced by different sectors over time due to carbon policies. Figure 1.2 shows the variations in the embodied carbon policy costs across countries; Figure 1.3 and Table 1.11 show the variations in direct and overall carbon policy costs among industries.

[6]Fullerton (1996): "No firms make abnormal profits, in the long run, after all prices and outputs have adjusted. The reasonableness of this assumption can be checked by looking at four-firm concentration ratios, the percent of each industry output produced by the largest four firms in the industry. When this ratio is less than half, Scherer (1979) concludes that the industry is adequately competitive."

[7]The costs are deflated to constant 2015 US dollars.

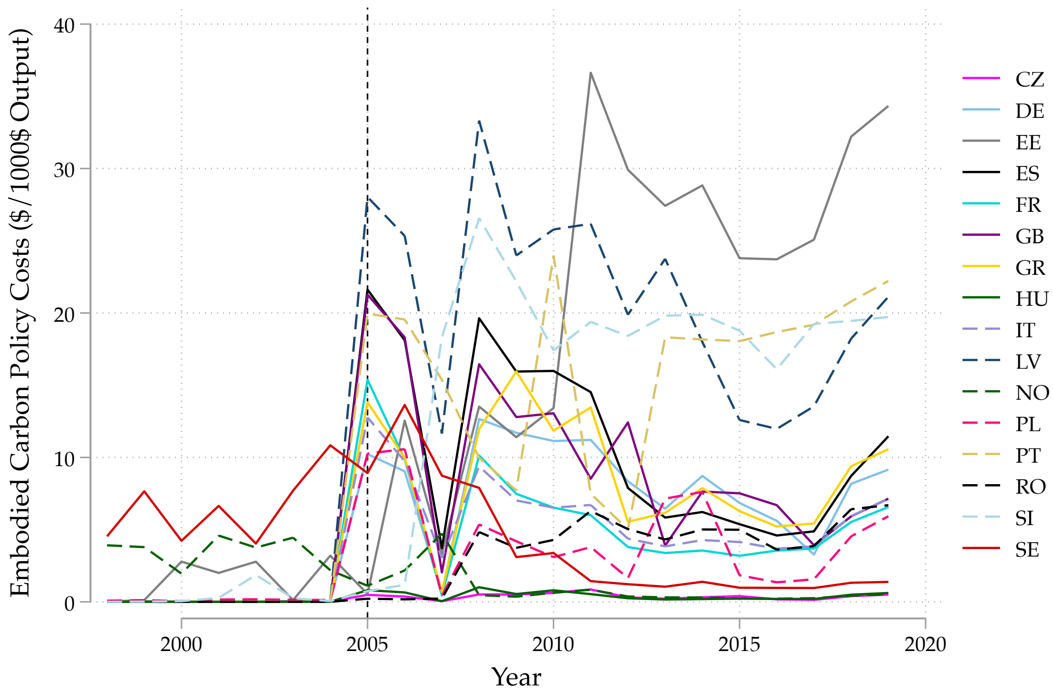


Figure 1.2. Embodied Carbon Policy Costs - All Sectors

Notes: The figure plots the average embodied carbon policy costs as defined in equation (1.1) across all sectors in 16 European countries from 1998 to 2019. The dashed line marked 2005 represents the year the European Emissions Trading System (EU ETS) was first introduced. The averages are calculated prior to merging with firm-level data. This is to avoid sample bias and to represent variations in carbon policy stringency across countries accurately.

This measure is similar to the continuous measures of the emission costs as in Naegele and Zaklan (2019), which calculates the costs based on several measures of environmental policy stringency.[8] This paper further generalizes the measure using the input-output tables, calculating the additional costs associated with the entire global supply chains. The embodied carbon price costs $g_{j,k},t$ captures the direct emission costs of the sector k and the indirect costs resulting from the carbon prices imposed on the suppliers of k, and the suppliers of the suppliers. I normalized the carbon policy costs in terms of "$ of carbon price per $1000 of output", enabling an easier comparison across different industries.

[8]Naegele and Zaklan (2019) argues that the abatement costs are a more appropriate measure of environmental policy stringency when studying the impact from the emissions trading system, and the emission costs are good proxies for the policy stringency.

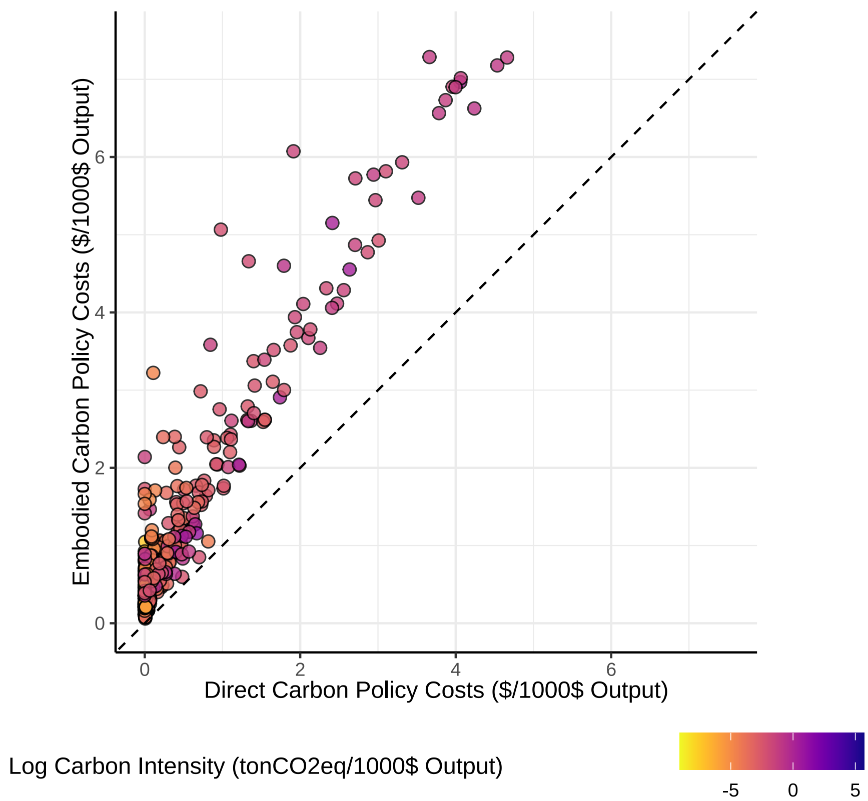


Figure 1.3. Carbon Pricing Exposures (Total and Direct) and Carbon Intensity, Industrial Sectors

Notes: The figure plots the average total carbon pricing exposure rate ($/1000$) against the average direct CO_2 carbon pricing exposure rate at NACE 3-digit sector levels over the years 1998-2019. The blue dots are filled with the average carbon emission intensity (tonCO_2eq/1000 $ Output), with darker colors representing more carbon-intense NACE 3-digit sectors. The dashed line is the 45-degree line.

When survey methods are absent, and the firms' emission abatement costs are unobservable, I argue that this measure provides a close picture of the carbon emission costs to the firms due to various climate change policies. Figure 1.3 provides a comparison between the direct carbon policy costs ${g^{\text{direct}}}_{jk,t} = E_{jk,t}\tau_{jk,t}$ and the overall carbon policy costs as in equation (1.1). The non-zero overall carbon policy costs, which are the main interests of this paper, are higher than the non-zero direct carbon policy costs. Around 48.6% of the observations have zero direct carbon policies, while all observations have non-zero overall carbon policy costs. The EU Member States might consider their own economic conditions when deciding on carbon prices.[9]

[9]For EU ETS, each country within the EU is responsible for determining the specific sectors and sub-sectors that

Thus, I instrument the carbon price costs using the changes in foreign carbon prices transmitted through inter-country input-output linkages.

1.3.3 Instruments for Embodied Carbon Policy Cost

Endogeneity concerns might rise when regression the embodied carbon policy costs on firm-level variables. This is because policymakers might consider domestic economic conditions when implementing carbon policies. These conditions could be correlated with unobserved firm-level variables, leading to biased estimates. To address this, I adopt the shift-share instrumental variable framework (SSIV)[10] by defining:

$$g_{jk,t}^{\text{foreign}} = \sum_{i \neq j,s} l_{ijsk,pre} E_{is,t} \tau_{is,t}, \tag{1.2}$$

where $g_{jk,t}^{\text{foreign}}$ denotes industry-specific carbon price costs in the country j through imports due to the changes in carbon policies in countries other than country j at year t. These are weighted sums of a set of emission-adjusted carbon policy shocks coming from foreign countries, with weights $l_{ijsk,pre}$ reflecting heterogenous pre-sample exposure shares. These weights are based on the multi-region input-output tables from the year 1997, which is the pre-sample year for our study period of 1998-2019. I use time-invariant shares for identification due to the concern that the changes in input-output structures might be driven by unobserved factors that also affect firm-level outcomes of interest.

will be included in the EU ETS, as well as the allocation of allowances to companies within each sector. The EU carbon taxes are set each year by the individual government based on various factors such as political will, level of economic development, energy mix and emissions profile, competitiveness concerns, etc., thus subject to the endogeneity issue.

[10]The shift-share instrumental variable framework has been used in many settings, such as exposure of countries to fluctuations in the U.S. food aid supply Nunn and Qian (2014), trade dynamics (Kovak, 2013), the effects of migration patterns (Derenoncourt, 2022; Fouka et al., 2022), international market fluctuations (Hummels et al., 2014; Berman et al., 2015).

Identifying Assumptions

The identifying assumption is that carbon policy shifts are uncorrelated with the unobserved shocks that affect domestic firm performance, thus the "shock exogeneity" according to Borusyak et al. (2022).[11] I assume that foreign carbon policies are not systematically related to unobserved determinants of firm outcomes — foreign policy shifts are driven by exogenous factors in those countries, like political shifts or international agreements. The relevance condition is ensured since cost changes due to foreign carbon policies are part of the changes in the domestic overall embodied carbon policy costs coming both from domestic policies and foreign policies. In other words, while foreign carbon policies might have an indirect effect by influencing domestic policy costs, they shouldn't have a direct impact on the outcome variable of interest (e.g., domestic firm performance).

1.3.4 Regression Specifications

2SLS Regression Specifications.

$$y_{fj,t} = \alpha_f + \theta g_{jk,t-h\to t} + \mu W_{fj,t} + \sigma_t + \varepsilon_{fj,t}, \tag{1.3}$$

Equation (1.3) estimates the average treatment effect of the embodied carbon policy costs. I define $y_{fj,t}$ as firm f's outcome variables in the country j year t.[12] I define $g_{jk,t-h\to t}$ as the current or three-year moving average of carbon price costs for sector k, country j, year t. I control for time-varying firm attributes $W_{fj,t}$, including firm age and size since larger firms might have different capacities and constraints and older firms might have different growth potentials, investment behaviors, and productivity levels compared to newer firms. I further include sector-level carbon intensity as an additional control variable, in order to disentangle the

[11] Recent studies on shift-share instruments have emphasized two distinct approaches for identification: assuming for exogenous shocks or for exogenous shares. Given the correlation between industry input-output tables and firms' outcome variables, I leverage the presumably plausibly exogenous variations resulting from changes in foreign carbon policies. This approach is undertaken while acknowledging that exposure shares may not be entirely random.

[12] Refer to Table 3.16 in the Appendix for outcome variable definitions.

effects stemming from carbon intensity (i.e., how emission-intensive the industry is) versus the effects arising from the carbon policy costs. For instance, firms in highly carbon-intensive sectors might inherently have different operational dynamics, cost structures, or market perceptions that influence their performance, irrespective of the carbon pricing policy in place. I also include country-level GDP in order to isolate the impact of carbon policy costs from broader macroeconomic influences and to make the firm-level regression results comparable across different countries.[13] I include firm-fixed and year-fixed effects controls for unobserved firm-specific heterogeneities and common time-varying shocks, respectively. Standard errors are clustered at the country-by-sector level because the key independent variable, carbon policy costs, varies across sectors (due to different emissions levels and sector inclusion status) and across countries (due to differences in carbon taxes and ETS implementations). All firm-level regressions are weighted by firm size (logged total asset). This ensures that any disproportionate influence from large firms is adequately addressed, offering a balanced view of the impacts across the spectrum of firm sizes.

1.3.5 Heterogeneous Treatment Effects

I test for the heterogenous effects of embodied carbon policy costs on firms' outcome variables based on different firm-level and sectoral-level characteristics. I include a time-invariant indicator[14] indicating whether a firm has a small size [15] Small-size firms might find it more challenging to adapt to the more stringent carbon policies due to its limited access to financial resources, the restricted geographic mobility, and the lack of economies of scale (Dechezleprêtre et al., 2023). According to (Trinks and Hille, 2023), firms might differ in their responses to the rising costs from carbon pricing depending on their different capital intensities. I include a time-invariant indicator[16] indicating whether a firm is capital intense.[17] To test for these

[13]In the appendix, I also show the regression results with less rich models as a robustness check.
[14]The indicator equals one if a firm's average size is over the sample median.
[15]The firm size is defined by the total asset.
[16]The indicator is set to one if a firm's average capital intensity is over the sample median.
[17]The capital intensity is defined by the total asset divided by the total operating revenue.

firm-level heterogeneous effects, I estimate the following regression:

$$
\begin{aligned}
y_{fj,t} = \alpha_f + \theta g_{jk,t-h\to t} + \beta g_{jk,t-h\to t} \times \mathbb{1}_{\text{small}} \\
+ \lambda g_{jk,t-h\to t} \times \mathbb{1}_{\text{capital intense}} + \mu W_{fj,t} + \sigma_t + \varepsilon_{fj,t},
\end{aligned}
\tag{1.4}
$$

where $\mathbb{1}_{\text{small}}$ is an indicator set to one for firms with an average size below the sample median; $\mathbb{1}_{\text{capital intense}}$ is set to one for firms whose average capital intensity exceeds the sample median.

I test for the heterogeneous results based on different sectoral carbon emissions, since the emission-intensive sectors are more likely to receive more stringent carbon policies. I also consider the country-level heterogeneities that might influence the results. Specifically, I test whether a firm operates in an EU country with a higher GDP leads to heterogeneous results. Firm in more economically developed countries may be better able to pass on the rising costs from the carbon policies, due to factors such as accesibility to capital and technology. Moreover, I also test for the heterogeneity according to whether or not countries have national carbon taxes on top of the emissions trading systems.

1.3.6 Test for Input Outsourcing

In this section, I test whether embodied carbon policy costs lead to substituting domestic inputs with those sourced from countries with lax or non-existent carbon policies. Previous literature found little empirical evidence that environmental policies affect trade flows. Although theoretically possible, there is little evidence showing that unilateral enhancement of carbon policies leads to "carbon leakage", a phenomenon where pollution is created elsewhere. Ederington et al. (2005) explain that industries with the highest pollution abatement costs are the least geographically mobile ones, or "footloose", due to transportation costs, plant fixed costs, or agglomeration economies. Rather than relocating production facilities entirely, industries might strategically recalibrate their supply chains facing embodied carbon policy costs. For example, consider a European car manufacturer facing stringent carbon policies that increase production costs. Carbon policies increase production costs in two ways: directly, by imposing costs on the manufacturer's own facilities, and indirectly, by affecting their supply chains. The manufacturer might continue to produce its final goods, but change where it sources its raw materials, components, or other inputs in response to embodied carbon policy costs. Instead of considering a costly relocation, the manufacturer might find it easier to source cheaper components from abroad instead of local suppliers. This could lead to a downsizing of jobs and sales for local businesses.

The hypothesis I test in this section is whether embodied carbon policy costs in Europe incentivize firms to source inputs from countries without such policies. I test the hypothesis by estimating the following sectoral-level[18] regression for the same sets of countries as in the main regression:

$$\text{InputShare}_{jk,t} = \beta g_{jk,t-h\to t} + \mu T_{jk,t} + \delta X'_{jk,t} + \gamma_{j,t} + \sigma_{k,t} + \varepsilon_{jk,t}, \tag{1.5}$$

where $\text{InputShare}_{jk,t} = \frac{\text{inputs sourced from non-policy countries}_{jk,t}}{\text{total imported inputs}_{jk,t}}$ denotes the fraction of inputs the industry sector k in country j sources from countries without carbon policies in year t, relative to total imported input. The countries without carbon policies include Brazil, China, Indonesia, India, Russia, Turkey, and South Africa.[19] $T_{jk,t}$ represents the average tariff rate applied to the imports from non-policy countries, including the trade barriers or protective measures potentially affecting business's sourcing decisions. $X'_{jk,t}$ is the vector of additional control variables that might affect sourcing decisions, such as the sector's carbon intensity, the average value of trade, and sectoral output.

[18]It would be ideal to obtain data on firm-level input-output information. However, I can only test for sectoral-level effects due to data constraints.

[19]The choice is due to the data limitations from the Exiobase.

1.4 Data

The selected sample includes data from sixteen European countries over the period between 1998 and 2019. The country sample includes high-income[20] regions such as Germany, Spain, France, Italy, Norway, Sweden, and the United Kingdom; middle-income regions such as Czech Republic, Estonia, Romania, Hungary, Greece, Portugal, Latvia, Romania, and Slovenia.[21]

1.4.1 Sectoral-level Carbon Pricing Data

The carbon pricing and coverage data is from the World Carbon Pricing Database (Dolphin and Xiahou, 2022).[22] This database provides carbon pricing information for 198 national jurisdictions from 1990 to 2020, including details on policy instruments that target CO_2 emissions, such as carbon taxes and cap-and-trade systems. It is the most comprehensive carbon pricing database to date in terms of sectoral coverage and the associated price signal. As compared to the more widely used World Bank Carbon Pricing Dashboard[23], this dataset provides more granular sectoral disaggregations.

1.4.2 Global Input-Output Data

I obtain the global input-output tables from Exiobae [24], which provides environmentally extended multi-region input-output (EE MRIO) tables from 1995 to 2022. This database has comprehensive sectoral and geographical coverages, including 163 industries from 44 countries worldwide. Additionally, Exiobase provides data on the direct carbon emissions per million euros of output, drawing from emission figures from the International Energy Agency (IEA).

[20] This classification is according to the average GDP per capita during the study period.

[21] The following countries in the sample have implemented carbon taxes during 1998-2019 on top of the EU ETS: Estonia, France, Latvia, Norway, Poland, Portugal, Sweden, Slovenia, the United Kingdom.

[22] https://github.com/g-dolphin/WorldCarbonPricingDatabase I thank Geoffroy Dolphin for our informative conversations regarding the dataset.

[23] https://carbonpricingdashboard.worldbank.org

[24] https://www.exiobase.eu/index.php/about-exiobase

Exiobase is preferred over other input-output databases, such as the World Input-Output Tables (WIOD)[25] and OECD Inter-Country Input-Output (ICIO)[26] due to its detailed sectoral coverages. The WIOD database covers 56 International Standard Industrial Classification (ISIC) sectors from 43 countries; the ICIO database covers only 45 unique ISIC sectors from 66 countries. Exiobase has its own detailed sector classifications, and when mapping into the ISIC codes, it offers more detailed sectoral disaggregations. This granular sectoral breakdown is useful for assessing environmental impacts at a more detailed level. Furthermore, given its support from the European Union, Exiobase is particulararly adept for studies focusing on European policies.

1.4.3 Firm-level Micro Data

I use microdata from Orbis on firm-level variables compiled by the commercial data provider Bureau van Dijk (BvD). Orbis is a global firm-level database that reports firm annual balance sheets and income statements in a global standard format, allowing for cross-country comparisons. I restrict the sample to periods of stable and high coverage within the best-covered European countries, focus only on a small number of best-covered European countries, and restrict firms with more than ten employees.[27] I focus only on the ‘’intensive” margin (how variables within a firm change over time) rather than the ‘’extensive” margin where firm entry or exit is allowed [28]. The final sample comprises a balanced panel of one million industrial firm observations spanning from 1998 to 2019 across 100 NACE 3-digit subsectors.[29] The firm-level outcome variables of interest are employment (total number of employees included in the company’s payroll), sales (net sales), total factor productivity (TFP), tangible fixed assets, and intangible fixed assets. Following the methodology proposed by Ackerberg et al. (2015), I

[25] https://www.rug.nl/ggdc/valuechain/wiod/

[26] https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

[27] Orbis has poor coverage of micro-firms having less than 10 employees, thus limiting the ability to conclude the entire population of firms (Bajgar et al., 2020)

[28] Orbis is not the ideal dataset to study exit or entry of firm over a period since firms appearing in the data and disappearing from it may be a result of change in data coverage.

[29] NACE is the statistical classification of economic activities in Europe, “Nomenclature statistique des activités économiques dans la Communauté europèene”.

calculate the TFP using a gross output approach with the cost of goods sold and tangible fixed assets as inputs. This paper also includes tangible and intangible fixed assets as firm outcome variables, which provides information on whether the firm is investing or not. An increase in the value of tangible or intangible assets suggests ongoing investments, while a decrease suggests either divestiture or insufficient investments aus dem Moore et al. (2019). Tangible fixed assets include machinery, buildings, etc.; Intangible fixed assets include research and development expenses[30], formation expenses, goodwill, and all other expenses with a long-term effect.

1.4.4 Additional EU ETS Data

I obtain the EU ETS-related data from the European Union Transaction Log (EUTL).[31] EUTL provides aggregated information on emissions and allowances at country-sector-year level. I obtain free allowances allocation information and then merge with firm-level data at the NACE 3-digit level.

1.4.5 Other Data

I obtain the sectoral-level tariff data from the CEPII Trade and Production Database (TradeProd). TradeProd is a comprehensive database providing data on both international and domestic trade glows and production, covering 9 industrial sectors in 162 countries from 1966 to 2018. Furthermore, I obtain the country-level GDP data, which serves as a control variable in the analysis, from the World Development Indicators (WDI) from the World Bank.

1.5 Results

1.5.1 First-stage Regression

Figure 1.4 plots the logged overall carbon policy costs ($/1000$ output) against the logged foreign carbon policy costs for all industrial sectors in 16 European countries at Nace

[30]Orbis does not report the R&D expenses directly

[31]https://www.eea.europa.eu/en/datahub/datahubitem-view/98f04097-26de-4fca-86c4-63834818c0c0

3-digit and country level. Each dot on the figure represents a sector in a country. The slope coefficient is 0.78 with a standard error of 0.05, indicating a strong predictive power of carbon policy costs due to foreign (all other EU countries in the sample other than the domestic country) carbon policies for overall carbon policy costs.

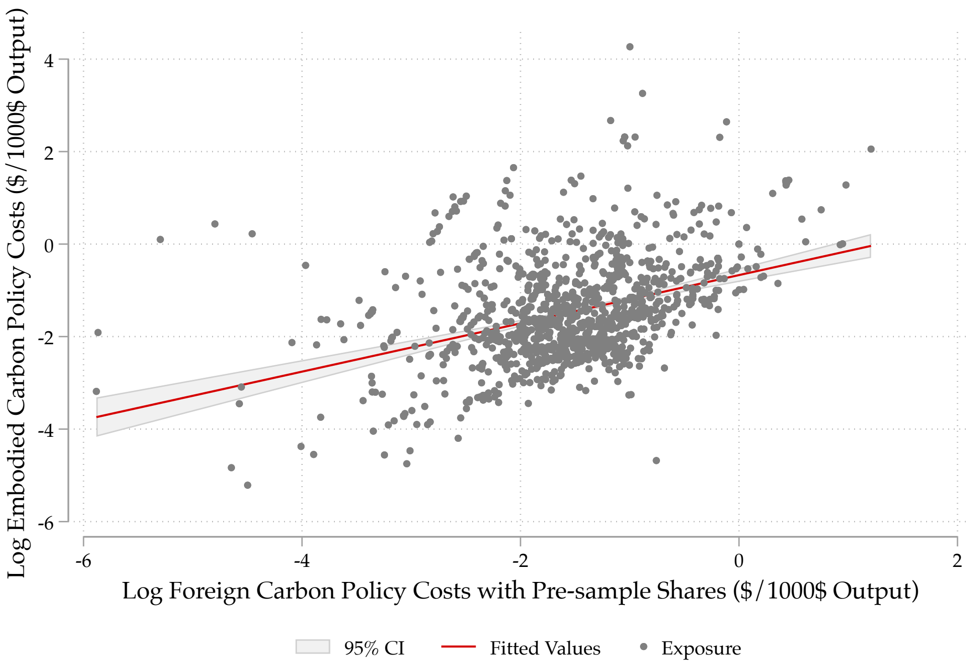


Figure 1.4. First Stage Regression, 1998-2019

Notes: The figure plots the first stage regression from equation (1.3). Each data point corresponds to a NACE 3-digit sector within one of the 16 countries. The line is fitted by OLS regression without additional controls. The 95% confidence interval is based on standard errors clustered at the country-sector level. The slope coefficient is 0.78 with a standard error of 0.05; the regression has an R-squared of 0.31.

1.5.2 Main Results

The two-stage least squares (2SLS) fixed-effects (FE) estimates show that overall carbon policy costs have negative and significant impacts on the employment and sales of surviving firms (only considering the intensive margin due to the Orbis data coverage issue). Table 1.1 shows that with a 1% increase in carbon price costs, everything else being equal, there is a

0.0456% decrease in firm employment, a 0.0187% decrease in sales, a 0.00783% increase in total factor productivity (TFP) and a 0.0425% increase in tangible assets investment. There is also a positive effect on intangible assets, although the result is not statistically significant. These results, controlled for firm-specific characteristics, GDP, sectoral CO2, and time effects, suggest that while embodied carbon policy costs might present challenges in terms of employment and sales, they could potentially encourage efficiency gains. To ensure the reliability of these findings, I undertake a comprehensive set of robustness tests with results presented in the Appendix.

Table 1.1. 2SLS Main Results: Embodied Carbon Policy Costs and Industrial Firm Performance

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0456***	-0.0187**	0.00783***	0.0425***	0.156
	(0.00924)	(0.00795)	(0.00267)	(0.0134)	(0.113)
Firm Controls	✓	✓	✓	✓	✓
GDP, Sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.394	0.865	0.0688	0.0198	-0.0176
Tests					
Kleibergen-Paap rk LM Stat	25.428	23.470	26.321	25.864	14.848
Kleibergen-Paap rk Wald F Stat	38.996	35.000	37.704	38.582	18.082

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

These findings contrast the estimates from Table 1.2, where embodied carbon policy costs are substituted with direct carbon policy costs as the key independent variable. In this table, the magnitudes of most estimated coefficients for various firm-level outcomes are notably smaller and less statistically significant, except for the coefficient related to intangible assets. Direct carbon costs might not provide the same incentive for efficiency improvements as embodied carbon costs. Embodied costs, being more comprehensive, might push firms to rethink their entire operation and supply chain, leading to investments in energy-efficient infrastructure and innovations that enhance TFP. Direct costs, being more immediate and operational, might not exert the same long-term strategic pressure on firms. The negative coefficient on the investment in intangible assets, as shown in column (5), might indicate that higher direct carbon costs are constraining firm resources or affecting profitability, which in turn might be limiting their ability to invest in intangible assets such as research and development, branding, or other strategic initiatives. Unlike direct carbon costs, which might have an immediate impact on firms' operations and profitability, embodied carbon costs might be perceived by firms differently. These costs reflect more on the longer-term strategic trajectory and industrial structure.

Table 1.2. Direct Carbon Policy Costs and Industrial Firm Performance

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(Direct cCost, 3MA)	-0.00409	0.00210	-0.00119	0.000420	-0.0785***
	(0.00291)	(0.00131)	(0.000958)	(0.00398)	(0.0128)
Firm Controls	✓	✓	✓	✓	✓
GDP, Sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.960	0.989	0.926	0.889	0.678

Notes: Columns 1-5 show the coefficient estimates from FE regression (1.3) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the direct carbon policy costs (emission-weighted carbon price). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Standard errors in parentheses are clustered at the country-sector level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

1.5.3 Heterogeneity

Heterogeneity by Firm Characteristics

Table 1.3 shows that embodied carbon policy costs have a more negative effect on small-sized or capital-intense firms. Smaller firms might lack the capacity to adjust to increasing costs associated with carbon pricing since they usually have less access to financial resources to invest in mitigation strategies.

Table 1.3. Heterogeneity by Firm Characteristics

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0415***	-0.0134*	0.00989***	0.0591***	0.220*
	(0.00892)	(0.00782)	(0.00300)	(0.0153)	(0.120)
Log(cCost, 3MA) x					
$\mathbb{1}_{\text{small}}$	-0.000907	-0.00401**	0.000790	-0.0274***	-0.0815***
	(0.00229)	(0.00188)	(0.000702)	(0.00441)	(0.0135)
Log(cCost, 3MA) x	-0.00476***	-0.00483***	-0.00329***	-0.00236	-0.0361***
$\mathbb{1}_{\text{capital intense}}$	(0.00180)	(0.00122)	(0.000720)	(0.00303)	(0.0139)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.394	0.865	0.0692	0.0202	-0.0153
Tests					
Kleibergen-Paap rk LM Stat	26.806	24.053	26.708	27.163	15.418
Kleibergen-Paap rk Wald F Stat	13.646	11.992	12.679	13.443	6.256

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.4) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the carbon policy costs constructed from equation (1.1). $\mathbb{1}_{\text{small}}$ is an indicator that equals one for firms with an average size below the sample median; $\mathbb{1}_{\text{capital intense}}$ equals one for firms whose average capital intensity exceeds the sample median. All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

The estimation results are also more negative for capital-intensive firms. This might be explained by their lack of flexibility in adapting to the changing regulatory environment. Those firms usually have incurred big sunk costs in purchasing machinery and equipment, making it harder to further invest in more sustainable technologies that improve production efficiency. The coefficient estimate on the interaction term with the capital-intense firm indicator in Column (5) shows a negative and relatively large result.

Heterogeneity by Sectoral Characteristics

Table 1.4 presents the results with sectoral-level heterogeneities. Firms in carbon-intensive sectors (those with average carbon intensity above the 75th percentile) experience less negative employment impacts, which might seem counterintuitive at first glance. Since the analysis focuses only on the intensive margin, it is plausible that firms in more carbon-intensive sectors capture larger market shares as their competitor struggle to survive in the market. Moreover, the firms in the carbon-intensive sectors might have greater political leverage or receive more government support and potentially benefit from subsidies, tax breaks, or transitional support.

Columns (3) to (5) in Table 1.4 suggest that firms in more carbon-intensive sectors receive less positive impact on their TFP, as well as the tangible and intangible assets, compared to firms in the average sectors. This result is in line with the argument made in Acemoglu et al. (2012)'s paper on the environment and directed technical change. Carbon-intensive sectors might experience productivity decline due to environmental regulations if there is not enough redireciton of innovation.

Heterogeneity by Country Characteristics

Table 1.5 and Table 1.6 show the estimation results when considering country-level heterogeneities. Firms in high GDP countries[32] receive less negative impacts on employment

[32] The high GDP countries in the sample are Belgium, Germany, Estonia, France, Italy, Norway, Sweden, and the UK.

Table 1.4. Heterogeneity by Sectors - Carbon Intensity

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0673***	-0.0238**	0.0116***	0.0722***	0.368**
	(0.00913)	(0.0109)	(0.00370)	(0.0175)	(0.167)
Log(cCost, 3MA) x	0.0265***	0.00575	-0.00440***	-0.0362***	-0.188***
$\mathbb{1}_{\text{carbon intense}}$	(0.00454)	(0.00496)	(0.00162)	(0.00886)	(0.0561)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.395	0.864	0.0694	0.0202	-0.0212
Tests					
Kleibergen-Paap rk LM Stat	41.970	38.500	38.638	42.947	19.864
Kleibergen-Paap rk Wald F Stat	34.368	29.571	27.746	33.234	11.421

Notes: Columns 1-5 show the coefficient estimates from 2SLS regression (1.4) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the carbon policy costs constructed from equation (1.1). $\mathbb{1}_{\text{carbon intense}}$ is an indicator that equals one for firms whose sectors have average carbon intensity above the 75th percentile. All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

and sales compared to the average countries. This finding could be explained by the fact that highly developed countries have sufficient infrastructure and technology to adapt to regulatory changes.

Table 1.6 shows that firms in countries with national carbon taxes receive more positive impacts on TFP and intangible assets. This result indicates that the dual approach of taxation and ETS incentivize firms to innovate and invest more in improving efficiency.

Table 1.5. Heterogeneity by Countries - GDP

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0788***	-0.0378***	0.0153***	0.0698***	0.256**
	(0.00805)	(0.0102)	(0.00327)	(0.0166)	(0.118)
Log(cCost, 3MA) x	0.0438***	0.0272***	-0.0106***	-0.0397***	-0.147***
$\mathbb{1}_{\text{high GDP}}$	(0.00466)	(0.00586)	(0.00164)	(0.00953)	(0.0337)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.404	0.866	0.0705	0.0214	-0.007
Tests					
Kleibergen-Paap rk LM Stat	26.453	25.100	26.506	26.405	16.636
Kleibergen-Paap rk Wald F Stat	21.453	19.885	19.557	20.772	10.479

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.4) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the carbon policy costs constructed from equation (1.1). $\mathbb{1}_{\text{high GDP}}$ is an indicator that equals one for firms in high GDP countries within the sample: Germany, Spain, France, Italy, Norway, Sweden, and United Kingdom. All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

1.5.4 Test for Input Replacement

Results in Table 1.7 show that a 1% increase in sectors' overall carbon policy costs corresponds to a 2 to 4 percentage points increase in the share of inputs sourced from countries without carbon policies. This result suggests that the industrial sectors adapt to carbon pricing by adjusting where they source their inputs from. There could be several effects captured here: First, sectors might shift their in-house intermediate good production to countries without carbon policies, which serves as a mechanism for explaining the negative effects on firm employment and sales. Second, sectors shift the inputs outsourced from other EU countries to countries without carbon policies. This serves a separate effect since sectors could maintain their employment

Table 1.6. Heterogeneity by Countries - Carbon Tax Countries

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0461***	-0.0185**	0.00903***	0.0415***	0.188
	(0.00934)	(0.00798)	(0.00274)	(0.0140)	(0.123)
Log(cCost, 3MA) x $\mathbb{1}_{\text{carbon tax}}$	-0.00168	0.00131	0.00396***	-0.00411	0.110***
	(0.00406)	(0.00304)	(0.00118)	(0.00704)	(0.0274)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.393	0.865	0.0687	0.0202	-0.0203
Tests					
Kleibergen-Paap rk LM Stat	32.095	28.320	31.264	33.426	16.026
Kleibergen-Paap rk Wald F Stat	25.064	21.308	22.679	25.259	9.759

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.4) for different logged-level outcome variables: employment, sales, total factor productivity (TFP), tangible assets, and intangible assets. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the carbon policy costs constructed from equation (1.1). $\mathbb{1}_{\text{carbon tax}}$ is an indicator that equals one for firms countries with carbon taxes: Estonia, France, United Kingdom, Latvia, Romania, Portugal, Sweden, and Slovenia. All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

and sales. Third, we could expect a mixture of the two effects mentioned above. Further investigation is needed to distinguish which is the dominant effect. The input outsourcing effect could potentially lead to the “carbon leakage”, where carbon emissions are simply transferred from countries to countries, without effective reductions. If countries without carbon policies emit more in the production process, there might also be a net increase in the global carbon emissions.

Table 1.7. Input Outsourcing and Lagged Carbon Policy Costs

	(1)	(2)	(3)	(4)
VARIABLES	InputShare	InputShare	InputShare	InputShare
Log(cCost), $t-1$	4.473***	2.406***		
	(0.751)	(0.624)		
Log(cCost, 3MA), $t-1$			4.717***	2.295***
			(0.881)	(0.711)
Sector Controls				
Tariff		-3.686		-3.695
		(3.334)		(3.618)
Log(CO_2 intensity)		-0.736**		-0.742**
		(0.285)		(0.306)
Log(Average Value of Trade)		0.401		0.493
		(0.476)		(0.496)
Log(Sectoral Output)		-1.412***		-1.370***
		(0.381)		(0.406)
Sector FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Observations	21,692	11,764	19,626	10,586
Adjusted R-squared	0.081	0.025	0.076	0.018
Tests				
Kleibergen-Paap rk LM Stat	33.847	20.858	30.014	18.892
Kleibergen-Paap rk Wald F Stat	185.827	146.866	146.726	127.717

Notes: Columns 1-2 show the coefficient estimates from the sectoral-level 2SLS regression (1.3) with independent variables to be the lagged embodied carbon policy costs constructed from (1.1); Columns 3-4 show the coefficient estimates with independent variables to be the lagged 3-year moving average (current, the first, and the second lag) of embodied carbon policy costs. The dependent variable *InputShare* is the fraction (x 100%) of inputs the industry sector k in country j sources from countries without carbon policies (Brazil, China, Indonesia, India, Russia, Turkey, and South Africa) in year t, relative to total imported inputs. Standard errors in parentheses are clustered at the Exiobase subsector level. *** p<0.01, ** p<0.05, * p<0.1.

In response to the potential challenge of “carbon leakage” and to protect domestic competitiveness, Europe has recently introduced the Carbon Border Adjustment Mechanism (CBAM) as part of the European Green Deal. The CBAM extends on the EU ETS by imposing a tariff on the imports based on their carbon contest, and whether or not the imports are subject to carbon polices in their original country of production.

1.5.5 Robustness

In this section, I examine the robustness of the firm-level results via several tests: (i) different control variables, (ii) different sets of fixed effects, (iii) varying lag structures, (iv) regressions without weighting by firm size, (v) interacting with free allowances indicators, (vi) current embodied carbon costs, (vii) alternative carbon policy costs measures, (viii) alternative instruments with time-varying shares, (ix) dynamic effects using local projections, (x) using event study analysis to understand the effects of direct carbon tax.

Different Control Variables

Table 1.12 presents specifications from less rich models without controls to richer models with full controls. Results are robust across different specifications with different sets of controls.

Different Sets of Fixed Effects

I incorporate different sets of fixed effects to validate the main results further. The results in Table 1.13 are consistent when controlling for different sets of unobserved heterogeneities. Results are robust when including firm fixed effects and year fixed effects or including country $\times$ sector fixed effects and year fixed effects.

Varying Lag Structures

A potential concern could be that the impact of carbon pricing on firms is not imminent. Factors such as postponements in the implementation of legislative measures can influence the adjustment period (Albrizio et al., 2014). To address this concern, I include up to four lags of carbon policy costs to investigate how past prices might still affect current firm behaviors. Table 3.12 presents the results of this robustness check. I chose 3-year moving averages of the carbon policy costs in the main regression analysis. This choice best captures the dynamic effects of the policy while providing a consistent and reliable fit to the data.

Regressions Without Weights

In the main regressions, I weight the regressions by firm size to mitigate potential heterogeneities introduced by larger firms. For robustness, Table 1.15 presents results without this firm size weighting. The estimates for various outcome variables remain consistent with those from the main analyses.

Interacting with Free Allowances Indicators

Free allowances within the EU ETS also play a crucial role in understanding the impacts of carbon policy costs on firms. The rationale behind granting free allowances is to reduce the risk of carbon leakage and protect industries at significant risk of relocating their production to countries with laxer emission constraints. The variation in the allocation of free allowances leads to a heterogeneous distribution of carbon costs among companies and sectors, which can affect firm performance (Känzig and Konradt, 2023). To test whether free allowance allocations influence the impact of carbon pricing, I check the robustness of the results by estimating the following equation:

$$y_{fj,t} = \alpha_f + \theta g_{jk,t-h\to t} + \beta g_{jk,t-h\to t} \times \mathbb{1}_{\text{free}_t} + \mu W_{fj,t} + \sigma_t + \gamma_f + \varepsilon_{fj,t} \tag{1.6}$$

, where $\mathbb{1}_{\text{free}}$ is an indicator that equals one when a NACE 3-digit sector has free allowances in year t. In Table 1.16, the interaction term with free allowance indicators yields no significant results, suggesting that the provision of free allowances does not significantly impact the competitiveness outcomes. This consistency might be attributed to the combined effects of ETS prices and carbon taxes in the embodied carbon policy costs, potentially offsetting the influence of free allowances from ETS.

Current Embodied Carbon Policy Costs

Table 1.17 presents the estimation results using the current carbon policy costs as the independent variable of interest, as opposed to the main regressions using 3-year moving averages of the embodied carbon policy costs. The estimated coefficients are consistent in signs and statistically significant but smaller in magnitude.

Alternative Carbon Policy Costs Measures Using Contemporaneous 'Shares'

In this robustness test, I employ contemporaneous 'exposure shares,' as opposed to pre-sample 'exposure shares' used in the SSIV instruments where foreign policy changes serve as 'shock' variables. While this approach yields larger first-stage F-statistics, suggesting stronger instruments, the trade-off is that it might introduce bias in the estimates – the changes in input-output structures might be influenced by unobserved factors, which could also affect the firm-level outcomes of interest. As demonstrated in Table 1.18, the estimated coefficients remain consistent in signs and exhibit statistical significance.

Event Study Analysis of Direct Carbon Tax Costs

This robustness test aims to strengthen the main results that the direct carbon policy costs, not considering the input-output linkages, leads to zero effects on firms. I restrict my sample to the countries that have implemented carbon taxes: France, Norway, Portugal, Sweden, Estonia, Latvia, and Slovenia, and the time frame to be 2009 to 2019 in order to isolate the confounding effects from the introduction of EU-wide ETS in 2005. Figure 1.7 presents the event study regression results. Post the treatment year, there is no significant effects on the firm outcomes. These null findings resonate with the main analysis, consolidating the argument that merely gauging direct carbon policy costs yields no effects on firms, as some of the previous literature suggests.

Placebo Test

To ensure that previous results do not capture declining trends of industrial firm employment that would occur in the absence of carbon policies, I conduct a randomization inference that shuffles placebo carbon policy costs across different sectors in each country. The placebo effects are indistinguishable from zero and consistently deviate from the actual employment effects.

Predicted Employment Effects

Figure 1.9 and 1.8 present the predicted employment effects of a 10% increase in the carbon price by different countries and industries. The results are obtained from the coefficients estimates in Table 1.4.

1.6 Conclusions and Policy Implications

This research contributes to the existing literature by empirically examining the systemic impacts of carbon pricing on industrial firm competitiveness outcomes. Embodied carbon policy costs, which account for the broader global value chain effects, lead to a reduction in employment and sales and a slight increase in firm total factor productivity (TFP) and potentially tangible assets investment. The impacts are not uniformly distributed among industrial firms. Small-size or capital-intense firms receive more negative impacts. Firms in carbon-intensive sectors surprisingly experience less negative employment impacts, possibly due to the emergence of "green jobs" and their ability to capture larger market shares as competitors exit. At the country level, firms in high GDP countries experience milder negative impacts on employment and sales but receive less pronounced benefits in TFP and investment. Interestingly, firms in countries with both carbon taxes and EU-ETS participation exhibit more significant TFP gains and positive effects on intangible assets, suggesting that a dual approach may foster innovation and efficiency improvements more effectively.

This paper also presents sectors' strategic adaptations in response to stricter carbon regulations. Sectors that are more exposed to embodied carbon policy costs increasingly source inputs from countries with laxer carbon regulations. Such supply-chain adaptations might undermine the overall efficacy of unilateral climate policies, leading to potential carbon leakage. Future research could assess the overall effects of carbon policies, including various second-best policies that do not have explicit prices on the CO_2 emissions. One could also investigate the counterfactual outcomes on firms and supply-chain implications coming from potential coordinated international agreements rather than unilateral policies.

1.7 Acknowledgements

Chapter 1 is being prepared for publication. The dissertation author is the sole author of this chapter.

1.8 Chapter 1 Appendix

1.8.1 Additional Figures and Tables

Figure 1.5. EU Carbon Permits

Notes: This figure shows the EU carbon permit prices over time. The data is sourced from the European Union Emissions Trading System (EU ETS), the world's largest cap and trade carbon emissions market. This figure shows significant time-series variation in permit prices, which is an equilibrium outcome based on the supply and demand of emission permits. Source: Tradingeconomics

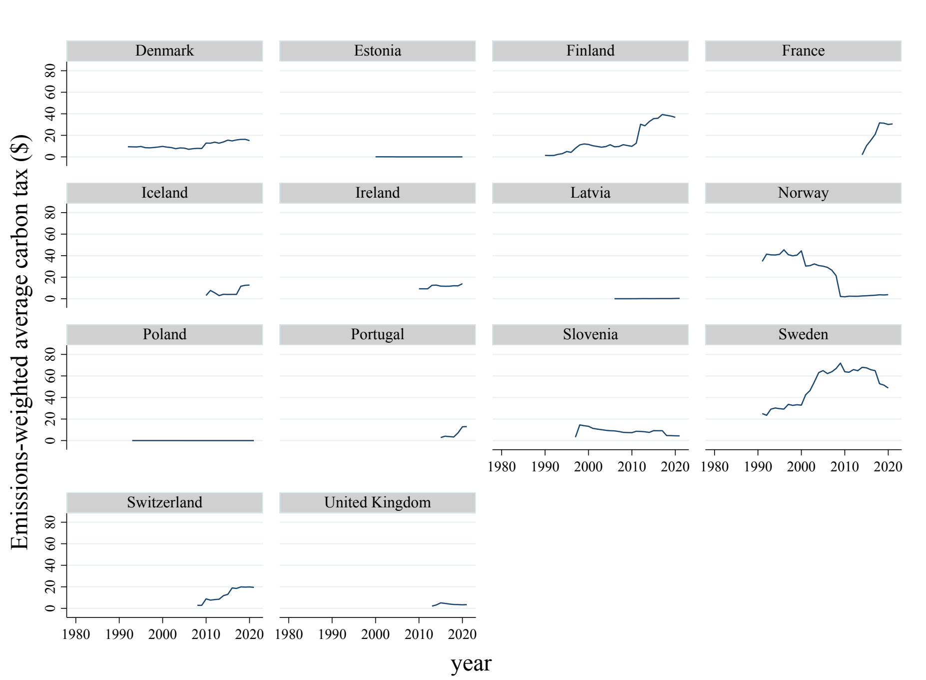


Figure 1.6. EU Carbon Taxes (Weighted by CO_2 Emissions Coverage)

Notes: This figure shows the average carbon taxes weighted by CO_2 Emissions Coverage for countries with national carbon taxes in Europe. It shows variation both in the timing of the first introduction of national carbon taxes and the variation in tax levels. Source: RFF(2021).

Table 1.8. Summary Statistics: Number of Observations by Sector

NACE	N	%
Civil engineering	20,501	1.96
Construction of buildings	85,247	8.13
Manufacture of basic metals	19,961	1.9
Manufacture of beverages	14,069	1.34
Manufacture of chemicals and chemical products	28,376	2.71
Manufacture of coke and refined petroleum products	1,703	.16
Manufacture of computer, electronic and optical products	18,740	1.79
Manufacture of electrical equipment	19,059	1.82
Manufacture of fabricated metal products	131,194	12.51
Manufacture of food products	76,130	7.26
Manufacture of furniture	29,555	2.82
Manufacture of leather and related products	17,596	1.68
Manufacture of machinery and equipment n.e.c.	67,501	6.44
Manufacture of motor vehicles, trailers and semitrailers	20,425	1.95
Manufacture of other non-metallic mineral products	43,896	4.19
Manufacture of other transport equipment	6,829	.65
Manufacture of paper and paper products	20,477	1.95
Manufacture of pharmaceutical products	7,103	.68
Manufacture of rubber and plastic products	52,532	5.01
Manufacture of textiles	27,642	2.64
Manufacture of tobacco products	279	.03
Manufacture of wearing apparel	18,499	1.76
Manufacture of wood	34,366	3.28
Mining and quarrying	17,689	1.69
Other manufacturing	22,401	2.14
Printing and reproduction of recorded media	31,445	3
Repair and installation of machinery and equipment	27,740	2.65
Specialized construction activities	187,093	17.84
Total	1,048,048	100

Table 1.9. Summary Statistics: Number of Firms by Country

Country Code	Country Name	N	%
CZ	Czech Republic	7,693	.73
DE	Germany	1,792	.17
EE	Estonia	12,059	1.15
ES	Spain	281,057	26.82
FR	France	171,453	16.36
GB	United Kingdom	34,259	3.2
GR	Greece	19,936	1.9
HU	Hungary	14,875	1.42
IT	Italy	244,749	23.35
LV	Latvia	1,670	.16
NO	Norway	83,440	7.96
PL	Poland	4,217	.4
PT	Portugal	21,356	2.04
RO	Romania	57,244	5.46
SE	Sweden	84,439	8.0
SI	Slovenia	7,809	.75
-	Total	1,048,048	100

Table 1.10. Summary Statistics: Firm-level Regressions

	Unit	N	Mean	SD	P25	P50	P75
Independent Variables							
Carbon policy costs (overall)	\$/1,000\$	1,048,048	6.70	28.79	.03	.34	1.2
	Log (\$/1,000\$)	1,047,525	-1.43	2.70	-3.61	-1.09	.18
Carbon policy costs (direct)	\$/1,000\$	1,048,048	4.40	19.90	0	0	.16
	Log (\$/1,000\$)	538,123	-2.07	3.66	-4.1	-1.9	.18
Carbon policy costs (indirect domestic)	\$/1,000\$	1,048,048	1.81	7.07	0	.12	.68
	Log (\$/1,000\$)	769,988	-1.34	2.44	-2.62	-1.14	-.04
Carbon policy costs (indirect foreign)	\$/1,000\$	1,048,048	.18	.26	.01	.11	.25
	Log (\$/1,000\$)	1,047,525	-1.85	2.13	-3.09	-1.55	-.87
Dependent Variables							
Employment	Log 2015 USD	810,982	3.55	1.04	2.77	3.33	4.08
Sales	Log 2015 USD	925,501	15.15	1.56	14.27	15.1	16.04
TFP	Unit	872,647	1.20	.46	.86	1.09	1.51
Tangible	Log 2015 USD	1,019,265	13.13	2.03	11.81	13.18	14.47
Intangible	Log 2015 USD	664,203	10.21	2.46	8.66	10.32	11.83
Firm-level Control Variables							
Size	Log 2015 USD	974,878	15.00	1.67	13.95	14.94	16
Age	Log years	974,878	3.11	.60	2.77	3.14	3.5
Capital intensity	Ratio	974,878	-.23	.75	-.68	-.3	.11
Other Variables							
CO_2 intensity	$TonCO_2eq/1,000\$$	1,048,048	1.60	7.32	.01	.02	.12
	Log ($TonCO_2eq/1,000\$$)	1,047,536	-3.17	2.38	-4.67	-3.71	-2.12
GDP	Log 2015 USD	1,048,048	20.64	1.03	19.89	20.93	21.37
Free allowances	$TonCO_2eq$	1,047,536	.09	4.12	0	0	0
$\mathbb{1}_{\text{Intermediate}}$	Binary	1,048,478	.6652023	.4719199	0	1	1

Notes: This table presents the summary statistics for the merged sample of firm-level microdata and NACE 3-digit level carbon price exposures. The merged data covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019.

Table 1.11. Summary Statistics: Carbon Emission Intensity and Embodied Carbon Policy Costs by Industrial Sectors

Nace2Names	CO_2_intensity	cCosts_overall	cCosts_direct	cCosts_indirect_domestic	cCosts_indirect_foreign
Manufacture of rubber and plastic products	.02	1.56	.16	1.05	.36
Construction of buildings	.03	1.79	.22	1.33	.24
Manufacture of fabricated metal products	.04	.62	0	.41	.2
Manufacture of motor vehicles, trailers and semitrailers	.05	1.66	.8	.57	.28
Repair and installation of machinery and equipment	.05	.81	.23	.38	.2
Manufacture of furniture	.06	.77	0	.51	.26
Manufacture of other transport equipment	.07	1.56	.74	.56	.25
Manufacture of textiles	.09	1.8	.36	1.05	.38
Manufacture of machinery and equipment n.e.c.	.09	.62	.09	.35	.19
Other manufacturing	.09	.73	0	.47	.26
Manufacture of computer, electronic and optical products	.09	.59	0	.37	.21
Printing and reproduction of recorded media	.1	1.95	.86	.81	.28
Manufacture of leather and related products	.11	1.08	.27	.6	.2
Manufacture of beverages	.12	2.02	.74	.99	.28
Manufacture of electrical equipment	.12	.54	0	.34	.2
Manufacture of wearing apparel	.22	4.2	2.5	1.39	.31
Manufacture of tobacco products	.26	1.91	1.3	.47	.14
Manufacture of food products	.31	3.92	2.38	1.31	.23
Manufacture of pharmaceutical products	.6	6.38	3.93	1.96	.49
Manufacture of wood	.97	2.97	1.15	1.42	.4
Manufacture of paper and paper products	6.29	7.72	4.78	2.59	.35
Manufacture of other non-metallic mineral products	6.67	15.15	10.09	4.7	.35
Manufacture of basic metals	9.07	5.55	2.72	2.55	.28
Manufacture of chemicals and chemical products	10.55	15.5	10.42	4.67	.41
Manufacture of coke and refined petroleum products	11.34	35.76	24.85	10.56	.35
Mining and quarrying	46.31	33.05	22.86	9.98	.21

Notes: This descriptive table presents sectoral-level direct CO_2 emission intensities, measured in tonCO_2eq per $1000 output, alongside the constructed embodied carbon policy costs, denoted as $ carbon price per $1000 output, as defined in (1.1) for industrial sectors. 'Costs_overall' represents the aggregate costs.' cCosts_direct' refers to costs directly imposed by policies on the respective sectors, without considering inter-sectoral linkages. 'cCosts_indirect_domestic' captures the costs attributed to linkages with domestic sectors, while' Costs_indirect_foreign' reflects costs associated with foreign policies realized through international trade.

Table 1.12. Robustness Check: Testing for Control Variables

VARIABLES	(1) Log(Employ)	(2) Log(Sales)	(3) ln(TFP)	(4) Log(Tangible)	(5) Log(Intangible)	(6) Log(Employ)	(7) Log(Sales)	(8) ln(TFP)	(9) Log(Tangible)	(10) Log(Intangible)	(11) Log(Employ)	(12) Log(Sales)	(13) ln(TFP)	(14) Log(Tangible)	(15) Log(Intangible)
Log(cCost,3MA)	-0.0492***	-0.0849***	-0.000414	0.0432***	0.165	-0.0233***	0.00273	0.00717***	0.0271**	0.148	-0.0456***	-0.0187**	0.00783***	0.0425***	0.156
	(0.00844)	(0.0139)	(0.00269)	(0.0126)	(0.122)	(0.00633)	(0.00533)	(0.00267)	(0.0124)	(0.124)	(0.00924)	(0.00795)	(0.00267)	(0.0134)	(0.113)
Log(Age)						0.0752***	-0.138***	-0.00286	0.388***	-0.291	0.142***	-0.0639***	-0.00253	0.369***	-0.158
						(0.0220)	(0.0230)	(0.00634)	(0.0371)	(0.179)	(0.0131)	(0.0117)	(0.00633)	(0.0337)	(0.144)
Log(Size)						0.518***	1.015***	0.0913***			0.526***	1.019***	0.0912***		
						(0.00548)	(0.00609)	(0.00454)			(0.00561)	(0.00565)	(0.00456)		
Log(Capital Intensity)						-0.372***	-1.001***	-0.107***	0.268***	0.0418	-0.379***	-1.005***	-0.107***	0.269***	0.0380
						(0.00928)	(0.00786)	(0.00534)	(0.0263)	(0.0292)	(0.0101)	(0.00673)	(0.00536)	(0.0265)	(0.0291)
Log(GDP)											-0.561***	-0.471***	0.00215	0.220**	-1.023***
											(0.0652)	(0.0671)	(0.0163)	(0.107)	(0.357)
Log(CO_2)											-0.00560	-0.00257	0.00188	0.0276*	0.161**
											(0.00484)	(0.00464)	(0.00172)	(0.0141)	(0.0658)
Firm Controls						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Controls (GDP, sectoral CO_2)											✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	674,352	802,967	762,524	833,536	551,687	674,264	802,851	762,428	833,420	551,612	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	-0.000710	0.00201	-3.18e-05	-0.00248	-0.0233	0.395	0.863	0.0690	0.0211	-0.0196	0.394	0.865	0.0688	0.0198	-0.0176

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables without any additional control variables; Columns 5-8 show the coefficient estimates with firm-level control variables; Columns 9-12 show the coefficient estimates with other control variables such as country's GDP and sector CO_2 intensity. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

Table 1.13. Robustness Check: Different Fixed Effects

VARIABLES	(1) Log(Employment)	(2) Log(Sales)	(3) Log(TFP)	(4) Log(Tangible)	(5) Log(Intangible)	(6) Log(Employment)	(7) Log(Sales)	(8) Log(TFP)	(9) Log(Tangible)	(10) Log(Intangible)
Log(cCost, 3MA)	-0.0456***	-0.0187**	0.00783***	0.0425***	0.156	-0.0445***	-0.0188**	0.00558*	0.0666***	0.166*
	(0.00924)	(0.00795)	(0.00267)	(0.0134)	(0.113)	(0.0101)	(0.00822)	(0.00293)	(0.0185)	(0.0915)
Firm Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Controls (GDP, sectoral CO_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓					
County × Sector FE						✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612	676,042	804,638	764,280	835,203	553,915
Adjusted R-squared	0.394	0.865	0.0688	0.0198	-0.0176	0.742	0.979	0.0978	0.0848	-0.00112

Notes: Columns 1-4 show the coefficient estimates from 2SLS regression (1.3) for different outcome variables by including firm fixed effects and year fixed effects; Columns 5-8 show the coefficient estimates by including country-by-sector fixed effects and year fixed effects. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

Table 1.14. Robustness Check: Testing for Different Lag Structures

VARIABLES	(1) Log(Employment)	(2) Log(Sales)	(3) Log(TFP)	(4) Log(Tangible)	(5) Log(Intangible)	(6) Log(Employment)	(7) Log(Sales)	(8) Log(TFP)	(9) Log(Tangible)	(10) Log(Intangible)	(11) Log(Employment)	(12) Log(Sales)	(13) Log(TFP)	(14) Log(Tangible)	(15) Log(Intangible)
Log(cCost)	-0.00971***	-0.00664***	0.0123***	0.00849**	-0.0769***	-0.00392**	-0.0105***	0.00643***	0.00801***	0.00461	-0.00345**	-0.00663***	0.00709***	0.00556*	0.0207**
	(0.00357)	(0.00226)	(0.00214)	(0.00399)	(0.0113)	(0.00182)	(0.00147)	(0.00111)	(0.00235)	(0.0147)	(0.00175)	(0.00101)	(0.00112)	(0.00293)	(0.0101)
L.Log(cCost)						0.000926	0.0109***	0.00142***	-0.00551***	-0.00854	0.00199**	0.00787***	0.000790	-0.00376	-0.00183
						(0.00119)	(0.00133)	(0.000424)	(0.00190)	(0.00582)	(0.000932)	(0.000942)	(0.000490)	(0.00240)	(0.00397)
L2.Log(cCost)						-0.00712***	-0.00297*	-0.00369***	0.000911	-0.133***	-0.00318***	0.00350***	-0.00367***	0.000578	-0.0253***
						(0.00203)	(0.00168)	(0.000988)	(0.00523)	(0.0259)	(0.000908)	(0.00114)	(0.00105)	(0.00188)	(0.00510)
L3.Log(cCost)											-0.000907	-0.00841***	-0.00251**	0.00380	-0.127***
											(0.000889)	(0.00105)	(0.00109)	(0.00373)	(0.0306)
L4.Log(cCost)											-0.00539***	0.00510***	0.00275***	-0.00621	-0.0427***
											(0.00181)	(0.00136)	(0.000910)	(0.00543)	(0.00653)
Firm Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Other Controls (GDP, sectoral CO_2)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations Observations	753,256	922,509	869,737	955,230	617,476	674,264	802,851	762,428	833,420	551,612	586,571	691,553	660,371	718,129	478,213
Adjusted R-squared	0.403	0.875	0.0575	0.0221	0.00575	0.408	0.866	0.0707	0.0228	0.0108	0.400	0.859	0.0774	0.0213	0.0149

Notes: This table shows the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables with different lag structures (current, current with two lags, current with four lags). The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

Table 1.15. Robustness Check: Regression Without Weighting by Firm Size

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0454***	-0.0205**	0.00776***	0.0451***	0.150
	(0.00913)	(0.00831)	(0.00262)	(0.0135)	(0.111)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.394	0.867	0.0690	0.0210	-0.0172

Notes: Columns 1-5 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are not weighted. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 1.16. Robustness Check: Free Allowance Allocations

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, 3MA)	-0.0424***	-0.0161*	0.00813***	0.0320	-0.0677
	(0.00900)	(0.00850)	(0.00273)	(0.0238)	(1.046)
Log(cCost, 3MA) x $\mathbb{1}_{\text{free}}$	0.147	0.106	0.0116	-0.567	-4.560
	(0.233)	(0.294)	(0.0740)	(1.401)	(23.97)
$\mathbb{1}_{\text{free}}$	-0.154	-0.128	-0.0158	0.491	4.064
	(0.246)	(0.267)	(0.0665)	(1.348)	(21.90)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.389	0.863	0.0680	-0.00362	-0.423

Notes: Columns 1-5 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables. The independent variable of interest is the 3-year moving average (current, the first, and the second lag) of the logged embodied carbon policy costs constructed from equation (1.1). All regressions are weighted by the firm size. Indicator $\mathbb{1}_{\text{free}}$ equals one if the firm's sector has free allowance allocations. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

Table 1.17. Robustness Check: Embodied Carbon Policy Costs (Current) and Industrial Firm Performance

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, current)	-0.0284***	-0.0185***	0.0189***	0.0361***	0.106
	(0.00592)	(0.00640)	(0.00386)	(0.01000)	(0.0762)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	753,256	922,509	869,737	955,230	617,476
Adjusted R-squared	0.399	0.874	0.0553	0.0204	-0.00804

Notes: Columns 1-5 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables. The independent variable of interest is the contemporaneous carbon policy exposure constructed from equation (1.1). All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

Table 1.18. Robustness Check: Alternative Instruments with Time-Varying Shares

	(1)	(2)	(3)	(4)	(5)
VARIABLES (in Logs)	Employment	Sales	TFP	Tangible	Intangible
Log(cCost, current)	-0.0186***	-0.0246***	0.00799***	0.0369**	0.374***
	(0.00597)	(0.00724)	(0.00292)	(0.0147)	(0.141)
Firm Controls	✓	✓	✓	✓	✓
GDP, sectoral CO_2	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓
Observations	674,264	802,851	762,428	833,420	551,612
Adjusted R-squared	0.407	0.864	0.0688	0.0205	-0.0724

Notes: Columns 1-5 show the coefficient estimates from 2SLS regression (1.3) for different logged-level outcome variables. All regressions are weighted by the firm size. The sample covers 16 European countries and 100 NACE 3-digit sectors from 1998 to 2019. Different sets of fixed effects and controls are further tested in the robustness checks in the appendix. Standard errors in parentheses are clustered at the country-sector level. *** p<0.01, ** p<0.05, * p<0.1.

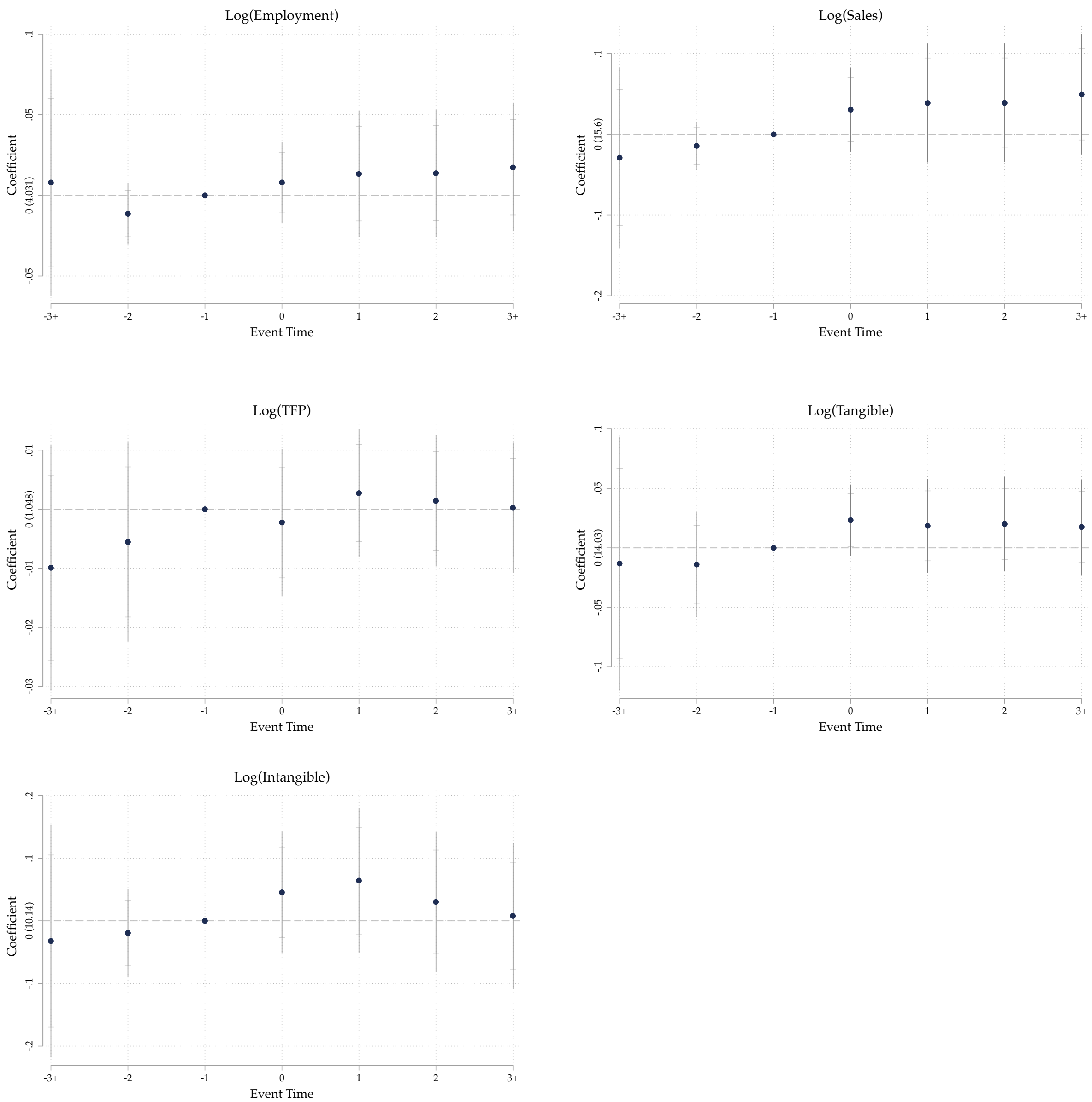


Figure 1.7. Robustness Test: Event Study Analysis with Direct Carbon Tax

Notes: The panel includes firms in countries with carbon taxes: France, Norway, Portugal, Sweden, Estonia, Latvia, Portugal, and Slovenia; the time frame is restricted from 2009 to 2019 in order to isolate the confounding effects from the introduction of EU ETS in 2005.

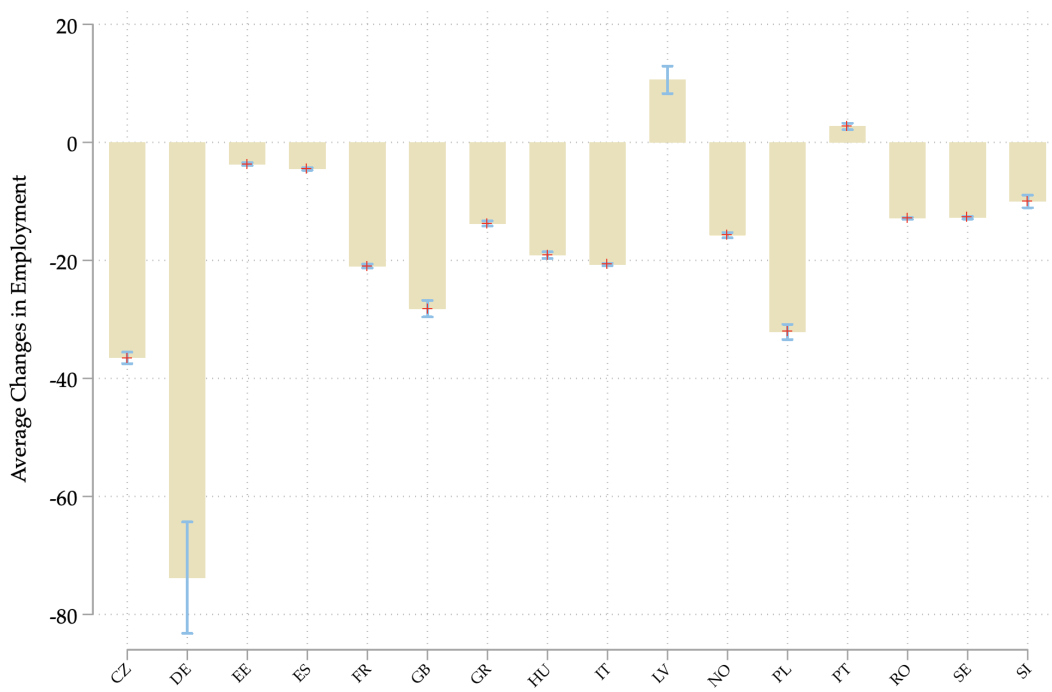


Figure 1.8. Estimated Effects on Employment for a hypothetical 10% Embodied Carbon Policy Costs Increase Across Countries

Notes: Estimated effects on firm employment for a hypothetical 10% embodied carbon policy costs increase based on the regression results in Table 1.1. The average changes in firm employment are calculated across different countries.

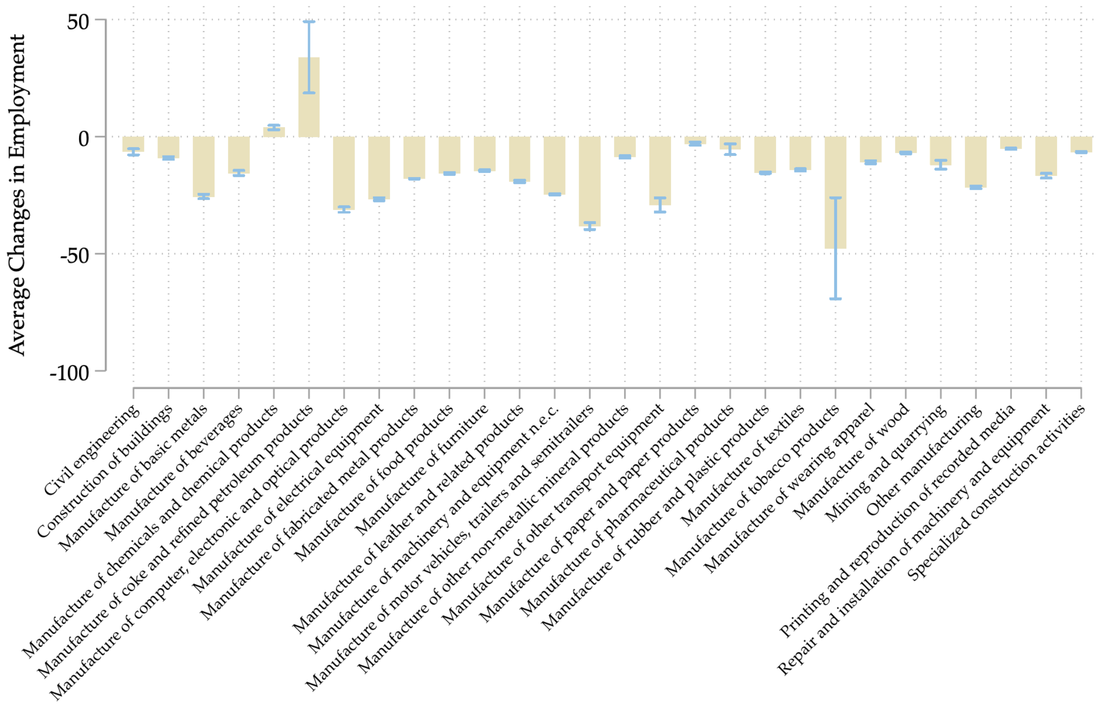


Figure 1.9. Estimated Effects on Employment for a hypothetical 10% Embodied Carbon Policy Costs Increase Across NACE 2-digit Sectors

Notes: Estimated effects on firm employment for a hypothetical 10% embodied carbon policy costs increase based on the regression results in Table 1.1. The average changes in firm employment are calculated across different NACE 2-digit sectors.

1.9 Data Details

List of Countries

Countries in the MRIO Data: Austria, Australia, Belgium, Bulgaria, Brazil, Canada, Switzerland, China, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, United Kingdom, Greece, Croatia, Hungary, Indonesia, Ireland, India, Italy, Japan, South Korea, Lithuania, Luxembourg, Latvia, Malta, Mexico, Netherlands, Norway, Poland, Portugal, Romania, Russia, Sweden, Slovenia, Slovakia, Turkey, Taiwan China, United States.

Countries in the Carbon Policy Data: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, South Korea, Latvia, Lithuania, Luxembourg, Malta, Mexico, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan China, Turkey, United Kingdom, United States.

Countries in the Merged Firm Regression Data: Czech Republic, Germany, Estonia, Spain, France, United Kingdom, Greece, Hungry, Italy, Latvia, Norway, Poland, Portugal, Romania, Sweden, and Slovenia.

Concordances

This paper integrates sectoral-level carbon price and input-output data with firm-level outcomes through multiple concordances.

Exiobase and ISIC sectors: Exiobase has its unique sector codes, but they closely align with ISIC industries. I established a connection by mapping Exiobase sectors to their corresponding ISIC sectors.

World Carbon Pricing Database Concordance: The sectors in this database are broken down by the Intergovernmental Panel on Climate Change (IPCC) source category and fuel types.[33][34] I utilize existing tables that link IPCC sectors with the International Standard Industrial Classification (ISIC). This allows me to subsequently connect the World Carbon Pricing Database to Exiobase via ISIC codes, and then calculate the sectoral-level carbon policy exposure after merging.

Linking Carbon Policy Exposure Data with Firm-level Data: Orbis provides firm-specific data categorized under NACE codes, ranging from 1- to 4-digit levels. I use published tables that bridge Exiobase sectors with NACE sectors. The level of granularity of the Exiobase sectors mirrors the NACE 3-digit levels approximately. Since my aim is to associate broader sectoral-level carbon policy details with more specific firm data, I also consider connecting at the NACE 2-digit level for sectors not initially merged using the Exiobase and NACE 3-digit sector concordance.

Firm-level Outcome Variable Details

Table 1.19. Variable Definitions

Outcome Variables	Definition
Employment	Total number of employees included in company's payroll
Sales	Net sales
TFP	Total factor productivity estimated following Ackerberg et al. (2015)
Tangible Fixed Assets	All tangible assets such as buildings, machinery, etc.
Intangible Fixed Assets	All intangible assets such as formation expenses, research expenses, goodwill, development expenses, and all other expenses with a long-term effect

[33]https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

[34]Some tax rates vary across fuels for a couple of reasons. Firstly, some places don't base their tax rate on the amount of CO2 produced, but on the quantity of the fuel itself, like its weight or volume. Secondly, specific sectors in certain places might be given exemptions for particular fuels.

Chapter 2

Tracing the Impact of Sustainable Investors

Abstract: This paper empirically investigates the impact of sustainable investing on firms' financial performance and real outcomes. Albeit promising in theory, it is not evident how the pressure for sustainability exerted by value-aligned investors in secondary markets becomes an allocative force across firms. Focusing on the prevalent portfolio tilting strategy in practice, we delineate the transmission mechanism from investor preference, intermediated by funds, to underlying firms. Leveraging a 2016 natural experiment for identification, we find that firms with greater exposure to low-sustainability fund ownership experience acute downward pressure on their valuation and equity financing. However, no significant impact is observed on firm debt financing, consistent with our observation that the transmission of investors' pressure for sustainability falls short of generating substantial real impacts on firms' investment decisions. To meaningfully facilitate any environmental or social changes, evidence from this early episode in the recent ESG movement underscores the critical mass and coordination among sustainable investors.

2.1 Introduction

Sustainable investing, a practice that combine the monetary gains and the investors' preference for long-term environmental or social values, has gained popularity in recent years

(Starks, 2009, 2023). The demand for such alignment resonates with the notion of sustainable investing potentially providing a market-based solution to the global sustainability challenges[1] we face. With Europe historically at the frontline of this movement, the expansion of sustainable investing assets has gained remarkable momentum worldwide since 2016. In the U.S., sustainable assets under management[2] made up a third of the $51 trillion that was professionally managed by the end of 2020.

Table 2.1. Snapshot of global sustainable investing assets: 2016-2018-2020, billion USD

REGION	**2016**	**2018**	**2020**
United States	8,723	11,995	17,081
Europe	12,040	14,075	12,017
Japan	474	2,180	2,874
Canada	1,086	1,699	2,423
Australasia	516	734	906
Total	22,839	30,683	35,301

Notes: Data are sourced from the fifth biennial report provided by the Global Sustainable Investment Alliance (GSIA). The classification and aggregation of assets by region are as detailed in GSIA (2020). Specifically, Europe and Australasia have enacted significant changes between 2016 and 2020 in the way sustainable investment is defined in these regions. For uniformity, currency conversions to USD were executed using exchange rates applicable on the date of reporting. As of the year 2020, the European region encompassed the following countries: Austria, Belgium, Bulgaria, Denmark, France, Germany, Greece, Italy, Spain, Netherlands, Poland, Portugal, Slovenia, Sweden, the United Kingdom, Norway, Switzerland, and Liechtenstein.

How does sustainable investing affect the real economy? It remains an open debate whether sustainable investing truly transforms corporate behavior and drives environmental and social improvements. Questions remain regarding the efficacy of the impact of sustainable investing beyond financial market, as trillions of dollars poured into the sustainable assets.

Previous theoretical literature has highlighted two potential channels through which sustainable investing reduce the negative externalities.[3] Firstly, sustainable investors could

[1] Challenges formally outlined in the United Nations Development Programme's Sustainable Development Goals: https://www.undp.org/sustainable-development-goals

[2] As classified by the U.S. SIF Foundation.

[3] Including but not limited to Heinkel et al. (2001); Davies and Van Wesep (2018); Berk and van Binsbergen (2021); Pástor et al. (2021); Broccardo et al. (2022); Edmans et al. (2022); Oehmke and Opp (2022).

limit the capital access to certain entities involved in pollution activities. Secondly, investors focusing on sustainability could also push the polluting firms to adopt more sustainable practices, potentially though managers' incentives to access chapter capital or through shareholders' incentives to command higher share prices.

We focus on the most prevalent sustainable investing strategy in practice[4], wherein sustainable investors buy securities issued by "clean" firms and sell off securities issued by "dirty" firms. This approach has deep historical roots, for example, the Anti-Apartheid Movement (Kaempfer et al., 1987; Teoh et al., 1999; Goodman, 2008). During this movement, various interest groups applied pressure on their pension funds and endowments to divest fully from American firms doing business in South Africa. In the context of contemporary ESG (environmental, social, and governance) empirical assessments on whether sustainable investing achieve desired impacts are needed .

We contribute to the ongoing work assessing whether sustainable investmenting can generate the real impact on firm dynamics. We rely on a framework that focus on the value-alignment preferences of sustainable investors, and consider the potential pass-through effect from the intermediating funds. Specifically, we trace the effects originated from investor preferences, intermediate by global funds, and ultimately influencing the underlying firms. The framework used in this study can be generalized beyond the real of sustainable investing.

In the empirical setting of this study, we acknowledge several practical elements that challenge the effectiveness of theoretically promising mechanisms. First and foremost, not all participants practicing sustainable investment are driven by an exclusive quest for impact. The distinction between value-alignment and consequentialism (Green and Roth, 2021; Broccardo et al., 2022; Landier and Lovo, 2022) is crucial to modeling the nature of the preference among sustainable investors. In the real-world setting, sustainable investors have numerous motivations

[4]Kölbel et al. (2020) and review the effectiveness and mechanisms of alternative strategies studied in the literature. Shareholder engagement emerges as the most reliable mechanism for investors seeking impact (Akey and Appel, 2019; Naaraayanan et al., 2021). Indirect impact mechanisms (including stigmatization, endorsement, benchmarking, and demonstration) have hardly any empirical support.

including virtue signaling, risk hedging, and return considerations (Giglio et al., 2023).

Additionally, it is important to note that the majority of the transactions sustainable investing are through the trade in secondary markets. Sustainable investors adjust their portfolios by primarily buying and selling bonds or stocks that are already in circulation. It is not immediate whether the pressure for sustainability exerted by value-aligned investors in secondary markets can become an allocative force across firms. Moreover, the transmission mechanism is further complicated by the fact that a significant portion of "sustainable investing assets" are bundled, labeled, and intermediated by financial institutions. Across major markets reported in Table 2.1, institutional holdings accounted for 80% of sustainable investing assets in 2016, 75% in 2018, and 75% in 2020 (GSIA, 2020). The size of the sustainable fund industry continues expanding worldwide, both in terms of the number of funds specializing in sustainable investing and the value of assets under their management (see Figure 2.1).

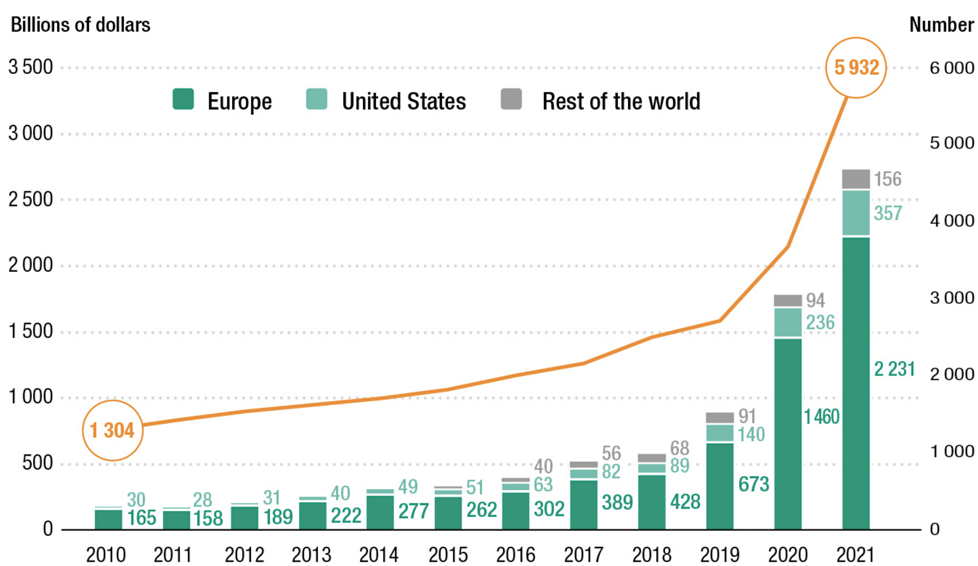


Figure 2.1. Sustainable funds and their assets under management (AUM)

Notes: Figure 2.1 is sourced from the UNCTAD World Investment Report (2023) based on data provided by Morningstar. The figure illustrates the global trends of investment funds that integrate environmental, social, and corporate governance (ESG) criteria in their investment process. The yellow line, plotted against the right scale, represents the count of sustainable funds; the columns, plotted against the left scale, represent the total value of assets under the management of these funds.

To causally identify the mechanism at work in the early stage of the recent ESG movement, we leverage a unique natural experiment from 2016. This event provides a unique scenario where only the sustainability "labels" of financial assets were shocked (Hartzmark and Sussman, 2019). In reaction to the revealed fund-level sustainability measure, investors who prefer to hold assets aligning with their values allocate their wealth across funds accordingly. Subsequent to the event, we can observe shifts in investors' demand for assets, which leads to funds experiencing inflows and outflows, prompting fund managers to adapt their portfolio allocations through the buying or selling of firms' securities.

Motivated by the insights from the fund flows and rebalancing observed in the firm-fund pair regressions, we proceed to construct a measure of firm-level exposure to the sustainability pressures exerted by end investors. We then assess the heterogeneous effects, or the absence thereof, on underlying firms' valuation, external financing, and investment decisions using event studies. We find that firms with greater exposure to low-sustainability fund ownership experience acute downward pressure on their valuation and equity financing. However, no significant impact is observed on firm debt financing, consistent with our observation that the transmission of investors' pressure for sustainability falls short of generating substantial real impacts on firms' investment decisions.

Related Literature

Our study methodologically aligns with the identification techniques developed and popularized in the banking literature (Gan, 2007; Khwaja and Mian, 2008; Jiménez et al., 2012; Chodorow-Reich, 2014). The inclusion of a full set of borrower fixed effects typically serves to absorb any borrower characteristics that might influence outcomes at the loan (borrower–lender pair) level. Khwaja and Mian (2008) relies on firm fixed effects to identify the transmission effect of bank liquidity shocks to borrowers. Following their approach, we estimate the transmitted impact from the unexpected inflows/outflows from the funds after the 2016 shock in the financial sector. We apply this established empirical toolkit to estimate the pass-through of sustainable investment preferences and their potential macroeconomic implications.

The transmission mechanism we hypothesize to connect fund flows with firm valuation shares the same theoretical foundation with the growing literature on demand system asset pricing (Koijen et al., 2019; Koijen and Yogo, 2019; Gabaix and Koijen, 2021). Recent works, such as those by van der Beck (2021), Baker et al. (2022), and Noh et al. (2022), build upon this structural framework to address pricing issues instrumental to understanding the role of sustainable funds. Specifically, van der Beck (2021) quantifies an upward price pressure generated by flows into sustainable funds, which the author believes supports a plausible mechanism for sustainable funds to lower the cost of capital for "clean" firms. In summary, these studies establish how, in equilibrium, the preferences of sustainable investors may alter firm valuation through institutional ownership.

Our research is also closely related to the q-theory literature, especially to the recent progress in equity-dependent firms and the growing significance of intangibles (Hayashi, 1982; Fischer and Merton, 1984; Baker et al., 2003; Bolton et al., 2011; Kogan and Papanikolaou, 2012; Peters and Taylor, 2017; Jeenas and Lagos, 2022). These provide economic intuitions that relate firm investment to its stock market evaluations in the presence of costly external financing. Our work applies the same intuitions to the sustainability discourse. To systematically test the relevance of our proposed mechanism in shaping aggregate output, we dissect firm dynamics by jointly examining valuation effects, the responses in external financing options, and ultimately, firms' physical and R&D investment.

Our study complements the literature studying the real outcomes from changes to institutional holdings initiated by regulatory rules or institution policies (Green and Vallee, 2022; Haushalter et al., 2022; Kacperczyk and Peydró, 2022; Sachdeva et al., 2022). By applying the analysis to the ESG setting, we reveal the real effects of institutional ownership driven bt investor preferences and information salience. Our work is also closely related to the strand of literature exploring the flow-performance sensitivity of funds (Bollen, 2007; Pástor and Vorsatz, 2020). Moreover, this study is also related to the previous work investigating the extend to which financial intermediaries may trade off portfolio returns for better sustainability performance (Riedl and Smeets, 2017; Nofsinger et al., 2019; Barber et al., 2021; Bauer et al., 2021; Li et al., 2021; Gantchev et al., 2022; Ceccarelli et al., 2023).

The rest of the paper is structured as follows. In Section 2.2, we describe the 2016 Morningstar Sustainability shock for identification. Section 2.3 presents detailed empirical design and the data sources. In Section 2.4, we present the results on the direct effect of investors' revealed preference and its transmission through institutional ownership. In Section 2.5, we first construct firm-level exposure to investors' divestment pressure for sustainability. Then we estimate the dynamic heterogeneous effects on firm valuation, external financing, and investment decisions using an event-study technique. Section 2.6 concludes.

2.2 The 2016 Natural Experiment

In March 1 2016, Morningstar, one of the biggest credit rating agencies, published sustainability ratings for global funds.[5] This new globe rating system, in addition to their original star ratings, provides an assessment for mutual funds and exchange-traded funds based on the ESG performance of their portfolio holdings. This new rating system measures a fund's sustainability performance relative to its peers in the same fund category. The globes rating ranges from one to five, and the funds having better sustainability performance receive higher globe ratings.

We rely on the 2016 Morningstar event for identification, in order to study the shifts in investor preferences, fund inflows and outflows, and the broader implications for ESG integration in investment strategies. The publication of Sustainability Ratings by Morningstar serve as a shock to the salience of sustainability in investment decisions due to its surprising nature. According to the Google search results, the first publication of sustainability scores attracted

[5] See Morningstar Press Release.

Distribution	Score	Descriptive Rank	Rating Icon
Highest 10%	5	High	
Next 22.5%	4	Above Average	
Next 35%	3	Average	
Next 22.5%	2	Below Average	
Lowest 10%	1	Low	

Figure 2.2. Morningstar Sustainability Rating: distribution, cutoffs, and icons

Notes: Based on their portfolio sustainability scores, funds are assigned absolute category ranks and percent ranks within their Morningstar Categories, provided that a category has at least 10 funds with portfolio sustainability scores. A fund's Morningstar Sustainability Rating is its normally distributed ordinal score and descriptive rank relative to the fund's category. Source: Morningstar Sustainability Rating Methodology (September 22, 2016), accessed at https://s21.q4cdn.com/198919461/files/doc_downloads/press_kits/2016/Morningstar-Sustainability-Rating-Methodology.pdf.

significant attention at its launch but not prior to its launch, ruling out the anticipation effect. The publication rely on the exiting and publicly information on the firm ESG scores and repackaged in a way that is more visible for investors. This initiative has a significant scale, as it involves more than $8 trillion USD in mutual fund assets.

The introduction of Morningstar's Sustainability Rating in March 2016 has attracted substantial attention from the recent literature (Ammann et al., 2019; Hartzmark and Sussman, 2019; Gantchev et al., 2022). Hartzmark and Sussman (2019). Hartzmark and Sussman (2019) show that this event led to a substantial net inflow of $24 billion into high-sustainability funds and a net outflow of $12 billion from low-sustainability funds. Most of the previous studies established the causal link between the Morningstar event and the fund flows. Our study distinguish from these studies by further investigating into how the event affec the underlying firm performance.

2.3 Data

2.3.1 Ownership Data

We obtain the historical fund holdings and characteristics data from FactSet. As mandated by the Securities and Exchange Commission (SEC) mandates, mutual funds should disclose their complete holdings lists on a quarterly basis, using SEC Forms N-Q and N-CSR. We utilize two key metrics: first, the adjusted holding (Adj_Holding), which is the number of shares held by the fund on the report date, adjusted for any corporate actions; second, the adjusted market value (Adj_MV), which is the share amount multiplied by the month-end share price, also adjusted for corporate actions according to FactSet's methodology.

For the identification purpose using firm-fund pair data with firm-level fixed effects, we focus on the firms held by more than 8 funds as of March 1, 2016. We concentrate our analysis on open-end mutual funds (OEF), exchange-traded funds (ETF), closed-end funds (CEF), and variable annuities (VAR).[6]

2.3.2 ESG Ratings

The firm ESG scores come from Sustainalytics database. Unfortunately, the initial release of Morningstar's globe ratings is proprietary and is no longer accessible publicly. In fact, Sustainalytics revised the globe rating method significantly in the November 2018 and November 2019 updates. These revisions have been thoroughly documented and analyzed in existing literature, including work by Gantchev et al. (2022).

The original fund-level globe ratings at the time of the first publication of the Morningstar Sustainability Rating are reconstructed by assigning pre-shock fund-level sustainability scores based on the portfolio asset-weighted average of company ESG scores from Sustainalytics. To closely approximate the initial release of the globe ratings, funds in the top and bottom deciles are classified as "high-sustainability" and "low-sustainability," respectively. See Figure 2.3 for

[6]Closed-end funds (CEF) constitute less than 5% of assets in our sample.

the cross-sectional variation in the reconstructed fund-level sustainability scores prior to the Morningstar event.

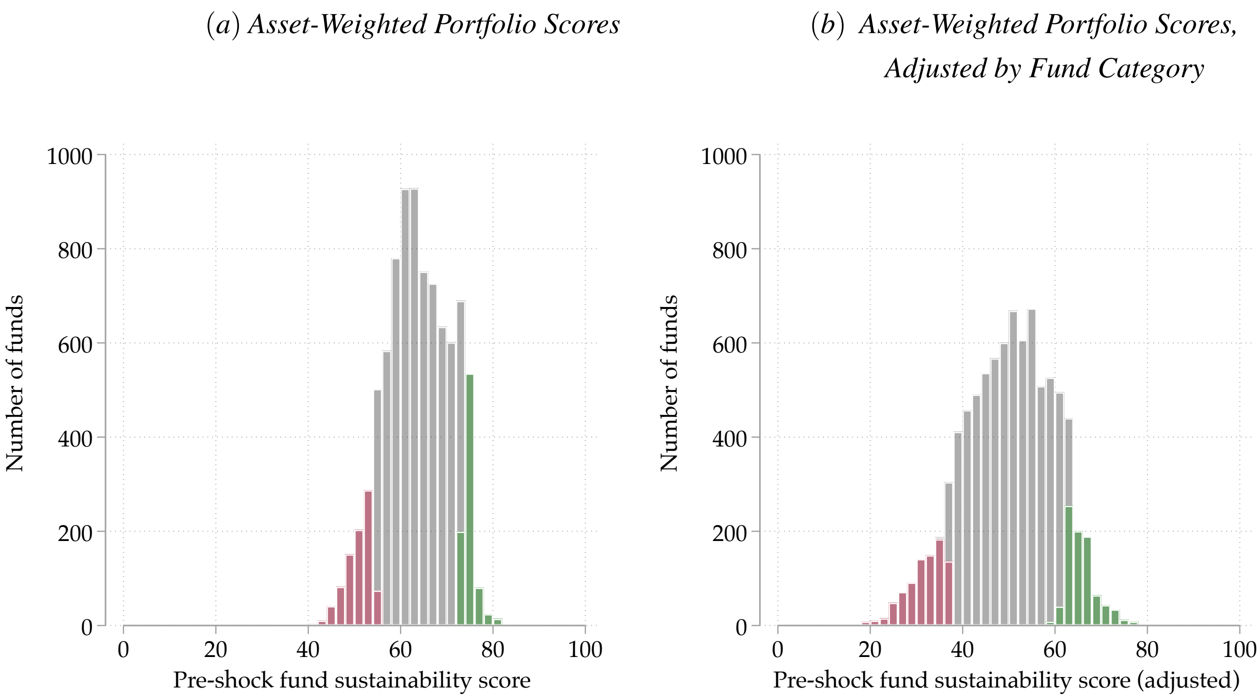


Figure 2.3. Distribution of fund-level sustainability scores as of March 1, 2016

Notes: This figure presents the distribution of fund-level sustainability scores for a sample of 8,561 funds as of March 1, 2016. The scores are reconstructed by the authors using fund equity holdings linked with firm-level ESG scores from Sustainalytics. The x-axis displays the absolute or relative scores, which range from 0 to 100, with higher scores indicating better pre-shock sustainability performance of the corresponding funds. The y-axis shows the number of funds at each sustainability score level. It is worth noting that funds are only assigned sustainability ratings if a sufficiently high portion of their portfolio is issued by firms that have ESG scores as of March 1, 2016. In panel (a), the pre-shock fund-level score is computed as the asset-weighted average of all firms in a fund's equity portfolio that were rated by Sustainalytics. Panel (b) presents a standardized z-score transformation of (a) within each fund category (scaled by 10 and shifted to have a mean of 50) to closer replicate the original methodology employed by Morningstar. Each histogram highlights the lowest and the highest deciles for easy identification.

2.3.3 Firm Fundamentals

We obtain firm fundamentals data at the quarterly frequency from the Compustat/CRSP-merged database following standard sample-selection criteria. This database allows for detailed analysis on firm dynamic since it provides updates at a quarterly frequency. Moreover, this database's coverage is extensive — it provides detailed balance sheet information for more than 32,000 securities across major exchanges

2.4 The Transmission of Pressure for Sustainability

We leverage the 2016 Morningstar event for causal identifications. This event offers a unique setting because it primarily revealed the sustainability "labels" of financial assets without changes in their fundamental attributes, as highlighted in the study by Hartzmark and Sussman (2019). In this section, we first show the direct impact of investors' preferences using the 2016 Morningstar event. We then investigate the transmission effect of these investors' preferences to underlying firms through institutional equity ownership.

2.4.1 Direct Effect of Investors' Revealed Preference

Figure 2.4 illustrates that one quarter after the 2016 Morningstar event, "low sustainability" funds (in the bottom decile) saw a reduction in equity portfolio size, whereas "high sustainability" funds (in the top decile) experienced an increase, compare to one quarter before the event.[7] The shrinkage of the equity portfolio size is more significant within "low sustainability" funds outside of the US.

Columns (1) and (2) in Table 2.2 show that a higher pre-shock sustainability score leads to greater growth in the fund's equity portfolio. Columns (3) and (4) explore this relationship further, revealing a nonlinear effect. Funds classified as low sustainability experienced significant

[7] Equity holdings represent the majority of total financial assets in U.S. non-money market funds. For more detailed information, please refer to the OECD report on institutional investors' statistics, available at https://doi.org/10.1787/instinv-2017-en.

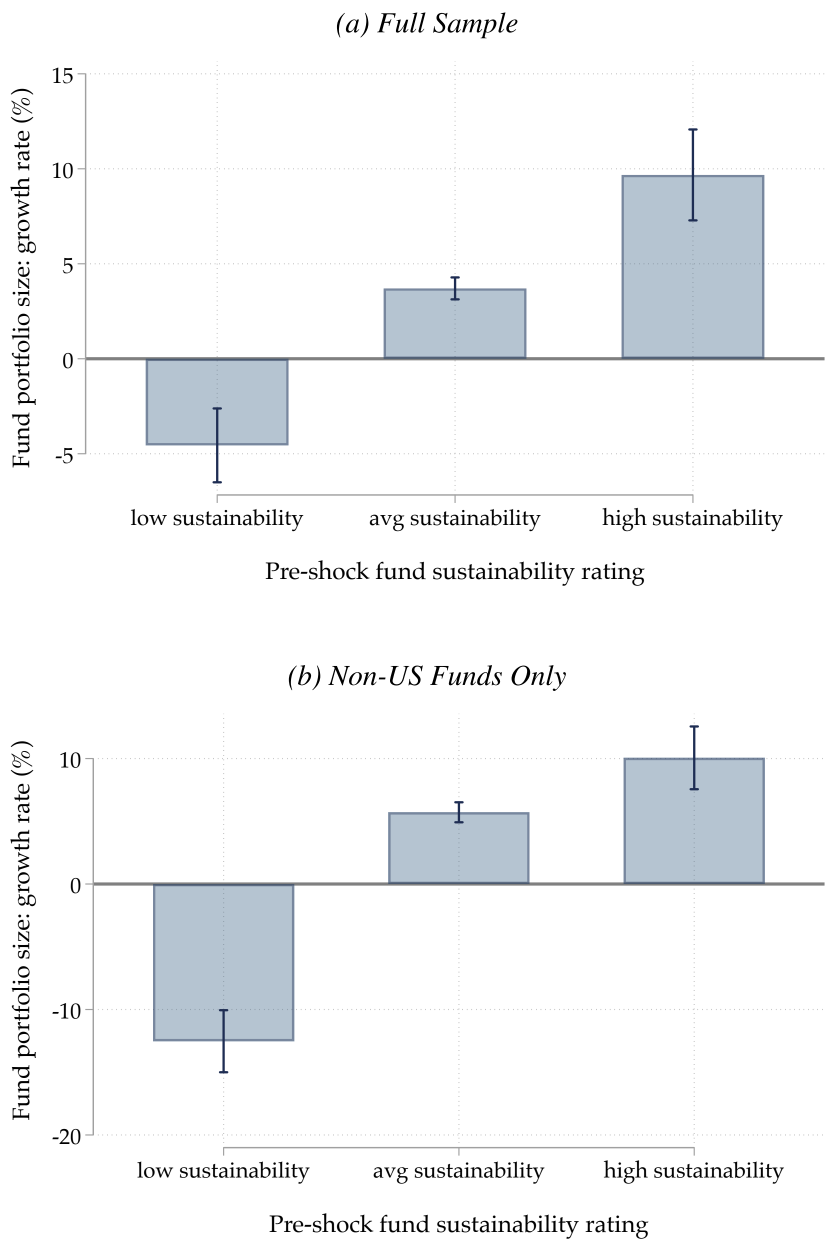


Figure 2.4. Size of funds' equity portfolios by sustainability rating: growth from 2015q4–2016q2

Notes: The growth rate is measured in terms of percentage change in the logarithm of a fund's equity portfolio size ($\Delta \log(M_f) \times 100\%$). Panel (a) presents data from 8,561 global funds, including 2,068 U.S.-domiciled funds (totaling 1.09 trillion USD) and 6,493 non-U.S. funds (totaling 0.63 trillion USD). The graph shows a weighted average for each pre-shock sustainability category. Panel (b) focuses exclusively on non-U.S. funds, with the top domiciles being Luxembourg, the United Kingdom, Norway, Canada, and France.

declines in their equity portfolio sizes compared to those with average sustainability. There is no significant impact on the portfolio sizes of the funds with high sustainability scores. The presence of fund-level control variables[8] in Columns (2) and (4) only slightly alters the coefficients compared to Columns (1) and (3).

2.4.2 Transmission Through Institutional Ownership

We observe the cash inflows and outflows to the funds with different sustainability labels after the event, similar to what the previous literature has established. This section further explores how these fund-level shifts compel fund managers to adjust their equity portfolio allocations by buying or selling company securities. These efforts from the fund managers essentially serve as a transmission mechanism to potentially influence the underlying firms.[9] In the following subsections, we quantity the transmission effects at both intensive (adjustment of firms' existing number of shares) and the extensive margins (selection of new firms into the equity portfolio).

Estimating the Intensive Margin

Denote the portion of fund f's asset under management (AUM), M_f, allocated to firm i's equity as ω_{if}. The following accounting identity must hold:

$$\omega_{if} M_f = P_i Q_{if} \ , \tag{2.1}$$

where Q_{if} is the number of shares issued by firm i and held by fund f, and P_i is firm i's share price. The identity above implies that

$$\mathrm{d}\log Q_{if} = \mathrm{d}\log M_f + \mathrm{d}\log \omega_{if} - \mathrm{d}\log P_i \ , \tag{2.2}$$

[8]Fund-level control variables include lagged fund size, fund styles, fund manager styles, fund type, and fund domicile country.

[9]Institutional ownership accounts for approximately 75% of equities in U.S. public firms during the period 2015-2020 Ferreira and Matos (2008).

Table 2.2. Changes in fund equity holdings before and after the first Globe Rating release

	$\Delta \log(M_f) \times 100\%$ growth of fund f's equity portfolio from 2015q1 to 2016q2			
(a) EQUAL-WEIGHTED	(1)	(2)	(3)	(4)
Pre-shock fund sustainability $S_{f,\text{pre}}$				
portfolio score	0.298***	0.201**		
	(0.0673)	(0.0897)		
if low-sustainability			-10.15***	-8.113***
			(1.868)	(1.974)
if avg-sustainability			0	0
			—	—
if high-sustainability			0.646	-0.375
			(1.322)	(1.624)
Fund-level controls	no	yes	no	yes
Observations	7,852	5,285	7,852	5,285
Adjusted R-squared	0.003	0.040	0.006	0.043

	$\Delta \log(M_f) \times 100\%$ growth of fund f's equity portfolio from 2015q1 to 2016q2			
(b) SIZE-WEIGHTED	(5)	(6)	(7)	(8)
Pre-shock fund sustainability $S_{f,\text{pre}}$				
portfolio score	0.372***	0.217		
	(0.125)	(0.181)		
if low-sustainability			-8.263***	-9.835***
			(2.205)	(2.608)
if avg-sustainability			0	0
			—	—
if high-sustainability			5.973	-4.308
			(5.549)	(5.951)
Fund-level controls	no	yes	no	yes
Observations	7,852	5,285	7,852	5,285
Adjusted R-squared	0.007	0.087	0.009	0.097

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Robust standard errors are in parentheses.

where the log change in the number of shares held ($d\log Q_{if}$) can be decomposed into the growth of the fund's assets under management, its portfolio composition adjustments to firm i's equity, and other firm-specific factors reflected by changes in firm i's share price. $d\log M_f$ is driven by fund f's pre-existing sustainability type in the context of the Morningstar event, $S_{f,pre}$, conditioning on other conventional fund characteristics ($\mathbf{X}_{f,pre}$).

The breakdown above motivates a regression model with firm-fund pairs with firm fixed effects (γ_i) to control for firm-specific characteristics:

$$\Delta \log Q_{if} = \gamma_i + \beta S_{f,pre} + \Gamma \mathbf{X}_{f,pre} + \varepsilon_{if} \, . \tag{2.3}$$

γ_i absorbs any changes in firm i's equity price and (homogeneous) fund rebalancing actions in response to firm fundamentals over the event period. The regression model, as specified in Equation (2.3), aims to isolate the transmission effect on the equity holdings of underlying firms, attributed to the sustainability characteristics of the owning funds, denoted as $S_{f,pre}$. β is the coefficient of interest here as it quantifies the extent of this transmission.

The inclusion of firm fixed effects absorbs unobserved firm-level characteristics. This approach necessitates that every firm in the regression must have multiple owning funds in the sample. The identification using multi-fund firms leverages the within-firm estimator, an empirical strategy widely used in the literature to study the real effects of shocks transmitted and amplified through financially constrained financial intermediaries (Kashyap et al., 1996; Khwaja and Mian, 2008; Paravisini, 2008; Paravisini et al., 2015). We also winsorize our sample at the top and bottom 0.5% of observations of $\Delta \log Q_{if}$ in order to ensure our results concerning the intensive margin are not driven by outliers.

Columns (1) and (2) in Table 2.3 assess whether the same firm, on average, when held by multiple funds, experiences more or less liquidation pressure from funds marked as low- or high-sustainability, respectively. Even though Column (1) does not show statistically significant buying/selling pressures linked to owning funds' pre-shock sustainability score, the nonlinear exploration in Column (2) depicts a more nuanced relationship. We find that the high-sustainability funds ownership significantly and positively impacts holdings growth relative to the ownership by average-sustainability funds. When accounting for managers' potential incentives to rebalance portfolios based on firms' varying ESG performances, the non-linear effects become more pronounced.

Table 2.3. Transmission of trading pressure to underlying firms: intensive margin

	$\Delta \log(Q_{if}) \times 100\%$ growth of fund f's holdings of firm i from 2015q1 to 2016q2		
	(1)	(2)	(3)
Pre-shock fund sustainability $S_{f,\text{pre}}$			
portfolio score	0.0792		
	(0.161)		
if low-sustainability		-1.431	-17.01**
		(3.963)	(7.249)
if low-sustainability $\times \text{ESG}_i$			0.296**
			(0.133)
if avg-sustainability		0	0
		—	—
if high-sustainability		6.575***	61.25***
		(1.808)	(8.624)
if high-sustainability $\times \text{ESG}_i$			-0.744***
			(0.110)
Firm FE	yes	yes	yes
Fund-level controls	yes	yes	yes
Observations	250,748	250,748	250,748
Adjusted R-squared	0.024	0.025	0.025

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors in parentheses are clustered at the fund level. Fund-level control variables include lagged fund size, fund styles, fund manager styles, fund type, and fund domicile country.

We document that there was a shrinkage in the size of equity portfolios held by low-sustainability funds following the initial release of fund-level sustainability ratings. As indicated by the coefficient on the interaction term between low fund sustainability and firm ESG score in Table 2.3, the firms with higher ESG scores receive less downward pressure. In contrast, the coefficient on the interaction between high fund sustainability and firm ESG score is found to be significantly negative. This finding implies that high-sustainability funds may be hesitant or reluctant to further augment their holdings in firms with strong ESG performance when allocating the additional inflows post-shock. Both pieces of evidence reported in Column (3) of Table 2.3 are more consistent with the notion of impacted funds rebalancing with a deliberate tilt rather than adjusting positions pro rata after the natural experiment event. The *tilts* we observed potentially contributed to the "greening" of portfolios among low-sustainability funds as these funds actively downweigh firms with weaker ESG profiles.[10]

Estimating the Extensive Margin

We then estimate how funds responded on the extensive margin through the inclusion and exclusion of firms in their equity portfolios, and how these decisions exert pressure on the underlying firms. This analysis is conducted by considering binary outcomes (exit or entry) a quarter after the shock in a Linear Probability Model (LPM):

$$\text{Exit}_{if} \quad or \quad \text{Entry}_{if} = \gamma_i + \beta S_{f,pre} + \Gamma \mathbf{X}_{f,pre} + \varepsilon_{if} \,, \tag{2.4}$$

where $\text{Exit}_{if} = 1$ denotes fund f divesting all holdings in firm i's stocks after the shock, and $\text{Entry}_{if} = 1$ indicates fund f initiating a position in firm i's stocks after the shock. The LPM is chosen here for its straightforward interpretability and the ease of statistical inference it provides.[11] The estimation results are presented in Table 2.4.

Table 2.4 shows no statistically significant effects on funds' decisions to exit positions (Columns (1) and (2)), regardless of the funds' pre-shock sustainability classification. There

[10]It is important to acknowledge that such effect on portfolio "greening" may be transient. While the process of "greening" existing funds is a contributing factor, substantial evidence underscores specialization and the establishment of new ESG-focused funds as the predominant drivers of the sustainable investment trend since 2016 (Boffo and Patalano, 2020; GSIA, 2020; Azémar and Giroud, 2023).

[11]While a probit model, typically better suited for binary outcomes, could be used, we prefer the LPM (Linear Probability Model) for this part of the analysis for its simplicity and clarity in interpretation.

is also no significant impact on the likelihood of exiting positions. In contrast, columns (3) and (4) show significant negative effects on the entry decisions. The aggregate sustainability score significantly influences the funds' decision to initiate positions in firms. As shown in the non-linear specification in Column (4)), we do not find differential impact on the entry margin at the two extreme ends of sustainability ratings.

Our insignificant findings on the extensive margin are not unexpected. As noted by Koijen and Yogo (2019), the set of stocks institutions invest in is typically small and highly persistent. In a series of surveys conducted by Krueger et al. (2020) from 2017 to 2018, it was revealed that exiting portfolio firms was the least used course of action by institutions to manage climate risk after investments had been made. More recently, Pastor et al. (2023) also observe that institutions are more inclined to adjust their investments in response to ESG factors by moderately reducing positions in "brown" stocks rather than completely eliminating them from their portfolios.

2.5 Assessing Firm-Level Impact

In this section, we further explore the impact of investor pressure for sustainability, triggered by the first release of fund sustainability ratings. We focus on assessing whether and how the trading pressure, identified earlier, translates into effects on the real operations of underlying firms in fund portfolios. Although secondary market trading is not directly allocative, it influences investor valuation of firms and sets a benchmark for the prices investors are willing to pay in the primary market for new issues, thereby potentially impacting firms' financing costs and investment decisions. Our analysis adds to the existing literature by providing causal evidence on firm dynamics in the presence of a sustainable investing movement.

We define a firm's exposure to sustainable investors' pressure based on its ownership characteristics, a construct previously utilized in studies such as Townsend (2015), Coppola (2021), and Green and Vallee (2022), among others. Our identification strategy exploits the

Table 2.4. Transmission of downward pressure to underlying firms: extensive margin

	If fund f exited/entered position in firm i ($\times$100%, 2015q4-2016q1)			
	Exit?		Entry?	
	(1)	(2)	(3)	(4)
Pre-shock fund sustainability $S_{f,\text{pre}}$				
portfolio score	-0.0308		-0.506***	
	(0.144)		(0.0987)	
if low-sustainability		5.440		1.531
		(4.869)		(1.363)
if avg-sustainability		0		0
		—		—
if high-sustainability		0.171		-1.374
		(1.317)		(0.935)
Firm FE	yes	yes	yes	yes
Fund-level controls	yes	yes	yes	yes
Observations	633,414	633,414	633,414	633,414
Adjusted R-squared	0.085	0.086	0.261	0.259

Notes: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors in parentheses are clustered at the fund level. Fund-level control variables include lagged fund size, fund styles, fund manager styles, fund type, and fund domicile country.

plausibly exogenous variation in exposure to fund sustainability at the firm level, arising from differences in pre-existing fund ownership. We construct a Bartik-style measure for each firm, quantifying its exposure to sustainable investors' pressure:

$$Z_i := \sum_f \pi_{if} \, S_{f,pre} \, , \tag{2.5}$$

where $S_{f,pre}$ is the pre-shock fund sustainability, and π_{if} denotes the percentage of institutional ownership of firm i held by fund f as of 2015q4.[12]

[12]The construction of our pressure measure in (2.5) is motivated by the results obtained from the firm-fund-level panel regressions. The measure, alongside its non-linear variants presented in (2.6)-(2.7), exploits the variation in ownership base composition across firms. It is important to note that the specific nature of the fund-level shock we examine and the differential trading pressure it created with respect to $S_{f,pre}$ are crucial for the validity of our

Furthermore, we recognize that the magnitude of the shock to a fund's portfolio is nonlinearly related to the fund's pre-shock ESG performance. Specifically, the funds with pre-shock ESG scores in the lowest decile receive the most pronounced downward pressure. To measure the downward pressure from exposure to low-sustainability funds, we replace $S_{f,pre}$ with a binary indicator $\mathbb{1}\{f \in \mathscr{F}^{\textbf{Low}}\}$, which categorizes fund f as low-sustainability pre-shock:

$$\begin{aligned} Z_i^L &:= \sum_f \pi_{if} \, \mathbb{1}\{f \in \mathscr{F}^{\textbf{Low}}\} \\ &= \frac{\sum_{f \in \mathscr{F}^{\textbf{Low}}} P_i Q_{if}}{\sum_{f \in \mathscr{F}} P_i Q_{if}} \times 100\% \,. \end{aligned} \tag{2.6}$$

Thus, Z_i^L effectively represents the percentage of ownership held by low-sustainability funds as of 2015q4. A firm is considered more exposed if a larger portion of its institutional ownership is held by funds under divestment pressure.

Similarly, we have

$$Z_i^H = \frac{\sum_{f \in \mathscr{F}^{\textbf{High}}} P_i Q_{if}}{\sum_{f \in \mathscr{F}} P_i Q_{if}} \times 100\% \,, \tag{2.7}$$

indicating the exposure to high-sustainability funds ownership. We focus on the downward pressure in our analysis for the precision of the estimates (as highlighted in the appendix, see Figures 2.13 and 2.14).

This is because funds classified as high-sustainability in this episode are generally smaller in size[13], resulting in a more limited set of firms with a nonzero value for Z_i^H.

We employ an event-study specification to estimate the dynamic effects of sustainable investors' pressure on firms' real outcomes. We estimate how firms respond to fund-level salience

measure. In a related context, Noh et al. (2022) presents a model-based, firm-level price pressure measure that aims to capture the price pressure on firms to become more sustainable. The closed-form expression they derived, which is determined by the sustainability demand coefficients and price elasticity, also takes the form of a weighted average over a firm's institutional owners.

[13] Pastor et al. (2023) find that, consistent with their theoretical predictions, ESG tilts are larger for institutions with smaller size and greater active share.

shock through their ownership structure at different horizons h:

$$y_{i,t} = \sum_{h \neq 0} \rho_h \, Z_i \times \mathbb{1}\{t = h\} \, + \, \theta \mathbf{X}_{i,t} \, + \, \varphi_i \, + \, \varphi_{\text{ind},t} \, + \, \varepsilon_{i,t} \; . \tag{2.8}$$

We investigate the dynamic effects of sustainable investing on the following three key aspects of the firm performance: valuation, external financing, and investment decisions. For valuation effects, we examine the impact on the firm's share price and the enterprise value. For external financing, we analyze both external equity financing and external debt financing. For investment decisions, we look at both the physical investment rates and the R&D investment rates.

The coefficient ρ_h in specification (2.8) captures how firms respond to the fund-level salience shock through their ownership structure at horizon h. We include firm fixed effects (φ_i) to control for unobserved firm-level heterogeneity. We include industry-by-time fixed effects ($\varphi_{\text{ind},t}$) to absorb the unobserved macroeconomic factors that affect all firms in an industry. We include lagged profitability (firm-specific and time-varying) as an additional control variable as defined in Gorodnichenko and Weber (2016).[14]

We interact the previous regression with an indicator GHG-intensive$_i$, since GHG-intensive sectors are major contributors to global greenhouse gas emissions and climate change. Sustainable investing strategies that focus on reducing GHG emissions in these GHG-intensive sectors can help reduce the overall carbon footprint and mitigate climate change.

$$y_{i,t} \; = \sum_{h \neq 0} \left(\rho_h \, Z_i + \chi_h \text{GHG-intensive}_i \times Z_i\right) \times \mathbb{1}\{t = h\} \; + \theta \mathbf{X}_{i,t} \; + \; \varphi_i \; + \; \varphi_{\text{ind},t} \; + \; \varepsilon_{i,t} \; , \tag{2.9}$$

where GHG-intensive$_i = 1$ if firm i GHG-intensive sectors (Mares and Flannery, 2022).[15] The

[14]Profitability is operating income before depreciation (Compustat item OIBDPQ) over lagged total assets (Compustat item ATQ) where both variables are measured on a quarterly basis.

$$\text{profitability} = \frac{\text{OIBDPQ (operating income before depreciation)}}{\text{lagged ATQ (Assets, Total)}} \times 100\% \; ,$$

which reflects a firm's cash-generating ability from its operations.

[15]GHG-intensive sectors, as classified in Mares and Flannery (2022), include SIC codes

additional coefficient of interest, χ_h in specification (2.9), captures whether firms in GHG-intensive sectors are more (or less) responsive to the fund ownership exposure. We report the overall margin $\rho_h + \chi_h$ for firms in GHG-intensive sectors in the following graphs.

2.5.1 Impact on Firm Valuation

According to Gabaix and Koijen (2021), trading pressures, arising from various market forces, have a direct impact on share prices. We focus on the firm's share price and valuation as they are closely related to share-based compensations and firms' cost of capital. According to Coppola (2021), although secondary market prices are not directly allocative, they significantly influence investor perception and set the benchmark for what investors are willing to invest for new issues on the primary market.

Figure 2.5 shows the estimates of ρ_h from equation (2.8) and $\rho_h + \chi_h$ from (2.9), with firm's quarterly share prices as the dependent variable.[16]

The coefficients show no significant pre-trends before the 016 Morningstar sustainability rating shock. Starting in the first quarter of 2016, right after the shock, exposure to low-sustainability fund ownership led to a decline in firms' share prices. An additional 1% exposure to low-sustainability funds contributed to a cumulative decrease in share prices by 10 to 20 basis points over the following year. Interestingly, this downward trend reversed in the second quarter of 2017. Notably, the point estimates for firms in GHG-intensive sectors suggest a BIGGER decline in share prices following the shock, indicating higher sensitivity of those firms to the downward pressure from fund ownership.

We also examine the valuation effect on portfolio firms' enterprise value, which is often

21. Mining, Quarrying, and Oil and Gas Extraction,

22. Utilities,

31-33. Manufacturing,

48. Transportation and Warehousing.

[16]Representative quarterly prices for each firm are calculated using the Market Value divided by Common Shares Outstanding from the Compustat/CRSP database: MKVALTQ / CSHOQ.

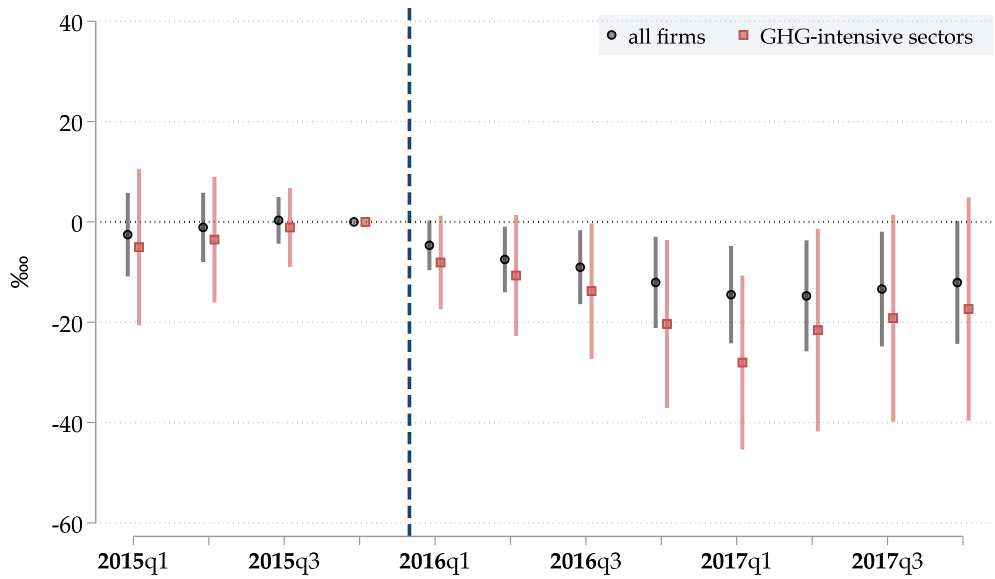


Figure 2.5. Coefficients on the exposure to low-sustainability funds: share price

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' share prices (in logarithm) respond to the fund-level sustainability salience shock through their ownership exposure at horizon h. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

considered as a more comprehensive measure of a firm's total value (Crouzet et al., 2022).[17] Figure 2.6 shows that an additional 1% exposure to low-sustainability fund ownership led to an immediate reduction in firm enterprise value for approximately 10 basis points. The impact on the enterprise value appears to be transient, disappearing completely one year after the shock.

[17]Following the definition in Crouzet et al. (2022), we compute as the aggregate market value of equity, plus the aggregate book value of debt, minus cash and cash equivalent using the Compustat/CRSP database:

- the aggregate market value of equity = PRCCQ (Price Close) × CSHOQ (Common Shares Outstanding);
- the aggregate book value of debt = DLTTQ (Long-Term Debt, Total) + DLCQ (Debt in Current Liabilities);
- cash and cash equivalent = CHEQ (Cash and Short-Term Investments).

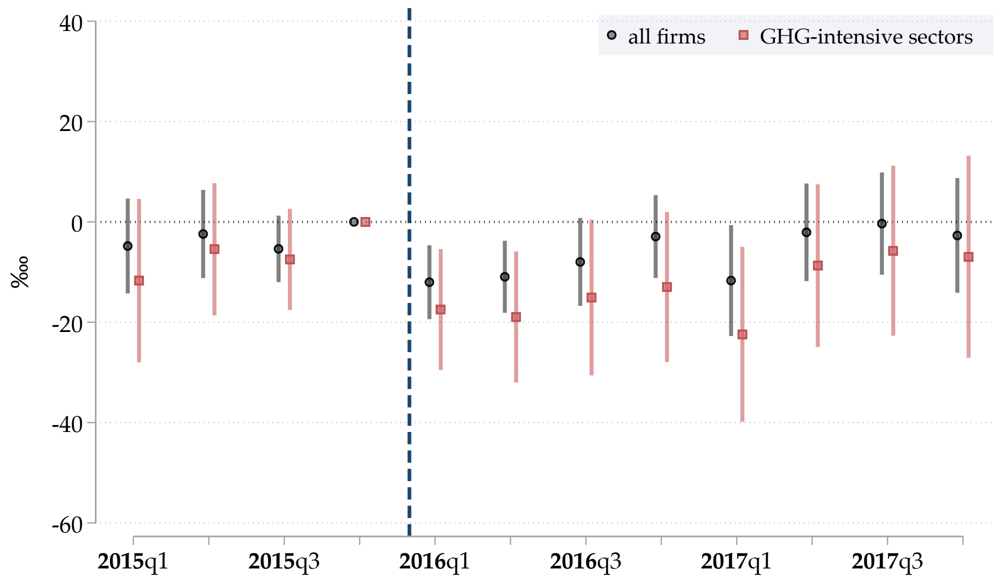


Figure 2.6. Coefficients on the exposure to low-sustainability funds: enterprise value

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' enterprise value (in logarithm) responds to the fund-level sustainability salience shock through their ownership exposure at horizon *h*. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

2.5.2 Impact on Firm External Financing

Changes in firm valuation, as the previous section proved, can significantly influence a firm's ability to obtain external financing. We focus on the dynamic impacts of the firms' external equity and debt financing, from exposure to trading pressure of the owing funds.

In line with the definitions used by Jermann and Quadrini (2012) and Begenau and Salomao (2019), we define the external equity financing as the net flow of funds from shareholders to the firm and external debt financing as the net flow of funds from creditors to the firm. Utilizing quarterly Compustat data, we compute external equity financing as *sale of common & preferred stock* net of *purchase of common & preferred stock* and *cash dividends*; we compute external debt financing as total changes in *long-term debt* plus *short-term debt* from one quarter to the next.[18]

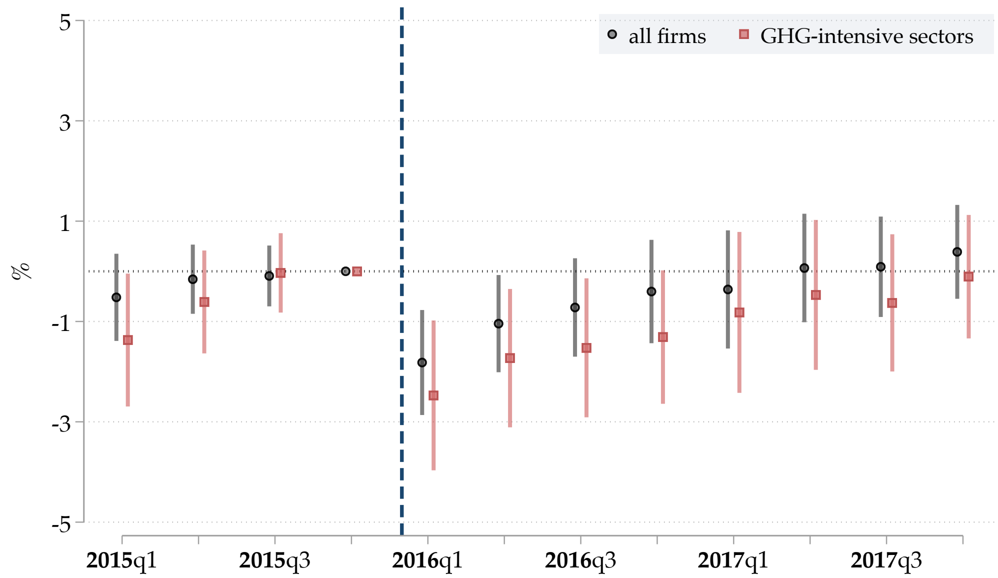


Figure 2.7. Coefficients on the exposure to low-sustainability funds: external equity financing

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' external equity financing (in logarithm) responds to the fund-level sustainability salience shock through their ownership exposure at horizon h. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

We find that a 1% increase in exposure to low-sustainability fund ownership leads to a 2% reduction in the firm's external equity financing. However, we do not find any negative effect on firm's external debt financing. The acute pressures that firms receive in the public inquiry market do not prevent firms from obtaining funds from other sources, such as private equity, credit markets, or internal cash flows. These results suggest an uncoordinated bottom-up sustainable investing approach. Sustainable investing may predominantly change the methods by

[18]For the calculation of these financing flows, we utilize the following Compustat data items from WRDS:

- External equity financing = *SSTKY* (sale of common & preferred stock) $-$ *PRSTKCY* (purchase of common & preferred stock) $-$ *DVY* (cash dividends),
- External debt financing = $\Big(DLTTQ$ (long-term debt) $+$ $DLCQ$ (short-term debt)$\Big)$ $-$ lagged$\Big(DLTTQ + DLCQ\Big)$.

which firms are financed rather than changing the actual firms or projects that receive financing (Duchin et al., 2022; Sachdeva et al., 2022).

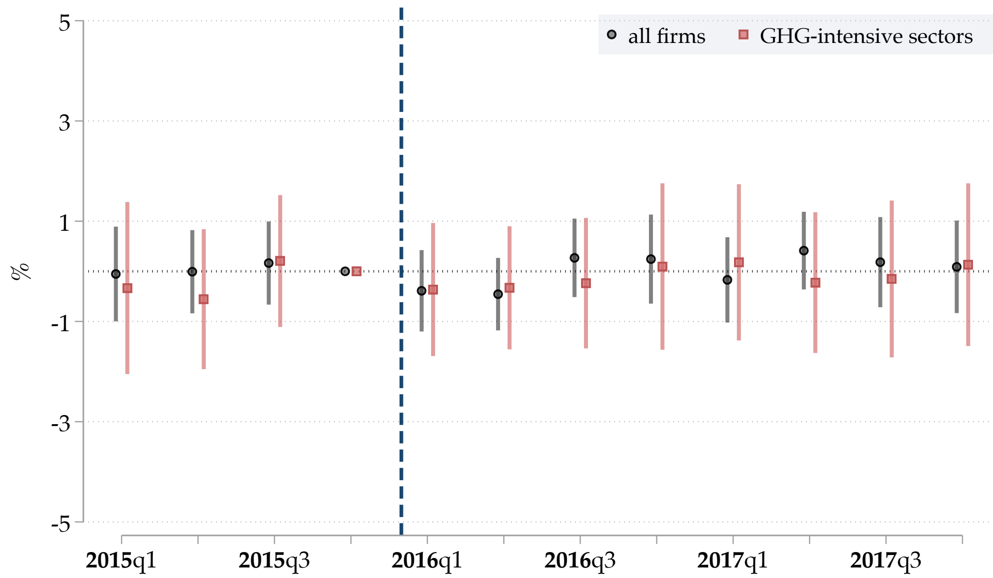


Figure 2.8. Coefficients on the exposure to low-sustainability funds: external debt financing

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' external debt financing (in logarithm) responds to the fund-level sustainability salience shock through their ownership exposure at horizon h. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

2.5.3 Impact on Firm Investment Decisions

In this segment, we examine changes in the scale of firms' production, as indicated by physical investment, and changes in the technology they operate, as reflected in firm R&D investment. Specifically, we estimate Equation (2.8) and (2.9), with the primary outcomes of interest being the physical and R&D investment rates, respectively. Both physical and R&D investment rates are computed as in Crouzet et al. (2022). We use annualized year-over-year flow rates to avoid fluctuations due to seasonality. Using quarterly Compustat data, physical investment rates are calculated with CAPX (*capital expenditures*, flow variable) divided by

PPEGTQ (*property, plant, and equipment*, stock variable). Similarly, R&D investment rates are calculated as the ratio of XRDQ (*research and development expense*, flow variable) to INTANQ (*intangible assets*, stock variable).

We compute physical and R&D investment rates following Crouzet et al. (2022). For physical investment rates, we use quarterly Compustat data, calculating them as the ratio of *capital expenditures* (CAPX, a flow variable)[19] to *property, plant, and equipment* (PPEGTQ, a stock variable). For R&D investment rates, we calculate them by dividing the *research and development expenses* (XRDQ, a flow variable) by total *intangible assets* (INTANQ, a stock variable). We use annualized year-over-year flow rates to avoid fluctuations due to seasonality.

Figure 2.9. Coefficients on the exposure to low-sustainability funds: physical investment

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' physical investment responds to the fund-level sustainability salience shock through their ownership exposure at horizon *h*. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

[19] CAPX is calculated using the Compustat data item CAPXY, which represents year-to-date capital expenditures. To determine quarterly capital expenditures (CAPX) for the second through fourth quarters of the year, we subtract the previous quarter's CAPXY value from the current quarter's CAPXY value.

Figure 2.10. Coefficients on the exposure to low-sustainability funds: R&D investment rate

Notes: This figure displays the estimates from Equation (2.8) and (2.9) that capture how firms' R&D investment responds to the fund-level sustainability salience shock through their ownership exposure at horizon h. The vertical lines represent 95% confidence intervals computed using the robust standard errors clustered at the firm level. The vertical dashed line marks the timing of the first release of the Morningstar Sustainability Ratings for global funds in March 2016. The coefficient for the quarter before the shock is normalized to zero. All regressions include firm fixed effects and industry-by-time fixed effects.

The absence of significant findings in Figures 2.9 and 2.10 suggests that investor pressure did not substantially influence firms' investment decisions. For sustainable investing to effectively generate the intended impact, it typically operates through either of the following two key channels. The first is inducing divestment from or reducing physical investments in environmentally harmful ("dirty") firms. The second involves motivating "dirty" firms to become cleaner by increasing their R&D spending on green innovation. Our result suggest that there is no significant impact on either of these investment decisions.

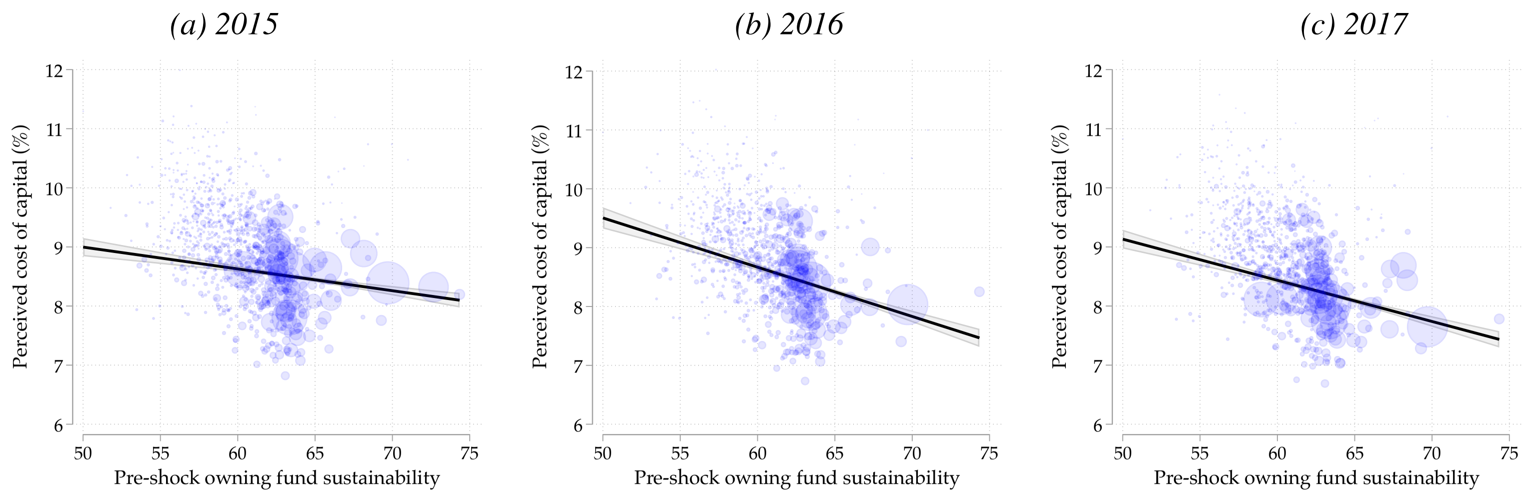
It is important to note that the impact mechanisms we are testing are specific to the particular episode we are studying, which is at the early phase of the ESG movement. Moreover, the impact of the sustainable investment we document is also specifically intermediate by funds. Nevertheless, the lack of significant impacts on firm investment decisions raises concerns about the real-world efficacy of sustainable investing strategies in driving substantial environmental and societal change. The goals of sustainable investing in achieving better environmental outcomes are not fulfilled without the shift in investment strategies favoring clean production.

Finally, we investigate whether investor pressure, as transmitted to portfolio firms during this event, alters these firms' perception of the capital cost for future investment. Standard textbook models suggest that a firm invests in a project when the expected returns exceed the cost of capital it faces. How a firm perceives its own capital cost is crucial in comprehending its capital allocation and investment decisions. According to Gormsen and Huber (2023b), the perceived cost of capital might deviate from the "true" expected returns that financial investors require from the firm's debt and equity. We utilize a hand-collected dataset constructed by Gormsen and Huber (2023a) from corporate conference calls, which provides a unique lens to the underpinnings of corporate investment decision-making.

Figure 2.11 presents the correlations between firms' perceived cost of capital and their pre-shock exposure to sustainable investors' pressure, both before and after the 2016 event. The pre-shock exposure, plotted on the horizontal axis, is defined in Equation 2.5 and measured as of 2015q4. Before the event, as presented in Panel (a) of Figure 2.11, the correlation between owning funds' sustainability scores and firms' perceived costs of capital is relatively small. However, Panels (b) and (c) show that this correlation becomes more pronounced post-shock. Firms that were less exposed to divesting pressure during the Morningstar event generally perceive a relatively lower cost of capital after 2016 compared to more exposed firms.[20] Gormsen et al. (2023) also identified 2016 as a pivotal year in their analysis of the difference in perceived cost of capital between the greenest and the brownest firms. They observed that this average difference, which was close to zero before 2016, fell to -2.6 percentage points in the subsequent years.

[20]There has been an active debate in the literature concerning whether sustainable investing has changed firms' cost of capital. Evidence from various settings does not always concur, as demonstrated in studies by Teoh et al. (1999), Chava (2014), Cheng et al. (2014), Berk and van Binsbergen (2021), van der Beck (2021), Kacperczyk and Peydró (2022), Green and Vallee (2022), Pástor et al. (2022), Gormsen et al. (2023), Laeven and Popov (2023), and many others. Our Figure 2.11 is structured to highlight the *cross-sectional* differences, particularly along the dimension of firms' exposure to fund investors' sustainability preferences. Solely based on this part of our findings, we do not assert that the pre-shock exposure to fund investors led to changes in the (realized) cost of capital for firms over time.

Figure 2.11. Correlations between firms' perceived cost of capital and pre-shock exposure



Notes: This figure illustrates the correlations between firms' pre-shock exposure and their perceived cost of capital for the years (a) 2015, (b) 2016, and (c) 2017. The pre-shock exposure, plotted on the horizontal axis, is defined in Equation 2.5 and measured as of 2015q4. Each blue bubble in the figure marks a public firm that has non-missing values for both pre-shock exposure through fund ownership, as per our replication, and perceived cost of capital data, as collected by Gormsen and Huber (2023a). In every panel of the figure, the size of the blue bubble is indicative of the total assets of the corresponding firm for that specific year. The solid black lines in the figure represent fits from OLS regressions, weighted by the total assets of the firms.

2.6 Conclusion

Despite its theoretical promise, if and how sustainability pressures exerted by value-aligned investors extend beyond the asset market is still up for debate. This paper empirically studies the potential of sustainable investing to generate environmental or social impact in the context of the prevailing portfolio tilting strategy. We delineate the pathway whereby investor preferences, channeled through funds, exert influence on underlying firms.

Anchored in a 2016 natural experiment, we unveil the macroeconomic implications of sustainable investing by testing for its allocative effects on firms subject to divestment pressure, contrasting them with firms not exposed to low-sustainability fund ownership. While a significant downward impact on valuation and equity financing is evident for firms exposed to low-sustainability fund ownership, we do not observe discernible impacts on firm debt financing. These results underscore the constrained real-world influence of investors' sustainability pressure on firm operations, particularly when the scale of sustainable investors' financial wealth remains dwarfed by the substantial resources accessible to "dirty" firms. Moreover, the absence of coordination across equity and debt markets exacerbates these outcomes—an uncoordinated, bottom-up sustainable investing approach might reshape how firms are financed but not which firms (or projects) are financed.

It is worth noting that the key results presented above pertain specifically to the early phase of the recent ESG movement. The ongoing expansion in green credit markets globally portends more profound changes on the horizon. The trend toward improved transparency and standardization of ESG disclosure augments the potential of sustainable investors to make meaningful actions happen faster and easier. The practical challenge remains in strategically optimizing the collective pressure—sufficient to drive positive transitions without relinquishing complete ownership of "dirty" firms to ESG-immune investors. However, our research methodology transcends this particular episode, providing insights for studying other value-alignment shocks[21] and their propagation within and beyond the financial domain.

2.7 Acknowledgements

Chapter 2 is co-authored with Xintong Li and is currently being prepared for publication. The dissertation author and Xintong Li are joint primary researchers of this chapter.

[21]This includes the anti-ESG sentiment within the investment community, particularly on the rise in the U.S., which may have deep, long-lasting effects on the fund industry (see https://news.bloomberglaw.com/banking-law/hsbc-says-rising-anti-esg-sentiment-in-us-is-impacting-funds, https://www.eiu.com/n/anti-esg-sentiment-in-the-us-weakens-esg-markets/). Studies conducted by Rajgopal et al. (2023) and Garrett and Ivanov (2022) have evaluated the effects of anti-ESG legislation against this backdrop.

2.8 Chapter 2 Appendix

2.8.1 Recovering Fund-Level Ratings

Table 2.5. Methodology history of Morningstar Sustainability Rating

VERSION	EFFECTIVE DATE	DESCRIPTION
Version 1.0	March 1, 2016	Initial Launch
Version 1.1	October 31, 2018	Update to use Morningstar Global Category instead of Morningstar Local Category for determining relative performance. Introduction of the 12-month historical score to increase stability.
Version 2.0	October 31, 2019	Update to use Sustainalytics' ESG Risk Ratings rather than ESG Ratings as the basis of the rating. Addition of buffer rules to increase stability and handle portfolios with extremely high overall ESG risk.
Version 3.0	November 8, 2021	Addition of sovereign risk to the rating. Introduction of a modular approach to combine multiple risk ratings frameworks.

Source: Morningstar Research and Sustainalytics Methodology & Portfolio Research (summary accessed at https://www.morningstar.com/content/dam/marketing/shared/research/methodology/744156_Morningstar_Sustainability_Rating_for_Funds_Methodology.pdf).

- Morningstar includes open-end mutual funds (OEF), exchange traded funds (ETF), closed-end funds (CEF), and variable annuities (VAR) in a single rated universe, and all of the portfolios within these legal structures contribute to a single ranking universe.

- Securities issued by companies that do not have Sustainalytics ESG scores are not covered. To receive a portfolio ESG score, a sufficient percentage of a portfolio's assets under management must have a company ESG score. Following the methodology used in the initial launch, to receive a portfolio ESG score in our replication, at least 10% of a portfolio's assets under management must have a company ESG score. The percentage of assets under management for the covered securities is then rescaled to 100% before calculating the portfolio ESG score.

- Morningstar Sustainability Rating reports a fund's normally distributed ordinal score and descriptive rank relative to the fund's category. For a fund to receive a sustainability rating, its Morningstar Category must have at least 10 funds with portfolio sustainability scores. Funds with pre-shock equity portfolios smaller than e^{10} USD disclosed in FactSet Ownership dataset are excluded from assigning the recovered Globe Rating.

- Note that the methodology employed in the initial launch also included extra deductions for holdings with controversies.[22]

2.8.2 Additional Tables & Figures

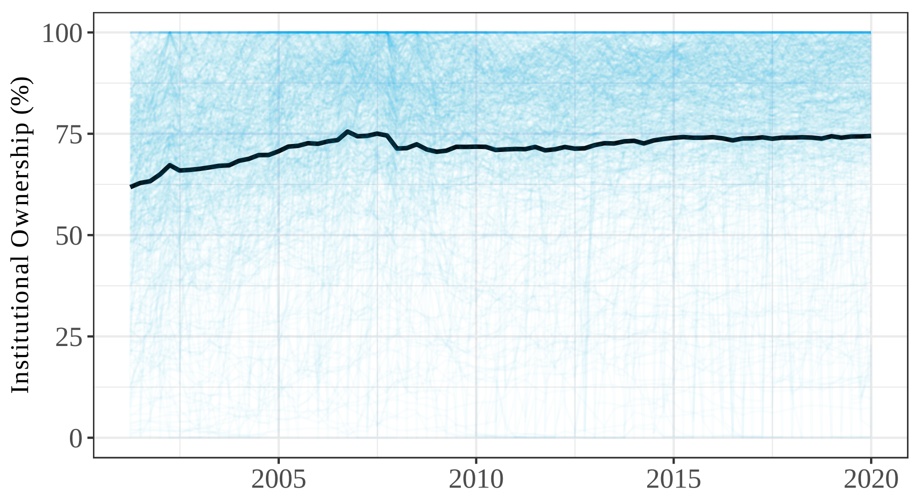


Figure 2.12. Institutional ownership of US public firms: 2001-2019, quarterly

Notes: The figure displays the institutional ownership of US public firms with a market capitalization above 10 billion USD (represented by the blue thin line) and the marketwide capitalization-weighted average of all 14,368 public firms domiciled in the US (represented by the thick black line), based on stock ownership data summarized by Ferreira and Matos (2008).

[22]Refer to Morningstar Sustainability Rating for further details.

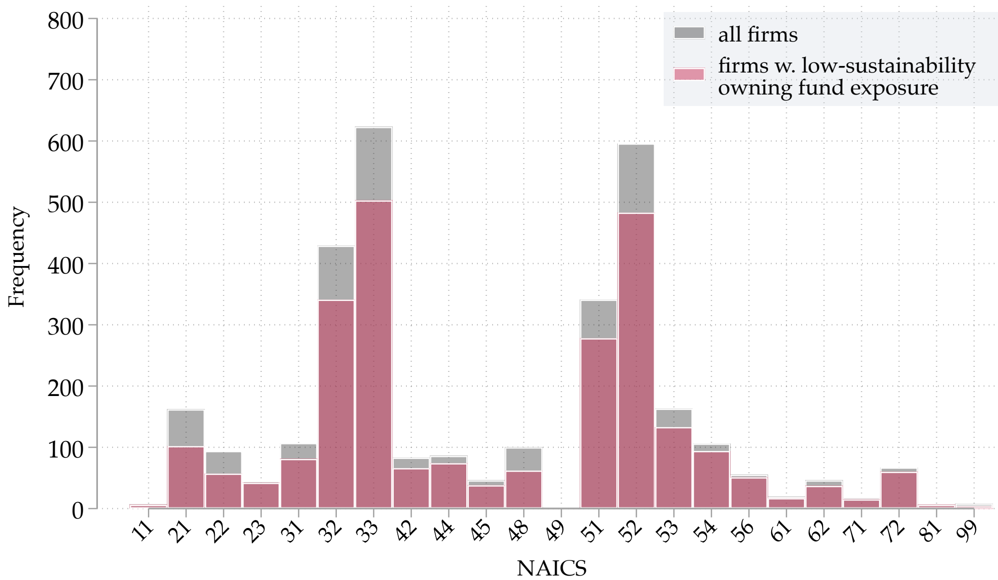


Figure 2.13. Sectoral distribution of firms exposed to low-sustainability owning funds: as of 2015q1

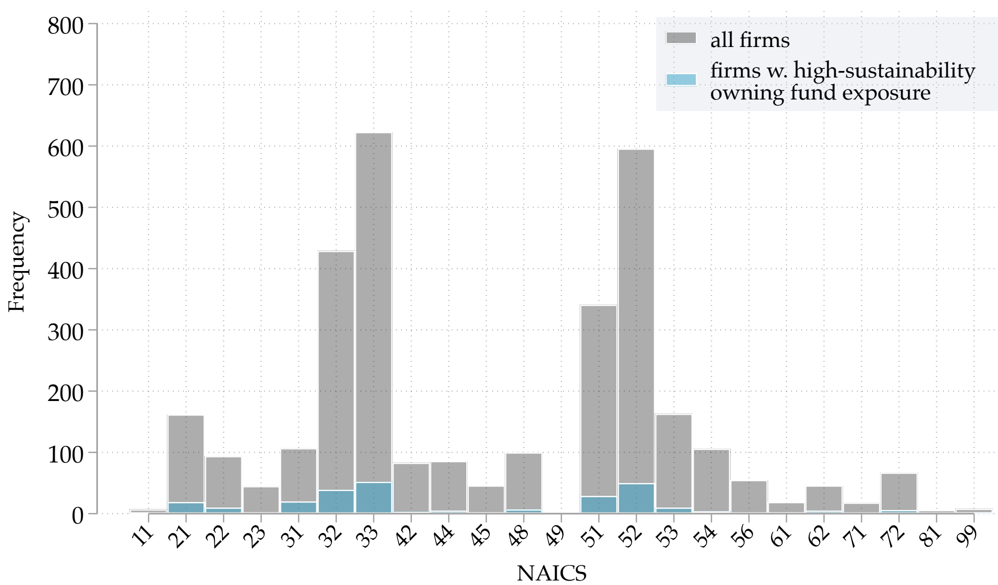


Figure 2.14. Sectoral distribution of firms exposed to high-sustainability owning funds: as of 2015q1

Chapter 3

Environmental Regulations and Firm Supply Chain Networks

Abstract: This paper investigates the impact of environmental regulations on global supply chain relationships. Using a detailed dataset linking customer firms to their suppliers, the study finds that customers are more likely to terminate supplier relationships in response to more stringent environmental policies in the supplier countries. This effect is less pronounced for customer firms operating in manufacturing sectors and supplier firms in countries with emissions trading systems. Further analysis shows that the impact of suppliers' EPS on customer firms' performance, as propagated through the production network, is relatively limited, possibly due to low switching costs and competitive supplier markets that allow customers to adapt to changes in their supply chain.

3.1 Introduction

Unilateral enhancement of environmental policies has raised concern regarding whether such policies are effective in curbing pollution at a global level. According to the Pollution Haven Hypothesis (PHH), stringent environmental policies may lead to firms relocating their polluting activities to regions with less stringent environmental policies (Copeland and Taylor, 2004; Levinson and Taylor, 2008). While there has been a growing literature investigating the impact of environmental regulations on firm behavior, trade patterns, foreign direct investment, and multinationals (Aichele and Felbermayr, 2015; Eskeland and Harrison, 2003; Hanna, 2010; Kellenberg, 2009; Kneller and Manderson, 2012; Shapiro and Walker, 2018), less attention has been paired to how firm adapt their global supply chains in response to increasing environmental regulations. According to the CDP Supply Chain Report 2022[1], firms' supply chain emissions are estimated to be 11.4 times more than their direct emissions. Understanding how firms adjust supply chains in facing environmental regulations, either directly from domestic policies or indirectly from policies imposed on their suppliers, becomes more important in today's interconnected world.

This paper focuses on the latter—how firms adjust supply chain networks in response to their supplier countries' environmental policy stringencies (EPSs). The central hypothesis is that firms with suppliers in countries with more stringent environmental policies will adapt their supply chain networks due to the rising costs and risks associated with these policies. To empirically test this hypothesis, I utilize a novel firm-level customer-supplier linked dataset reporting thousands of supplier relationships globally from 2003 to 2020. Specifically, I estimate how environmental policy stringency in supplier countries affects the probability of a downstream US customer terminating a supplier relationship and the duration of such relationship. Whether or not shocks propagate in the production networks has been a central focus of the literature investigating firm-level impacts from financial shocks (Khwaja and Mian, 2008; Amiti and Weinstein, 2018; Chodorow-Reich, 2014), and natural disaster shocks (Carvalho et al., 2021; Barrot and Sauvagnat, 2016). Similarly, this paper further tests whether there are any supply chain propagation effects on the customer firm's performance.

To establish the causal link between supplier countries' environmental policies and customer-supplier relationships, I exploit cross-sectional and temporal variations of environmental policy stringency (EPS) in the supplier countries using a fixed-effects regression framework. To address the potential omitted variable bias concerns related to country-level EPS, I include various supplier country-level controls to control for factors that could influence both the EPS

[1]https://www.cdp.net/en/research/global-reports/scoping-out-tracking-nature-across-the-supply-chain

and the customer-supplier relationships. Following Cajal-Grossi et al. (2023), I conceptualize a firm's sourcing strategy as a buyer-level decision, not influenced by other transaction-specific factors. I include customer firm-level controls, customer-firm fixed effects, supplier-firm fixed effects, customer industry-by-year fixed effects, and supplier-country-by-customer-industry fixed effects to control for both observable and unobserved heterogeneity that may affect customer firms' supply chain management practices. The identification strategy relies on the assumption that conditional on the control variables and fixed effects, changes in supplier countries' environmental policy stringency are exogenous to customer-supplier relationships. This assumption is supported by the argument that US customer firms have limited influence over the environmental policy-making of foreign supplier countries. Given the geographic separability of domestic policy-making processes, changes in the EPS of supplier countries can be considered plausibly exogenous policy shocks from the perspective of US firms.

This paper finds that environmental policy stringency in supplier countries has a significant impact on supplier chain decisions. The main results suggest that EPS in supplier countries has significant spillover effects on customer firms' supply chain decisions. A one-unit increase in the supplier country EPS (ranges from 0 to 6) leads to a 1.8 to 2.75 percentage point increase in the likelihood of a customer-supplier relationship ending, holding other factors constant. The effects are found to be heterogeneous based on different customer firm industries and supplier country characteristics. Customer firms in manufacturing sectors (especially in the textile sector) are more likely to maintain supplier relationships when facing the tightening of the EPS. Moreover, the presence of an emissions trading system (ETS) in the supplier country also reduces the effect of EPS on relationship termination.

How are the customer firms affected when there are supply chain disruptions? On one hand, the effects of environmental regulations on global supply chains may be absorbed in production networks. Customer firms often structure their business strategies to minimize the impact of policy changes in their suppliers' countries and maintain the flexibility to adapt their supplier pool when necessary. On the other hand, the presence of switching costs can introduce friction in this process, hindering customers' ability to respond to the policy shifts swiftly (Barrot and Sauvagnat, 2016). In such cases, rising costs due to environmental policy changes could propagate through the production network and ultimately affect customer firms' financial outcomes. To test whether and how customer firms are affected in the supply chain, I estimate a customer firm-level regression.

Customer firm-level regression results suggest that EPS has a limited impact on customer firm performance despite supply chain disruptions. I find limited negative impact on customer firms' sales growth and the cost of goods sold (COGS) growth, with coefficients only significant at the 10% and 5% levels, respectively. There is no significant impact on other firm-level variables, such as the changes in profits, inventory intensity, R&D investment, and CO_2 intensity. These results could be explained by low switching costs and competitive supplier markets, which allow customer firms to adapt their supply chains in response to policy changes. The average Herfindahl-Hirschman Index (HHI) across all customer firms was calculated to be 0.11, indicating a relatively competitive supplier market. Moreover, the average switching frequency of the customer firms is found to be 0.54, suggesting that customer firms face low switching costs when changing their suppliers. Overall, these findings suggest that customer firms operate in a competitive supplier market with low costs for switching suppliers.

This paper contributes to the broader discussion of the unintended consequences of environmental regulations. The results obtained in this paper suggest that firms actively adapt their supply chains in response to changes in environmental policy stringency by terminating supplier relationships or reducing their duration. In spite of supply chain disruptions, the customer firms do not receive negative impacts propagated through the supply chains.

Related literature and contribution

This research contributes to the growing literature related to the Pollution Haven Hypothesis (PHH). Empirical evidence supporting the pollution havens has been mixed, with some studies finding evidence of firms relocating to countries with laxer environmental standards

(Kellenberg, 2009; Hanna, 2010; Aichele and Felbermayr, 2015), while others find little or no evidence of such behavior (Eskeland and Harrison, 2003; Kneller and Manderson, 2012). The existing literature on PHH often focuses on firm location choices, the establishment of multinational productions, and foreign direct investment (FDI) patterns. There is a gap in understanding the effect of environmental policies on the dynamic of global supply chains and the potential spillover effects propagated through the production networks.

Globalization has created complex global supply chains, increased interdependence among firms and countries, and increased sharing of economic benefits (Acemoglu et al., 2016b). Recent studies have investigated the propagation of shocks from natural disasters through supply-chain linkages and their impact on customer firms (Barrot and Sauvagnat, 2016; Carvalho et al., 2021; Pankratz and Schiller, 2023). Pankratz and Schiller (2023) show that suppliers' exposure to heat and floods negatively affects both their own and their customers' operating income, leading to an increased likelihood of customers terminating supplier relationships. This paper builds upon this strand of literature by examining the impact of environmental regulations on global supply-chain networks.

In contrast to the pollution haven literature, which investigates the relocation of polluting activities to regions with laxer environmental regulations, this study explores the reverse effect: how the tightening of environmental regulations in supplier countries affects the continuation or termination of customer-supplier relationships. The idea in this paper is closely related to that of the Kellenberg (2009), which investigated the impact of the environmental regulations of foreign countries where U.S. firms have affiliates. Kellenberg (2009) finds that the declining stringency of the environmental policies in foreign countries explains the growth of the U.S. multinational affiliates.

This paper also relates to recent studies on the impact of trade policy uncertainty and supply chain disruptions on firm performance. Huang et al. (2023) finds that firms with greater exposure to the U.S.-China trade war through their supply chains experience significant negative stock returns and increased stock price volatility following. Benguria et al. (2022) documents the negative effects of trade policy uncertainty on firm-level investment, R&D expenditures, and profits. This paper draws parallels between the effects of trade policies and environmental policies since both policies lead to changes in the costs and risks faced by firms operating in the global production networks.

Additionally, this research extends on the previous studies investigating the role of switching costs in the transmission of firm-level shocks to the setting of environmental policies (Khwaja and Mian, 2008; Barrot and Sauvagnat, 2016; Chodorow-Reich, 2014; Amiti and Weinstein, 2018). Barrot and Sauvagnat (2016) finds that the idiosyncratic shocks received by the supplier firms from natural disasters can propagate and amplify as they spread from firm to firm through the supply chain. This propagation can be explained by the nature of the shocks and the high switching costs when facing supply chain disruptions. In contrast, this research's results indicate a more muted effect of environmental policies on customer firms, possibly due to the slow adjusting nature of the environmental policies.

The rest of the chapter proceeds as follows. Section 3.2 presents empirical methods. Section 3.3 describes the data. Section 3.4 presents the summary statistics. Section 3.5 presents and discusses the results. Section 3.6 reports the results from various robustness tests, and Section 3.7 concludes.

3.2 Empirical Methods

3.2.1 Main Regression

This paper's empirical strategy tests whether firms adapt their production networks in response to increases in their suppliers' climate policy stringency. Specifically, I hypothesize that firms will be more likely to terminate existing supply-chain relationships and adjust their supplier networks as environmental policy stringency increases. To test this hypothesis, I exploit cross-sectional and temporal variations in the environmental policy stringencies supplier firms face across different countries. Following Pankratz and Schiller (2023); Chen et al. (2023), I create an indicator measuring the customer-supplier relationship probability. I estimate the following customer-supplier pair regression using a linear probability model (LPM):[2]

$$\mathbb{1}(\text{End})_{ij,t} = \beta \times \text{EPS}_{d(j),t} + \delta_1 X'_{i,t-1} + \delta_2 Z'_{d(j),t} + \sigma_{n(i),t} + \theta_{d(j)n(i)} + \gamma_i + \gamma_j + \varepsilon_{ij,t} \qquad (3.1)$$

The main outcome variable, $\mathbb{1}(\text{End})_{ij}$, is an indicator that equals zero for active customer-supplier relationships during the observed years and switches to one in the final year of these relationships, marking the termination point of the supply chain relationship.[3] The indicator is then scaled by 100 to express the results in percentage points.

The independent variable of interest $\text{EPS}_{d(j),t}$ is the supplier country's environmental policy stringency. I include time-varying customer firm characteristics $X'_{i,t-1}$ such as firm size, profitability, leverage, capital intensity, and liquidity as control variables. I also include the supplier country's control variables $Z'_{d(j),t}$: GDP per capita, GDP growth, trade openness index, political stability index, and an indicator equal to one if a country has an emissions trading system (ETS) in place. These control variables address for potential omitted variable bias, by controlling for various economic, institutional and political factors that may affect the customer-supplier relationships and are also correlated with EPS.

I conceptualize a firm's sourcing strategy as a buyer-level decision following Cajal-Grossi et al. (2023). This is to assume that the impact of environmental policies on customer-

[2]Although a probit model is generally more appropriate for analyzing binary outcomes, I use the Linear Probability Model (LPM) due to its straightforward interpretation and simplicity. Moreover, the LPM also allows the inclusion of multiple fixed effects.

[3]The outcome variable is determined using the starting and ending dates of the supplier-customer relationships, which are recorded on a monthly basis in the FactSet Revere database. The beginning of a supplier-customer relationship is marked by the year in which the relationship first appears in the FactSet Revere database. The end of a relationship is indicated by the year in which the relationship is reported as ended in the database. In some cases, the start and end dates may coincide if updates occur consecutively. Thus, the data is processed to ensure that the ending date does not precede the starting date. For currently active relationships, the end date is recorded as January 1, 4000, which represents an 'indefinite end date' in the FactSet Revere database.

supplier relationship outcomes comes from the overall strategic decision of the customer firm to manage their supply chain relationships. Such a decision does not adjust according to different transactions or specific products coming from a specific country of origin.[4] Baaed on this conceptualization, I include the customer-firm control variables and customer-firm fixed effects, controlling for both observable factors and time-invariant unobserved factors that may influence a firm's supply chain decisions in response to the changes in supplier-country environmental policies.

Due to data limitations for the non-US supplier firms' financial information[5], I do not include supplier firm-level control variables in my analysis. I include the supplier firm fixed effects in order to mitigate concerns about omitted variable bias arising from unobserved supplier firm heterogeneity. These fixed effects control for the time-invariant characteristics of the supplier firms that may be correlated with both the outcome variables and the environmental policy stringency of the supplier countries. In line with the previous literature on supply chains such as Pankratz and Schiller (2023); Agca et al. (2022); Chen et al. (2023)., I cluster the standard errors at the customer-supplier relationship level.

Identification

Supplier country EPS could serve as a plausibly exogenous source of variation for identifying impacts on U.S. customer firms' supply chain decisions. From the perspective of US firms, changes in supplier countries' environmental policy stringency can be considered external policy shocks. Environmental policies in supplier nations are unlikely to be directly correlated with unobserved characteristics, such as productivity shocks, demand conditions, or other unobserved factors affecting US-based customers' sourcing decisions.

Furthermore, the EPS index is a country-level measure of environmental policy stringency

[4]This is to assume that customer firms develop a general sourcing strategy that guides their decisions to maintain or terminate supplier relationships.

[5]Compustat Global database has a much smaller coverage of global firms compared to Compustat North American database.

and does not vary at the individual supplier firm level. This aggregation helps to mitigate potential endogeneity concerns, making it less likely that the supply chain decisions would directly influence the overall environmental policy stringency of the supplier country. Nonetheless, it is important to acknowledge that there may still be unobserved factors that could influence both EPS and the stability of customer-supplier relationships. As illustrated above, including the supplier country's control variables in the regression helps to control for some of the confounding factors. Including various fixed effects (e.g., customer-industry-by-year, supplier-country-by-customer-industry) in the regression also helps to further control for potential confounding factors and supports the causal interpretation of the results.

3.2.2 Alternative dependent variable

In addition to the binary dependent variable $\mathbb{1}(\text{End})_{cst}$, I also consider the depth of the supply chain commitment using the duration (in years) of the customer-supplier relationship as a continuous variable, following Fee et al. (2006); Phua et al. (2018); Pankratz and Schiller (2023). This metric represents the extent of commitment in supply-chain relationships, with longer durations indicating more stable and established relationships between customers and suppliers. I defined the start of the relationship as the first year in which both the customer and supplier are linked in the Factset Revere database. I track the relationship until the year when it is broken (end year). I use the Kaplan-Meier estimator to adjust the duration variable for the firm pairs whose relationships are marked as "infinite," thus the right-censored observations. Examining the impact of environmental policy stringency on both the likelihood of relationship termination and the duration of ongoing relationships provides a more comprehensive understanding of how environmental regulations shape the structure and resilience of global supply chains.

3.2.3 Heterogeneous Effects

I test the heterogeneous effects of EPS on customer-supplier relationships according to different customer firm industries and supplier country characteristics. First, I examine whether the impact of supplier country EPS on relationship termination differs across different customer firms' industries. By including the interaction terms of the EPS variable with the customer firm's industry indicators, I can identify potential differences in the sensitivity of customer-supplier relationships to EPS across industries. Instead of including the customer-industry-by-year fixed effects or customer-industry-by-supplier-country fixed effects, which can absorb the variation in the sector indicators, I include year fixed effects to control for any common trends that affect all firms in a given year, along with the customer fixed effects and supplier fixed effects. Second, I explore the heterogeneous effects based on supplier country characteristics, such as the presence of an Emissions Trading System (ETS) and the GDP per capita. I did not include the customer-industry-by-supplier-country fixed effects in this regression, which can absorb the variation in the supplier country's characteristics.

3.2.4 Customer Firm-level Regression

I collapsed the customer-supplier linked data to the customer-firm level to investigate the impact of EPS in supplier countries on customer firms' financial performance. This approach builds on the work of Barrot and Sauvagnat (2016), who examine whether firm-level idiosyncratic shocks propagate in production networks and find that suppliers affected by natural disasters impose substantial output losses on their customers. The customer firm-level regression specification is as follows:

$$Y_{i,t} = \beta \times \overline{\text{EPS}}_{d(j),t} + \delta_1 X'_{i,t-1} + \delta_2 \overline{Z}'_{d(j),t} + \theta_i + \gamma_t + \varepsilon_{i,t}, \tag{3.2}$$

where $Y_{i,t}$ represents various customer firm outcomes, such as sales growth, cost of goods sold growth, profits, inventory, and carbon emissions. $\overline{\text{EPS}}_{d(j),t}$ represents the average Environmental Policy Stringency (EPS) across all supplier countries for customer firm i in year t. This firm-level independent variable captures the average exposure of each customer firm to the environmental regulations faced by its suppliers. $X'_{i,t-1}$ and $\overline{Z}'_{d(j),t}$ are vectors of customer firm-level and supplier country-level control variables, respectively. θi and γ_t represent customer firm and year fixed effects. This regression specification captures the extent to which customer firms are affected by the average environmental policy stringency faced by their suppliers, as propagated through the global supply chains. Changes in supplier country EPS may affect supplier firms' costs of production, and these rising costs may be passed on to customers firms in the forms of higher input prices.

3.3 Data

This paper combined detailed firm-level supply-chain data from FactSet Revere with firm financial data from the Compustat North America database and environmental policy stringency (EPS) indices from the OECD. The merged data sample covers 2,273 unique US customer firms and their supplier relationships with 5,658 unique supplier firms located across 32 countries from 2003 to 2020.

3.3.1 Customer-Supplier Links Data

The global firms' supply chain data comes from Factset Revere, a new database that provides the most comprehensive information on supply chain relationships, as compared to the previous supply-chain databases such as Compustat Segment.[6] This dataset gained much popularity in recent publications related to supply chains (Pankratz and Schiller, 2023; Huang et al., 2023; Choi et al., 2024). The Factset Revere database gathers information from multiple

[6]This analysis is based on Factset Revere data accessed in 2024.

public sources, including annual and quarterly reports (such as 10-K, 8-K, and 10-Q), investor briefings, official company websites, and news releases. The database includes information on approximately 200,000 companies worldwide, of which more than 30,000 are publicly listed. In total, the database has captured over 725,000 distinct business relationships among these companies since 2003.

One key aspect of the FactSet Revere database is that it incorporates two sources of supply-chain relationship information using a dual-sourcing approach. It includes not only the direct disclosures made by a source company about its relationships with other firms, but also includes other companies' reverse disclosures regarding their relationship with the source company. This dual-sourcing approach enhances the completeness of the supply-chain data and also increases the reliability of the information. Another key benefit of using the FactSet Revere database is the availability of customer-supplier relationships' start and end dates, as mentioned in (Pankratz and Schiller, 2023). This feature provides valuable insights into the formation and termination of business relationships, allowing researchers to analyze the dynamics of supply chain networks over the years. Although the FactSet Revere database relies on public disclosures, which concentrate only on larger-sized firms, it remains one of the best commercially available firm-level supply-chain sources. Despite this limitation, this database is a highly valuable resource for supply-chain analysis.

3.3.2 Firm Financial Data

This paper focuses on customer firms with headquarters in the U.S. because they represent a diverse range of industries engaged in global supply chains. Moreover, concentrating on US customer firms allows for a standardized assessment by excluding the potential confounding effects of other regulatory or economic factors on supply chain decisions. By analyzing customer-supplier firm pairs where the customer firms are based in the U.S., I effectively control for the home-country effects that could complicate the analysis.

The customer firm's financial data is obtained from the Compustat North America Fundamentals Yearly Database, which provides fundamental and market data on both active and inactive publicly traded companies in the U.S. and Canada. This database offers a comprehensive set of financial information, including over 300 yearly and quarterly data points from various financial statements such as the Income Statement, Balance Sheet, and Statement of Cash Flows, as well as additional supplementary data. In contrast, the Compustat Global Database has a more restricted scope, covering a limited number of firms from a small set of countries worldwide. Consequently, this study does not incorporate the financial information of supplier firms in non-U.S. countries when linking the Factset Revere relationship data to the Compustat data.

I exclude the firms in the financial sectors (NAICS 52) over the 2003-2020 period. All firm variables are trimmed at their distributions' 1st and 99th percentiles to remove the potential outliers. I deflate the variables into 2015 US dollars using the GDP deflator from the Bureau of Economic Analysis, allowing for comparisons over time without the inflation effects.

3.3.3 Environmental Policy Stringency Indicator

Brunel and Levinson (2016) discusses the four main obstacles in measuring the environmental regulations' stringency: multidimensionality, simultaneity, industrial composition, and capital vintage.[7] Recognizing the need for a consistent and comprehensive measure of environmental policy stringency, the Organisation for Economic Co-operation and Development (OECD) developed the Environmental Policy Stringency (EPS) index (Botta and Koźluk, 2014; Kruse et al., 2022). The EPS index is a country-specific measure of environmental policy stringency, covering 40 countries from 1990-2020. It is defined as the degree to which environmental

[7]Challenges in measuring environmental policy stringency as mentioned in Brunel and Levinson (2016) are as follows. 1. Multidimensionality: it is hard to capture environmental regulations by a single measure of stringency; 2. Simultaneity: regulations are designed to affect emission levels, but emission levels can also influence the stringency of regulations, as jurisdictions with more severe pollution problems may impose stricter regulations; 3. Industrial Composition: the average business in a jurisdiction with a more pollution-intensive industry mix will automatically face more stringent regulations; 4. Capital vintage: new pollution sources usually face stricter regulatory standards, which may lead firms to keep older plants, affecting the measure of regulation stringency.

policies (13 instruments related to climate and air pollution) put an explicit or implicit price on pollution behavior.[8]

The EPS index allows for cross-country and intertemporal analyses of the effects of environmental regulations. The index ranges from 0 (not stringent) to 6 (high stringency) and reflects the relative stringency of a country's environmental policy instruments in a particular year.[9] The EPS index addresses some of the key challenges identified by Botta and Koźluk (2014); Kruse et al. (2022) in cross-country analysis of the economic effects of environmental policies, which is often hindered by the lack of reliable and comparable measures of stringency OECD (2016). The index is composed of both market-based and non-market policies. The market-based component includes instruments that set explicit prices on externalities, such as various taxes (e.g., those on CO_2, SO_2, NO_x, and diesel fuel) and trading schemes (e.g., CO_2 trading, renewable energy certificates, energy efficiency certificates, feed-in tariffs, and deposit-refund schemes). The non-market component includes command-and-control instruments, such as standards and policies supporting technology, for example, government subsidies for research and development. Figure 3.3 shows the time series of the EPS index for 32 supplier countries. The OECD countries have a higher average EPS than the non-OECD countries in the sample, and the countries participating in the European Union Emissions Trading System (EU ETS) have a higher EPS than the non-EU ETS countries. Recent studies have widely used the EPS index in their analysis Albrizio et al. (2017); Marin and Vona (2019); Dechezleprêtre et al. (2020); Furceri et al. (2023); Ciccarelli and Marotta (2024). The EPS index is an ideal tool for examining the impact of environmental regulations across different temporal and geographical contexts.

3.3.4 Sectoral- and Firm-level Carbon Intensity

Sectoral-level carbon intensity data comes from Exiobase, which is a comprehensive global input-output database. Exiobase provides a time series of environmentally extended

[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 environmental policy implemented.

multi-region input-output (EE MRIO) tables for 44 countries worldwide from 1995 to 2022.[10] The major benefit of this database, compared to another input-output database, such as the World Input-Output Database (WIOD), is that it has detailed sectoral disaggregations (it reports 163 sectors). This study uses the reported direct carbon emissions per million euros of output from Exiobase, which is derived from the International Energy Agency (IEA).

I obtained the firm-level carbon emission data from the Carbon Disclosure Project (CDP). CDP provides the most comprehensive corporate environmental information on the Scope 1, 2, and 3 emission categories. Scope 1 emissions are directly from the burning of fossil fuels; Scope 2 emissions cover indirect emissions linked to the consumption of electricity or steam; and Scope 3 emissions report those associated with a firm's upstream and downstream supply chains. Because Scope 1 emission data is the most available and the most comprehensive, this study focuses on Scope 1 emissions.

3.4 Summary Statistics

Table 3.1 presents summary statistics. Panel A reports the summary statistics of the customer firm sample. A firm is included in the sample if a customer-supplier relationship is recorded in the FactSet Revere data. A customer firm has an average number 4.91 unique suppliers in a given year.[11] Panel B presents the summary statistics of the supplier firm sample. The average environmental policy stringency index faced by a supplier firm is 3.05, and a supplier firm is related to an average of 3.19 customer firms in a given year. Panel C shows the summary statistics at the customer-supplier relationship level. The average probability of ending a supplier relationship is 49.61%, and the average duration of a relationship is 3.72 years.

[10] 28 EU nations and 16 other major economies.

[11] These include only the unique suppliers. On average, a customer firm has 8.91 suppliers in a given year.

Table 3.1. Summary Statistics

	Unit	Observations	Mean	SD	P1	P50	P99
Panel A: Customer-firm Level							
Size	ln($)	14,332	6.45	2.23	1.2	6.5	11.33
Profitability	ratio	13,924	-.14	2.28	-2.08	.02	.34
Leverage	ratio	13,972	.06	6.15	-.91	.01	1.83
Capital intensity	ratio	14,084	9.7	193.41	.31	1.34	76.98
Liquidity	ratio	13,509	3.2	4.2	.26	2.2	17.25
Sale growth	%	10,235	.07	.42	-1.19	.07	1.24
COGS growth	%	10,219	.06	.46	-1.38	.07	1.16
Δ Profit	$	10,105	62.89	396.02	-630.69	8.88	1,434.91
Inventory rate	ratio	13,922	.12	.56	0	.08	.68
CO_2 intensity	ln(tonne/$)	3,736	2.16	2.37	-1.89	1.95	7.59
Av. num suppliers	#	14,517	4.91	6.75	1	3	30
Panel B: Supplier-firm Level							
Av. EPS	index(0-6)	22,354	3.05	.81	.64	3.11	4.72
Av. # customers	#	22,354	3.19	5.87	1	1	32
Panel C: Relationship Level							
$\mathbb{1}$(End)	dummy x 100	71,343	49.61	50	0	0	100
Duration	years	71,343	3.72	3.54	1	2	17

Notes: This table presents the summary statistics at the customer firm, supplier firm, and customer-supplier relationship level. The main variables of interest are the indicator marking the supply chain relationship's termination indicator and the relationship's duration. The variables are defined in Appendix Table 3.16.

3.5 Results

3.5.1 Customer-supplier Firm Pair Regression Results.

Table 3.2 shows the main regression results. The OLS estimates from columns (1) to (5) suggest that a one-unit increase in the EPS index of the supplier country leads to a 1.8 to 2.75 percentage points increase in the likelihood of the customer-supplier relationship termination, holding other factors constant. Moreover, the negative coefficient on the quadratic term in column (5) suggests a non-linear, inverted U-shaped relationship between EPS and the likelihood of relationship termination. This non-linear result suggests that the likelihood of the relationship termination increases at a decreasing rate. Alternatively, I also use the Cox proportional hazard model to estimate the hazard ratio, which represents the relative risk of failure events (relationship termination) associated with a one-unit change in the independent variable (EPS), holding other variables constant. The results in Table 3.15 in the Appendix present similar results to the main estimates. Table 3.3 indicates that higher Environmental Policy Stringency in supplier countries leads to shorter durations of customer-supplier relationships, although the coefficient estimates are less significant. This result is consistent with the main estimates.

Table 3.2. Environmental Policy Stringency and Customer-Supplier Firm Relationship Termination

	$\mathbb{1}(\text{End})_{ij}$				
	(1)	(2)	(3)	(4)	(5)
$\text{EPS}_{d(j)}$	2.459***	2.752***	1.807**	2.711***	10.88**
	(0.820)	(0.865)	(0.904)	(1.031)	(4.315)
$\text{EPS}^2{}_{d(j)}$					-1.332*
					(0.686)
Supplier country controls			✓	✓	✓
Firm controls (lagged)		✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓	✓
Sup-country-Cus-ind FE				✓	✓
Observations	69,484	62,298	62,298	62,094	62,094
Adjusted R-squared	0.244	0.254	0.255	0.256	0.256

Notes: This table presents the OLS regression estimates from Equation (3.1). The dependent variable $\mathbb{1}(\text{End})_{ij}$ is an indicator that equals zero for active customer-supplier relationships during the observed years and switches to one in the final year of these relationships, marking the termination point of the supply chain relationship. The indicator is then scaled by 100 to express the results in percentage points. The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

The customer-supplier relationship terminations might be due to the increasing costs for the suppliers as a result of increasing environmental policy stringencies. These increased costs could be passed on to customer firms along the production chain, potentially affecting their performance. Section 5.3 further shows whether and how customer firms' financial performance is affected due to the increasing EPS in the supplier countries.

Table 3.3. Environmental Policy Stringency and Customer-Supplier Firm Relationship Duration

	Duration_{ij}				
	(1)	(2)	(3)	(4)	(5)
$\text{EPS}_{d(j)}$	-0.0832**	-0.0856**	-0.0913**	-0.107**	-0.0840
	(0.0377)	(0.0408)	(0.0425)	(0.0443)	(0.181)
${\text{EPS}^2}_{d(j)}$					-0.00379
					(0.0286)
Supplier country controls			✓	✓	✓
Firm controls (lagged)		✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓	✓
Sup-country-Cus-ind FE				✓	✓
Observations	69,484	62,298	62,298	62,094	62,094
Adjusted R-squared	0.416	0.414	0.414	0.474	0.474

Notes: This table presents the OLS regression estimates. The dependent variable Duration_{ij} is the customer-supplier relationship durations (in years). The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.5.2 Heterogeneity

Heterogeneity by Customer Industry Characteristics

Table 3.4 reports the heterogeneous results based on different customer industries. Columns (1) and (3) show that the effect of effect of EPS on customer-supplier relationship termination is smaller for customer firms operating in the manufacturing industry compared to firms in other industries. This result suggests that U.S. manufacturing customer firms may be better able to maintain supplier relationships when the supplier EPS increases. This could be possibly explained by the nature of the industry — manufacturing firms tend to have longer-term and more established relationships with suppliers, which are not easily changed in response to the supplier countries' environmental policies. Further breakdown of the manufacturing sub-industries was shown in columns (2) and (4) of Table 3.4. The customer firms operating in the textile sector are found to be less sensitive to changes in the supplier country's EPS. In fact, the estimation results show that these customer-supplier relationships are more likely to be maintained as EPS increases. In comparison, the chemical sector is found to be more likely to terminate supplier relationships.

Heterogeneity by Supplier Country Characteristics

Table 3.5 presents the heterogeneity results for different supplier country characteristics. Column (1)'s estimate indicates that if an Emissions Trading System (ETS) is implemented in the supplier country, the effect of EPS on relationship termination is mitigated. The presence of an ETS may suggest a more predictable and stable regulatory environment, reducing the uncertainty and risks associated with the supply chain relationships. Moreover, suppliers in countries with an ETS policy might be better able to adapt to further increases in environmental policy stringencies.

Column (2) shows that the supplier countries' GDP per capita does not exhibit significant heterogeneity in the impact of EPS on the likelihood of relationship termination. However, if the outcome variable is the relationship duration instead, the results show heterogeneity due to the supplier countries' GDP per capita. The higher GDP per capita in the supplier country leads to a less negative impact on the customer-supplier relationships. Customer firms with suppliers located in more economically developed countries may be better able to maintain the supply-chain relationship in the face of increasing environmental policy stringency.

Table 3.4. Heterogeneity Results by Customer Industry Characteristics

	$\mathbb{1}(\text{End})_{ij}$		Duration_{ij}	
	(1)	(2)	(3)	(4)
$\text{EPS}_{d(j)}$	2.015*	2.024*	-0.145**	-0.144**
	(1.071)	(1.070)	(0.0683)	(0.0683)
$\mathbb{1}(\text{Mining\_constr})_{n(i)}$ x $\text{EPS}_{d(j)}$	0.0478	0.186	0.00987	0.00196
	(2.058)	(2.065)	(0.122)	(0.122)
$\mathbb{1}(\text{Manu})_{n(i)}$ x $\text{EPS}_{d(j)}$	-2.314***	-2.508***	0.153**	0.192***
	(0.856)	(0.898)	(0.0644)	(0.0682)
$\mathbb{1}(\text{Wholes\_retail})_{n(i)}$ x $\text{EPS}_{d(j)}$	-2.697	-2.714	0.211	0.211
	(2.478)	(2.478)	(0.158)	(0.158)
$\mathbb{1}(\text{Textile})_{n(i)}$ x $\text{EPS}_{d(j)}$		-12.41**		0.565
		(5.689)		(0.346)
$\mathbb{1}(\text{Chemical})_{n(i)}$ x $\text{EPS}_{d(j)}$		3.272**		-0.295**
		(1.543)		(0.146)
$\mathbb{1}(\text{Food\_beverage})_{n(i)}$ x $\text{EPS}_{d(j)}$		-3.217		0.168
		(4.287)		(0.299)
$\mathbb{1}(\text{Automotive})_{n(i)}$ x $\text{EPS}_{d(j)}$		-0.131		-0.111
		(1.462)		(0.137)
Supplier country controls	✓	✓	✓	✓
Firm controls (lagged)	✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
Observations	63,210	63,210	63,210	63,210
Adjusted R-squared	0.127	0.127	0.391	0.391

Notes: This table presents heterogeneous OLS regression results across different customer industries. The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.5. Heterogeneity Results by Supplier Country Characteristics

	$\mathbb{1}(\text{End})_{ij}$		Duration_{ij}	
	(1)	(2)	(3)	(4)
$\text{EPS}_{d(j)}$	3.849***	1.410	-0.161**	-0.189**
	(1.132)	(1.169)	(0.0730)	(0.0768)
$\mathbb{1}(\text{ETS})_{d(j)}$	14.63***		-0.384	
	(5.213)		(0.315)	
$\mathbb{1}(\text{ETS})_{d(j)}$ x $\text{EPS}_{d(j)}$	-4.420***		0.150	
	(1.500)		(0.0949)	
$\mathbb{1}(\text{High GDP})_{d(j)}$		-3.121		-0.516*
		(4.373)		(0.294)
$\mathbb{1}(\text{High GDP})_{d(j)}$ x $\text{EPS}_{d(j)}$		0.514		0.154**
		(1.182)		(0.0753)
Supplier country controls	✓	✓	✓	✓
Firm controls (lagged)	✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓
Observations	62,094	62,094	62,094	62,094
Adjusted R-squared	0.256	0.474	0.256	0.474

Notes: This table presents heterogeneous OLS regression results by supplier country characteristics. $\mathbb{1}(\text{ETS})_{d(j)}$ equals one if the supplier country has an emissions trading system (ETS) in a given year. $\mathbb{1}(\text{High GDP})_{d(j)}$ equals one if the supplier country's GDP is in the top 25% of the GDP distribution across all supplier countries. The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

3.5.3 Customer Firm-level Regression Results

Building on the work of Barrot and Sauvagnat (2016), who studies whether firm-level shocks propagate or are absorbed in production networks by examining how natural disasters that hit suppliers impose significant output losses on their customers, this paper investigates the impact of changes in environmental policy stringencies in supplier countries on customer firms through the production network. While natural disasters represent sudden and unpredictable shocks, changes in environmental policy stringencies are typically more gradual, which may lead to different propagation effects in production networks.

The customer firm-level regression results in Table 3.6 suggest that increases in the EPS of supplier countries lead to decreases in sales growth and cost of goods sold (COGS) growth, although the coefficients are only significant at the 10% and 5% levels, respectively. There is no significant impact on other firm-level variables, including the changes in profits and inventory intensity[12], R&D investment[13], and CO_2 intensity.[14]

In contrast to the findings of Barrot and Sauvagnat (2016), which show that natural disasters hitting supplier firms significantly affect customer firms' sales growth and COGS growth, the results of this study suggest a more muted impact of environmental policy stringency on customer firms. This difference can be explained by the nature of the shocks: firms may have limited time and capacity to adjust in response to sudden and unexpected natural disasters, whereas environmental regulations are typically introduced gradually and over a longer time horizon, allowing firms to adapt their supply chains more smoothly.

I conducted several tests on supplier switching costs and the competitiveness of the supplier market. To estimate the level of supplier market concentration, I calculated the Herfindahl-Hirschman Index (HHI) for each customer firm's supplier base. I also calculated the customer

[12] The inventory intensity is defined as the inventory level divided by the revenue, as in Benguria et al. (2022).

[13] The R&D investment rate is defined as the research and development expenses divided by the total intangible assets, as in Crouzet et al. (2022)

[14] The CO_2 intensity is the defined as the Scope 1 carbon emissions divided by the total sales, the carbon emissions data is obtained from the Carbon Disclosure Program (CDP).

Table 3.6. Customer Firm-level Regression Results

	Sale growth (1)	COGS growth (2)	ΔProfit (3)	Inventory (4)	R&D invest (5)	CO_2 intensity (6)
$\overline{\text{EPS}}_{d(j)}$	-0.0270*	-0.0397**	-23.43	0.00127	-0.0667	-0.0523
	(0.0161)	(0.0166)	(16.79)	(0.00540)	(1.033)	(0.168)
Supplier country controls	✓	✓	✓	✓	✓	✓
Firm controls (lagged)	✓	✓	✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓
Observations	9,043	9,030	9,069	12,525	7,908	380
Adjusted R-squared	0.0950	0.0701	0.152	0.441	0.334	0.956

Notes: This table presents customer firm-level OLS regression results from Equation (3.2). $\overline{\text{EPS}}_{d(j)}$ represents the average EPS across all suppliers' countries for each customer firm. CO_2 intensity denotes the logged customer firm-level carbon emissions/sale (tonCO_2eq/$). For other firm-level variables, see Table 3.1 for variable summary statistics and Table 3.16 for variable definitions. Robust standard errors are clustered at the customer firm level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

firms' average switching frequency to understand the switching costs to new suppliers. In these calculations, I considered the full data sample, including both US and non-US suppliers.[15]

Supplier concentration

The supplier concentration for customer firms is represented by HHI_customer$_{i,t} = \sum_{j=1}^{N_{i,t}} (s_{ij,t})^2$, where $N_{i,t}$ is the number of suppliers for customer firm i in year t, and $s_{i,j,t} = \frac{1}{N_{i,t}}$ is the market share of each supplier j for customer firm i in year t.[16] The HHI_customer$_{i,t}$ ranges from $\frac{1}{N_{i,t}}$ to 1 (higher values indicate a higher supplier concentration). An HHI value close to 1 suggests that the customer firm relies on a single dominant supplier, while a value close to $\frac{1}{N_{i,t}}$ indicates a more evenly distributed and competitive supply base.

The Summary Table 3.7 shows that the average HHI across all customer firms is 0.11. This

[15] I did not include the US suppliers in my main regression data sample due to the endogeneity concerns. Since US customer firms are not likely to directly influence the EPS of the non-US supplier countries, the exclusion of the US customer firms allows me to isolate the effect of foreign environmental regulations on supply chain relationships.

[16] In the supplier concentration calculation, I assume equal weight when calculating the supplier share for each customer. This is because of the lack of information on the value of transactions between customers and suppliers. Further research with access to more detailed transaction-level data could improve the analysis by calculating a more realistic supplier share.

indicates that, on average, customer firms operate in relatively competitive and unconcentrated supplier markets. Customer firms have access to a diverse range of suppliers, which may enable them to switch suppliers more easily in response to changes in their supply chain.

Supplier Switching Frequency

To analyze the supplier switching frequency, I first generate a variable $\mathbb{1}(\text{new\_supplier})_{ij,t}$ indicating whether supplier j is new for customer firm i in year t. This variable is defined in a way that includes both unique new suppliers and those reappearing after a break in the relationship. Table 3.7 also provides summary statistics for the number of terminated suppliers and the number of unique new and terminated suppliers, considering only the first occurrence of a new supplier or the last occurrence of a terminated supplier, to offer a complementary perspective on supplier turnover. The new supplier indicator is defined as:

$$\mathbb{1}(\text{new\_supplier})_{ij,t} = \begin{cases} 1, & \text{if start year}_{ij} = t \\ 0, & \text{otherwise} \end{cases} \quad , \tag{3.3}$$

where $\text{start\_year}_{i,j}$ represents the year in which the relationship between customer firm i and supplier j is first established. The number of new suppliers for each customer firm i in year t, denoted as $\#\text{ new suppliers}_{i,t}$, is calculated by summing the $\mathbb{1}(\text{new\_supplier})_{i,j,t}$ indicator within each customer-year group:

$$\#\text{ new suppliers}_{i,t} = \sum_{j=1}^{N_{i,t}} \mathbb{1}(\text{new\_supplier})_{ij,t} \quad , \tag{3.4}$$

where $N_{i,t}$ represents the total number of suppliers for customer firm i in year t.

The switching frequency for each customer firm i in year t, denoted as $\text{switching frequency}_{i,t}$, is calculated as the ratio of the number of new suppliers to the total number of suppliers:

$$\text{switching frequency}_{i,t} = \frac{\#\text{ new suppliers}_{i,t}}{N_{i,t}} \quad . \tag{3.5}$$

The switching frequency variable implies the switching costs of customers — a higher switching frequency suggests lower switching costs. Table 3.7 shows that the average switching frequency is 0.54, implying that customer firms, on average, switch a significant portion of their suppliers each year. This switching frequency calculation suggests that customer firms face relatively low switching costs when adapting their supply chain relationships in response to changes in suppliers' environmental policy stringency.

Table 3.7. Supplier Concentration and Switching Frequency Measures - Full Sample

	Unit	Observations	Mean	SD	P1	P50	P99
# New suppliers	#	236,671	17.13	30.42	0	9	124
# Terminated suppliers	#	236,671	17.18	38.29	0	7	123
# Unique new suppliers	#	236,671	4.24	9.82	0	2	43
# Unique terminated suppliers	#	236,671	5.72	16.30	0	2	52
HHI customer	0-1	236,671	.11	.17	.01	.06	1
Switching frequency	0-1	236,671	.54	.26	0	.56	1

Notes: This table presents the summary statistics for calculating the supplier concentration and switching frequency measures. These measures are calculated based on the full sample, including US suppliers, to better reflect the concentration and switching frequency of customer firms' supplier networks. # new_suppliers represents the number of new suppliers for a customer firm per year, including unique new suppliers and those reappearing after a break in the relationship; # terminated_suppliers represents the number of terminated suppliers for a customer firm per year, including multiple terminations within a relationship; # unique_new_suppliers represents the number of unique new suppliers for a customer firm per year, considering only the first occurrence of a new supplier, disregarding subsequent reappearance;

3.5.4 Endogeneity Concerns

The identification strategy relies on the assumption that the supplier country EPS is uncorrelated with the factors affecting customer firm behavior. Although international agreements like the Paris Agreement influence global environmental policy, each country usually determines its own domestic environmental policies. Endogeneity could arise from reverse causality (e.g.

if the relationship termination affects the stringency of environmental policies), omitted variable bias (e.g., unobserved factors affecting both EPS and customer-supplier relationships), or measurement error in the EPS variable.

This paper makes several efforts to address the potential endogeneity issues. Following Albrizio et al. (2017), I conduct a robustness check to test whether past customer-supplier relationships can predict current levels of EPS. The results shown in Table 3.10 and 3.11 indicate that there are limited reverse causality issues. I include a rich set of control variables and fixed effects to mitigate the omitted variable bias. To prove the accuracy of the EPS variable, I conduct a test as shown in Table 3.10 as explained in the next section.

To further address the endogeneity concerns, one could use the instrumental variables (IV). A valid instrument should be correlated with the endogenous variable (EPS) but not directly related to the outcome variable (customer-supplier relationship termination probability and duration) except through their effect on EPS. One of the potential candidate instruments is the vote share of green parties or the proportion of left-wing parties in cabinet positions since these factors may influence environmental policy decisions but are likely not directly influencing the customer-supplier relationships. However, preliminary analyses using Green Party vote share as an instrument yielded small coefficients for the first stage, suggesting a weak instrument problem. This is likely explained by the fact that only a subsample of the supplier countries, mainly the OECD countries, have data on the Green Party vote share. Previous studies also consider using extreme weather events, such as the number of flood events, as instruments for EPS (Furceri et al., 2023). However, this choice of instrument cannot be used in this study since extreme weather events might have a direct impact on the supply chain networks, violating the exclusion restriction required for valid instruments (Pankratz and Schiller, 2023). Further research could consider using alternative instruments to address the potential endogeneity concerns, particularly in different data sub-samples.

3.6 Robustness

I implement a series of checks to test the robustness of the results.

3.6.1 Coverage and Accuracy of the Environmental Policy Stringency Index

As mentioned in Albrizio et al. (2017), the Environmental Policy Stringency (EPS) index might not accurately represent countries' environmental stringencies if fossil fuel is not a major source of electricity generation. This is because most of the policy tools that contribute to creating the EPS index predominantly focus on the regulation of fossil-fuel-based power generation. I conduct the robustness check by leaving out the supplier countries where less than 30% of the electricity is generated from fossil fuels. As shown in Table 3.10, the overall findings remain largely unchanged.

3.6.2 Test for Reverse Causality

I test for the potential reverse causality: whether the past customer-supplier termination probabilities or the relationship durations predict the current EPS levels in the supplier countries. To do this, I include lagged terms of the dependent variable ($\mathbb{1}(\text{End})_{ij,t}$) and the relationship duration ($\text{Duration}_{ij,t}$) up to three years back in the regression, along with other control variables. Results in Table 3.11 show there is limited evidence supporting the potential reverse causality. The coefficients for the lagged terms of $\mathbb{1}(\text{End})_{ij,t}$ or $\text{Duration}_{ij,t}$ are mostly not statistically significant, indicating that past customer-supplier termination probabilities do not predict the current EPS levels in the supplier countries.

3.6.3 Testing for the Delayed Impact of the EPS

To test for the potential delayed impact of the supplier's environmental policies, I add the first and the second lags of EPS in the regression. I also include the three-year moving average of the supplier country's environmental policy stringency in the regression.[17] The results presented in Table 3.12 show that coefficients for the lagged EPS terms are not statistically significant. This result suggests that the contemporaneous EPS has a more significant effect on the dependent variable than the lagged EPS terms. Furthermore, the estimation results using the three-year moving average of the supplier country's environmental policy stringency ($\text{EPS}_{d(s)t-h \to t}$) are similar to those in the main regression. These results indicate that the main findings are robust to alternative measures of environmental policy stringency, accounting for potential delays in policy implementation and compliance.

3.7 Conclusions

This paper presents novel findings on the impact of environmental policy stringency on global supply chain relationships. Using a detailed dataset linking US customer firms to their suppliers across multiple countries, the study finds that customers are more likely to terminate supplier relationships in response to more stringent environmental policies in supplier countries. Specifically, a one-unit increase in a supplier country's EPS lead to a 1.8 to 2.75 percentage points increase in the likelihood of the customer-supplier relationship termination, holding other factors constant. The analysis also reveals heterogeneous effects based on different customer firm industries and supplier country characteristics. Customer firms in manufacturing sectors experience a smaller impact on the probability of relationship termination. Moreover, the presence of an emissions trading system (ETS) in the supplier country also mitigates the effect of EPS on relationship termination. Firm-level regressions indicate that the spillover effects of supplier country EPS on customer firm performance through the production network are relatively limited. This finding can be explained by low switching costs and competitive supplier

[17] Taking moving averages smooths year-to-year policy fluctuations and aligns with the typical medium to long-term business decision-making cycles. It also accounts for the time lag in policy implementation and compliance, providing a more realistic representation of policy effects on the supply chain relationships.

markets, which explain why customer firms might be able to adapt to supply chain changes quickly.

This study contributes to understanding the impact of environmental regulations on firm performance and supply chain dynamics. The findings highlight the importance of considering the cross-border implications of environmental policies, which should be designed not only to curb emissions but also to promote global supply chain resilience. To further investigate the underlying mechanisms behind supplier termination, future research could explore the characteristics of the supplier that customers switch to in response to the increasing environmental policy stringency. Moreover, future studies could also examine the implications of the customer-supplier relationship terminations for environmental policies. If customers switch to suppliers located in countries with laxer environmental regulations or poorer environmental performance, it raises concerns about pollution havens and the shifting of burdens across borders. Research could also investigate the long-term impacts of supply chain adaptation in response to environmental policy changes.

3.8 Acknowledgements

Chapter 3 is being prepared for publication. The dissertation author is the sole author of this chapter.

3.9 Chapter 3 Appendix

3.9.1 Additional Figures and Tables

Table 3.8. Number of Observations by Supplier's Origin Countries

Country Code	Country Name	Observations	%
AT	Austria	313	.44
AU	Australia	2,048	2.87
BE	Belgium	590	.83
BR	Brazil	909	1.27
CA	Canada	6,339	8.89
CH	Switzerland	2,214	3.1
CN	China	4,450	6.24
CZ	Czech Republic	34	.05
DE	Germany	8,436	11.82
DK	Denmark	567	.79
ES	Spain	1,116	1.56
FI	Finland	261	.37
FR	France	4,978	6.98
GB	United Kingdom	10,763	15.09
GR	Greece	105	.15
HU	Hungary	32	.04
ID	Indonesia	208	.29
IE	Ireland	1,335	1.87
IN	India	2,149	3.01
IT	Italy	1,385	1.94
JP	Japan	13,021	18.25
KR	South Korea	3,699	5.18
NL	Netherlands	2,392	3.35
NO	Norway	366	.51
PL	Poland	410	.57
PT	Portugal	89	.12
RU	Russia	440	.62
SE	Sweden	1,849	2.59
SI	Slovenia	25	.04
SK	Slovakia	21	.03
TR	Turkey	314	.44
ZA	South Africa	485	.68
Total	-	71,343	100

Table 3.9. Number of Observations by Supplier's Industries

NAICS 2-Digit Name	Observations	%
Accommodation and Food Services	217	.3
Administrative and Support and Waste Management and Remediation Services	931	1.3
Agriculture, Forestry, Fishing and Hunting	56	.08
Arts, Entertainment, and Recreation	190	.27
Construction	835	1.17
Educational Services	262	.37
Finance and Insurance	55	.08
Health Care and Social Assistance	249	.35
Industries not classified	977	1.37
Information	14,315	20.07
Manufacturing	39,544	55.43
Mining, Quarrying, and Oil and Gas Extraction	1,400	1.96
Other Services (except Public Administration)	84	.12
Professional, Scientific, and Technical Services	5,284	7.41
Real Estate and Rental and Leasing	3038	4.26
Retail Trade	566	.79
Transportation and Warehousing	1,193	1.67
Utilities	361	.51
Wholesale Trade	1,524	2.14
Total	71,343	100

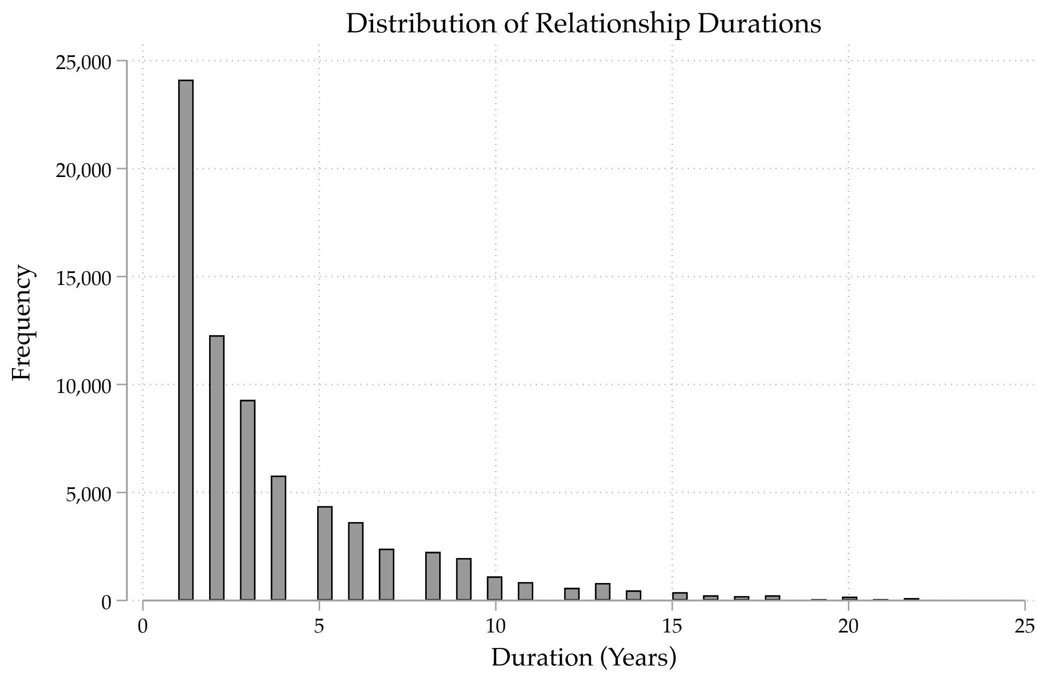


Figure 3.1. Distribution of Customer-Supplier Relationship Durations

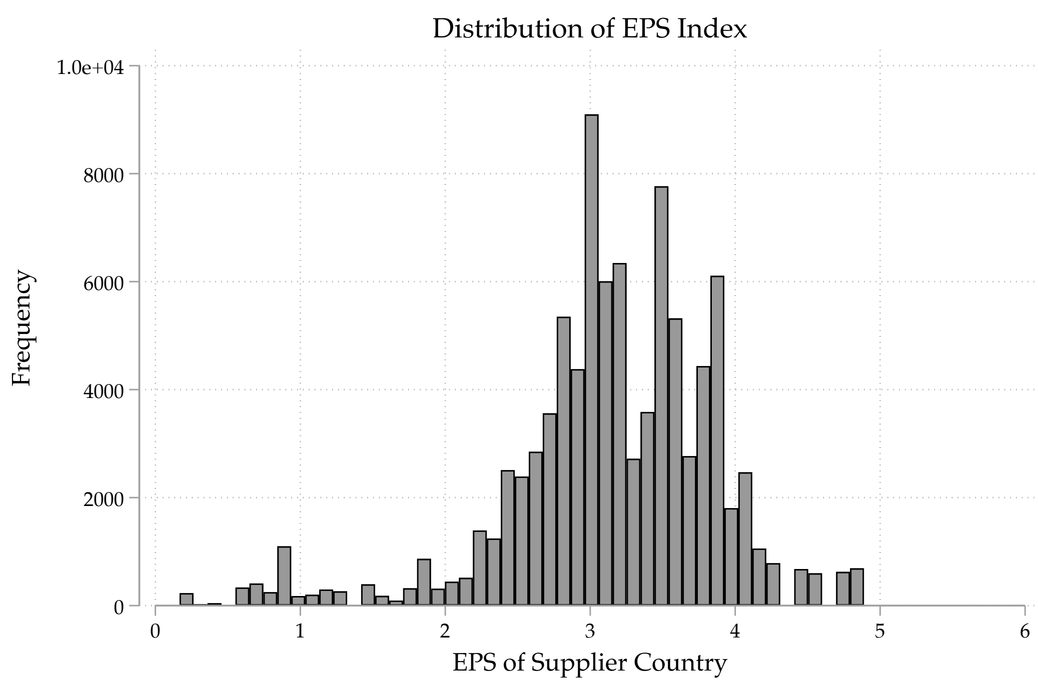


Figure 3.2. Distribution of EPS Index (Supplier Country)

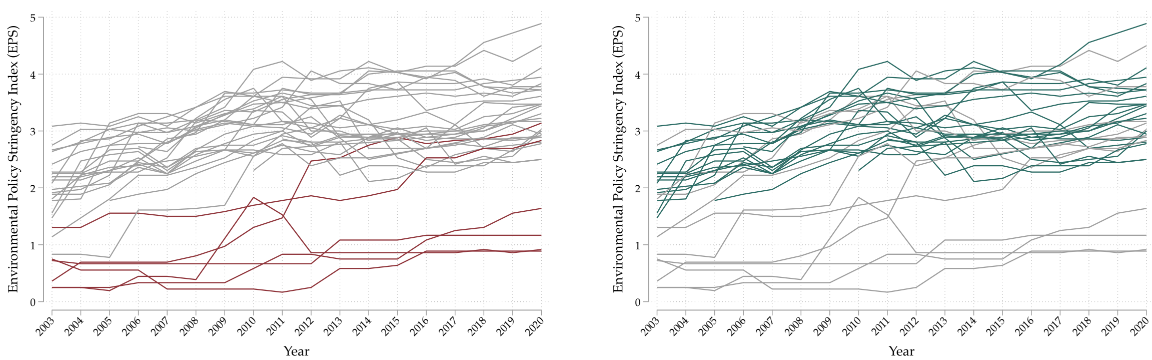


Figure 3.3. Cross-sectional and Temporal Variations of EPS Index

Notes: This figure shows the temporal evolution of the Environmental Policy Stringency (EPS) index for 32 supplier countries whose customer firms are located in the United States. The EPS index serves as a measure of the stringency of environmental policies and regulations in each country over time. The left subfigure presents the EPS index trajectories for OECD countries (light gray) and non-OECD countries (maroon), while the right subfigure displays the EPS index trajectories for countries participating in the European Union Emissions Trading System (EU ETS) (emerald) and non-EU ETS countries (light gray).

Table 3.10. Robustness Check: Supplier Countries with Higher Electricity Generations from Fossil Fuels

	$\mathbb{1}(\text{End})_{ij}$				
	(1)	(2)	(3)	(4)	(5)
$\text{EPS}_{d(j)}$	3.176***	3.424***	1.919	2.701**	6.792
	(1.039)	(1.097)	(1.221)	(1.366)	(5.838)
$\text{EPS}^2{}_{d(j)}$					-0.708
					(0.986)
Supplier Country controls			✓	✓	✓
Firm Controls (lagged)		✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓	✓
Sup-country-Cus-ind FE				✓	✓
Observations	52,432	46,960	46,960	46,840	46,840
Adjusted R-squared	0.250	0.261	0.262	0.263	0.263

Notes: This table presents the OLS regression estimates from Equation (3.1). The dependent variable $\mathbb{1}(\text{End})_{ij}$ is an indicator set to zero for active customer-supplier relationships during the observed years and switches to one in the final year of these relationships, marking the termination point of the supply chain relationship. The regression sample excludes the supplier countries where less than 30% of the electricity is generated from fossil fuels (Austria, Brazil, Canada, Finland, France, Norway, Sweden, Switzerland). Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.11. Robustness Check: Test for Reverse Causality

	$\text{EPS}_{d(j),t}$	
	(1)	(2)
$\mathbb{1}(\text{End})_{ij,t-1}$	-0.000263	
	(0.000431)	
$\mathbb{1}(\text{End})_{ij,t-2}$	-0.000725	
	(0.000603)	
$\mathbb{1}(\text{End})_{ij,t-3}$	0.000104	
	(0.000630)	
$\text{Duration}_{ij,t-1}$		0.0118*
		(0.00643)
$\text{Duration}_{ij,t-2}$		-0.0103
		(0.0100)
$\text{Duration}_{ij,t-3}$		-0.00140
		(0.00927)
Constant	-7.613***	-7.595***
	(2.875)	(2.861)
Firm Controls (lagged)	✓	✓
Cus-firm FE	✓	✓
Sup-firm FE	✓	✓
Cus-ind-year FE	✓	✓
Sup-country-Cus-ind FE	✓	✓
Observations	3,963	3,963
Adjusted R-squared	0.896	0.896

Notes: This table presents the OLS regression estimates for the test of reverse causality: whether the past customer-supplier termination probabilities or relationship durations profit the current EPS levels in the supplier countries. The independent variable is the supplier country's EPS, and the dependent variables lagged $\mathbb{1}(\text{End})_{ij,t-1}$ and $\text{Duration}_{ij,t-1}$ as defined in the previous sections. The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.12. Robustness Check: Lagged Effects of EPS on Customer-Supplier Relationship Termination Probability

	$\mathbb{1}(\text{End})_{ij,t}$											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$\text{EPS}_{d(j),t}$	1.819	2.984**	2.328*	2.606*	1.803	2.972**	2.330*	2.601*				
	(1.192)	(1.253)	(1.292)	(1.408)	(1.193)	(1.253)	(1.292)	(1.409)				
$\text{EPS}_{d(j),t-1}$	0.854	-0.309	-0.700	0.149	1.150	-0.100	-0.292	-0.138				
	(1.120)	(1.176)	(1.204)	(1.304)	(1.396)	(1.466)	(1.467)	(1.552)				
$\text{EPS}_{d(j),t-2}$					-0.386	-0.273	-0.571	0.425				
					(1.070)	(1.123)	(1.163)	(1.259)				
$\text{EPS}_{d(j),\text{3MA}}$									2.445***	2.269**	1.192	2.607**
									(0.882)	(0.932)	(0.976)	(1.127)
Supplier Country controls			✓	✓			✓	✓			✓	✓
Firm Controls (lagged)		✓	✓	✓		✓	✓	✓		✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sup-country-Cus-ind FE				✓				✓				✓
Observations	69,484	62,298	62,298	62,094	69,484	62,298	62,298	62,094	69,484	62,298	62,298	62,094
Adjusted R-squared	0.244	0.254	0.255	0.255	0.244	0.254	0.255	0.255	0.244	0.254	0.255	0.255

Notes: This table presents the OLS regression estimates from Equation (3.1) with different lag structures. The dependent variable $\mathbb{1}(\text{End})_{ij}$ is an indicator set to zero for active customer-supplier relationships during the observed years and switches to one in the final year of these relationships, marking the termination point of the supply chain relationship. $\text{EPS}_{d(j),\text{3MA}}$ denotes the 3-year moving average (the first, the second, and the third lag) of the supplier country's EPS. The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.13. Heterogeneity Results by Customer Firm Carbon Emission Intensity

	$\mathbb{1}(\text{End})_{ij,t}$ (1)	Duration_{ij} (2)
$\text{EPS}_{d(j)}$	13.10	-0.262
	(15.51)	(0.501)
CO_2 intensity_i	13.10	-0.262
	(15.51)	(0.501)
$\text{EPS}_{d(j)}$ x CO_2 intensity_i	-1.777	-0.00682
	(2.910)	(0.135)
Firm Controls (lagged)	✓	✓
Cus-firm FE	✓	✓
Sup-firm FE	✓	✓
Cus-ind-year FE	✓	✓
Sup-country-Cus-ind FE	✓	✓
Observations	2,604	2,604
Adjusted R-squared	0.478	0.598

Notes: This table presents heterogeneous OLS regression results by customer firm carbon emission intensity. CO_2 intensity denotes the logged customer firm-level carbon emissions/sale (tonCO_2eq/$). The sample covers 2,273 unique US customer firms and 5,658 unique supplier firms from 32 non-US countries from 2003 to 2020. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.14. EPS and Customer-Supplier Firm Relationship Termination: Restricted OECD Country Sample

	$\mathbb{1}(\text{End})_{ij}$				
	(1)	(2)	(3)	(4)	(5)
$\text{EPS}_{d(j)}$	0.785	0.986	1.072	2.181*	16.47***
	(0.942)	(0.989)	(1.024)	(1.150)	(5.979)
$\text{EPS}^2{}_{d(j)}$					-2.196**
					(0.904)
Supplier Country controls			✓	✓	✓
Firm Controls (lagged)		✓	✓	✓	✓
Cus-firm FE	✓	✓	✓	✓	✓
Sup-firm FE	✓	✓	✓	✓	✓
Cus-ind-year FE	✓	✓	✓	✓	✓
Sup-country-Cus-ind FE				✓	✓
Observations	61,016	54,932	54,932	54,741	54,741
Adjusted R-squared	0.248	0.258	0.258	0.260	0.260

Notes: This table presents the OLS regression estimates from Equation (3.1) for the restricted OECD country sample. The dependent variable $\mathbb{1}(\text{End})_{ij}$ is an indicator set to zero for active customer-supplier relationships during the observed years and switches to one in the final year of these relationships, marking the termination point of the supply chain relationship. The regression sample exludes the supplier firms from non-OECD countries (Brazil, China, Indonesia, India, Russia, South Africa). Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.15. Cox Proportional Hazard Model

	$\mathbb{1}(\text{End})_{ij}$ (1)
$\text{EPS}_{d(j)}$	1.745*** (0.073)
Supplier Country controls	✓
Firm Controls (lagged)	✓
Cus-firm strata	✓
Sup-firm strata	✓
Sup-country-Cus-ind strata	✓
Observations	63,860

Notes: This table presents the estimated hazard ratio using Cox proportional hazard model, which represents the relative risk of failure event (relationship termination) associated with a one-unit change in the independent variable (EPS), holding other variables constant. Robust standard errors are clustered at the customer-supplier firm pair level. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3.16. Variable Definitions

Variable	Definition
$\mathbb{1}$(End)	an indicator switches to one in the final year of customer-supplier relationships
Duration	customer-supplier relationship duration in years, adjusted by the Kaplan-Meier estimator
Size	(logged) total assets
Profitability	net income/ total assets
Capital intensity	total assets/ sale
Liquidity	total current assets/ total current liabilities
Sale growth	sale growth over the last year
COGS growth	cost of goods sold growth over the last year
Δ Profit	changes in gross profits from the last year
Inventory rate	total inventories/total revenue (Benguria et al., 2022)
R&D investment rate	research and development expenses/total intangible assets (Crouzet et al., 2022)
Ind CO_2 intensity	(logged) customer industry-level carbon emissions/output (tonCO_2eq/1000\$)
CO_2 intensity	(logged) firm-level scope 1 carbon emissions/sale (tonCO_2eq/\$)
EPS	environmental policy stringency index
GDPcapita15	(logged) GDP per capita (2015 US dollars)
GDPgrowth15	GDP growth rate
Trade of GDP	trade openness index
Political Stability	political stability index
$\mathbb{1}$(ETS)	an indicator equals one if a country has emissions trading systems in place

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