Environmental Policy Coordination *

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March 1, 2025

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Abstract

This paper studies how carbon policies in Europe lead to inadvertent local environmental regulation adjustments in China. Using a novel dataset covering two decades of Chinese environmental penalties and a comprehensive measure of European sectoral carbon costs, we construct a shift-share measure of yearly city-sector-specific exposure to EU carbon price costs among Chinese firms for identification. We find that a one-standard-deviation increase in export-weighted carbon price exposure corresponds to a 2.30% to 3.97% rise in the amounts of environmental penalties and a 4.39% to 7.52% increase in the values of these penalties. We also observe an increase in the intensity of penalties, suggesting that emissions leakage is not simply absorbed by the importing cities but also triggers stricter environmental regulation in response to increased pollution pressure. Conversely, industries more reliant on imports from the EU see a decline in exports and experience fewer environmental penalties. Further evidence reveals that the increased enforcement is concentrated in tradable sectors rather than reflecting a city-wide policy shift. In addition, local regulators offset reduced environmental enforcement in sectors reliant on EU imports by imposing stricter penalties on non-tradable sectors.

Keywords: Enforcement of Environmental Regulations, Policy Coordination, Carbon Price, EU ETS

JEL Codes: Q56, Q58, F18, F64, O13

*For helpful comments and suggestions, we thank Vittorio Bassi, Lydia Cox, Willam Darity, Rafael Dix-Carneiro, Gabriel Englander, Carolyn Fischer, Anais Galdin, Agustin Gutierrez, Gautam Rao, Xavier Jaravel, Ken Kikkawa, Philipp Kircher, Evan Kresch, Ahmad Lashkaripour, Abdoulaye Ndiaye, Paulina Oliva, Mac Jeuland, Jeffrey Weaver, and seminar participants at Sanford and World Bank. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

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1 Introduction

Climate change poses an existential global challenge and requires coordinated action from all nations. A key concern with unilateral carbon policies is carbon leakage, where production shifts to countries with more lenient emission standards. This undermines emission reduction efforts and raises questions about the overall effectiveness of such policies (Känzig et al., 2024; Laeven and Popov, 2023; Schroeder and Stracca, 2023; Li et al., 2024). Addressing carbon leakage requires coordination of global environmental policies (Kortum and Weisbach, 2023; Farrokhi and Lashkaripour, 2024). An open question remains regarding how pollution-importing countries respond to production shifts—whether they passively absorb emission leakage or adopt stricter regulations to mitigate environmental harm. Despite its importance, there is a significant gap in empirical research on the existence, magnitude, and direction of cross-country coordination in climate and environmental policies.

This paper studies the causal impacts of stricter climate policies in Europe on the stringency of local environmental regulation in China. Specifically, it investigates how increased carbon costs in Europe, driven by the European Union Emissions Trading System (EU ETS), influence local environmental penalties imposed by Chinese regulators and the resulting pollution outcomes from 2000 to 2020, using a shift-share research design. The *share* is constructed as the ratio of a sector's exports (or imports) to (from) a country in the EU for each Chinese city in the year preceding the implementation of the EU ETS. Meanwhile, the variation in sector-country-specific embodied carbon costs in Europe, including both direct carbon costs from emissions and indirect carbon costs incurred through the supply chain, serve as the common *shift*.

To measure the embodied carbon costs in Europe, we utilize data from the EXIOBASE project, which provides multi-regional input-output tables, total carbon emissions, and emission intensity of each sector in Europe. We also use detailed sectoral carbon prices and carbon tax of each country obtained from Resources for the Future (RFF) (Dolphin and Xiahou, 2022). Additionally, we leverage the Chinese customs dataset provided by the General Administration of Customs of China, which includes the universe of Chinese international transactions, to calculate the fixed sectoral trade ratios with EU countries and sectoral trade outcomes. To measure the stringency of environmental regulation among local Chinese officials, we use a novel dataset covering the universe of Chinese administrative environmental penalties, along with a text-based analysis that generates a local environmental regulation stringency index from Chinese official government work reports.

These measures of exposure to EU carbon prices act as plausibly exogenous shocks, enabling us to causally identify the impacts of higher carbon prices in the EU on local environmental regulations in China, as well as the impacts on total export, total import, and environmental outcomes to explore the mechanisms behind these passive policy responses. The validity of the causal identification and consistency of the estimates of our empirical strategy relies on the exogeneity of the shares or shifts (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2022). We claim that the varying sectoral carbon costs in the EU between 2005 and 2020, which mainly capture changes in carbon prices in the EU, are exogenous to local city and city-sector level outcomes in China.

Our findings indicate that Chinese firms with higher export-weighted exposure to EU carbon prices are subject to more stringent environmental regulation. This is reflected in both the increased frequency of environmental penalties and higher penalty amounts per unit of output. Specifically, a one-standard-deviation increase in carbon prices corresponds to a 2.30% to 3.97% rise in the amounts of environmental penalties and a 4.39% to 7.52% increase in the values of these penalties. Conversely, a one-standard-deviation higher import-weighted exposure to EU carbon prices leads to a 2.49% to 4.28% decrease in environmental penalty amounts and a 3.92% to 6.41% decrease in total penalty values. It suggests that local regulators may be balancing stricter enforcement with mitigating adverse input cost effects. Further analysis shows that higher export-weighted EU carbon costs also lead to increased sectoral exports and slightly higher emissions in terms of PM2.5 levels, while higher import-weighted exposure results in increased import values, higher import unit prices, lower emissions, and reduced pollutant concentrations.

These findings imply that local Chinese officials adjust environmental regulations in response to increased environmental pressure from higher exports of Chinese firms while also offering slight leniency to firms more reliant on EU imports through fewer penalties. This policy response could be either sector-specific or city-wide. Heterogeneity analysis shows that stricter regulations are primarily targeted at tradable sectors, which benefit the most from higher export demand. However, there is suggestive evidence that in cities experiencing greater import-induced EU carbon cost pressures, local officials implement stricter measures on non-tradable sectors. This suggests a strategic response by local officials to offset the environmental impact of leniency toward tradable sectors and aim to maintain overall environmental outcomes.

To further investigate whether the increase in environmental penalties indicates more stringent regulations or simply reflects a mechanical or proportional change, we present additional evidence. First, our findings reveal that cities facing higher exposure to export-weighted carbon costs in the EU impose more environmental penalties and experience elevated PM2.5 levels but fewer major pollutants. Second, regression analysis on the intensity of environmental penalties, calculated as penalties divided by total pollution indicators, also shows evidence of increased penalty intensity. These results suggest that the observed passive policy response reflects more stringent environmental regulation.

The dynamic analysis also shows the impulse response of main outcomes on varying exposure to carbon cost change in the EU. Higher export-weighted exposure to the EU carbon costs leads to an immediate and strong response on environmental penalties, as well as quick and large responses on sectoral export values and export volumes, as well as persistent increases in wastewater and PM2.5 density. Similarly, import-weighted exposure to higher EU carbon prices causes immediate and insignificant rises in environmental regulation stringency, immediate and large increases in imports, and persistent and strong decreases in major pollutants and carbon emissions.

Multiple robustness checks using different specifications, including alternative fixed effects, lagged independent variables, different weights in the shift-share measures, and alternative carbon price measures, provide consistent results on the associations between carbon policies in the EU and local environmental regulations in China. Our findings challenge the prevailing assumption that unilateral carbon policies do not influence environmental regulations in other countries. Instead, we demonstrate that such policies can induce passive environmental regulation adjustments abroad, suggesting that the scale of carbon leakage is not as large as what researchers used to estimate. Furthermore, these findings contribute to the design of optimal trade policy to mitigate carbon leakage.

Related literature and contributions This paper contributes to several strands of literature. First, it is connected to the literature on international policy coordination, particularly in the context of environmental policies. Several theoretical studies have highlighted the potential benefits of international coordination of macroeconomic policies, including environmental measures (Oudiz and Sachs, 1985; Fischer, 1987; Ederington, 2001; Canzoneri et al., 2005). More recent work has shifted towards understanding why coordination is infrequent, despite the apparent gains, focusing on factors such as differences in country size, economic conditions, policy objectives, and the externalities associated with unilateral policies (Ostry and Ghosh, 2016; Bhattarai et al., 2021; Trein et al., 2021).

There is also a growing body of literature examining international environmental policy coordination, particularly focusing on the conditions under which coordination is feasible and beneficial and the role of policy spillovers (Hoel, 1997; Ulph and Maddison, 1997; Finus et al., 2013; Bayham et al., 2019; Kollenbach and Schopf, 2022; Cadoret and Padovano, 2024). Two recent papers, Zhou (2023) and Hsiao (2024), are particularly relevant. Zhou (2023) shows that import restrictions on environmentally harmful goods in China can lead to similar restrictions in other cities due to spillover effects. In contrast, Hsiao (2024) demonstrates that coordinated import tariffs can achieve much of the effectiveness of domestic environmental taxes. Our paper extends this literature by providing empirical evidence of passive international policy coordination induced by unilateral carbon policies. We show that carbon policies in the EU can influence local environmental regulation in China through spillover effects at the cross-nation level.

Second, our work contributes to the literature on the relationship between trade, the environment, and carbon leakage. Existing studies have documented the effects of economic growth and trade on environmental outcomes, including the environmental Kuznets curve, which posits that environmental degradation first increases and then decreases with economic growth (Grossman and Krueger, 1995; Copeland and Taylor, 2004; Cristea et al., 2013; Shapiro, 2021; Copeland et al., 2021; Felbermayr et al., 2022). The concept of carbon leakage has also been extensively studied, with empirical evidence showing that trade can undermine the effectiveness of carbon policies by shifting production to countries with lower carbon costs (Schroeder and Stracca, 2023; Laeven and Popov, 2023; Li et al., 2024; Känzig et al., 2024). Our findings contribute to this literature by providing a new piece of direct evidence on carbon leakage.

Third, our paper informs the design of optimal unilateral carbon and trade policies. Theoretical literature proposes various strategies to combat climate change in the absence of a unified global carbon market, such as carbon border taxes, climate clubs, and green subsidies (Nordhaus, 2015; Thivierge, 2023; Kortum and Weisbach, 2023; Fontagné and Schubert, 2023; Weisbach et al., 2023; Blanchard et al., 2023; Farrokhi and Lashkaripour, 2024). These theoretical works often assume that only the home country enacts carbon policies. Our findings demonstrate that unilateral carbon policies can provoke environmental policy responses abroad, adding a new dimension to future theoretical analysis of optimal policy design.

Fourth, we contribute to the empirical evaluation of the EU ETS. While previous research has focused on the EU ETS's impact on European firm-level activities, emissions, productivity, and macroeconomic outcomes (Känzig and Konradt, 2023; Känzig, 2023; Wang, 2024; Colmer et al., 2024), few studies have examined its spillover effects on other countries. We fill this gap by showing that the EU ETS influences environmental regulation in China, the world's largest exporter and carbon emitter, providing new insights into the global implications of this major carbon pricing initiative.

This paper also contributes to the growing literature on the local enforcement of environmental regulations. While the design of environmental regulations is important, their effectiveness often depends on the enforcement at the local level (Buntaine et al., 2024). Compared to the design of environmental regulations, local enforcement tends to be more flexible depending on local factors. For instance, Limited enforcement capacity can lead to targeting strategies, such as focusing only on highly polluting plants (Duflo et al., 2018). Additionally, local regulators face trade-offs between economic development and pollution reduction, which may drive strategic behaviors like targeting plants located upstream or upwind of pollution monitors (He et al., 2020; Xie and Yuan, 2023; Yang et al., 2023) or strategically shutting down monitors (Zou, 2021; Mu et al., 2024). This paper provides new evidence on when local regulators choose to enhance enforcement, extending beyond purely political motivations (Kahn et al., 2015; Wang and Wang, 2020; Kong and Liu, 2023).

Lastly, this paper expands the application of shift-share instruments in measuring local exposure to trade-related shocks (Autor et al., 2013; Dix-Carneiro and Kovak, 2015; Dai et al., 2020, 2021). By constructing city-sector-level measures of EU carbon price exposure, we provide a methodological contribution that can be applied to other contexts involving international policy spillovers.

Outline The remainder of the paper is structured as follows. Section 2 provides institutional background on carbon policies in Europe and environmental regulations in China. Section 3 describes the data sources and presents descriptive evidence. Section 4 outlines the methodology for measuring carbon price exposure and the identification strategy. Section 5 presents the main regression results and discusses the mechanisms behind the observed policy coordination. The final section concludes the paper.

2 Institutional Background

2.1 Carbon Policies in Europe

Established in 2005, the EU ETS is the cornerstone of the EU's climate policy and the world's first and largest cap-and-trade carbon market. It covers over 12,000 installations in the energy and manufacturing sectors and aircraft operators flying within the EU and to Switzerland and the United Kingdom (UK). The EU ETS accounts for approximately 40 percent of Europe's greenhouse gas emissions and 5 percent of global emissions (Känzig and Konradt, 2023). As a cap-and-trade system, the EU ETS sets an annually decreasing cap on total greenhouse gas emissions.[1] Under this cap, companies receive or purchase emission allowances through auctions, which they can trade in the market. Firms are required to monitor and report their annual emissions and surrender enough allowances to cover their total emissions each year.

The EU ETS applies to all 27 EU member states, including the UK, until its departure in 2021, as well as Iceland, Liechtenstein, and Norway through the European Economic Area (EEA) agreement and Northern Ireland for electricity generation. UK companies were participants in the EU ETS during the whole time interval of our study in this paper [2] Another special case is Switzerland, and the Switzerland (Swiss) ETS started in 2013 [3] Since 2020, the Swiss Emissions Trading System has been linked to the EU ETS. Therefore, we include the corresponding yearly average carbon prices for the UK and Swiss sectors throughout our study period. In total, we analyze sectoral carbon prices from 32 countries, which include the EU 27, the UK, Iceland, Liechtenstein, Norway, and Switzerland. For simplicity, we will refer to these 32 countries as "the EU" for the remainder of this paper.

Carbon Price Dynamics of the EU ETS The EU ETS allows companies to trade surplus EU allowances (EUAs) in the market, with the average yearly price of EUAs in spot and futures markets reflecting the balance of supply and demand. The EU ETS has evolved throughout its different trading phases by adjusting the annual emission cap, shifting from free allocation to auctioning allowances, expanding coverage to include additional gases and sectors, introducing international credits, and establishing a market stability reserve. These policy adjustments have influenced carbon prices (Känzig, 2023) and signify the

[1] Currently in its fourth trading phase (2021–2030), the EU ETS reduces the emission cap linearly by 2.2% each year. Check the official website of EU ETS for more details: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

[2] The new UK Emissions Trading Scheme (UK ETS), which replaced the UK's participation in the EU ETS on January 1, 2021, operates similarly. Although the UK ETS began on January 1, 2021, British companies were required to comply with the EU ETS until the end of the scheme year in April 2021. Consequently, the UK carbon market did not open for trading until May 2021. The UK ETS closely mirrors the EU ETS in terms of coverage and operational structure, with the main difference being a slower rate of emission cap reduction compared to the EU ETS starting from 2024. Check the official website of UK ETS for more details: https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets

[3] The Swiss ETS started in 2008 with a five-year voluntary phase. After that, participation was mandatory for large, energy-intensive entities and voluntary for medium-sized entities. Switzerland takes a hybrid approach to reducing its GHG emissions, with a carbon tax (i.e., the CO2 levy covering 51% of CO2 emissions) and ETS (covering 33% of CO2 emissions) operating simultaneously. Check the official website of the Swiss ETS for more details: https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/ets.html

EU's commitment to mitigating climate change.

Figure 1 illustrates the time trend of the carbon costs due to EU ETS carbon across all sectors in EU countries from 2005 to 2020. The first period of the EU ETS price trajectory was from 2005 to 2007, corresponding to phase one of the trading regime. The carbon price dropped largely from 2005 to 2007 since the total allowances were too high, and the price went to zero since the extra allowances could not be transferred to the next phase. The phase two of the EU ETS regime was from 2008 to 2012. Despite the overall regulatory events meant to raise the carbon price, including fewer free allowances and more auctions happening, declining annual emission caps, and increasing sectoral coverages, the caps were still higher than needed, mostly due to the 2008 financial crisis and the EU ETS carbon price remained at a moderate level. The more recent phase 3 of the EU ETS trading regime was from 2013 to 2020, parallel with a steadily increasing price. This trajectory of rising prices was mainly due to further stricter carbon policies regarding the EU ETS, including the start of the EU-wide cap requirements and the market stability reserve, as well as broader sector and gas coverage [4]. Hence, the trajectory of the EU ETS carbon prices is a feasible indicator of the stringency of carbon policies in the EU. We restrict our analysis until the end of 2020 to minimize the impacts of the Coronavirus disease 2019 (COVID-19) pandemic, as well as the unusual surge of the EU ETS carbon price since 2021 due to the economic recovery and Russian invasion of Ukraine.

Other Climate Policies in Europe In addition to the EU ETS, European countries have implemented other climate policies, such as carbon taxes, the forthcoming EU ETS2, and the EU's Carbon Border Adjustment Mechanism (CBAM). Some European countries impose carbon taxes on sectors not covered by the EU ETS to avoid double taxation. Moreover, the EU ETS2 is a new emissions trading system scheduled to commence in 2027, covering emissions from fuel combustion in buildings, road transport, and other sectors currently outside the scope of the EU ETS. The CBAM, set to start in 2026, is designed to address carbon emissions embedded in imported goods by requiring EU importers to declare these emissions and surrender corresponding carbon emission allowances annually. Because other carbon mechanisms have not yet been implemented, our analysis focuses solely on the EU ETS and its carbon price trajectory. While carbon taxes primarily apply to non-tradable sectors, they can also increase production costs in tradable sectors through the supply chain. Therefore, we also calculated a composite measure of carbon costs that includes both carbon allowance prices and carbon taxes as an alternative measure for ro-

[4] Also see Känzig (2023) and Ellerman et al. (2016) for more detailed descriptions of the history of EU ETS's phases

bustness checking.

2.2 Environmental Policies and Enforcement in China

China's GDP grew by 588% in the two decades following the Reform and Opening in 1978, driven primarily by industrial manufacturing, which resulted in significant air and water pollution. According to the World Health Organization (WHO), outdoor air pollution contributed to an estimated 300,000 premature deaths annually in China (Cohen et al., 2005).

Since the early 1990s, a range of environmental regulations has been introduced in China to address the rising pollution problems. The two main regulatory tools are emission standards and pollutant discharge permits. The Chinese Ministry of Environmental Protection (MEP) sets and periodically updates sector-specific emission standards. Pollutant discharge permits were introduced in 2003, requiring polluting firms to purchase permits for their emissions. In 2018, these permits evolved into an emissions tax[5].

Environmental regulations in China are typically established by central or provincial governments but often lack detailed guidelines for enforcement and inspections. This gives local regulators at the prefecture or lower levels significant flexibility in deciding how to enforce these regulations. They hold the authority to shut down non-compliant firms or impose environmental fines. However, local officials were historically evaluated for promotion based on GDP growth. Under the trade-offs between promoting economic growth and enforcing environmental regulations, these regulations were often loosely applied. As shown in Figure 3, despite rising emissions from industrial sectors, local regulators issued few penalties before 2010, even with environmental regulations in place.

To incentivize local officials to take action against pollution, the central government introduced a series of reforms, including changes to political incentives and improvements in monitoring. In 2005, the central government altered promotion criteria, which had previously been based solely on economic growth. After the reform, local officials were required to meet specific environmental targets to be eligible for promotion. Once those targets were achieved, economic growth performance determined the likelihood of promotion. Kahn et al. (2015) demonstrated that local officials nearing the age threshold for promotion were motivated to reduce water pollution more actively.

In addition to these political incentives, the central government enhanced environmen-

[5]Pollutant discharge permits were managed by the MEP at the local level. The responsibility for collecting emissions taxes was transferred to local Tax Bureaus in 2018.

tal governance through centralization. In 2016, the Ministry of Environmental Protection (MEP) reformed the personnel appointment process, transferring the authority to appoint prefectural MEP directors from the local governments, headed by mayors and city secretaries, to the provincial MEP. This reform reduced the economic pressures on local regulators tied to promotion concerns from mayors and city officials, which allowed for stricter enforcement of environmental regulations. Kong and Liu (2023) found that this reform significantly increased both the number and amount of fines issued by local regulators, leading to significant improvements in environmental quality.

Furthermore, to address the principal-agent problem between the central government and local regulatory enforcement, the central government significantly enhanced pollution monitoring and data collection. The Ministry of Environmental Protection (MEP) began rolling out pollution monitors nationwide in 2014 and required plants in high-emission industries to install Continuous Emissions Monitoring Systems (CEMS) as early as 2007. By 2020, over 1,600 pollution monitors were installed across 367 Chinese cities. Additionally, by the end of 2013, 14,410 firms had integrated into the system, continuously uploading hourly, pollutant-specific emission data to an online platform accessible at the provincial level. This use of technology has markedly improved regulatory enforcement and air quality (Greenstone et al., 2022).

Despite political incentives and enhanced monitoring from the central government, local enforcement of environmental regulations remains incomplete, largely due to the persistent trade-offs between economic growth and environmental protection. Local regulators have been found to strategically target polluting plants located upstream or upwind of pollution monitors (He et al., 2020; Xie and Yuan, 2023; Yang et al., 2023) in order to improve monitor readings without fully addressing broader pollution issues. They also strategically loosen the regulation stringency facing negative trade shocks (Du and Li, 2024). This paper will investigate whether economic shocks induced by EU carbon policies can influence and shift local enforcement of environmental regulations.

3 Data Source

This paper utilizes data from various sources, including sector-specific carbon prices within EU countries, the UK, and Switzerland each year, multi-regional input-output tables for each year within the EU, detailed customs data from China, city-level environmental outcomes such as major total pollutants discharges, estimates of city-level total carbon emissions, and yearly average PM2.5 levels, and detailed measures of environmental regulation stringency including environmental penalty records and a text-based measure of local environmental regulation stringency index.

3.1 Carbon price in Europe

The carbon price data at the sector level that we use is from the World Carbon Pricing Database compiled by Resources for the Future (RFF)[6] (Dolphin and Xiahou, 2022). The database provides information on the coverage and rates of both cap-and-trade allowances and carbon taxes on the sector-fuel levels in 201 jurisdictions from 1990 to 2022, and it is so far the most comprehensive resource for carbon price regimes with rich coverage in both jurisdictions and sectors. All carbon prices across years and countries are converted into 2015 Euros per tonne of CO_2 equivalence. Additional details about the sector disaggregation standards, sector concordance, and data sources of this database can be found in A.1.

3.2 Global Input-Output Table

We require a global input-output table to calculate the embodied sectoral carbon costs, including both direct and indirect costs, of a specific industry within the EU. We use data from Exiobase[7] (Stadler et al., 2018). The latest Exiobase version 3 provides detailed input-output tables from 2000 to 2020 and the direct CO_2 emissions of each industry and country pair, sourced from the International Energy Agency (IEA). Exiobase covers 44 countries, including all 27 EU countries, the UK, Norway, Switzerland, and 14 other major economies. It contains 200 products and 163 industries [8]. There are several other global input-output database available, including the World Input-Output Database (WIOD)[9], the OECD Input-Output Tables database (OECD IOTs) [10], and the Eora multi-region input-output table (Eora MRIO)[11]. The Exiobase environmentally-extended multi-region input-output (EE MRIO) tables are widely used for analyzing global environmental trade-related issues (Shapiro, 2021; Wang, 2024). In our case, Exiobase is preferred due

[6] https://www.rff.org/publications/data-tools/world-carbon-pricing-database/, and the database is hosted here: https://github.com/g-dolphin/WorldCarbonPricingDatabase

[7] The homepage of Exiobase: https://www.exiobase.eu/index.php/about-exiobase

[8] Iceland and Liechtenstein are not included in the Exiobase database

[9] The homepage of WIOD: https://www.rug.nl/ggdc/valuechain/wiod/

[10] The homepage of OECD IOTs: https://www.oecd.org/en/data/datasets/input-output-tables.html

[11] The homepage of Eora MRIO: https://www.worldmrio.com/

to its coverage of additional sectors and their corresponding direct carbon emissions. Furthermore, Exiobase has been developed through projects supported by the European research framework programs, making it particularly suitable for studying the carbon policies within the EU (Wang, 2024). Details of sectors, data structure, and sector concordance process can be found in A.2.

We also use China's national input-output tables from 2002 to 2020, available for 2002, 2005, 2007, 2010, 2012, 2015, 2017, 2018, and 2020. These tables are sourced from China's National Bureau of Statistics (NBS). In recent years (after 2017), the NBS has provided two versions of the input-output tables: the competitive and non-competitive. The competitive input-output table considers importing inputs substitutes for domestic inputs, whereas the non-competitive version separates sections for importing inputs. We rely on the national input-output tables to compute the upstream-weighted and downstream-weighted carbon pricing exposure for a specific sector at the sector-city-year level. Therefore, we use the competitive version to consider the substitution and complement effects of importing products.

3.3 Custom Data in China

We use detailed custom data of 2004, one year before the implementation of the EU ETS, to calculate the export (or import) weights of a specific industry from a Chinese city to (or from) a particular EU country within the total exports (or imports) of the city. The data source is the universe of Chinese transaction-level trade records, including detailed information on firm registration code, HS-8 product code, quantity and values of each trade transaction, and destination or original country. China's General Administration of Customs provides the data, and it is available with the firm's registration information, thus the city location, from 2000 to 2013 [12]. Using such information, we can also generate the total exports and imports of the city-industry level each year from 2000 to 2013. Details of sector concordance can be found in A.3.

3.4 China's Environmental Outcomes

We collected data on the city-level emissions of several major pollutants from industrial processes in China from the City Statistical Yearbook spanning 2004 to 2020, provided by the NBS. This includes data on wastewater, sulfur dioxide (SO_2), nitrogen oxide (NO_x),

[12] We appreciate Kang Zhou for providing generous instruction and guidance on this data source.

and particulate matter (smoke and dust).

We have access to yearly average PM2.5 density estimates from the Tracking Air Pollution in China (TAP) platform [13] (Geng et al., 2021; Xiao et al., 2021). This platform provides a 10km x 10km level grid yearly average PM2.5 density measure. To aggregate the grid data into city-level information, we utilize the Chinese prefecture-level geo-map data from GADM [14].

We also use estimates of the county-level CO_2 emission inventory in China from 1997 to 2017 to measure the city-level carbon emission during this period. The data is from the Carbon Emission Accounts and Datasets(CEADs) platform [15] (Chen et al., 2020).

3.5 Environmental Regulation Stringency Index

To gauge the strictness of environmental regulations at the city level, we also use the text-based index of environmental regulation stringency (ESI), originally proposed by Chen et al. (2018) and used by Du and Li (2024) in a similar context. In China's political landscape, the government's annual work report is a vital document at the national, provincial, and city levels. Typically published in the first quarter of each year, it serves two main purposes: summarizing the achievements of the previous year and outlining plans for the upcoming year. These annual work reports are seen as strong indicators of the government's policy priorities and the expectations for their implementation (Chen et al., 2018). Additionally, another reason the text-based stringency index, created from city-level government work reports, is particularly suitable for our study is that local officials generally have considerable discretion in developing their plans. They also have strong incentives to fulfill their commitments, as the implementation of the initiatives outlined in each year's annual report is crucial for their performance evaluations and promotion.

The city-level environmental regulation stringency index is calculated by dividing the length of sentences containing environment-related words by the total length of the full work report each year. We choose 14 environment-related words, which include PM2.5, PM10, SO_2, CO_2, COD, pollution, emission, emission reduction, air, low carbon, protect the environment, environmental protection, smog, and energy consumption intensity.

[13] The homepage of TAP: http://tapdata.org

[14] The homepage of GADM: https://gadm.org/about.html

[15] The homepage of CEADs: https://www.ceads.net/

3.6 Environmental Penalty in China

To directly measure the stringency of environmental regulation at the city level, we use official records of environmental administrative penalties. We have access to a novel dataset containing the universe of environmental penalty records from 2000 to 2020, with rich information including the date, city, penalty type, fine amount, and firm sector. The penalties encompass fines, license revocations, orders to rectify or suspend operations, sealing, seizures, professional restrictions, confiscation of property or illegal gains, administrative detention, and criminal arrests.

3.7 Summary Statistics and Descriptive Evidence

Summary Statistics Table 1 presents summary statistics of the main indicators and outcomes used in this paper, divided into sector-city-level variables and city-level variables.

Panel A of Table 1 displays the summary statistics of the main city-sector-level outcomes and measures of sectoral exposure. On average, each sector received 16.51 environmental penalties per year, with total fines amounting to 686.5 thousand RMB. Among all sectors that received at least one penalty during the year, 58% are tradable sectors, namely agriculture, manufacturing, and mining.

Regarding carbon price exposure, the average sector has an export-weighted exposure of 0.918 million euros and an import-weighted exposure of 1.472 million euros to EU carbon costs. The export-weighted exposure to carbon cost rates averages 285.32 euros per million euros of outputs, while the import-weighted exposure averages 359.6 euros per million euros of outputs.

In terms of trade, the average sectoral total export value is 245.33 million USD, with an average export volume of 255.32 million units and a value-weighted average unit price of 139716.48 USD. Conversely, the average sectoral import values, volumes, and average unit prices are 218.9 million USD, 392.04 million units, and 194061.01 USD, respectively.

Panel B of Table 1 presents summary statistics for city-level variables. On average, the Environmental Regulation Stringency Index (ESI) is 0.06, indicating that 6% of the sentences in yearly government work reports are related to environmental topics. The average total number of environmental penalties imposed in a city is 78.91, with an average total of 3.36 million RMB in fines. Additionally, the average city-level export-weighted exposure to EU carbon costs amounts to 1.62 million euros, while the import-weighted exposure is 0.916 million euros. The average city-level export-weighted exposure to carbon cost rates is 191.95 euros per million, while the import-weighted exposure is 468.75 euros per million.

Our measures of environmental outcomes are all at the city level. The average estimated total yearly carbon emissions are 21.84 million tonnes of CO_2. On average, cities discharge 68.99 million tons of wastewater, 136.2 thousand tonnes of SO_2, 49.4 thousand tonnes of NOx, and 29.4 thousand tonnes of industrial particulates annually. During this period, the average annual PM2.5 concentration is 46.52 μg/m^3 (micrograms per cubic meter).

China cities in our sample have an average population of 4.29 million, an average total GDP of 150.17 billion RMB, and an average of 38646.12 RMB of GDP per capita.

Descriptive Evidence Figure 2 illustrates time trends of average economic and environmental outcomes among Chinese cities. Panel (a) shows the steady and substantial increase in GDP per capita over time. Panels (c), (d), and (e) display similar patterns for pollution measures such as NO_x emissions, wastewater discharge, and annual average PM2.5 levels, all of which increased rapidly after China joined the World Trade Organization in 2001, remained at high levels until around 2013, and then declined as the central government emphasized environmental outcomes. China's national campaigns against pollution were effective in reducing major pollutants and PM2.5 levels, as evidenced by the sharp drops observed after 2013.

An exception is city-level carbon emissions, shown in panel (b) of Figure 2. Total carbon emissions continued to grow even after 2013 until around 2017. This is because carbon emissions were not included in national or local environmental goals during that period, and efforts were primarily focused on mitigating major pollutants.

Figure 3 illustrates the surge in environmental penalties, both in terms of the number of events and the total amount of penalties, as well as the regional distribution of penalties in China from 2000 to 2020. The number and total amount of environmental penalties were very low before 2010, began to increase in 2012, and remained moderate until 2015. Starting in 2016, both the number and amount of penalties dramatically increased, peaking in 2018. After 2018, there was a slight decline, but penalties remained at high levels. The regional distribution shown in Figure 3 indicates that penalties are concentrated in the eastern coastal areas, particularly in the major economic zones surrounding Beijing, Shanghai, and Guangzhou/Shenzhen.

4 Empirical Strategy

We begin by calculating the embodied carbon price burden of specific sectors in the EU, accounting for both direct costs of purchasing emission allowances to account for fuel combustion carbon emissions and indirect costs transmitted through upstream sectors. We then construct a shift-share (Bartik-like) measure of carbon price exposure for Chinese cities at the city-sector-year level, using fixed pre-EU ETS export (or import) proportions as weights. Finally, we employ regression models to causally identify the impact of changes in carbon price exposure on trade, local environmental outcomes, and, crucially, the stringency of local environmental regulations in China.

4.1 Measuring Sectoral Embodied Carbon Price in Europe

Under the EU ETS, regulated firms must monitor and surrender sufficient emission allowances to cover their direct greenhouse gas emissions, primarily from fuel combustion and certain industrial processes, such as cement production. This creates a direct carbon pricing cost, which is often passed downstream through supply chains. Due to the interconnectedness of industries, an increase in carbon pricing in one sector affects downstream sectors and even other countries, especially within the EU. Even relatively cleaner industries bear indirect carbon costs from their upstream suppliers. To capture the total carbon impact of a product or industry—including both direct and indirect emissions—we adopt a life-cycle carbon footprint approach.

Following Shapiro (2021) and Wang (2024), we consider a global economy with N countries, each divided into S sectors. Let A be the $NS \times NS$ input-output matrix, where each column represents the inputs required by an industry from all other industries, both domestically and abroad, and each row represents the outputs supplied by an industry. Let x be the $NS \times 1$ vector of total outputs, and d be the $NS \times 1$ vector of final demands. The accounting identity $x = Ax + d$ holds, indicating that total output equals intermediate inputs plus final demand. This can be rearranged to $x = (I - A)^{-1}d$, where $(I - A)^{-1}$ is the Leontief inverse matrix, capturing the total input requirements—including all direct and indirect inputs—to produce a unit of final demand.

Using this framework, we express the embodied carbon price burden for sector k in country j at time t as:

$$g_{jk,t} = \sum_{i,s} l_{ijsk,t} E_{is,t} \tau_{is,t}, \tag{1}$$

where $g_{jk,t}$ is the embodied carbon price burden per unit of output in sector k in country j at time t. The term $l_{ijsk,t}$ is an element of the Leontief inverse matrix $(I - A)^{-1}$, representing the monetary amount of inputs from sector s in country i required to produce one monetary unit of output in sector k in country j. The variable $E_{is,t}$ denotes the direct carbon emission intensity of sector s in country i at time t, that is, the direct emissions per unit of output. Alternatively, we also use an alternative definition of $E_{is,t}$ as the total direct carbon emission of sector s in country i at time t. $\tau_{is,t}$ is the carbon price applicable to sector s in country i at time t, determined by sectoral coverage and the average yearly price of EU ETS allowances.

This formulation assumes perfect competition and complete pass-through of carbon costs along the supply chain, meaning that additional carbon costs are proportionally transmitted to downstream sectors. All monetary values in the input-output tables and related datasets are converted to 2015 Euros for standardization purposes.

4.2 Measuring City-Sector Carbon Pricing Exposure in China

To measure the sector-level exposure of Chinese cities to EU ETS carbon prices, we construct a weighted average of the EU carbon price burdens at the EU country-sector level, using fixed pre-EU ETS export or import shares in China as weights. Using contemporary trade proportions could introduce bias due to unobserved economic factors and concurrent domestic policies affecting trade and environmental outcomes. Therefore, following the shift-share methodology widely used in the international trade literature (Kovak, 2013; Hakobyan and McLaren, 2016; Dix-Carneiro and Kovak, 2015, 2017, 2019; Dai et al., 2021, 2020), we use export and import shares from the year before the EU ETS implementation (year 2004).

Specifically, we define the carbon pricing exposure for sector k in city c at time t as:

$$\text{Exposure}_{ckt} = \sum_{j} g_{jk,t} R_{cjk,2004}. \tag{2}$$

and the city-level exposure for city c at time t as:

$$\text{Exposure}_{ct} = \sum_{j,k} g_{jk,t} R_{cjk,2004} S_{ck,2004}, \tag{3}$$

Here, Exposure_{ckt} is the overall carbon pricing exposure of sector k in the city c in year t, and Exposure_{ct} is the exposure of city c in year t. The term $g_{jk,t}$ is the embodied carbon price burden for sector k in EU country j in year t, as defined in equation (1)[16]. The weights $R_{cjk,2004}$ are the ratios of city c's exports or imports in sector k, to or from EU country j in 2004, relative to total exports or imports in sector k in 2004[17]. $S_{ck,2004}$ are the ratios of city c's exports or imports in sector k relative to total exports or imports in 2004. We also test alternative weighting schemes, such as using average export or import shares from 2002 to 2004 or expressing weights as ratios to total GDP in 2004, as robustness checks. Additional details on the data construction, including the alignment of sector categories across different classification systems, are provided in Section A.3 of the Appendix.

Figure 4 displays the time trends of the average export- and import-weighted carbon price exposures among Chinese cities from 2000 to 2020. Both the import- and export-weighted exposures to EU carbon costs or carbon cost rates follow similar time trends to the trajectory of carbon prices in the EU, as shown in Figure 3. However, the variations are mostly across cities or different sectors within the same cities. Figure 5 illustrates the regional variation of carbon price exposure at the city level. We observe that the four measures of carbon price exposure exhibit significant regional variations. Moreover, the regional distributions of export- and import-weighted carbon price exposures do not coincide, implying that they capture different city or sectoral attributes affecting import and export structures. Additionally, the regional variations of carbon price exposure are widely dispersed and not concentrated solely in coastal areas. These dispersions support our identification strategy, as they suggest that the shift-share carbon price exposure measures can be considered exogenous shocks.

4.3 Regression Model

To identify the causal impacts of changing carbon prices driven by stricter climate policy in the EU on local Chinese environmental regulations, and any possible channels of these

[16] When $g_{jk,t}$ is calculated based on the embodied carbon price burden per unit of output in sector k in country j at time t, we refer to this measure as the *exposure rate*. Alternatively, when $g_{jk,t}$ is calculated using the total embodied carbon price burden in sector k in country j at time t, we refer to it as the *exposure*.

[17] Note that the sum of weights across EU countries is less than 1. Following the practical guide to shift-share instruments in Borusyak et al. (2024b), we include city fixed effects to account for potential endogeneity arising from *incomplete shares*.

impacts, we estimate the following regression models:

$$\ln(Y_{ct}) = \beta \ln(\text{Exposure}_{ct}) + \Gamma X_{ct} + \delta_t + \sigma_c + \epsilon_{ct}, \tag{4}$$

$$\ln(Y_{ckt}) = \beta \ln(\text{Exposure}_{ckt}) + \Gamma X_{ckt} + \delta_t + \sigma_c + \epsilon_{ckt}. \tag{5}$$

Here, $\ln(Y_{ct})$ denotes the logarithm of city-level outcomes for city c at time t, such as total exports, imports, trade volume, environmental indicators (e.g., pollutant emissions, carbon emissions, average PM2.5 levels), environmental regulation stringency indices, and city total environmental penalties. Similarly, $\ln(Yckt)$ represents the logarithm of sector-level outcomes for sector k in the city c at time t, such as city-sector exports, imports, and sectoral environmental penalties.

The main explanatory variables, $\ln(\textit{Exposure}_{ct})$ and $\ln(\textit{Exposure}_{ckt})$, are the logarithms of the carbon pricing exposure measures defined earlier. The coefficient β thus captures the elasticity of the outcome variable with respect to carbon price exposure.

X_{ct} and X_{ckt} are vectors of control variables at the city and city-sector levels, respectively. The terms σ_c and δ_t represent city fixed effects and year fixed effects, controlling for time-invariant city characteristics and common temporal shocks. In city-sector specifications, we include city-year and sector-year fixed effects. The error terms ϵ_{ct} and ϵ_{ckt} are clustered at the city level.

4.4 Identification Assumptions and Potential Threats

First introduced by Bartik (1991) and formalized by Blanchard and Katz (1992), the shift-share (or Bartik) method has been widely used to identify the effects of common shocks across different units. Recent methodological work has explored the validity of shift-share instruments as two-stage least squares (TSLS) estimators, examining their consistency and identification assumptions (Adão et al., 2019; Borusyak et al., 2022; Goldsmith-Pinkham et al., 2020); see also Borusyak et al. (2024a) for a review. These studies have established the equivalence between using shares or shocks as instruments and have highlighted key identification conditions, the relevance condition, and the exogeneity condition.

The relevance assumption requires that the weights (shares) have predictive power for the current exposure to shocks. The exogeneity assumption, analogous to the exclusion restriction in TSLS, requires that the shares are exogenous to the error terms after controlling for covariates and fixed effects. Importantly, even if the shares are not exogenous, consistent estimates can be obtained if the shocks are independent and exogenous (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2022). Even though the validity of identification and estimation consistency is often illustrated in an instrumental variable setting in recent methodological literature (Goldsmith-Pinkham et al., 2020; Adão et al., 2019; Borusyak et al., 2022), the exclusion restriction remains the same when shift-share measures are used in reduced-form specifications (Goldsmith-Pinkham et al., 2020).

In our context, we construct the carbon pricing exposure of Chinese cities using predetermined export (or import) shares and exogenous variations in EU carbon pricing. The exogeneity of the EU country-sector-level carbon price burdens stems from EU policy changes and global economic conditions, which are plausibly independent of contemporaneous outcomes in Chinese cities. The pre-EU ETS export shares from 2004 are unlikely to be correlated with later changes in city-level outcomes, especially given significant shifts in China's environmental policies after 2013. As Goldsmith-Pinkham et al. (2020) note, identification is strengthened when the research design resembles a difference-in-differences framework with pre-treatment periods; we utilize data from 2001 to 2004 as such preperiods.

To further mitigate endogeneity concerns, we also incorporate novel measures of EU carbon pricing changes proposed by Känzig (2023): the *carbon policy surprise* and the *carbon policy shock*. The carbon policy surprise captures high-frequency fluctuations in EUA futures prices around regulatory events, relative to wholesale electricity prices. It can effectively isolate policy-induced price changes from broader economic influences. The carbon policy shock, derived using an external instruments VAR model with the surprise series as an instrument, further addresses potential reverse causality.[18] We re-estimate our main regressions using the alternative measure of carbon policy shock and find consistent results (see Section 5.5 and Appendix C for details).

Additional Identification Threats Our identification strategy is based on the exogeneity of EU carbon pricing shocks and predetermined export shares; however, some potential threats remain. One key concern is that unobserved factors influencing initial export or import shares and subsequent outcomes could bias our estimates. For instance, cities with higher initial exposure may differ systematically in ways that affect environmental regulation independently of EU carbon pricing. To address this issue, we include fixed effects

[18] Data available at `https://github.com/dkaenzig/carbonpolicyshocks`; we thank Diego Känzig for providing these data.

for cities and years, and in various specifications, we also include city-year and sector-year fixed effects to control for both time-invariant and time-variant city-specific unobserved heterogeneity, as well as common temporal shocks.

Another concern is that changes in China's domestic environmental policies or global economic conditions might impact cities differently based on their initial export or import composition. Additionally, some Chinese cities may have already adjusted their trade shares with the EU in anticipation of the forthcoming EU ETS. To mitigate this concern, we perform robustness checks using alternative weighting schemes, such as employing average export shares from 2002 to 2004 or expressing weights relative to total GDP to accommodate different economic scales of the cities. We also control for city-level economic variables that might influence the stringency of environmental regulation, including GDP per capita and registered population.

A further concern is reverse causality, where economic conditions, trade volumes, or shifts in national economic policy in China could influence climate policy decisions in the EU and affect the demand for EUAs. However, we believe that during our study period, it is unlikely that the economic situation or government policy in China would determine climate policy or the market price of the EU ETS. To further address the concern about the potential effects of common economic shocks influencing both the demand for the EU ETS and Chinese production and trade volumes, as well as specific shocks to China, we will also utilize alternative measures of carbon prices in the EU. These alternative measures will include high-frequency changes in carbon prices relative to prevailing wholesale electricity prices that occur within one day following a regulatory event, as discussed in Känzig (2023).

Finally, we are aware that measurement errors in the constructed exposure variables could attenuate our estimates. However, we believe this is less of a concern for our study design because the carbon cost sectoral coverage and average price are derived from official documents, and the trade ratios for 2004 are calculated using transaction-level records from China's customs data.

5 Results

To directly assess whether local regulators in China passively accept pollution leakage due to EU ETS—if any—or strategically tighten environmental regulations in response, We first examine the impact of stricter carbon policies in the EU on local environmental penalties in China between 2000 and 2020. To explore the mechanisms underlying local regulators' responses, we further investigate how changes in carbon costs in the EU affect sectoral exports, imports, and pollution measures at the city level in China. Additionally, we present results that highlight the varying impacts across different sectors and the intensity of penalties. These findings indicate that regulatory changes in China are more reflective of increasing regulation stringency rather than simply a mechanical response to pollution leakage. We also provide suggestive evidence of positive spillovers on carbon efficiency in Chinese production.

5.1 Impacts of EU Carbon Pricing on Local Environmental Regulation in China

We begin by assessing the causal impact of EU carbon prices on environmental regulations across different sectors within Chinese cities. Table 2 presents the regression results based on Equation (5), which utilizes city-sector-level environmental penalty data. Specifically, a 100% increase in exposure to EU carbon prices is associated with a 1.1% rise in the number of environmental penalties within affected sectors that are involved in exporting to EU countries, a 2.1% increase in the total monetary amount of penalties, and a 0.7% increase in average penalty values. It indicates that a higher exposure to EU carbon prices, measured through export ratios, leads to an increase in environmental regulatory actions. These changes in environmental penalties are primarily driven by the extensive margin—an increase in the number of penalties issued—rather than the intensive margin, which refers to the penalty amount per fine.

In contrast, higher import-weighted exposure to carbon costs in the EU leads to significantly fewer environmental penalties for Chinese firms, evidenced by fewer penalty amounts, lower penalty values, and lower average fine values. Specifically, a 100% increase in exposure to EU carbon prices, measured by import ratios, is associated with a 0.7% decrease in the number of environmental penalties, a 1.1% decrease in the total monetary value of penalties, and a 0.4% decrease in the average penalty amount. Similar to export-weighted exposure, these changes in environmental penalties are primarily driven by the extensive margin—an increase in the number of penalties issued—rather than the intensive margin, which refers to the penalty amount per fine.

We also consider alternative measures of the exposure to European carbon costs, the weighted average of EU carbon cost rates, measured by the cost of carbon emissions per million Euros of output rather than the total costs of carbon emissions. The regression results using this measure, shown in columns (4) to (6) of Table 2, are consistent with our main findings with larger magnitudes.

Overall, our findings in Table 2 indicate that the carbon policy in Europe has spillover effects on local environmental regulation stringency in China. Moreover, these policy spillovers have different directions on environmental enforcement in China. We show stricter regulation against sectors with higher export ratios to the EU or sectors with similar export ratios but larger carbon cost burden in the EU and looser regulation on sectors that were more reliant on imports from Europe. These findings represent causal evidence of inadvertent environmental policy coordination in some sectors and unintentional negative coordinated actions in others. We then provide further evidence on sectoral trade outcomes and city-level environmental outcomes to show that carbon leakage and the induced targeted policy response are the main mechanisms behind the coordinated environmental actions.

5.2 Impacts of EU Carbon Pricing on Trade in China

To explain the mechanism behind these environmental enforcement responses among local Chinese regulators, we examine how carbon price exposure impacts sectoral exports and imports. The regression results presented in Table 3 indicate that higher export-weighted exposure to EU carbon prices increases total export values. Notably, this increase is achieved mainly through a rise in export volumes with a slight increase in exporting product value-weighted average unit price. Specifically, a 100% increase in carbon price exposure leads to a 4.2% rise in total sectoral exports and a 2.4% increase in sectoral export volumes without notable changes in unit prices. The regression results utilizing export-weighted exposure to embodied carbon cost rates in Europe yield results that are similar but twice as large as previous estimates.

On the other hand, greater exposure to EU carbon costs leads to an increase in import values, while import volumes remain unchanged. The notable rise in average unit prices suggests that the growth in import values is primarily driven by higher prices. Specifically, a 100% increase in import-weighted carbon price exposure corresponds to an insignificant 1.3% rise in total sectoral imports and a 1.2% increase in import unit prices. There are larger and more significant increases in total import values if using import-weighted exposure to the carbon cost rates, which are also only from increases in average unit prices.

These findings suggest that as carbon costs and production costs in the EU rise, Chinese competitors in the same sectors with greater exposure to these increasing costs, particularly those that exported more to the EU in 2004, gain a competitive advantage. They are able to expand exports while maintaining stable unit prices. Conversely, sectors more reliant on imports from the EU, which face higher import-weighted exposure to EU carbon costs, experience an increase in total import values driven primarily by higher unit prices rather than larger import volumes. This pattern aligns with the expectation that higher carbon costs in the EU lead to rising production costs.

This evidence can be rationalized by the hypothesis that stricter EU carbon policies have reshaped production and export patterns. As carbon prices rise in the EU, regulated firms either lose market share to Chinese competitors, both domestically and internationally or decide to relocate their production to countries like China. This has contributed to an increase in China's total exports. Thus, we provide direct evidence of the existence of carbon leakage due to rising carbon costs in the EU, particularly from the EU to China, at the sector level. Additionally, Chinese sectors that rely more on imports from the EU, particularly those in carbon-intensive sectors in the EU, experience higher average import unit prices due to increased production costs in the EU. This suggests that these sectors are absorbing negative cost shocks stemming from EU carbon policies.

To provide a more comprehensive illustration of production shifts resulting from changes in EU carbon costs, we separate trade outcomes by trade with the EU and with the rest of the world (ROW). The regression results shown in Table C.1 indicate that the increases in total export values and volumes from Chinese sectors to the EU with higher export-weighted exposure to EU carbon pricing are greater than the relative increases in total export values and volumes. In contrast, Table C.2 presents the regression results regarding trade outcomes with the rest of the world in relation to changes in carbon prices within the EU. There is some indicative evidence suggesting that total exports to the rest of the world, in addition to those to the EU, may increase.

To further illustrate that international trade is the primary channel for these environmental policy responses, we analyze the varying impacts of exposure to carbon costs within the EU, distinguishing between tradable and non-tradable sectors. In Table 4, we present the regression results for tradable sectors, which include agriculture, manufacturing, and mining. Our findings indicate that tradable sectors with higher export-weighted exposure experience significantly larger increases in environmental penalty amounts and values. Conversely, tradable sectors with higher import-weighted exposure tend to face lower penalties, although this effect is less pronounced. Similarly, we obtain comparable estimates using exposure to carbon cost rates in the EU as explanatory variables, although with a larger magnitude.

In contrast, Table 5 reveals that there is little evidence of enforcement response in non-tradable sectors. If anything, we find some suggestive evidence that there are some spillovers to non-tradable sectors in cities with higher import-weighted exposure to carbon costs in the EU by imposing slightly more penalties against non-tradable sectors. We consider this as evidence of the strategic response of local officials to negative trade shocks. When sectors were negatively affected by the cost shock from the EU, they received fewer penalties and lower fine values. To balance the total emission and pollution accounts and to control the overall pollution at the city level, local officials impose more penalties against non-tradable sectors. This finding of strategic environmental enforcement response echoes other empirical studies, including Xie and Yuan (2023); Du and Li (2024).

5.3 Impacts of EU Carbon Pricing on Environmental Outcomes in China

The trade shocks, either positive or negative, further lead to production change and, eventually, emission and pollution output changes. As described in Section 2, with advanced and high-frequency monitoring technology, the city-local officials could respond promptly due to the accurate and real-time environmental measures and political incentives.

We explore the causal impacts of rising carbon costs in the EU on Chinese local environmental outcomes in Table 6. The results show that higher export-weighted exposure to the EU carbon costs leads to slightly higher city-level carbon emissions, as well as higher industrial wastewater discharge, and higher yearly average city-level PM2.5 levels. It implied that the positive production shocks induced by the external positive shocks lead to increases in carbon emissions, some major pollution discharge, and higher average PM2.5 levels, at cities that benefit more from higher carbon costs faced by European firms.

The positive impacts on pollution align with the standard narrative of carbon leakage: higher carbon prices in the EU increase production costs for EU firms, prompting them to move operations or productions to countries with lower carbon prices. This shift results in increased environmental pressure and emissions in those foreign countries. The rise in wastewater levels highlights the mechanisms behind the policy changes of local officials in China when compared to major air pollutants and PM2.5 levels. Wastewater is not concentrated in sectors that have higher carbon emissions and is less detectable and inspected, particularly when city officials focus on carbon-intensive sectors experiencing surges in exports. As we discussed in Section 2, environmental outcomes and pollution are playing an essential role in local officials' performance evaluation and promotion, especially after the CEMS started to operate with public disclosure and records. We claim that the decrease in NO_x and SO_2 is due to rising environmental penalties.

In contrast, results in Table 6 also show evidence of significant negative impacts of higher import-weighted carbon price exposure on total carbon emissions, with some decreases in NO_x and SO_2 discharges. These findings suggest that stricter EU carbon policies lead to negative production shocks in China through import channels in sectors that are more reliant on inputs from the EU, decreasing industrial pollution and carbon emission levels. The first two columns also show that with similar changes in carbon emissions, the regulation responses due to increases in emissions and pollution, are relatively larger than the response to better-off environmental measures. It also suggests the asymmetric responses of local officials' regulation on pollution.

5.4 Further Discussion

In this subsection, we examine the mechanisms behind our key findings regarding the ripple effects of stricter carbon policies in the EU on the stringency of environmental regulations in China. We present additional evidence indicating that the primary channel for this passive coordination of environmental policy is the increased environmental and pollution pressures resulting from trade shocks. Notably, the stringent regulations primarily focus on tradable sectors rather than representing a city-wide policy shift. However, we also observe suggestive evidence that local officials employ strategic responses with non-tradable sectors to balance overall environmental impacts. Furthermore, we provide further evidence demonstrating that the rise in environmental penalties represents stricter regulations rather than a mere mechanical or proportional change due to increased production.

Trade-off Between Economic Performance and Environmental Protection As described in Section 2, local officials in China face trade-offs between economic performance and environmental outcomes, with environmental standards increasingly weighted in promotion evaluations. Regression results in Table 3 indicate that industries with higher export-weighted exposure to the EU carbon price are exporting more quantities, primarily to the EU and also to the rest of the world, due to the rising competitive advantages of corresponding Chinese industries. The surges in exports further lead to higher city-level PM2.5 levels and wastewater discharges, triggering regulation responses by more penalties, as shown in Table 2.

These passive policy responses can be either targeted within cities, meaning only those firms that benefit from higher carbon costs of their EU counterparts are regulated more stringently, or they can be present between cities, where cities benefit more from the increasing carbon prices in the EU increase the enforcement of environmental regulations. These responses could happen because the positive economic changes provide local regulators with more flexibility to implement stricter regulations. This aligns with the Environmental Kuznets Curve (Andreoni and Levinson, 2001; Kijima et al., 2010), which suggests that at a certain income level, societies become more aware of environmental issues and demand cleaner air, water, and stronger regulations, prompting governments to implement environmental policies to address these concerns.

Stricter Regulations vs. Mechanical Changes The rise in environmental penalties may indicate stricter environmental regulations, or it could simply be a mechanical response associated with increased production. We will provide multiple pieces of evidence to demonstrate that the escalating environmental penalties reflect tighter environmental regulations rather than a mechanical increase in penalties due to higher production.

First, we analyze city-level environmental penalty amounts, total fines, and average fines, with city-level controls of all environmental measures. These regression results show the change in city-level responses given that total emission and pollution measures stay the same. Our results, presented in Table 7, confirm that higher carbon costs within the EU lead to a slightly increased intensity of environmental penalties in cities with higher export exposure with the EU and decreased intensity of penalties in cities with higher imported-weighted exposure. Additionally, the city-level Regulation Stringency Index (ESI), measured using Equation (4), increases in cities with higher export-weighted exposure, though the effect is not statistically significant. These findings suggest that sectors experiencing positive trade shocks face greater regulatory stringency on enforcement of environmental regulations, even when their emissions levels remain unchanged compared to before.

In addition, the regression results in Table 6 indicate that cities with greater export-weighted exposure to EU carbon costs experience higher levels of PM2.5 pollution and increased total wastewater output. However, even with this higher production and increased total exports, we observe a reduction in both city-level total carbon emissions and major air pollutants due to passive policy responses. These results imply that in cities exporting more to EU countries, production efficiency is improving, resulting in decreased major pollutants, which suggests the implementation of stricter regulations.

Dynamic Impacts of Carbon Price Exposure We also explore the dynamic impacts of both export and import-weighted exposure to EU carbon costs on environmental regulations, total trade, and environmental outcomes, using the local projection impulse response functions method proposed by Jordà (2005). Specifically, we estimate the following regression models:

$$\ln(Y_{c,t+h}) = \beta \ln(\text{Exposure}_{ct}) + \Gamma X_{c,t+h} + \delta_{t+h} + \sigma_c + \epsilon_{c,t+h}, \tag{6}$$

$$\ln(Y_{ck,t+h}) = \beta \ln(\text{Exposure}_{ckt}) + \Gamma X_{ck,t+h} + \delta_{t+h} + \sigma_c + \epsilon_{ck,t+h}. \tag{7}$$

Figure B.1 shows the dynamic impacts of carbon price exposure on Chinese local environmental penalties. The figures demonstrate that increases in environmental penalty numbers and sums respond quickly to higher export-weighted exposure to EU carbon prices. Meanwhile, there are persistent positive impacts of export-weighted exposure to EU carbon costs and opposite impacts of import-weighted exposure on the Environmental Regulation Stringency Index (ESI).

Similarly, the regression results shown in Figure B.2 indicate that total sectoral exports increase more in response to higher export-weighted exposure in the current year, driven solely by higher export volumes with no change in unit prices. There are also persistent impacts of higher export-weighted EU carbon costs on sectoral export values and volumes, though the magnitudes are smaller. Subfigures (e) and (f) in Figure B.2 show no changes in unit prices even after several years, suggesting limited pass-through to the unit prices of Chinese exports. In contrast, Figure B.3 displays the dynamic regression results on total import values, volumes, and unit prices. There are similarly strong and immediate increases in import total values, volumes, and unit prices, driven by higher import-weighted exposure to EU carbon prices.

Figure B.4 and Figure B.5 illustrate the dynamic regression results using Equation (6) on environmental outcomes. Figure B.4 shows that higher export-weighted carbon price exposure leads to small and non-persistent decreases in total city carbon emissions, but large and persistent increases in total industrial wastewater discharges. There is also evidence of persistent decreases in NOx although statistically insignificant, implying that higher environmental pressure incentivizes rapid policy responses, offsetting increases in pollution. However, subfigures (e) and (f) in Figure B.5 both show evidence of strong and immediate increases in average PM2.5 levels. Conversely, higher import-weighted carbon price exposure causes large, immediate, and persistent decreases in all environmental outcomes, including carbon emissions, major pollutants, and PM2.5 levels.

In summary, the findings using Equation (7) and Equation (6) clearly show that higher export-weighted carbon price exposures lead to quick responses among Chinese local officials through stricter environmental regulations, driven by immediate increases in total exports and heightened environmental pressures. On the other hand, higher import-weighted exposure to EU carbon prices causes a small and insignificant drop in regulation stringency due to quick increases in import unit prices and persistent declines in pollution.

5.5 Robustness Checks

In this subsection, we validate our regression results on the impacts of higher carbon prices in the EU on the stringency of local environmental regulations in China using several robustness checks. We show regression results using different regression model specifications, including the one incorporating different fixed effects, the one using different lagged values of carbon price exposure, and the one using different weights within the shift-share measures. Additionally, we incorporate one alternative novel measure of EU carbon pricing changes proposed by Känzig (2023): the *carbon policy shock*, to validate the robustness of our identification strategy.

Different Fixed Effects We validate our results by incorporating different fixed effects. Table C.3 and Table C.4 contain the regression results of carbon price exposure on sector-specific penalties and trade outcomes using two alternative regression model specifications in Equation (5), one with year fixed effects, city fixed effects, and sector fixed effects, and the other one containing sector fixed effects and city-year fixed effects. The results regarding environmental penalties remain consistent with those obtained from the main regression specifications in both direction and magnitude, although the effects are slightly smaller. Furthermore, the findings on the causal impacts of EU carbon prices on sectoral exports and imports in China show similar trends. There are significant increases in total export values and quantities, while changes in total imports are minimal to nonexistent. However, there are notable increases in import unit prices, along with large decreases in import quantities. These findings strengthen our narrative, as they suggest that with higher carbon and production costs in the EU, Chinese cities' sectoral imports are higher due to higher unit prices, but quantities are less, bringing negative cost shocks.

Using Lagged Carbon Price Exposure To account for price rigidity in international trade and allow for potential adjustments in trade patterns and supply networks, we explore the causal impacts of lagged values of carbon price exposure on environmental penalties, trade outcomes, and pollution outcomes. Table C.5 shows consistent estimation results in signs and magnitudes of the impacts of lagged carbon cost exposure on environmental penalties. Table C.6 also shows consistent results regarding impacts on trade values, volumes, and unit prices, as well as similar estimation results in Table C.7 for pollution outcomes. Moreover, to further account for this concern, we also conduct regressions using the three-year moving averages (averages of the current, the one-year lagged, and the two-year lagged values) of the exposures to carbon prices in the EU as explanatory variables. Table C.8, Table C.9, and Table C.10 show the regression results on environmental penalties, total trade, and environmental outcomes, and all the main coefficients estimates are consistent with the main specification, even though some estimates turn to be less significant.

Using Different Weights in Carbon Price Exposure As discussed in Section 4, to mitigate the concerns that different Chinese cities or different Chinese sectors might respond in advance, foreseeing the upcoming EU ETS, we also conduct our main regression using alternative measures of the fixed sectoral export and import ratios with EU countries before the EU ETS, the average trade ratios between 2002 and 2004. China joined the WTO in December 2001, so 2002 is the earliest reasonable year we can use to calculate the trade ratios.

Table C.11 shows the impacts of changes in EU carbon prices on environmental penalties using the alternative shift-share measures. We still find consistent and significant results on the increases of environmental penalties in amounts and values regarding sectors with higher export-weighted exposure, as well as strong evidence of significant decreases with higher import-weighted exposure to carbon cost rates in the EU. Table C.12 also show similar results on the impacts of carbon costs exposure on sectoral exports and imports, as well as similar findings in Table C.13 of increasing wastewater discharges and higher PM2.5 levels with higher export-weighted exposure and larger, consistent, and significant decreases in emissions and pollutants with higher import-weighted exposure.

Using Different Measures of Carbon Price To further address potential endogeneity bias and concerns that common economic shocks could affect both carbon prices in the EU and trade and environmental outcomes in China or that Chinese-specific economic or policy-related shocks might reversely affect EU climate policies or EU market structures, we also use alternative measures of sectoral carbon costs change in the EU. We replace the yearly average EU ETS market price with the *carbon policy shock* from Känzig (2023), which captures price changes within very short intervals (one day) following major regulatory events, measured as euro change in carbon price, relative to prevailing wholesale electricity price, and then, further identified using the external instruments VAR using the surprise series as an instrument for the energy price residual.

Table C.14 indicates significant increases in environmental penalty values and city-level indicators of environmental regulation stringency with higher export-weighted exposure. There is no significant evidence of decreasing environmental penalties with higher import-weighted exposure. Table C.15 demonstrates consistent and significant impacts on sectoral export values, quantities, and unit prices. There is also evidence of higher import average unit prices with higher import-weighted exposure. Additionally, Table C.16 shows that higher export-weighted exposure corresponds to elevated carbon emissions and PM2.5 levels. In comparison, higher import-weighted exposure is associated with lower particulate pollution.

Alternative Explanations Beyond the mechanism illustrated above, whereby Chinese officials balance economic and environmental outcomes with targeted passive policy responses, other possible explanations exist for why stricter carbon policies in the EU are associated with higher environmental regulation stringency in China. We discuss these possibilities and demonstrate that none of them could convincingly explain our main findings.

One alternative explanation is that the stricter regulation in China results from a nationwide policy shift due to heightened concerns about environmental outcomes or international agreements. However, our identification strategy and the variations in carbon price exposure rule out this possibility. By utilizing variation at the city, sector, and year levels and controlling for both city-year and sector-year fixed effects, we effectively exclude common national policy shocks and time trends at both the sector and city levels.

Another potential explanation is that stricter environmental regulations are due to local industrial policies that increase production and pollution. For this to account for our findings, these local industrial policies would need to correlate with city export ratios to EU countries in 2004. Even if this were the case, it would not rule out the causality between EU carbon prices and environmental regulation in China, as the causality could also come from the orthogonality between sectoral embodied carbon price changes in the EU and outcomes in China.

It is also possible that the observed policy responses are reactions to carbon policy changes in other countries, such as the United States. However, this explanation would require that the export ratios to all EU countries in 2004 proportionally reflect export ratios to the U.S. and that carbon policy changes in the U.S. match those in the EU regarding sectoral embodied carbon price changes. These conditions are unlikely to hold, making this explanation implausible.

6 Conclusion

A major concern with unilateral carbon policies is the risk of carbon leakage. Extensive theoretical discussions and policy practices have emerged to address the effects of production and carbon emission leakage. However, one crucial aspect that has been overlooked in both theoretical and practical debates is the unintended consequences of environmental policy coordination and the spillover effects of carbon policies across countries.

This paper contributes to the ongoing debate by demonstrating that carbon policies implemented in one major economy can result in the transfer of production and carbon emissions to foreign countries. However, these policies may also trigger passive responses in environmental regulations from foreign nations, particularly when the resulting environmental outcomes align with their own policy objectives. Specifically, we analyze the causal effects of increasing carbon prices within the EU ETS regime on environmental regulations in China, utilizing a novel dataset that encompasses all local environmental penalties in China.

To establish a causal relationship, we employ a shift-share measure of exposure to EU carbon prices at the city and sector levels in China. This approach uses fixed pre-EU ETS trade ratios and varying embodied carbon costs within the EU, which includes both direct and indirect carbon costs from supply chains. Our findings suggest that the extent of carbon leakage and welfare loss could be more significant due to the passive policy response in China. Conversely, this indicates that the actual carbon leakage may be smaller than previously estimated if we overlook the unintentional coordination of policies across borders.

Our results indicate that greater exposure to export-weighted EU carbon prices results in higher environmental penalties, both in terms of amount and total value. In contrast, increased exposure to import-weighted carbon prices leads to slightly fewer environmental penalties. Specifically, a one standard deviation increase in exposure to carbon costs in the EU is associated with a 2.299% rise in the amounts of environmental penalties and a 4.389% increase in the values of these penalties. We provide further evidence that the stricter regulations are a result of increasing total exports, total production, and pollution. In contrast, the more lenient regulations come from higher unit prices of EU-imported intermediates and lower environmental content. We also show that the stricter environmental regulations are targeted against tradable sectors and not a city-wide policy change. However, the local officials switched policies strategically by raising penalties against non-tradable sectors while relaxing regulation on reversely affected tradable firms.

This paper is one of the first empirical studies demonstrating how carbon policies in one country can influence the environmental policy decisions by lcoal regulators in another country. Additionally, we contribute to the theoretical literature by exploring the potential for dynamic global interactions in carbon policy. The Carbon Border Adjustment Mechanism (CBAM) in the EU will soon become binding for European importers from 2026. The goal of the CBAM is to prevent carbon leakage and address disparities in carbon pricing between the EU and other countries, including China. Using China as a case study, our findings suggest that the differences in carbon costs may be smaller than we previously thought.

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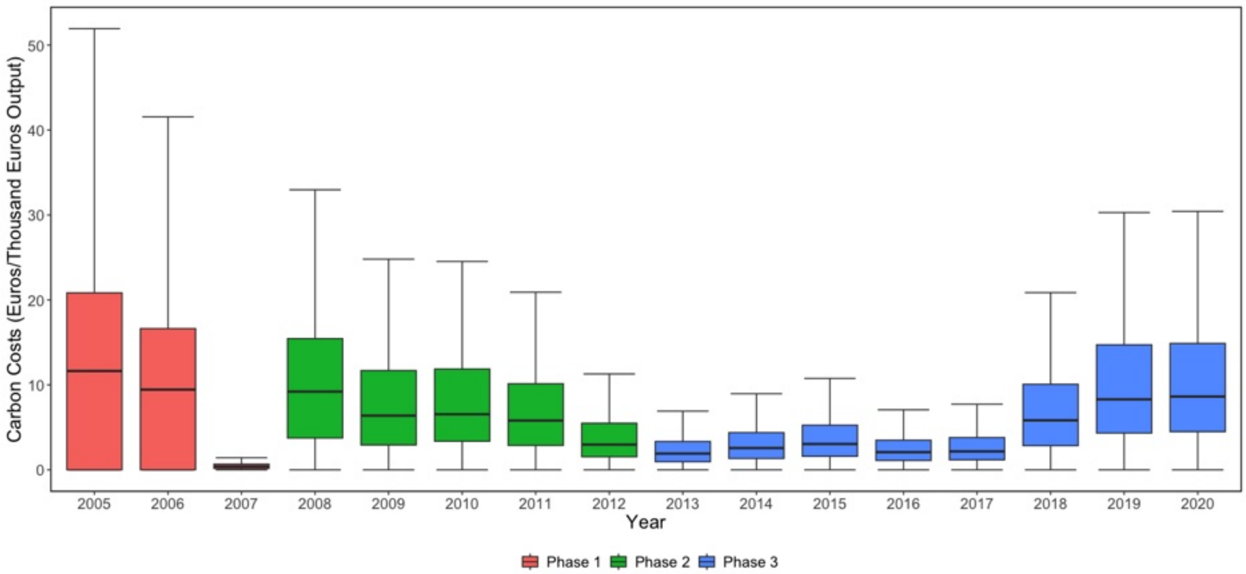
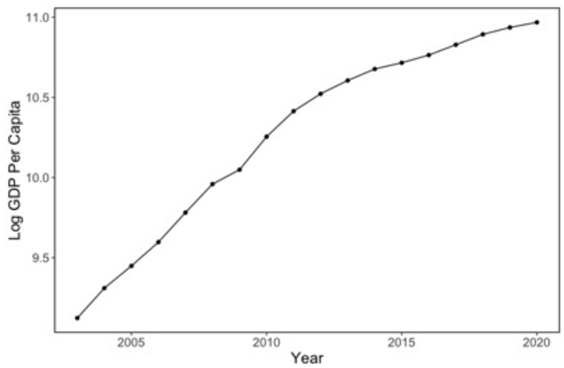
Figures

Figure 1: Carbon Costs in Europe

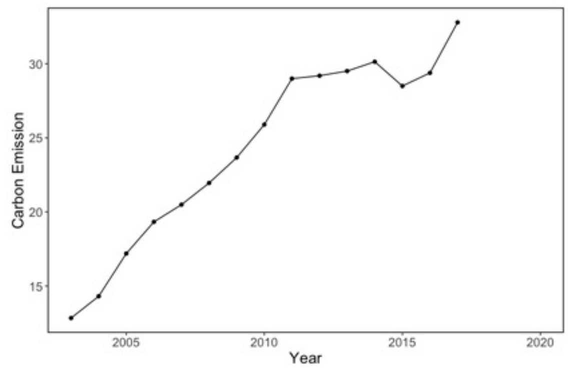


Note: This figure illustrates the distribution of embodied direct and indirect carbon costs across all sectors and EU countries by year. The time trend of the carbon permit prices in the EU shows significant timing variation as a result of both stricter carbon policies and changing supply and demand. The source of the carbon price is the World Carbon Pricing Database managed by RFF.

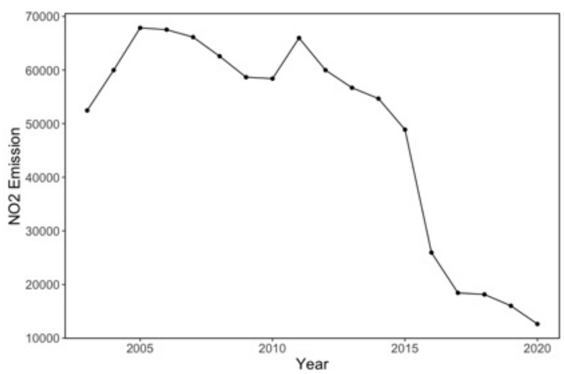
Figure 2: Economic and Pollution Trends in Chinese Cities



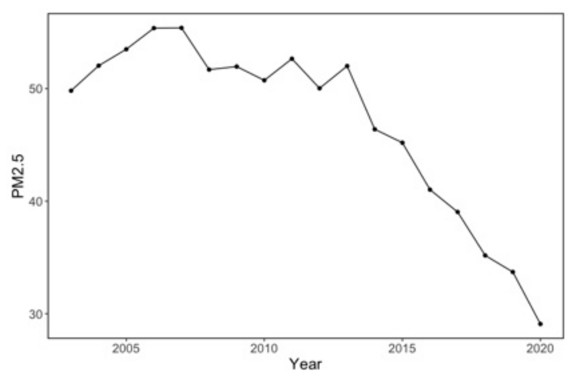
(a) Log GDP Per Capita



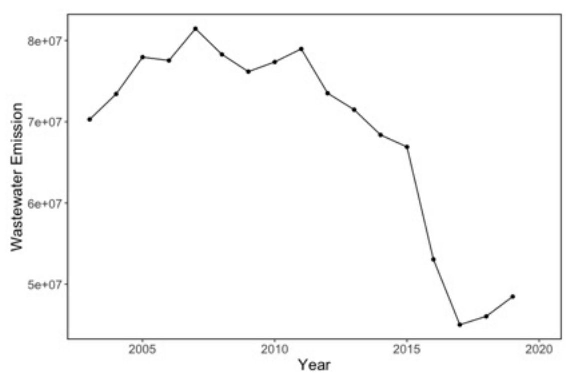
(b) Carbon Emission



(c) NO_x Emission



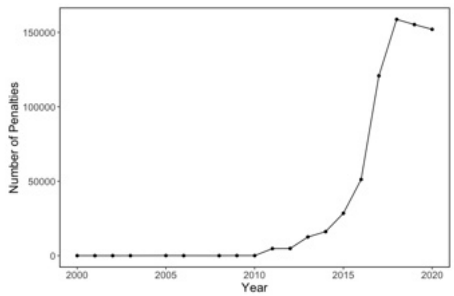
(d) $PM_{2.5}$



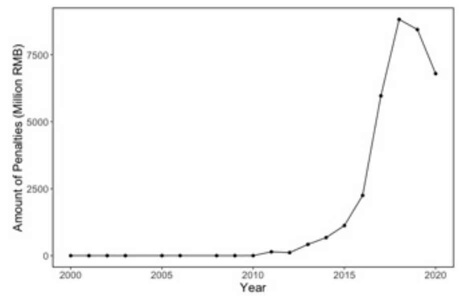
(e) Waste Water Emission

Note: This figure shows logged values of GDP per capita, carbon emissions, NO_x and wastewater discharges, and yearly average PM2.5 levels averaged by prefectures in China from 2000 to 2020. Sources of each outcome can be found in Section 3.

Figure 3: Environmental Penalties in Chinese Cities



(a) Number of Penalties



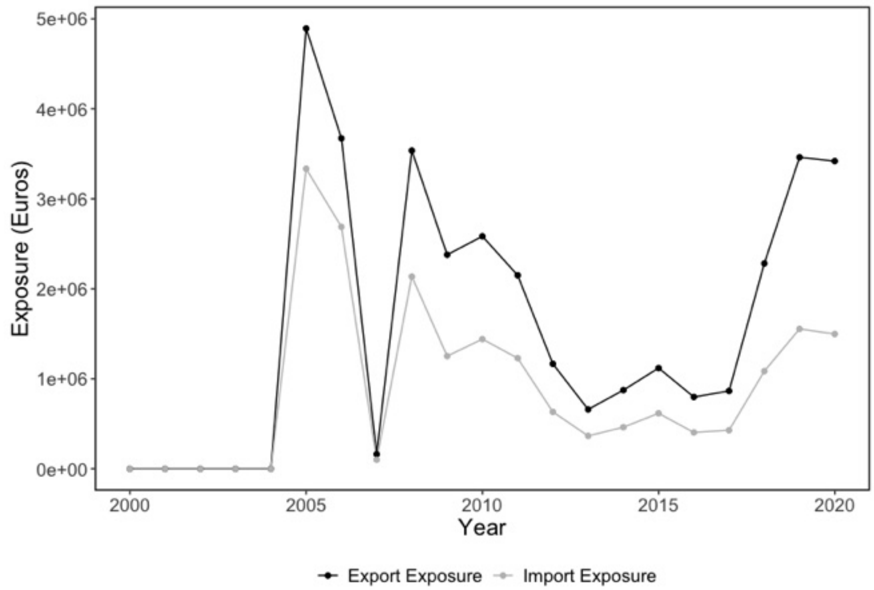
(b) Amount of Penalties (Million RMB)

(c) Number of Penalties

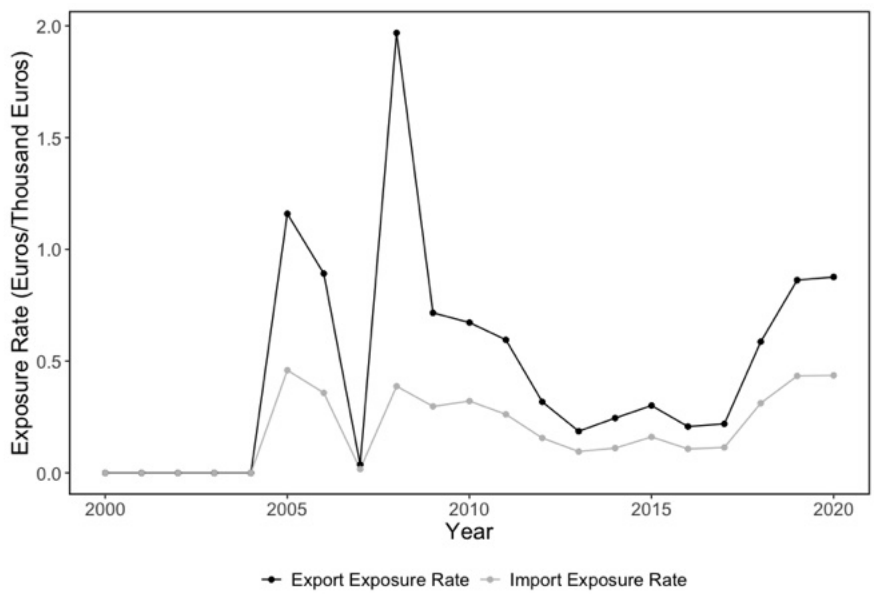
(d) Amount of Penalties (Million RMB)

Note: This figure shows the total number and sum of values of environmental penalties in China from 2000 to 2020, as well as the distribution of the total number and total values of penalties from 2000 to 2020. The time trends of environmental penalties show dramatic increases over time, especially after 2013. The geographic distributions of the total penalties show the dispersion of the penalties and show that most penalties were concentrated in east coastal regions. Sources of each outcome can be found in Section 3.

Figure 4: Carbon Exposure Trends in Chinese Cities



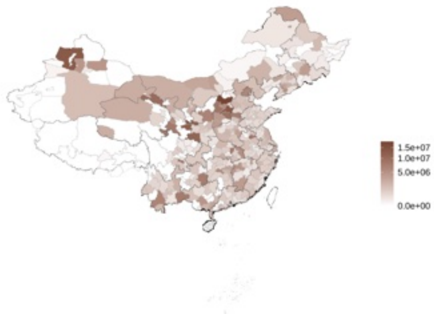
(a) Exposure (Euros)



(b) Exposure Rate (Euros/Thousand Euros)

Note: These figures show the time trends of the shift-share measures of export and import-weighted exposures to carbon total cost and carbon cost rates at the city level in China from 2000 to 2020, calculating using Equation (3). They show a consistent trajectory with the change of the EU carbon price.

Figure 5: Maps of Carbon Exposure in Chinese Cities



(a) Export Exposure (Euros)

(b) Import Exposure (Euros)

(c) Export Exposure Rate (Euros/Thousand Euros)

(d) Import Exposure Rate (Euros/Thousand Euros)

Note: These figures show the geographic distribution of the average measures of the shift-share measures of export and import-weighted exposures to carbon total cost and carbon cost rates at the city level in China from 2000 to 2020, calculating using Equation (3). It shows that the regional distributions of exposures to total carbon costs and carbon cost rates are similar, but the export and import-weighted carbon price exposure show very different geographic distribution patterns. Moreover, none of them coincide with the geographic distribution of total environmental penalties and the sum of environmental penalties, validating our identification strategy.

Tables

Table 1: Summary Statistics

	Summary Statistics		
Variable	**N**	**Mean**	**SD**
Panel A: Sector-Level Variables			
Number of Penalties	27,053	16.51	62.69
Total Penalties (in 10 Thousand CNY)	27,053	68.65	245.04
Tradable Sector	27,053	0.58	0.49
Sector Export Exposure (in 2015 Euro)	27,053	918,265.86	5,349,537.93
Sector Import Exposure (in 2015 Euro)	27,053	1,472,079.99	9,174,399.11
Sector Export Exposure Rate (Euro/million 2015 Euro)	27,053	285.32	1,006.75
Sector Import Exposure Rate (Euro/million 2015 Euro)	27,053	359.60	1,406.64
Total Sector Exports (in million USD)	68,770	245.33	2,303.04
Total Sector Export Amount (in million units)	68,770	255.32	2,563.78
Sector Export Price (USD per unit)	62,019	139,716.48	2,385,797.12
Total Sector Imports (in million USD)	68,770	218.90	2,267.65
Total Sector Import Amount (in million units)	68,770	392.04	3,695.98
Sector Import Price (USD per unit)	60,307	194,061.01	3,852,311.47
Panel B: City-Level Variables			
ESI	4,948	0.06	0.04
City Export Exposure (in 2015 Euro)	6,562	1,620,413.52	3,977,758.57
City Import Exposure (in 2015 Euro)	6,562	915,952.76	4,390,984.81
City Import Exposure Rate (Euro/million 2015 Euro)	6,562	191.95	908.36
City Export Exposure Rate (Euro/million 2015 Euro)	6,562	468.75	4,248.17
Carbon Emissions (in million tons)	5,499	21.87	21.77
Wastewater Emissions (in million tons)	4,496	68.99	88.35
SO_2 Emissions (in tons)	2,319	136,160.57	216,019.40
NO_x Emissions (in tons)	4,743	29,434.50	110,840.80
Particulate Emissions (in tons)	4,750	49,351.37	49,005.09
PM2.5 Concentration (μg/m^3)	6,499	46.52	22.23
Registered Population	4,964	428.68	269.08
GDP (current billion RMB)	3,855	150.17	227.96
GDP per capita (Current RMB)	4,670	38,646.12	32,311.67
City Total Number of Penalties	6,562	78.91	397.56
City Total Penalties (in 10 Thousand CNY)	6,562	336.04	1,636.40
City Total Exports (in million USD)	5,456	4,917.47	20,389.48
City Total Export Amount (in million units)	4,347	4,045.52	16,816.42
City Total Imports (in million USD)	5,409	4,437.06	22,921.81
City Total Import Amount (in million units)	4,305	6,270.21	28,978.83

Note: This table shows the summary statistics for the city-sectoral level and the city-level datasets. The city-sectoral level dataset contains sector information of 37 unique sectors from 338 prefectures from 2000 to 2020. The city-level dataset contains city information on 338 prefectures from 2000 to 2020.

Table 2: Carbon Price Exposure and Environmental Regulation in China

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.011*	0.021**	0.007			
	(0.006)	(0.009)	(0.005)			
Log(Exposure-Import)	−0.007**	−0.011*	−0.004			
	(0.003)	(0.006)	(0.003)			
Log(Rate Exposure-Export)				0.019*	0.036**	0.012
				(0.011)	(0.017)	(0.009)
Log(Rate Exposure-Import)				−0.012*	−0.018*	−0.006
				(0.006)	(0.010)	(0.005)
Year-City FE	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y
Observations	27,053	27,053	27,053	27,053	27,053	27,053
R^2	0.599	0.511	0.390	0.599	0.511	0.390

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1, 2, 3, 5, 6, and 7 report the coefficient estimates from the regression Equation (5) for three logged values of the city-sector level environmental regulation outcomes: the total number of penalties, sum of fines, and average fine for each penalty. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. Columns 4 and 7 report the estimates from regression Equation (4) for the logged values of the city-level environmental regulation stringency index (ESI). The independent variable is the city-level weighted sums of four exposures to the EU carbon prices. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions on city-level outcomes. Standard errors in parentheses are clustered at the city level.

Table 3: Carbon Price Exposure and Exports/Imports in China

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.042***		0.024**		0.009							
	(0.012)		(0.012)		(0.007)							
Log(Rate Exposure-Export)		0.081***		0.047**		0.016						
		(0.021)		(0.022)		(0.013)						
Log(Exposure-Import)							0.013		0.004		0.012**	
							(0.009)		(0.010)		(0.005)	
Log(Rate Exposure-Import)								0.027*		0.010		0.022**
								(0.016)		(0.018)		(0.009)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	68,770	68,770	68,770	68,770	53,589	53,589	68,770	68,770	68,770	68,770	53,589	53,589
R^2	0.648	0.648	0.608	0.608	0.714	0.714	0.624	0.624	0.649	0.649	0.783	0.783

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table 4: Mechanism Analysis: Tradable Sectors

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.016**	0.022**	0.005			
	(0.006)	(0.009)	(0.005)			
Log(Exposure-Import)	−0.003	−0.004	−0.001			
	(0.004)	(0.005)	(0.003)			
Log(Rate Exposure-Export)				0.028**	0.040**	0.009
				(0.011)	(0.017)	(0.008)
Log(Rate Exposure-Import)				−0.005	−0.007	−0.002
				(0.006)	(0.010)	(0.005)
Year-City FE	Y	Y	Y		Y	Y
Year-Sector FE	Y	Y	Y		Y	Y
Observations	15,741	15,741	15,741	15,741	15,741	15,741
R^2	0.626	0.555	0.449	0.626	0.555	0.449

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–6 report the coefficient estimates from the regression Equation (5) for three logged values of the city-sector level environmental regulation outcomes: the total number of penalties, sum of fines, and average fine for each penalty. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 23 unique tradable sectors, mainly based on Chinese sector categorization, and 337 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table 5: Mechanism Analysis: Non-tradable Sectors

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	−0.026	0.576	0.472			
	(0.375)	(0.538)	(0.344)			
Log(Exposure-Import)	0.573	0.962	0.427			
	(0.415)	(0.660)	(0.303)			
Log(Rate Exposure-Export)				0.015	0.564	0.403
				(0.386)	(0.543)	(0.350)
Log(Rate Exposure-Import)				0.539	0.940	0.453
				(0.401)	(0.703)	(0.338)
City FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y
Observations	8,768	8,768	8,768	8,768	8,768	8,768
R^2	0.256	0.204	0.116	0.256	0.204	0.116
Note:						$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Columns 1–6 report the coefficient estimates from the regression Equation (5) for three logged values of the city-sector level environmental regulation outcomes: the total number of penalties, the sum of fines, and the average fine for each penalty. The independent variables are Chinese city-level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 14 unique non-tradable sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions, as well as city controls, including the logged value of GDP per capita and logged values of the total population. Standard errors in parentheses are clustered at the city level.

Table 6: Carbon Price Exposure and Pollution in China

	Pollution Outcomes											
	Carbon		Wastewater		NO_x		SO_2		Particulate		PM2.5	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.011		0.036*		−0.028		−0.193		−0.025		0.008***	
	(0.007)		(0.020)		(0.026)		(0.335)		(0.030)		(0.003)	
Log(Exposure-Import)	−0.010***		0.002		−0.014		−0.401		0.004		0.001	
	(0.004)		(0.016)		(0.040)		(0.376)		(0.027)		(0.003)	
Log(Rate Exposure-Export)		0.019		0.054		−0.053		−0.223		−0.060		0.016***
		(0.012)		(0.035)		(0.047)		(0.426)		(0.053)		(0.005)
Log(Rate Exposure-Import)		−0.018***		0.004		−0.020		−0.262		0.003		0.001
		(0.006)		(0.030)		(0.067)		(0.394)		(0.048)		(0.007)
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,809	3,809	4,239	4,239	4,478	4,478	2,310	2,310	4,484	4,484	4,631	4,631
R^2	0.989	0.989	0.871	0.871	0.730	0.730	0.901	0.901	0.823	0.823	0.961	0.961

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report coefficient estimates from the regression specified in Equation (4), where the dependent variables are the logarithms of various city-level environmental outcomes: total carbon emissions, annual wastewater discharge, NO_x, SO_2, particulate emissions, and average annual PM2.5 levels. The key independent variables measure Chinese city-sector level exposure to EU carbon pricing, constructed as export-weighted and import-weighted logged values of total cost or cost rates. The sample covers 338 prefectures in China over the period 2000–2020. All regressions control for year fixed effects, city fixed effects, and city-level covariates—including the logarithms of GDP per capita and registered population. Standard errors, reported in parentheses, are clustered at the city level.

Table 7: Carbon Price Exposure and Environmental Regulation Intensity in China

	Enforcement of Environmental Regulations: Penalties Intensity							
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	ESI	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	ESI
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(Exposure-Export)	0.005	0.011	0.009	0.001				
	(0.026)	(0.034)	(0.012)	(0.001)				
Log(Exposure-Import)	-0.046^{***}	-0.060^{***}	-0.024^{**}	-0.002				
	(0.017)	(0.023)	(0.009)	(0.001)				
Log(Rate Exposure-Export)					0.009	0.018	0.014	0.001
					(0.042)	(0.054)	(0.019)	(0.002)
Log(Rate Exposure-Import)					-0.088^{***}	-0.110^{***}	-0.040^{**}	-0.002
					(0.031)	(0.040)	(0.017)	(0.002)
City FE	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y
Emissions and Pollution Controls	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,731	3,731	3,731	3,717	3,731	3,731	3,731	3,717
R^2	0.712	0.686	0.564	0.529	0.712	0.686	0.564	0.529

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Columns 1–6 report coefficient estimates from the regression specified in Equation (4), where the dependent variables are the logarithms of various city-level environmental outcomes: the total number of penalties, the sum of fines, and the average fine for each penalty. The key independent variables measure Chinese city-sector level weighted average exposure to EU carbon pricing, constructed as export-weighted and import-weighted logged values of total cost or cost rates. The samples include 338 unique prefectures in China from 2000 to 2020. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita, $PM_{2.5}$ levels, and all city-level environmental outcomes, are included in the regressions. Standard errors in parentheses are clustered at the city level.

Appendices

A Data Details

A.1 European Carbon Prices

We obtain European carbon price data from the World Carbon Pricing Database hosted by Resources for the Future (RFF)[19] (Dolphin and Xiahou, 2022). Specifically, we use carbon price data from 2000 to 2020 for 32 countries, including all 27 current EU member states, the UK, Switzerland, Iceland, Liechtenstein, and Norway—covering all countries participating in the EU ETS during this period and Switzerland. The carbon prices are provided at the jurisdiction-sector level, with yearly averages of daily prices in local currency units. We also unify all carbon prices at the EU ETS and the Swiss ETS as 2015 Euros, using the GDP deflator index and currency exchange rates data from the World Bank database[20].

It is noticeable that the EU ETS and the Swiss ETS are not the only operating cap-and-trade system in the world during this period. According to the State and Trends of Carbon Pricing Dashboard updated by the World Bank [21] as well as the carbon price data source we use, there are New Zealand ETS, Kazakhstan ETS, (South) Korea ETS, Canada federal OBPS, Mexico pilot ETS already implemented before 2020 at the national level, and much more at the subnational levels in the US, Canada, and in China. To simplify our analysis and to focus on EU ETS, the earliest, one of the largest, and arguably the most successful cap-and-trade systems, we ignore all other regimes and consider the carbon prices all as zero during the whole period.

The EU ETS carbon price data in the World Carbon Pricing Database originates from the Allowance Price Explorer of the International Carbon Action Partnership (ICAP), which provides European Union Allowance (EUA) spot price data from the European Energy Exchange (EEX) Group. Swiss ETS prices are calculated based on auction clearing prices and allowances sold by the Swiss Emissions Trading Registry.

The carbon prices by country and sector in the World Carbon Pricing Database are disaggregated using the Intergovernmental Panel on Climate Change (IPCC) source and

[19] https://www.rff.org/publications/data-tools/world-carbon-pricing-database/; database available at https://github.com/g-dolphin/WorldCarbonPricingDatabase

[20] See the website https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?skipRedirection=true&view=map for more details

[21] See the website https://carbonpricingdashboard.worldbank.org/ for more detials

sector categories.[22]

A.2 Input-Output Tables

To calculate the embodied carbon price burden within the EU—including both direct carbon costs and indirect costs through industrial processes—we use the multi-regional input-output (MRIO) tables from EXIOBASE, specifically EXIOBASE version 3.8.2, updated on October 21, 2021.[23] EXIOBASE 3 provides a time series of environmentally extended MRIO (EE MRIO) tables for 44 countries and five rest-of-the-world regions from 1995 onward, with data presented in millions of current euros. We utilize annual tables to capture key sectors, obtaining the input-output matrix A, the final demand matrix C, the total output vector Y, and the emission intensity vector E from tables A, Y, x, and D_{pda}, respectively. The embodied emission rates are calculated as $E(I - A)^{-1}$, and the total embodied emissions are given by $E(I - A)^{-1}C$.

EXIOBASE employs its own industry and product classification system, encompassing 163 industries and 200 products.

A.3 Sector Concordance

We employ several concordance tables to harmonize sector categories across different classification systems, using the EXIOBASE sector classification as our baseline. First, we align the IPCC sectors from the carbon price data with the EXIOBASE sectors, which requires two concordance tables[24]. One converts EXIOBASE codes to ISIC Rev.3 codes, provided by the EXIOBASE research team,[25] and the other converts ISIC Rev.4 codes to IPCC codes, included in the World Carbon Pricing Database.[26] To complete the concordance, we also use tables converting ISIC Rev.3 to ISIC Rev.4 codes from the United Nations Statistics Division (UNSD) Classifications on Economic Statistics.[27]

Due to many-to-many relationships between IPCC codes and EXIOBASE sector codes,

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

[23] https://zenodo.org/record/5589597

[24] We thank Hanyi Wang for generous support on sector concordance.

[25] All concordance tables mentioned are available at https://ntnu.app.box.com/v/EXIOBASEconcordances/file/282981251742.

[26] https://github.com/g-dolphin/WorldCarbonPricingDatabase/tree/main/_aux_files/classifications_concordances

[27] https://unstats.un.org/unsd/classifications/Econ

some EXIOBASE sectors correspond to multiple IPCC codes with different carbon prices. We manually matched and verified all concordances to generate country-year-sector-specific carbon prices using the EXIOBASE sector classification.

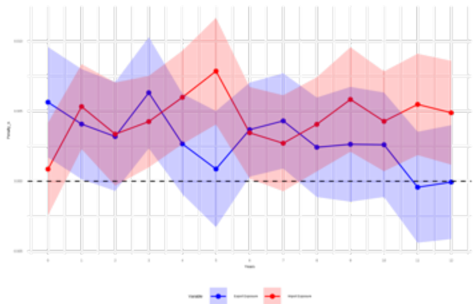
Second, we align the EXIOBASE sector codes with the Harmonized System (HS) codes in China's customs data. We use a bridge file between HS codes (version 1996) and EXIOBASE 2 codes provided by the EXIOBASE project team. We also convert HS codes from each year to HS 1996 using concordance tables provided by the UNSD. We manually check and amend the concordance between HS 1996 codes and EXIOBASE 2.0 codes when necessary.

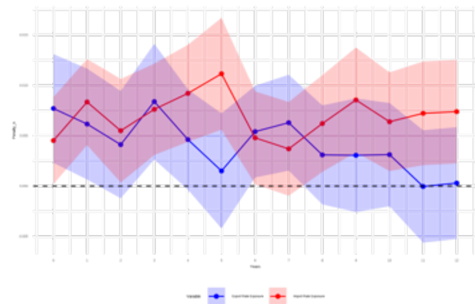
Finally, we process penalty data that includes sector information for 42 sectors, categorized according to China's industrial classification system. We concord the EXIOBASE sectors with Chinese sectors using a concordance table between Chinese industrial classification system and EXIOBASE codes, also provided by the EXIOBASE team. Given that the primary focus of the paper is to evaluate how carbon exposure in Europe influences environmental penalties in China, and since China's industrial classification system is more aggregated, we adopt China's industrial classification categories as the main sectoral classification for our analysis.

As a result, sector-specific carbon exposure measures constructed in Section 4.2 are based on China's industrial classification system. Specifically, the city-sector-specific carbon exposure in equation (2), Exposure_{ckt}, and the city-specific carbon exposure in equation (3), Exposure_{ct}, are first calculated based on EXIOBASE codes and subsequently aggregated to the sector level according to China's industrial classification system.

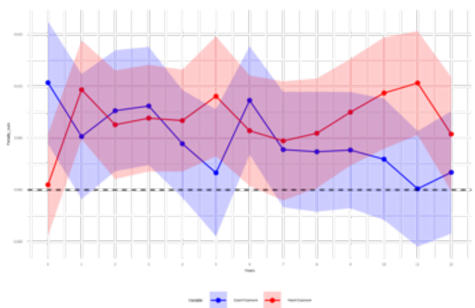
B Figures

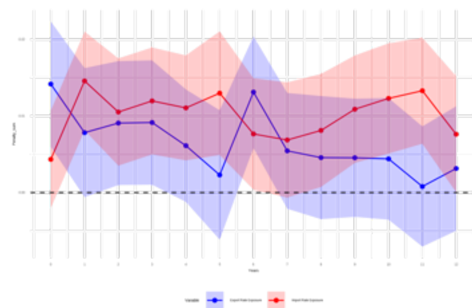
Figure B.1: Dynamic Impacts on Environmental Regulations



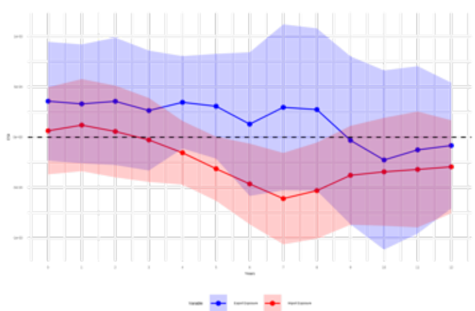


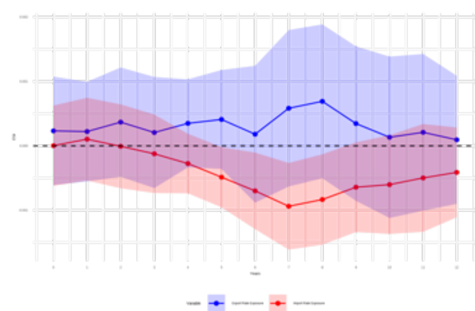
(a) Number of Penalties **(b) Number of Penalties**





(c) Sum of Penalties **(d) Sum of Penalties**

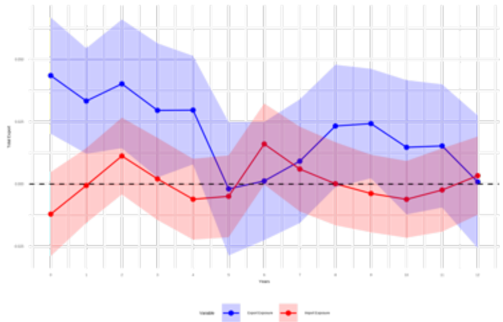




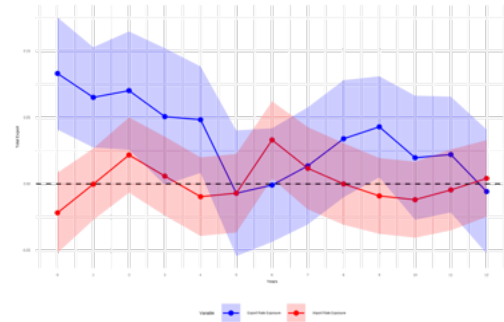
(e) ESI **(f) ESI**

Note: Figures report the coefficient estimates from the regression Equation (7) for logged values of the environmental regulation outcomes: number of penalties, sum of penalties, and city-level environmental regulation stringency index (ESI). The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. City-year and sector-year fixed effects are included, and standard errors are clustered at the city level. The solid line is the point estimate, and the blue and red shaded areas are 90 percent confidence bands of export-weighted and import-weighted exposures dynamic coefficients estimates, respectively.

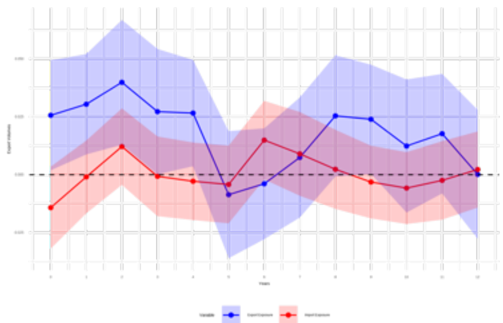
Figure B.2: Dynamic Impacts on Export



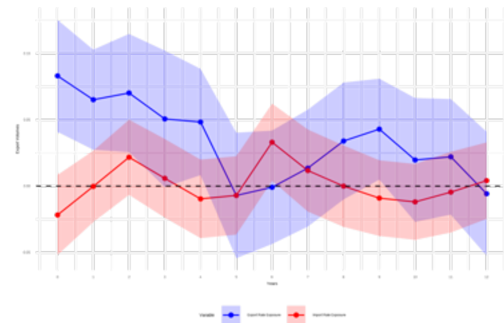
(a) Export Values



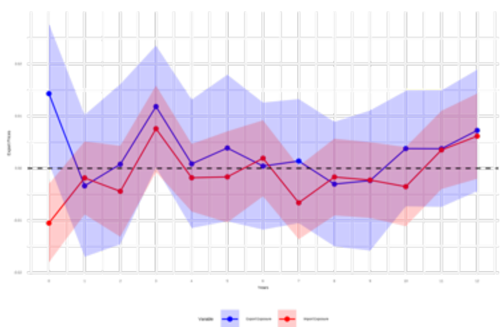
(b) Export Values



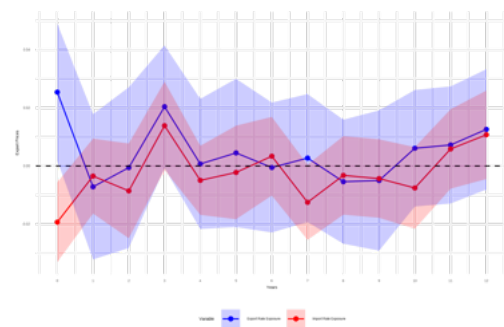
(c) Export Volumes



(d) Export Volumes



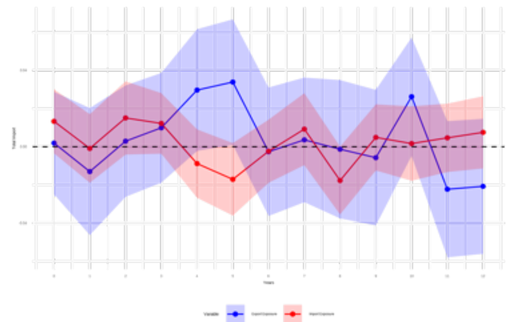
(e) Export Unit Prices



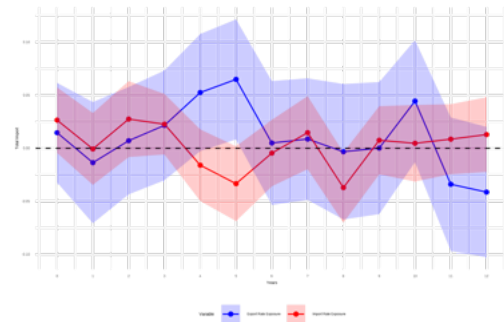
(f) Export Unit Price

Note: Figures report the coefficient estimates from the regression Equation (7) for logged values of the total export values, total export volumes, and export unit prices. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. City-year and sector-year fixed effects are included, and standard errors are clustered at the city level. The solid line is the point estimate, and the blue and red shaded areas are 90 percent confidence bands of export-weighted and import-weighted exposures dynamic coefficients estimates, respectively.

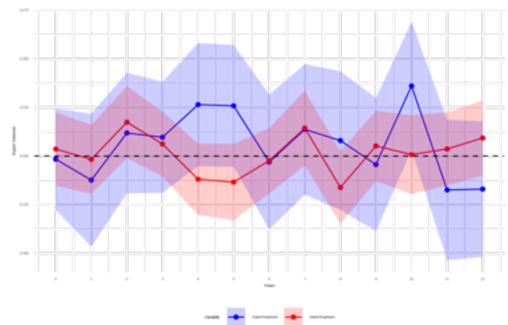
Figure B.3: Dynamic Impacts on Import



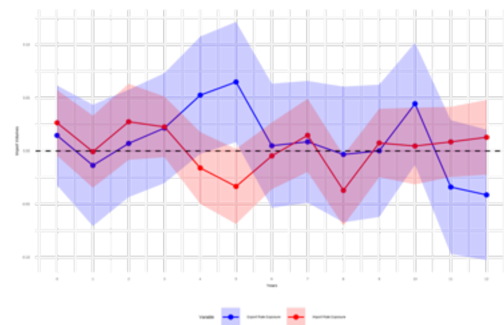
(a) Import Values



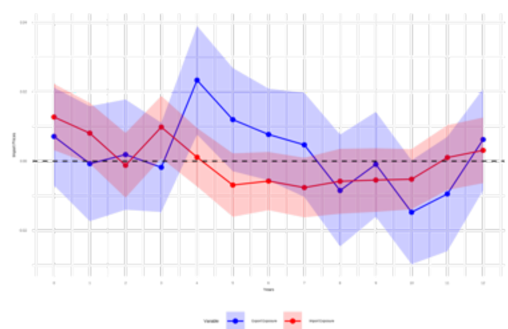
(b) Import Values



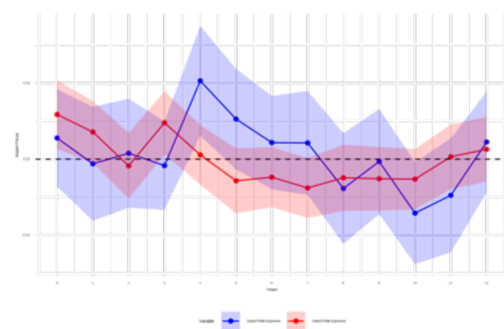
(c) Import Volumes



(d) Import Volumes



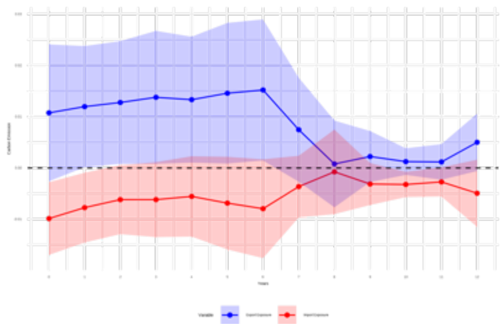
(e) Import Unit Prices



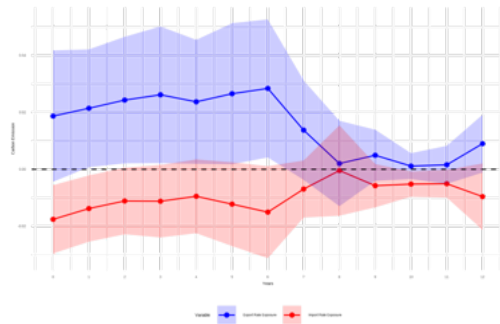
(f) Import Unit Price

Note: Figures report the coefficient estimates from the regression Equation (7) for logged values of the total export values, total export volumes, and export unit prices. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. City-year and sector-year fixed effects are included, and standard errors are clustered at the city level. The solid line is the point estimate, and the blue and red shaded areas are 90 percent confidence bands of export-weighted and import-weighted exposures dynamic coefficients estimates, respectively.

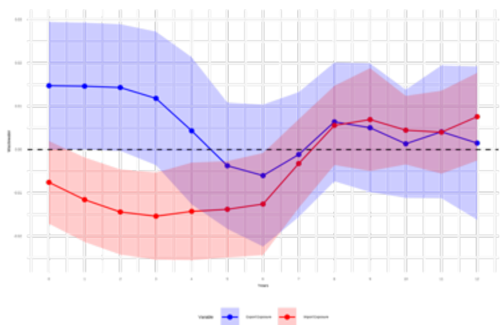
Figure B.4: Dynamic Impacts on Environmental Outcomes



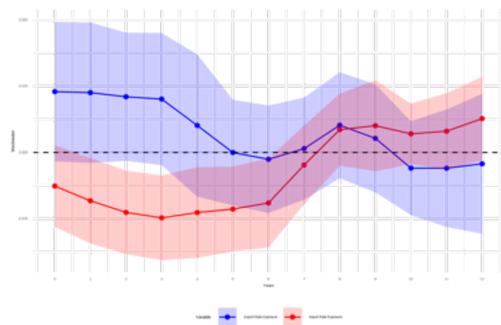
(a) **Carbon Emissions**



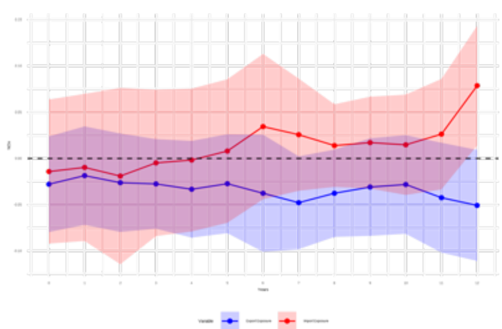
(b) **Carbon Emissions**



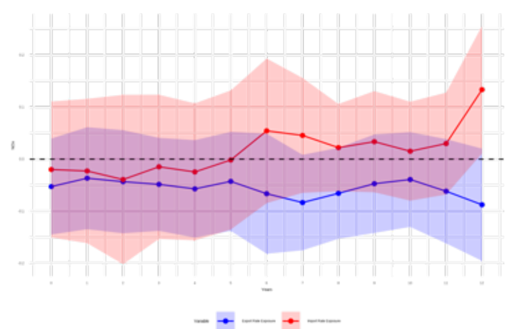
(c) **Wastewater**



(d) **Wastewater**



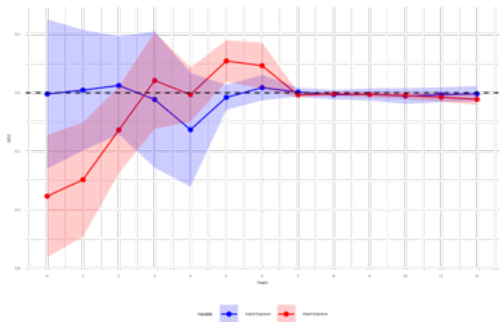
(e) NO_x



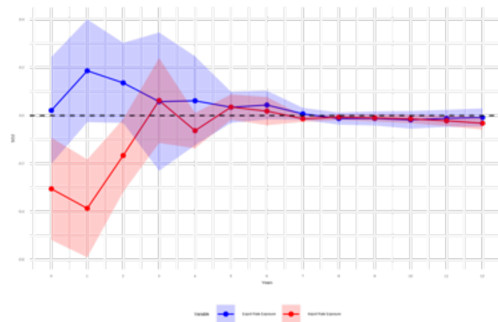
(f) NO_x

Note: Figures report the coefficient estimates from the regression Equation (6) for logged values of city-level carbon emissions, wastewater discharges, and NO_x discharges. The independent variables are Chinese city-level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 338 unique prefectures in China from 2000 to 2020. City and sector fixed effects are included, and standard errors are clustered at the city level. The solid line is the point estimate, and the blue and red shaded areas are 90 percent confidence bands of export-weighted and import-weighted exposures dynamic coefficients estimates, respectively.

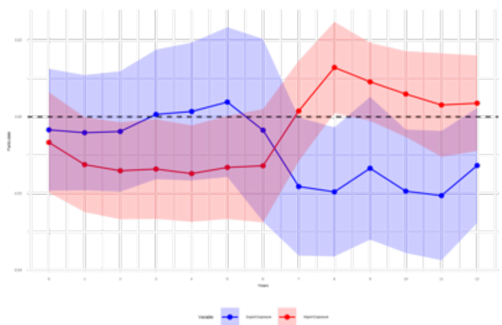
Figure B.5: Dynamic Impacts on Environmental Outcomes (Continued)



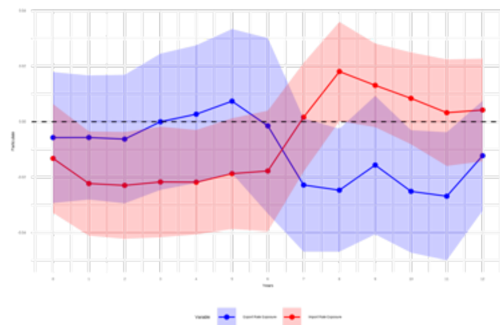
(a) SO_2



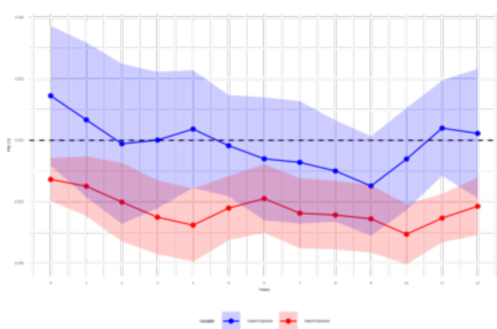
(b) SO_2



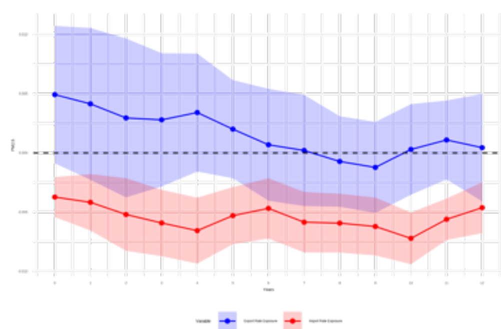
(c) Particulate



(d) Particulate



(e) PM2.5



(f) PM2.5

Note: Figures report the coefficient estimates from the regression Equation (6) for logged values of city-level SO_2 emissions, industrial particulate discharges, and yearly average PM2.5 levels. The independent variables are Chinese city-level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 338 unique prefectures in China from 2000 to 2020. City and sector fixed effects are included, and standard errors are clustered at the city level. The solid line is the point estimate, and the blue and red shaded areas are 90 percent confidence bands of export-weighted and import-weighted exposures dynamic coefficients estimates, respectively.

C Tables

Table C.1: Carbon Price Exposure and Exports/Imports with EU in China

	Sectoral Trade of China with EU											
	Log(Value)		Log(Volume) Export to EU		Log(Prices)		Log(Value)		Log(Volume) Import from EU		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.194***		0.183***		0.004							
	(0.021)		(0.020)		(0.007)							
Log(Rate Exposure-Export)		0.366***		0.344***		0.007						
		(0.037)		(0.036)		(0.013)						
Log(Exposure-Import)							0.087***		0.083***		−0.008	
							(0.010)		(0.010)		(0.006)	
Log(Rate Exposure-Import)								0.166***		0.159***		−0.014
								(0.019)		(0.019)		(0.012)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	68,770	68,770	68,770	68,770	37,780	37,780	68,770	68,770	68,770	68,770	37,780	37,780
R^2	0.669	0.669	0.653	0.653	0.608	0.608	0.686	0.686	0.671	0.671	0.773	0.773

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports, all with the EU. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.2: Carbon Price Exposure and Exports/Imports with ROW in China

	Sectoral Trade of China with ROW											
	Log(Value)		Log(Volume) Export to ROW		Log(Prices)		Log(Value)		Log(Volume) Import from ROW		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.011		−0.001		0.002							
	(0.013)		(0.013)		(0.007)							
Log(Rate Exposure-Export)		0.023		0.001		0.007						
		(0.024)		(0.024)		(0.013)						
Log(Exposure-Import)							-0.032^{***}		-0.041^{***}		0.016^{***}	
							(0.010)		(0.010)		(0.005)	
Log(Rate Exposure-Import)								-0.059^{***}		-0.075^{***}		0.029^{***}
								(0.018)		(0.019)		(0.010)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	68,770	68,770	68,770	68,770	51,484	51,484	68,770	68,770	68,770	68,770	51,484	51,484
R^2	0.641	0.641	0.603	0.603	0.721	0.721	0.623	0.623	0.652	0.652	0.761	0.761

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports, all with the rest of the world except for the EU. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.3: Robustness Checks: Different FE

	Dependent variable:					
	Log(Penalty Number)		Log(Penalty Sum)		Log(Average Penalty)	
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.009	0.009	0.016^{*}	0.018^{*}	0.004	0.007
	(0.006)	(0.006)	(0.009)	(0.009)	(0.005)	(0.005)
Log(Exposure-Import)	-0.007^{**}	-0.008^{**}	-0.011^{**}	-0.011^{*}	-0.004	-0.003
	(0.003)	(0.004)	(0.006)	(0.006)	(0.003)	(0.003)
Year FE	Y		Y		Y	
City FE	Y		Y		Y	
Sector FE	Y	Y	Y	Y	Y	Y
Year-City FE		Y		Y		Y
Observations	27,053	27,053	27,053	27,053	27,053	27,053
R^2	0.489	0.574	0.383	0.493	0.233	0.374
Note:						*p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–6 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique tradable sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. We include two different sets of fixed effects in the regressions: (1) year fixed effects, sector fixed effects, and city fixed effects, and (2) sector fixed effects and city-year fixed effects. Standard errors, reported in parentheses, are clustered at the city level. Standard errors in parentheses are clustered at the city level.

Table C.4: Robustness Checks: Different FE (Continued)

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.038***	0.051***	0.021*	0.034***	0.012*	0.007						
	(0.011)	(0.011)	(0.012)	(0.011)	(0.007)	(0.007)						
Log(Exposure-Import)							0.004	0.007	−0.023**	−0.024**	0.028***	0.033***
							(0.009)	(0.008)	(0.010)	(0.009)	(0.004)	(0.005)
Year FE	Y		Y		Y		Y		Y		Y	
City FE	Y		Y		Y		Y		Y		Y	
Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-City FE		Y		Y		Y		Y		Y		Y
Observations	68,770	68,770	68,770	68,770	53,589	53,589	68,770	68,770	68,770	68,770	53,589	53,589
R^2	0.567	0.612	0.522	0.570	0.664	0.697	0.560	0.606	0.580	0.618	0.741	0.767

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the carbon total cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. We include two different sets of fixed effects in the regressions: (1) year fixed effects, sector fixed effects, and city fixed effects, and (2) sector fixed effects and city-year fixed effects. Standard errors, reported in parentheses, are clustered at the city level. Standard errors in parentheses are clustered at the city level.

Table C.5: Robustness Checks: Using Lags

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.009	0.018	0.007			
	(0.008)	(0.011)	(0.005)			
Log(Exposure-Import)	−0.009**	−0.012*	−0.003			
	(0.004)	(0.006)	(0.003)			
Log(Rate Exposure-Export)				0.017	0.030	0.010
				(0.014)	(0.020)	(0.009)
Log(Rate Exposure-Import)				−0.015**	−0.019	−0.004
				(0.007)	(0.012)	(0.006)
Year-City FE	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y
Observations	19,659	19,659	19,659	19,659	19,659	19,659
R^2	0.606	0.514	0.408	0.606	0.514	0.408

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1, 2, 3, 5, 6, and 7 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level first-period lagged logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU. Columns 4 and 8 report the estimates from regression Equation (4) for the logged values of the city-level environmental regulation stringency index (ESI). The independent variable is the city-level weighted sums of four exposures to the EU carbon prices. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions on city-level outcomes. Standard errors in parentheses are clustered at the city level.

Table C.6: Robustness Checks: Using Lags (Continued)

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Lag Log(Exposure-Export)	0.033***		0.019*		0.006							
	(0.011)		(0.011)		(0.007)							
Lag Log(Rate Exposure-Export)		0.064***		0.037*		0.011						
		(0.020)		(0.020)		(0.013)						
Lag Log(Exposure-Import)							0.010		0.003		0.010**	
							(0.008)		(0.009)		(0.005)	
Lag Log(Rate Exposure-Import)								0.023		0.009		0.018**
								(0.015)		(0.017)		(0.009)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	63,011	63,011	63,011	63,011	50,053	50,053	63,011	63,011	63,011	63,011	50,053	50,053
R^2	0.650	0.650	0.611	0.611	0.718	0.718	0.626	0.626	0.654	0.654	0.782	0.782

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the first-period lagged logged values of the export-weighted and import-weighted exposure of the Chinese city-sector level to the total carbon cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.7: Robustness Checks: Using Lags (Continued)

	Pollution Outcomes											
	Carbon		Wastewater		NO_x		SO_2		Particulate		PM2.5	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Lag Log(Exposure-Export)	0.012*		0.033*		−0.028		−0.274		−0.021		0.006**	
	(0.007)		(0.020)		(0.027)		(0.232)		(0.029)		(0.003)	
Lag Log(Exposure-Import)	−0.009**		0.007		−0.017		−0.596		−0.004		0.003	
	(0.004)		(0.019)		(0.043)		(0.439)		(0.034)		(0.004)	
Lag Log(Rate Exposure-Export)		0.022*		0.051		−0.053		−0.272		−0.049		0.012**
		(0.012)		(0.034)		(0.050)		(0.263)		(0.052)		(0.005)
Lag Log(Rate Exposure-Import)		−0.016**		0.014		−0.036		−0.684		−0.017		0.005
		(0.007)		(0.035)		(0.073)		(0.533)		(0.055)		(0.007)
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,809	3,809	4,239	4,239	4,478	4,478	2,310	2,310	4,484	4,484	4,631	4,631
R^2	0.989	0.989	0.872	0.871	0.730	0.730	0.901	0.901	0.823	0.823	0.961	0.961

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (4) for logged values of the city-level environmental outcomes: estimates of total carbon emissions, yearly total wastewater, NO_x, SO_2, particulates discharges, and yearly average estimated PM2.5 levels. The independent variables are the first-period lagged logged values of the export-weighted and import-weighted exposure of the Chinese city-sector level to the total carbon cost or cost rates in the EU. The samples include 338 unique prefectures in China from 2000 to 2020. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions. Standard errors in parentheses are clustered at the city level.

Table C.8: Robustness Checks: Using MA(3)

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.006	0.012	0.006			
	(0.009)	(0.013)	(0.006)			
Log(Exposure-Import)	−0.010**	−0.012	−0.002			
	(0.005)	(0.008)	(0.004)			
Log(Rate Exposure-Export)				0.009	0.019	0.009
				(0.017)	(0.023)	(0.011)
Log(Rate Exposure-Import)				−0.017**	−0.019	−0.002
				(0.009)	(0.014)	(0.007)
Year-City FE	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y
Observations	13,823	13,823	13,823	13,823	13,823	13,823
R^2	0.631	0.528	0.426	0.631	0.528	0.426
Note:						*p<0.1; **p<0.05; ***p<0.01

Note: Columns 1, 2, 3, 5, 6, and 7 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level three-year moving average (average of the current, the one-year lagged, and the two-year lagged values) of the logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU. Columns 4 and 8 report the estimates from regression Equation (4) for the logged values of the city-level environmental regulation stringency index (ESI). The independent variable is the city-level weighted sums of four exposures to the EU carbon prices. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions on city-level outcomes. Standard errors in parentheses are clustered at the city level.

Table C.9: Robustness Checks: Using MA(3) (Continued)

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export, MA3)	0.032***		0.016		0.008							
	(0.012)		(0.012)		(0.008)							
Log(Rate Exposure-Export, MA3)		0.062***		0.032		0.016						
		(0.021)		(0.022)		(0.014)						
Log(Exposure-Import, MA3)							0.010		0.002		0.011**	
							(0.009)		(0.010)		(0.005)	
Log(Rate Exposure-Import, MA3)								0.022		0.008		0.020**
								(0.016)		(0.018)		(0.009)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	57,427	57,427	57,427	57,427	46,444	46,444	57,427	57,427	57,427	57,427	46,444	46,444
R^2	0.653	0.653	0.614	0.614	0.723	0.723	0.629	0.629	0.659	0.659	0.779	0.779

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the three-year moving average (average of the current, the one-year lagged, and the two-year lagged values) of the logged values of the export-weighted and import-weighted exposure of the Chinese city-sector level to the total carbon cost or cost rates in the EU. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.10: Robustness Checks: Using MA(3) (Continued)

	Pollution Outcomes											
	Carbon		Wastewater		NO_x		SO_2		Particulate		PM2.5	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export, MA3)	0.015*		0.039		−0.035		−0.353		−0.018		0.008**	
	(0.008)		(0.025)		(0.033)		(0.325)		(0.034)		(0.003)	
Log(Exposure-Import, MA3)	−0.012**		0.013		−0.022		−0.603		−0.002		0.003	
	(0.005)		(0.023)		(0.054)		(0.497)		(0.041)		(0.004)	
Log(Rate Exposure-Export, MA3)		0.030*		0.064		−0.069		−0.347		−0.049		0.016***
		(0.016)		(0.046)		(0.064)		(0.396)		(0.063)		(0.006)
Log(Rate Exposure-Import, MA3)		−0.022**		0.026		−0.042		−0.565		−0.012		0.006
		(0.009)		(0.046)		(0.094)		(0.573)		(0.070)		(0.008)
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,809	3,809	4,239	4,239	4,478	4,478	2,310	2,310	4,484	4,484	4,631	4,631
R^2	0.989	0.989	0.872	0.872	0.730	0.730	0.901	0.901	0.823	0.823	0.961	0.961

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (4) for logged values of the city-level environmental outcomes: estimates of total carbon emissions, yearly total wastewater, NO_x, SO_2, particulates discharges, and yearly average estimated PM2.5 levels. The independent variables are the three-year moving average (average of the current, the one-year lagged, and the two-year lagged values) of the logged values of the export-weighted and import-weighted exposure of the Chinese city-sector level to the total carbon cost or cost rates in the EU. The samples include 338 unique prefectures in China from 2000 to 2020. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions. Standard errors in parentheses are clustered at the city level.

Table C.11: Robustness Checks: Using Average Trade Ratio Between 2002 and 2004

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.011	0.019**	0.006			
	(0.006)	(0.010)	(0.005)			
Log(Exposure-Import)	−0.006*	−0.010*	−0.003			
	(0.004)	(0.006)	(0.003)			
Log(Rate Exposure-Export)				0.019	0.035**	0.011
				(0.011)	(0.018)	(0.009)
Log(Rate Exposure-Import)				−0.010	−0.017	−0.005
				(0.006)	(0.010)	(0.006)
Year-City FE	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y
Observations	27,053	27,053	27,053	27,053	27,053	27,053
R^2	0.599	0.511	0.390	0.599	0.511	0.390

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Note: Columns 1, 2, 3, 5, 6, and 7 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the average export or import ratios with EU countries from 2002 to 2004 as fixed shares. Columns 4 and 8 report the estimates from regression Equation (4) for the logged values of the city-level environmental regulation stringency index (ESI). The independent variable is the city-level weighted sums of four exposures to the EU carbon prices. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions on city-level outcomes. Standard errors in parentheses are clustered at the city level.

Table C.12: Robustness Checks: Using Average Trade Ratio Between 2002 and 2004

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.046***		0.028**		0.009							
	(0.012)		(0.012)		(0.008)							
Log(Rate Exposure-Export)		0.090***		0.054**		0.017						
		(0.021)		(0.022)		(0.014)						
Log(Exposure-Import)							0.013		0.005		0.008	
							(0.009)		(0.010)		(0.005)	
Log(Rate Exposure-Import)								0.027*		0.013		0.014
								(0.016)		(0.018)		(0.009)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	68,770	68,770	68,770	68,770	53,589	53,589	68,770	68,770	68,770	68,770	53,589	53,589
R^2	0.648	0.648	0.608	0.608	0.714	0.714	0.624	0.624	0.649	0.649	0.783	0.783

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the average export or import ratios with EU countries from 2002 to 2004 as fixed shares. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.13: Robustness Checks: Using Average Trade Ratio Between 2002 and 2004

	Pollution Outcomes											
	Carbon		Wastewater		NO_x		SO_2		Particulate		PM2.5	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Log(Exposure-Export)	0.013*		0.035*		−0.030		−0.147		−0.016		0.009***	
	(0.007)		(0.019)		(0.027)		(0.346)		(0.031)		(0.003)	
Log(Exposure-Import)	−0.013**		0.002		−0.072*		−0.667		−0.029		−0.001	
	(0.006)		(0.030)		(0.037)		(0.606)		(0.038)		(0.005)	
Log(Rate Exposure-Export)		0.023*		0.056*		−0.060		−0.171		−0.049		0.017***
		(0.013)		(0.033)		(0.048)		(0.423)		(0.056)		(0.005)
Log(Rate Exposure-Import)		−0.022**		0.003		−0.101*		−0.518		−0.040		−0.002
		(0.009)		(0.047)		(0.059)		(0.690)		(0.063)		(0.009)
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,809	3,809	4,239	4,239	4,478	4,478	2,310	2,310	4,484	4,484	4,631	4,631
R^2	0.989	0.989	0.871	0.871	0.730	0.730	0.901	0.901	0.823	0.823	0.961	0.961

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (4) for logged values of the city-level environmental outcomes: estimates of total carbon emissions, yearly total wastewater, NO_x, SO_2, particulates discharges, and yearly average estimated PM2.5 levels. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the average export or import ratios with EU countries from 2002 to 2004 as fixed shares. The samples include 338 unique prefectures in China from 2000 to 2020. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions. Standard errors in parentheses are clustered at the city level.

Table C.14: Robustness Checks: Using Carbon Price Shock Measures from Känzig (2023)

	Enforcement of Environmental Regulations: Penalties					
	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)	Log(Penalty Number)	Log(Penalty Sum)	Log(Average Penalty)
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Exposure-Export)	0.010	0.020*	0.010			
	(0.006)	(0.011)	(0.007)			
Log(Exposure-Import)	0.004	0.003	0.001			
	(0.003)	(0.006)	(0.004)			
Log(Rate Exposure-Export)				0.020	0.057*	0.033
				(0.018)	(0.032)	(0.021)
Log(Rate Exposure-Import)				0.011	0.004	−0.001
				(0.010)	(0.017)	(0.012)
Year-City FE	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y
Observations	27,053	27,053	27,053	27,053	27,053	27,053
R^2	0.599	0.511	0.390	0.599	0.511	0.390

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1, 2, 3, 5, 6, and 7 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the yearly sum of EU carbon policy shocks as alternative measures of carbon costs in the EU, as described in Känzig et al. (2024). Columns 4 and 8 report the estimates from regression Equation (4) for the logged values of the city-level environmental regulation stringency index (ESI). The independent variable is the city-level weighted sums of four exposures to the EU carbon prices. The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions on city-level outcomes. Standard errors in parentheses are clustered at the city level.

Table C.15: Robustness Checks: Using Carbon Price Shock Measures from Känzig (2023)

	Sectoral Trade of China											
	Log(Value)		Log(Volume) Export		Log(Prices)		Log(Value)		Log(Volume) Import		Log(Prices)	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Lag Log(Exposure-Export)	0.020		0.010		0.017**							
	(0.013)		(0.013)		(0.007)							
Lag Log(Rate Exposure-Export)		0.058*		0.031		0.048***						
		(0.033)		(0.032)		(0.018)						
Lag Log(Exposure-Import)							0.004		0.002		0.009	
							(0.009)		(0.010)		(0.005)	
Lag Log(Rate Exposure-Import)								0.014		0.014		0.020
								(0.024)		(0.026)		(0.014)
Year-City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year-Sector FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	68,770	68,770	68,770	68,770	53,589	53,589	68,770	68,770	68,770	68,770	53,589	53,589
R^2	0.648	0.648	0.608	0.608	0.714	0.714	0.624	0.624	0.649	0.649	0.783	0.783

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (5) for logged values of the city-sector level trade outcomes: the total values, volumes, and unit prices of total exports and total imports. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the yearly sum of EU carbon policy shocks as alternative measures of carbon costs in the EU, as described in Känzig et al. (2024). The samples include 37 unique sectors, mainly based on Chinese sector categorization, and 338 unique prefectures in China from 2000 to 2020. Year-city fixed effects and year-sector fixed effects are included in the city-sector regressions. Standard errors in parentheses are clustered at the city level.

Table C.16: Robustness Checks: Using Carbon Price Shock Measures from Känzig (2023)

	Pollution Outcomes											
	Carbon		Wastewater		NO_x		SO_2		Particulate		PM2.5	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Lag Log(Exposure-Export)	0.002		−0.001		−0.011		−0.0004		−0.009		0.002	
	(0.001)		(0.007)		(0.010)		(0.014)		(0.008)		(0.002)	
Lag Log(Exposure-Import)	0.001		0.005		0.010		−0.020		−0.023***		0.0003	
	(0.001)		(0.008)		(0.013)		(0.012)		(0.005)		(0.002)	
Lag Log(Rate Exposure-Export)		0.007***		−0.012		−0.027		−0.0001		−0.020		0.006
		(0.003)		(0.016)		(0.026)		(0.034)		(0.022)		(0.004)
Lag Log(Rate Exposure-Import)		0.0001		0.012		0.022		−0.045		−0.059***		0.003
		(0.005)		(0.022)		(0.036)		(0.033)		(0.013)		(0.005)
City FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
City Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	3,809	3,809	4,239	4,239	4,478	4,478	2,310	2,310	4,484	4,484	4,631	4,631
R^2	0.989	0.989	0.871	0.871	0.730	0.730	0.901	0.901	0.823	0.823	0.961	0.961

Note: *p<0.1; **p<0.05; ***p<0.01

Note: Columns 1–12 report the coefficient estimates from the regression Equation (4) for logged values of the city-level environmental outcomes: estimates of total carbon emissions, yearly total wastewater, NO_x, SO_2, particulates discharges, and yearly average estimated PM2.5 levels. The independent variables are the Chinese city-sector level logged values of the export-weighted and import-weighted exposure to the total carbon cost or cost rates in the EU, using the yearly sum of EU carbon policy shocks as alternative measures of carbon costs in the EU, as described in Känzig et al. (2024). The samples include 338 unique prefectures in China from 2000 to 2020. Year fixed effects, city fixed effects, and city-level controls, including logged values of GDP per capita and registered total population, are included in the regressions. Standard errors in parentheses are clustered at the city level.