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Has the carbon emission trading scheme induced investment leakage in China? Firm-level evidence from China's stock market

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A R T I C L E I N F O

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A B S T R A C T

This study investigates the causal relationship between the Emission Trading Scheme (ETS) and investment leakage in China, using firm-level subsidiary data for 4480 A-share listed companies with the Two-Way Fixed Effects (TWFE) Difference-in-Differences (DID) method under staggered treatment adoption. The results indicate that the ETS has significantly induced regulated firms to increase the share of investment in the non-pilot area by 2.5 %, and the number of subsidiaries in the non-pilot by 2.035, suggesting that the policy has caused investment leakage. The rising operating cost due to ETS compliance may explain why regulated firms expand their outward investment. Furthermore, regulation intensity and social responsibility moderate the investment leakage effect. This study provides the first direct empirical evidence on the domestic investment leakage associated with the gradual ETS rollout in China and enriches the theory of the pollution haven effect by illuminating how the policy drives investment from the pilot area towards the non-pilot area.

1. Introduction

The Emission Trading Scheme (ETS), as a cap-and-trade system, is a vital component of the carbon pricing mechanism providing a market-based solution to internalize the emission abatement cost and curb the volume of carbon emissions. The China ETS was initially announced as a pilot policy by the China National Development and Reform Commission (CNDRC) in 2011, with the pilot area covering two provinces, Guangdong and Hubei, and four municipalities, Beijing, Shanghai, Chongqing, and Tianjin, together with one special economic zone, Shenzhen. Five years later 2016, Fujian province was declared the eighth pilot. After about a decade of experimenting in regional pilot markets, on July 16th 2021, China formally launched its national carbon trading market designed to include eight prominent carbon-intensive sectors to transact in the national market (albeit only involving the electricity sector currently) with other sectors still participating in the regional pilot markets. So far, the China ETS has already surpassed the European Union (EU) ETS and ranked as the world's largest carbon trading market (The State Council Information Office of the People's Republic of China, 2021).

As of April 2022, 34 ETSs were operating worldwide (World Bank, 2022), among which the EU ETS and the China ETS are the most representative and influential. Behind the remarkable prosperity lies a lingering question on the existence of carbon leakage, which could significantly impair the effectiveness of ETS. Carbon leakage is the reduced carbon emission in the regulated area under an asymmetric emission abatement policy offset by the emission lifted in the non-regulated area (Branger and Quirion, 2014).[2] Theoretically, according to the Pollution Haven Hypothesis (PHH) articulated by Levinson and Taylor (2008), unilateral environmental regulations should stimulate entities to relocate polluting plants to places where the compliance cost could be lowered, resulting in the shift of pollution from the regulated area to the non-regulated area and the change of trade flow. In the case of Greenhouse Gas (GHG) emission, the carbon price differentials caused by the unilateral ETS coverage ought to prompt regulated firms to transfer production to places with lower abatement costs, thereby inevitably resulting in carbon leakage, which is proposed as the Carbon Haven Effect (CHE) by Branger and Quirion (2014).

In the existing scholarly discourse, carbon leakage is categorized through two distinct frameworks. The first classification is based on the

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[1] Equal contributors to this work and designated as co-first authors.
[2] In this study, we embrace the definition of carbon leakage from the perspective of the ultimate alterations in carbon emission outcomes.

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attributability of carbon leakage to specific climate asymmetric policies, while the second focuses on the mechanisms by which carbon leakage occurs. Within the first taxonomy, carbon leakage is divided into strong and weak forms (Peters et al., 2011). Strong carbon leakage, which is unambiguously linked to targeted policy interventions, is also termed policy-driven displacement (Meyfroidt and Lambin, 2009). In contrast, weak carbon leakage pertains to demand-driven net emission transfers, arising from the collective demand in non-regulated areas and not directly tied to specific climate policies (Peters et al., 2011). The second classification delineates carbon leakage into the competitiveness channel and the fossil fuel market channel (Böhringer et al., 2022). The competitiveness channel is characterized by a reduction in production among industries subject to unilateral regulation, counterbalanced by an increase in production among unregulated competitors. Conversely, the fossil fuel market channel is activated when emission regulations in open economies diminish the demand for fossil fuels, leading to a decline in global fossil fuel prices and consequently spurring demand in unregulated regions (Böhringer et al., 2022). The prosperous literature quantifying ETS-related carbon leakage could be divided into ex-ante and ex-post studies. The former group mainly uses the computable general equilibrium (CGE) approach (Böhringer et al., 2021, 2012; Elliott et al., 2010; Fischer and Fox, 2012; Gerlagh and Kuik, 2014; Mattoo et al., 2009; Tan et al., 2018), whereas the latter usually employs the multi-region input-output (MRIO) or the econometric method (Gao et al., 2020; Peters et al., 2011; Peters and Hertwich, 2008).

The concept of investment leakage is aligned with the competitiveness channel of carbon leakage, signifying the long-term shift in production capacity attributable to competitiveness erosion (Branger and Quirion, 2014), and is intimately connected to strong carbon leakage, as it represents an investment displacement instigated by particular climate policies. Although carbon leakage is a subject of interest in both academic and policy spheres (Naegele and Zaklan, 2019), the academic consensus on its subchannel—investment leakage—remains elusive, with divergent findings yielded by various methodologies. It is unequivocal that investment leakage requires heightened attention (Verde, 2020), particularly given its direct relevance to critical issues in international trade, such as the Carbon Border Adjustment Mechanism (CBAM).

Two converse hypotheses could be employed to explain the investment leakage caused by ETS: the PHH articulated by Levinson and Taylor (2008) and Porter's Hypothesis proposed by Porter (1991). The former states that environmental regulations increase the cost of regulated firms and thus drive them to shift operations to places with more lenient regulations, supporting the forward investment leakage (i.e., investment moving to non-regulated areas), while the latter claims that environmental regulations enhance the competitiveness of regulated firms by spurring innovation and upgrading, partially explaining the reverse investment leakage (i.e., investment attracted to regulated areas). If no investment leakage is observed, it should be attributed to low emission prices, free allowances and the fact that capital-intensive EITE industries usually have high sunk costs of existing installations and thus hardly relocate (Böhringer et al., 2022).

Research on investment leakage induced by ETS predominantly uses the econometric method, particularly the Difference-in-Differences (DID) method, based on firm-level FDI data from the *ex-post* perspective. It is captured that both the EU ETS and the China ETS significantly facilitate the Outward Foreign Direct Investment (OFDI) of regulated firms compared with non-regulated firms, thus providing evidence of investment leakage and supporting the PHH (Koch and Basse Mama, 2019; Yu et al., 2021). Yet undeniably, it is rather difficult to derive the net effect of ETS on investment leakage from other confounding factors, which deteriorates in transnational cases due to the vast regime variations across different countries. Nonetheless, to date, very little firm-level research is determining the existence of the ETS-provoked investment leakage inside a single jurisdiction.

Investment leakage could be proxied by the following indicators: OFDI, including the breadth and depth of OFDI, subsidiary number, and financial indicators stretching from fixed assets, investment expenditure, profits, sales, to revenue. The econometric evaluation of the causal effect of ETS on international investment leakage (proxied by the foreign affiliate number) yields the same significantly positive results for both the EU ETS and the China ETS. Taking advantage of the delicate firm-level foreign affiliate data of German multinational firms, Koch and Basse Mama (2019) evaluated how the EU ETS affected the extensive and intensive margin of FDI flows and found that the sample average treatment effect of the EU ETS on regulated firms' FDI was relatively small and statistically insignificant, with a small group of regulated firms which paradoxically neither belong to energy-intensive sector nor are emission-intensive proved to have expanded their investment outside EU, which indicates that investment leakage does exist but with minimal consequences for the overall EU ETS. This evidence impairs the rationality of mandating the unilateral EU CBAM. When it comes to the China ETS, similar to Koch and Basse Mama (2019), based on the firm-level FDI data, Yu et al. (2021) also explored how ETS affected the two aspects of FDI: depth and breadth, and found that the China ETS boosted both aspects of FDI, suggesting that the China ETS has induced investment leakage towards other countries.

In summary, the econometric assessment of ETS on various investment-related indicators remains inconsistent and thus needs more econometric evidence from different ETSs. Furthermore, there has not been an econometric study on the strong investment leakage caused by ETS inside one country, especially in China. To fill this gap, this paper investigates the causal impact of China ETS on domestic investment leakage utilizing a comprehensive dataset that integrates China ETS pilot firm inventory and A-share listed firms' financial and subsidiary data from 2003 to 2021. Employing the Two-Way Fixed Effects (TWFE) Difference-in-Differences (DID) model under staggered treatment adoption, our baseline results demonstrate that the ETS has prompted regulated firms to enhance their investment share in non-pilot regions by 2.5 % and to establish 2.035 additional subsidiaries in these areas. To verify the parallel trends assumption and assess dynamic effects, we exercise an event study approach, revealing no significant pre-ETS coefficients and policy effects emerging from the second year of post-regulation. To reinforce the robustness of our findings, alongside placebo tests using Monte Carlo permutations, we also implement Propensity Score Matching (PSM) to align treated and control groups, followed by re-estimation of the TWFE DID model, which corroborates our initial results. Furthermore, we apply Heterogeneity-Robustness Estimators (HRE) of the Staggered DID, introduced by de Chaisemartin and D'Haultfœuille (2020) and Callaway and Sant'Anna (2021), to reinforce the consistency of our baseline estimates. Subsequently, we delve into mechanism analysis, confirming the cost-boost pathway where ETS escalates the total operating cost of regulated firms. Regarding moderating effects, we discover that heightened regulatory intensity exacerbates investment leakage, while a stronger sense of corporate social responsibility mitigates it. Heterogeneity analysis reveals sectoral disparities in investment leakage, with carbon-intensive and labor-intensive regulated firms exhibiting the most pronounced leakage effects when categorized accordingly. Supplementary evidence from transaction behavior data uncovers an additional, indirect pathway for investment redistribution, namely operational leakage, which occurs not only directly but also through increased related transactions with subsidiaries outside pilot regions.

Compared with the several studies most similar to us (Dechezleprêtre et al., 2023; Dong et al., 2022; Du et al., 2023; Koch and Basse Mama, 2019; Yu et al., 2021; Zhang and Wang, 2021), this study could yield more robust and comprehensive evidence on the domestic investment leakage induced by the China ETS in terms of data, method, and perspective. The possible contributions of this paper can be concluded in the following four aspects: 1) in terms of the data, we elaborate a comprehensive dataset combining the pilot firm list with detailed company characteristics, enabling us to explore the firm-level investment leakage; 2) regarding method, the baseline model used in this paper captures the variant treatment time of ETS and the HREs used in robustness check section take into consideration the heterogeneous treatment effect and thus can yield relatively more robust evidence; 3) different from the previous literature mainly focusing on the cross-border investment leakage (Koch and Basse Mama, 2019; Yu et al., 2021), this paper attempts to portray how the domestic investment pattern alters and to explore whether domestic investment leakage is triggered by the implementation of the ETS, in which case the unobservable intrinsic cultural and other regime-related differences affecting firms' investment behavior can be well eliminated, meanwhile, different from the previous literature solely focusing on one dimension, either outward or inward investment (Du et al., 2023), we not only explore the changes in outside investment, but also speculates how its share in the overall investment alters, thereby reinforcing the identification of the causal effect of the ETS on investment leakage; 4) theoretically, the PHH under ETS is further enriched by clarifying the micro-level influencing mechanism for the first time and discovering another hidden pathway through which the regulated firms avoid complying with environmental regulations, i.e., beyond directly relocating investment from the pilot area towards the non-pilot area, the regulated firms also strengthen related transactions with their subsidiaries locating outside the pilot area, which to some extent echoes with the so-called *operational leakage* defined by Branger and Quirion (2014).

The rest of this paper is organized as follows: Section 2 describes the methodology and data, Section 3 presents the empirical results, and Section 4 concludes this paper with policy implications.

2. Methodology and data

2.1. Data description

Detailed data processing is described in Appendix. Concerning the identification of the treated firms, the extant firm-level empirical study focusing on China ETS (Zhang and Wang, 2021) did not use the accurate pilot firm inventory but rather either perceived all of the firms in specific selected industries as the treatment group or regarded all the firms registered in the pilot area as the regulated group, which inevitably undermines the credibility of the results. By manually compiling the pilot firm list through collecting information scattered in different official disclosure channels, we get a comprehensive pilot firm list containing each pilot firm's name, location and sector. Further substantiating the authenticity and currency of our compiled list, we have cross-verified its contents with the most recent iteration of the pilot firm list as updated by the esteemed database, CSMAR, thereby ensuring congruence with an authoritative source in the field.

The determination of a firm's investment location decision is a complex process that is influenced concurrently by a multitude of internal and external factors (Brouwer et al., 2004; Kapitsinis, 2017; Kronenberg, 2013; Pennings and Sleuwaegen, 2000; Sleuwaegen and Pennings, 2006; Wang et al., 2020). These factors are reflected in the respective firm-level and regional-level control variables. At the firm-specific stratum, similar to prior researches (Du et al., 2023; Zhang and Wang, 2021), the control variables include the composition of equity, the metrics of profitability, the market valuation, the degree of financial leverage, and the chronological age of the corporation. On the regional stratum, the control variables are comprised of the prevailing economic structure, the labor cost dynamics, the general price level, and the institutional environment that shapes the regional context. Table 1 demonstrates the definition and calculation of all variables. Due to the missing values of some covariates in specific years, after merging the data of all variables, an unbalanced panel of 30,026 company-year observations was obtained covering 4480 A-share listed firms from 2003 to 2021.

Finally follows, the calculation of the dependent variables.

Table 1
Variable definition.

	Variable	Definition
Explained variable	Outratio	The proportion of the subsidiaries located outside the pilot area, defined in Eq.(1)
	Noutpilot	Number of subsidiaries located outside the pilot area
Explanatory variable	treat	equals 1 if firm i has subsidiaries in the pilot list
	post	equals 1 is year $t \geq ETSyear$, 0 otherwise.
	ETSyear	The earliest year when a subsidiary of firm i is included in the pilot list
	post_ETS	Equals 1 if firm i owns any pilot subsidiary in year t, 0 otherwise.
Control variables: Firm-level	LnLargestHolder	Natural logarithm of the largest shareholder's shareholding ratio (in percentage points)
	LnTopTenHolders	Natural logarithm of the top ten shareholders' shareholding ratio (in percentage points)
	LnPER	Natural logarithm of the price-earnings ratio
	LnPCFR	Natural logarithm of the price-cash-flow ratio
	LnTobin's Q	Natural logarithm of the Market Value / Total Assets ratio
	LnEBIT	Natural logarithm of the Total Market value / Earnings before interest and taxes ratio
	LnMainRevenue	Natural logarithm of the Prime Operating Revenue
	LnCapexp	Natural logarithm of the Change in property, plant and equipment together with current depreciation
	LnAge	Natural logarithm of the duration since the established year
	Leverage	Debt to asset ratio; %
	EPS	Net profit/number of outstanding shares; yuan
Control variables: Regional-level	SecondindustryGDPratio	The proportion of GDP occupied by the second industry of the province where firm i is located; %
	Lnavesalary	Natural logarithm of the average salary of the province where firm i is located
	CPI	Consumer Price Index of the province where firm i is located
	Marketization	The composite index measuring the institutional environment of the province where firm i is located
Moderating variables	Npilotsubsidiary	The number of pilot subsidiaries owned by firm i
	NpilotMarket	The number of pilot markets to which firm i adheres
	ESG	The composite score measuring firm i' performance on environmental, social, and governance
Grouping variables	Carbon-intensive	Equals 1 if firm i is in the eight carbon-intensive sectors, 0 otherwise.
	Non-carbon-intensive	Equals 1 if firm i is not in the eight carbon-intensive sectors, 0 otherwise.
	Capital-intensive	Equals 1 if firm i is in capital-intensive sectors, 0 otherwise.
	Labor-intensive	Equals 1 if firm i is in labor-intensive sectors, 0 otherwise.
	Tech-intensive	Equals 1 if firm i is in technology-intensive sectors, 0 otherwise.
Other variables	OperatingCost	Natural logarithm of the total operating cost

$$Outratio_{it} = Noutpilot_{it} / Ntotal_{it} \tag{1}$$

In Eq. (1), $Noutpilot_{it}$ and $Ntotal_{it}$ represent the number of the company i's subsidiaries located outside the pilot area and sum of subsidiaries in China in year t, respectively. Detailed variable definition is presented in Table 1.

2.2. Method: TWFE DID model under staggered treatment adoption

$ETSyear_i$ represents the treatment year of company i, defined as the earliest year when any of A-share listed company's subsidiaries is announced as the ETS pilot firm, indicating the first year when company i starts to be regulated by the ETS. The TWFE DID model under staggered treatment adoption is employed given that the treatment year in the whole sample is variant rather than uniform. Referring to Beck et al. (2010), the model specification is as follows:

$$y_{it} = \alpha_0 + \beta post\_ETS_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{2}$$

In Eq. (2), i and t represent company and year, respectively; y_{it} stands for a group of outcome variables measuring the investment leakage, including $Outratio_{it}$ and $Noutpilot_{it}$; $post\_ETS_{it}$ is the key explanatory variable denoting whether firm i is regulated by the ETS in year t; X_{it} corresponds the control variables[3]; u_i and v_t correspond to the firm and time fixed effects, respectively; ε_{it} is the error term. The coefficient of $post\_ETS_{it}$ measures the ETS's average treatment effect (ATE) on the regulated firms.

3. Results

3.1. Descriptive summary

Table 2 presents the descriptive statistics of all variables in baseline model. The sample companies averagely own 10.38 subsidiaries outside the pilot area, occupying 64.1 % of the overall subsidiaries in mainland China. Further descriptive statistics are included in Appendix.

3.2. Baseline regression results

Table 3 presents the baseline regression results, derived from the application of the TWFE DID model. By incrementally incorporating control variables and fixed effects, the coefficients of the DID estimator, pertaining to the dependent variables *Outratio* and *Noutpilot*, demonstrate robust consistency and statistically significant positive values. These findings indicate that the ETS has stimulated an increase in the investment share of regulated firms in non-pilot regions by 2.5 %, and has catalyzed the establishment of 2.035 additional subsidiaries within these zones. The congruence between the shifts in these two outcome variables substantiates the assertion that the ETS has propelled a reallocation of investment by regulated firms towards non-pilot regions, surpassing that of unregulated firms. This strategic investment shift has culminated in an enduring augmentation of production capacity in unregulated domains, indicative of a phenomenon of domestic investment leakage.

Our findings are congruent with recent scholarly work that has quantified the impact of China's ETS on corporate domestic investment (Pan and Yu, 2024), where the reported coefficients for the influence of the China ETS on the proliferation of off-site manufacturing subsidiaries among regulated firms are 1.676 and 2.356, in the presence and absence of covariates, respectively. It is noteworthy that the aforementioned study diverges from ours in its delineation of the treatment group, identifying all industrial listed firms within the pilot area as the treatment cohort, rather than relying on the officially disclosed list of pilot firms. Furthermore, as elucidated in the appendix, our approach extends the scope of treatment firms to include parent companies of entities listed in the official pilot inventory, thereby affording a more nuanced capture of the policy's impact. Concurrently, our baseline findings resonate with macro-level evidence of investment leakage induced by the ETS, as manifested in both OFDI and interprovincial carbon leakage (Gao et al., 2020; Koch and Basse Mama, 2019; Yu et al., 2021). They are also partially corroborated by prior research highlighting the ETS's influence in prompting unregulated firms to curtail investment within the pilot area (Du et al., 2023). Additionally, the majority of the control variables exhibit significant coefficients in relation to the dependent variables, which serves to reinforce the credibility and robustness of our model.

In align with Koch and Basse Mama (2019), our baseline regression results provide groundbreaking direct causal evidence on the veracity of the risks regarding domestic relocation and investment leakage in the China ETS, thereby potentially suggesting the presence of domestic carbon leakage. As Verde (2020) posits, compared to other indicators, investment leakage is akin to an early warning enabling us to anticipate the future effects rather than current impact of ETS on domestic production activity. The relocation of production to unregulated areas could potentially result in relative job displacement and a decline in other economic activities within the regulated regions. In this sense, confronting the peril of investment leakage is of particularly significance, as the loss of production capacity entails long-term economic erosion such as employment loss in the regulated area, and long-lasting carbon leakage that undermines the environmental efficacy of ETS. This underscores the necessity of balancing environmental objectives with economic competitiveness by refining the rules within the policy framework. It necessitates that policymakers take rapid and targeted measures to address the potential negative economic effects, either by compensating specific sectors at high risk of relocating with free allowances or by expanding the scope of the national ETS market to neutralize the propensity of regulated firms to shift investments towards non-pilot areas.

3.3. Parallel trend test

Like the standard DID, the DID under staggered treatment adoption also has the prerequisite of parallel trend. However, due to the varying treatment time of each regulated firm, the parallel trend test method of the standard DID (i.e., simply drawing a figure of the dependent variable's mean value of the control group and the treatment group) is no longer appropriate. Instead, following Huang et al. (2022), the dynamic DID method derived from event study is employed to investigate whether the parallel trend assumption before the event adoption is satisfied and to simultaneously estimate the dynamic effects of ETS. Different from the standard DID condition, in the staggered scenario, the treatment time is not universal but variant (*ETSyear* in this paper) for each regulated firm. Each year relative to the *ETSyear* is assigned with a dummy variable and multiplied with the treatment state indicator *treat* to generate the interaction terms in Eq. (3). Only when all of the coefficients of the interaction terms before the treatment adoption year (i.e. *ETSyear*) are not significantly different from 0, can the parallel trend be testified.

$$\begin{aligned} y_{it} = {} & \alpha_0 + \beta_s^{precut}\left[treat_i \times \mathbf{1}\left(t - ETSyear_i < \underline{EW}\right)\right] + \sum_{s=\underline{EW}}^{-2} \beta_s^{pre}\left[treat_i \times \mathbf{1}\left(t - ETSyear_i = s\right)\right] + \sum_{s=\underline{0}}^{\overline{EW}} \beta_s^{post}\left[treat_i \times \mathbf{1}\left(t - ETSyear_i = s\right)\right] \\ & + \beta_s^{postcut}\left[treat_i \times \mathbf{1}\left(t - ETSyear_i > \overline{EW}\right)\right] + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \end{aligned} \tag{3}$$

[3] In the staggered treatment adoption scenario, post_ETS = treat*post = post, where treat equals 1 when any of company i's subsidiaries is located in the pilot area, and 0 when none of company i's subsidiaries is located in the pilot area; post equals to 1 if year $t \geq$ ETSyear, and 0 otherwise.

Table 2
Descriptive Statistics.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	N	mean	sd	min	p25	p50	p75	max
Outratio	30,026	0.641	0.342	0	0.360	0.734	1	1
Noutpilot	30,026	10.38	15.60	0	2	5	12	101
LnLargestHolder	30,026	3.475	0.468	2.145	3.164	3.516	3.835	4.318
LnTopTenHolders	30,026	4.053	0.286	3.118	3.893	4.110	4.267	4.561
LnPER	30,026	3.695	0.972	1.684	3.054	3.589	4.217	6.933
LnPCFR	30,026	3.346	1.203	0.641	2.536	3.263	4.048	7.193
LnTobin's Q	30,026	0.553	0.474	−0.132	0.192	0.451	0.811	2.201
LnEBIT	30,026	3.018	0.629	1.766	2.588	2.946	3.363	5.675
LnMainRevenue	30,026	21.46	1.451	16.91	20.46	21.31	22.31	25.47
LnCapexp	30,026	18.72	1.775	11.90	17.69	18.73	19.80	23.02
LnAge	30,026	2.722	0.436	0	2.485	2.773	3.045	3.466
Leverage	30,026	0.416	0.198	0.0529	0.257	0.411	0.565	0.865
EPS	30,026	0.528	0.569	0.00968	0.159	0.354	0.682	3.282
SecondindustryGDPratio	30,026	42.38	9.337	16.20	39.35	43.80	48.60	57.30
Lnavesalary	30,026	11.04	0.598	9.439	10.71	11.14	11.46	12.16
CPI	30,026	102.3	1.353	98.46	101.5	102.3	102.8	106.0
Marketization	30,026	9.259	1.819	3.796	8.312	9.494	10.56	12.39

Note: all the control variables are winsorized at 1 % and 99 % percentile.

Table 3
Baseline regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Outratio	Outratio	Outratio	Outratio	Noutpilot	Noutpilot
post_ETS	0.019***	0.023**	0.020***	0.025**	2.454***	2.035*
	(4.10)	(2.13)	(4.00)	(2.26)	(7.87)	(1.80)
LnLargestHolder			0.018***	0.019*	−0.920***	−0.224
			(3.89)	(1.75)	(−3.47)	(−0.31)
LnTopTenHolders			−0.020***	−0.020*	0.802**	1.678**
			(−3.20)	(−1.67)	(2.09)	(2.01)
LnPER			0.010***	0.010***	−0.275**	−0.006
			(6.00)	(3.27)	(−2.55)	(−0.03)
LnPCFR			−0.003***	−0.002*	−0.055	0.026
			(−2.82)	(−1.79)	(−0.86)	(0.29)
LnTobin's Q			0.010***	0.010	−2.499***	−2.428***
			(2.84)	(1.48)	(−12.06)	(−5.13)
LnEBIT			−0.026***	−0.023***	1.542***	1.360***
			(−7.99)	(−3.75)	(7.71)	(3.11)
LnMainRevenue			−0.005***	−0.006	3.645***	3.612***
			(−2.73)	(−1.39)	(34.93)	(10.99)
LnCapexp			0.009***	0.008***	0.749***	0.747***
			(9.95)	(4.55)	(13.00)	(6.85)
LnAge			0.036***	0.004	1.198***	−1.913
			(5.63)	(0.22)	(3.63)	(−1.53)
Leverage			0.029***	0.030	4.114***	3.840***
			(3.37)	(1.61)	(7.94)	(3.29)
EPS			−0.004	−0.005	0.239	0.606
			(−1.40)	(−1.03)	(1.44)	(1.31)
SecondindustryGDPratio			0.003***	0.001	−0.066***	0.071*
			(10.31)	(1.20)	(−4.68)	(1.68)
Lnavesalary			0.018***	−0.063	2.502***	−2.632
			(3.09)	(−1.52)	(7.88)	(−1.11)
CPI			−0.001	−0.003	−0.177***	0.124
			(−0.80)	(−1.09)	(−4.41)	(0.88)
Marketization			−0.011***	0.000	−0.112	−0.129
			(−6.51)	(0.07)	(−1.25)	(−0.51)
Constant	0.630***	0.615***	0.378***	1.461***	−95.366***	−81.149***
	(129.34)	(55.81)	(4.33)	(3.06)	(−17.70)	(−3.00)
Observations	30,026	30,026	30,026	30,026	30,026	30,026
R-squared	0.001	0.003	0.006	0.010	0.261	0.276
Number of ID	4480	4480	4480	4480	4480	4480
Company FE	NO	YES	NO	YES	NO	YES
Year FE	NO	YES	NO	YES	NO	YES

z-statistics in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In Eq. (3), $\mathbf{1}(\bullet)$ is the indicative function, $ETSyear_i$ is the treatment year, $\underline{EW}$ and $\overline{EW}$ represent the start and end of the event window, respectively. In order to suitably control the temporal scope of the event window, a restriction is placed on the event window, spanning from the past 8 years to the subsequent 8 years, while eliminating any years that fall outside this designated window. Correspondingly, $\underline{EW}$ and $\overline{EW}$ are

−8 and 8, respectively. As recommended by the previous literature (Freyaldenhoven et al., 2021.; Liu et al., 2022; Huang et al., 2022), pre1, as the year before the adoption year, is selected as the base period and dropped afterwards.

Fig. 1 demonstrates the trend of the coefficients of the yearly interaction terms on *Outratio* and *Noutpilot*. As shown in the two sub-figures of Fig. 1, none of the coefficients of the yearly interactions before the treatment year is statistically significant, confirming the parallel trend assumption.

In addition, regarding the dynamic effects of the ETS, the positive effects of the ETS on *Noutpilot* and *Outratio* start to manifest two and four years after the treatment adoption, respectively. It seems to take several years before the carbon price signal affects the investment behavior. The lagged rather than instant effects could be attributed to the time-lag between invisible investment decisions and tangible subsidiary establishment, meaning that even after the decision-maker determines to change the investment pattern, setting up new subsidiaries takes time and cannot be fulfilled instantly.

3.4. Robustness check

3.4.1. Placebo test

The Monte Carlo permutation is adopted to perform the placebo test. First, the value of post_ETS is randomly assign as 0 or 1 among the whole sample; then, the altered data is processed to perform the regression as before, yielding a new coefficient of the DID estimator. In this way, the resampling process is repeated 500 times. Finally, the 500 coefficients estimated using the Monte Carlo method are presented in the kernel density curve in Fig. 2 where all the kernel density distributions are similar to the normal distribution. Notably, the mean values of the distribution for the two dependent variables (displayed by the black solid lines) are almost equal to 0 and markedly different from the actual coefficients estimated using the original data (displayed by the red dash lines), with most of the *p*-value being larger than 10 %. Therefore, the study successfully passed the placebo test.

3.4.2. PSM-DID

To further reinforce the robustness of the results, we adopt the PSM method to eliminate the differences between the treated and untreated groups. With the nearest neighboring method employed to match the propensity score, the matching is effective and valid, as shown in Fig. 3 and Fig. 4. Fig. 3 illustrates that all the standardized biases across covariates decrease from more than 10 % before the PSM to less than 10 % after the PSM, implying that the matched data is balanced. Meanwhile, Fig. 4 demonstrates that most of the propensity scores of the treated and untreated firms are on support. Then the data after PSM is estimated using the method mentioned in section 2, with results presented in Table 4.

As displayed in Table 4, the coefficients of the newDID, the PSM-DID estimator, remain consistent with the baseline estimation across all the dependent variables. Not only do the significance level and the sign of the coefficients maintain unchanged, but the size of the coefficients also keeps stable, which enhances the robustness of the baseline results.

3.4.3. Heterogeneity-robust estimators of staggered DID

As indicated by Liu et al. (2022), with the challenges posed by the heterogeneity of treatment effects across different groups and periods in the staggered treatment adoption scenario, the traditional TWFE model would trigger unexpected estimated errors. Thus, the application of delicately designed Heterogeneity-Robust Estimators of staggered DID is the corresponding solution to this problem.

Following the method introduced by Mou and Xu (2023), the treatment status of each regulated firm in the panel dataset is visualized in Fig. 5. As illustrated in Fig. 5, most of the treatments happen in the latter part of the whole sample period, from which we could generally infer that the estimation by the TWFE model is tenable. Nonetheless, further investigation is still needed to confirm the anticipation.

The method proposed by de Chaisemartin and D'Haultfœuille (2020) is used to inspect how the weights are attached to the TWFE, finding that among 1801 Average Treatment Effects on Treated (ATT), 1707 ATTs receive positive weights and 94 receive negative weights, suggesting that the results estimated by the TWFE model are fundamentally robust given that the majority of ATTs are assigned with positive weights.

Furthermore, we reevaluate the dynamic effects of ETS employing the HREs provided by de Chaisemartin and D'Haultfœuille (2020) and by Callaway and Sant'Anna (2021). The results displayed in Fig. 6 and Fig. 7 stand in line with the TWFE estimations, also supporting the parallel trend between the treated and untreated groups before the ETS implementation. Therefore, the results estimated by the HREs strengthen the solidity of our investigation.

Further robustness check is demonstrated in Appendix, describing how we obtained additional supporting evidence of the outward investment leakage.

3.5. Mechanism analysis

As illustrated in Fig. 8, the mechanism of investment leakage induced by ETS is summarized as follows: Firstly, the investment leakage stems from the rising compliance cost induced by ETS, moderated by the regulation intensity, meaning that the more intensively regulated a firm is, the higher compliance cost it has to bear, leading to the higher possibility of investment leakage.

Accordingly, we propose H1 and H2.

H1. ETS would drive up the regulated firm's total compliance cost.

H2. Higher regulation intensity would deteriorate investment leakage.

Subsequently, based on the trade-off between compliance and relocating costs, the regulated firms must decide among remaining, relocating, and production shifting. If the relocating cost outweighs the compliance cost, relocating would be an insensible choice; in this case, compromising by shifting production through related transactions would be a better solution. Conversely, if compliance cost surpasses relocating cost, the regulated firms should transfer investment outside, resulting in investment leakage. The final decision based on the trade-off would be moderated by social responsibility. The more socially responsible a firm is, the more likely it is to comply with environmental regulations.

Correspondingly, we propose H3.

H3. Higher social responsibility would curb investment leakage.

The examinations of these assumptions are delivered in the following part.

3.5.1. Cost-boost mechanism: Operating cost

The PHH states that environmental regulations would increase the abatement cost of the regulated firms, thereby resulting in the shift of plant locations (Levinson and Taylor, 2008), which is summarized as the cost-boosting mechanism. Accordingly, the possible mechanism behind the investment leakage induced by the ETS could be that the ETS drives up the compliance cost of regulated firms and therefore incentivizes them to transfer investment to places with lower costs.

Although the direct compliance cost is hardly separately disclosed in the cost accounts (Cui and Zhou, 2017), all indirect compliance costs related to the ETS would be summed into the *Total Operating Cost* account. Thus, instead, we investigate the causal relationship between the ETS implementation and the total operating cost. The detailed explanation on why we choose to examine this indicator to explore the cost-boost mechanism is presented in Appendix. As shown in Table 5, the ETS significantly improved the regulated firms' total operating cost by 3.4 %, providing evidence for the cost-boosting mechanism.

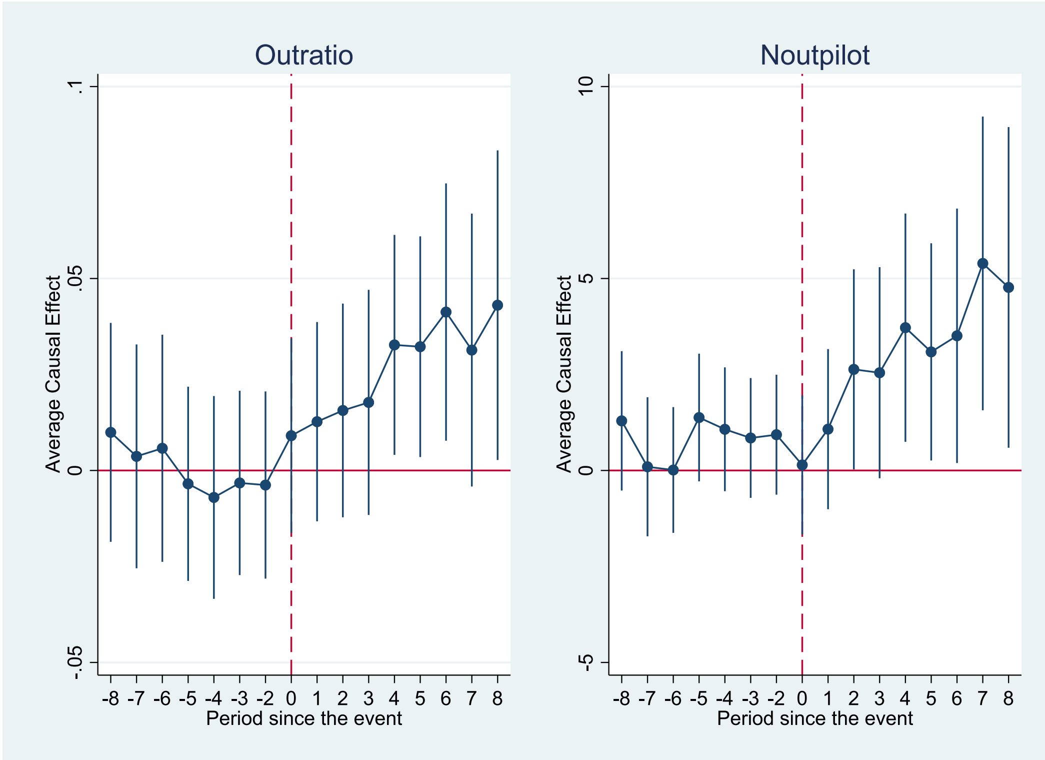

Fig. 1. Parallel trend test.

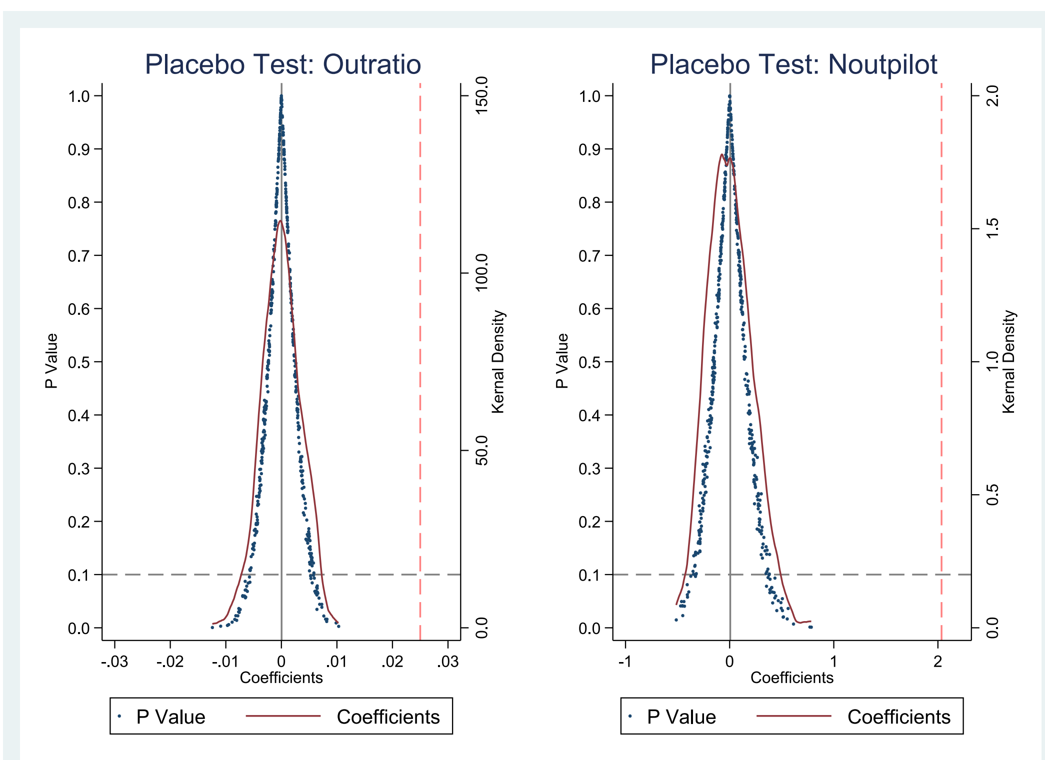

Fig. 2. Robustness check: Placebo test.

3.5.2. The moderating effect of regulation intensity

The regulation intensity is measured in two aspects: the number of pilot subsidiaries owned by firm i and the number of pilot markets to which firm i adheres, denoted by Npilotsubsidiary and Npilotmarket, respectively. If an A-share listed firm possesses many pilot subsidiaries, its total compliance cost will rise, and the carbon pricing signal it receives will also strengthen. Therefore, we anticipate that the more pilot subsidiaries a regulated firm owns, the larger its investment leakage

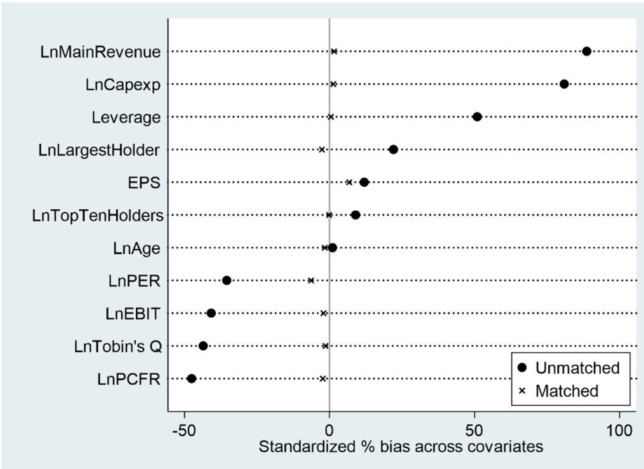

Fig. 3. PSM-Standardized bias across covariates.

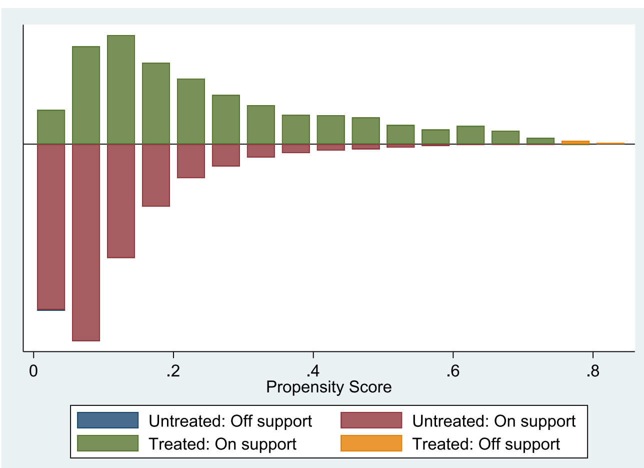

Fig. 4. PSM-Propensity score on and off support.

Table 4
Robustness check-PSM-DID.

	(1)	(2)
VARIABLES	PSM-Outratio	PSM-Noutpilot
newDID	0.026**	2.035*
	(2.36)	(1.78)
Constant	1.390***	−83.785***
	(2.95)	(−3.08)
Observations	29,976	29,976
R-squared	0.010	0.277
Number of ID	4480	4480
Control Variables	YES	YES
Company FE	YES	YES
Year FE	YES	YES

Robust t-statistics in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

tendency will be. Likewise, if an A-share listed firm is regulated by a greater number of pilot markets, we expect the firm to bear higher compliance costs and to deal with more ETS-related affairs. In this way, the firm ought to acquire more information on carbon pricing, making it more probable to relocate to the non-pilot area.

Columns (2) and (3) in Table 5 illustrate the moderating effects of Npilotsubsidiary and Npilotmarket on the ETS policy effect, respectively. Both of the coefficients of the interaction terms are significantly positive, indicating that the regulation intensity magnifies the impact of ETS on investment leakage. Besides, being regulated by multiple ETS pilot markets has a more pronounced influence on investment leakage than owning multiple pilot subsidiaries.

3.5.3. *The moderating effect of social responsibility*

As demonstrated by Dam and Scholtens (2008), the more environmentally and socially responsible a company is, the less likely it will be to transfer pollutants and avoid environmental regulation. Thus, the social responsibility level might moderate the investment leakage towards the non-pilot area. A corporate's Environmental-Social-Governance (ESG) rating could reflect its social and environmental responsibility. The higher the company's ESG rating is, the more socially responsible the company could be.

The results forcefully support our prediction and coincide with the findings of Dam and Scholtens (2008). As shown in column (4) in Table 5, the coefficient of the interaction term is significantly negative, implying that the regulated firms with higher ESG ratings have lower investment leakage levels and are less likely to shirk the emission abatement responsibility through transferring investment outside the pilot area.

3.6. *Heterogeneity analysis*

The investment pattern could differ vastly across sectors due to their divergent inherent features. To explore the heterogeneous effects of ETS across sectors, the sample firms are categorized in two different ways, corresponding to columns (1)–(2) and columns (3)–(5) in Table 6, respectively.

In fact, different to the previous study(Zhang and Wang, 2021), the pilot company list relates to 27 sectors, among which eight sectors are deemed as carbon-intensive and thus designed to be covered by the national ETS market, namely Power, Aviation, Chemical, Ferrous, Nonferrous Metal, Non-metal Mineral, Papermaking, and Petroleum, corresponding to the following two-digit industry codes: C22, C25, C26, C30, C31, C32, D44 and G56.

From columns (1)–(2) in Table 6, we observed that the regulated firms in the eight carbon-intensive sectors significantly expanded their investment outside the pilot area while there appears to be no significant effect on non-carbon-intensive regulated firms, affirming the necessity and urgency to cover the eight sectors into the national ETS market. Columns (3)–(5) in Table 6 depicts a detailed analysis of the distinct impacts experienced by capital-intensive, labor-intensive, and technology-intensive sectors. As indicated by Koch and Basse Mama (2019), the capital-intensive sector that relies heavily on capital input is anticipated to be less footloose and less prone to relocate in response to environmental regulations due to the high installation cost. The results in column (3) in Table 6 confirm this anticipation, indicated by the insignificant coefficient. By contrast, some sectors such as labor-intensive sectors are more footloose to relocate thanks to lower installation cost, thus could be more vulnerable to environmental regulations and more probable to transfer due to cost-benefit trade-off (Pennings and Sleuwaegen, 2000). This anticipation is supported by the results in column (4) that the regulated firms in the labor-intensive sector exhibit a significantly strong outward investment leakage pattern. The technology-intensive sector reports insignificantly inward investment leakage as showed in column (5), which might be attributed to the fact that the technology-intensive sectors is highly dependent on talents who agglomerate mainly in the economically-developed provinces which overlap with the pilot area.

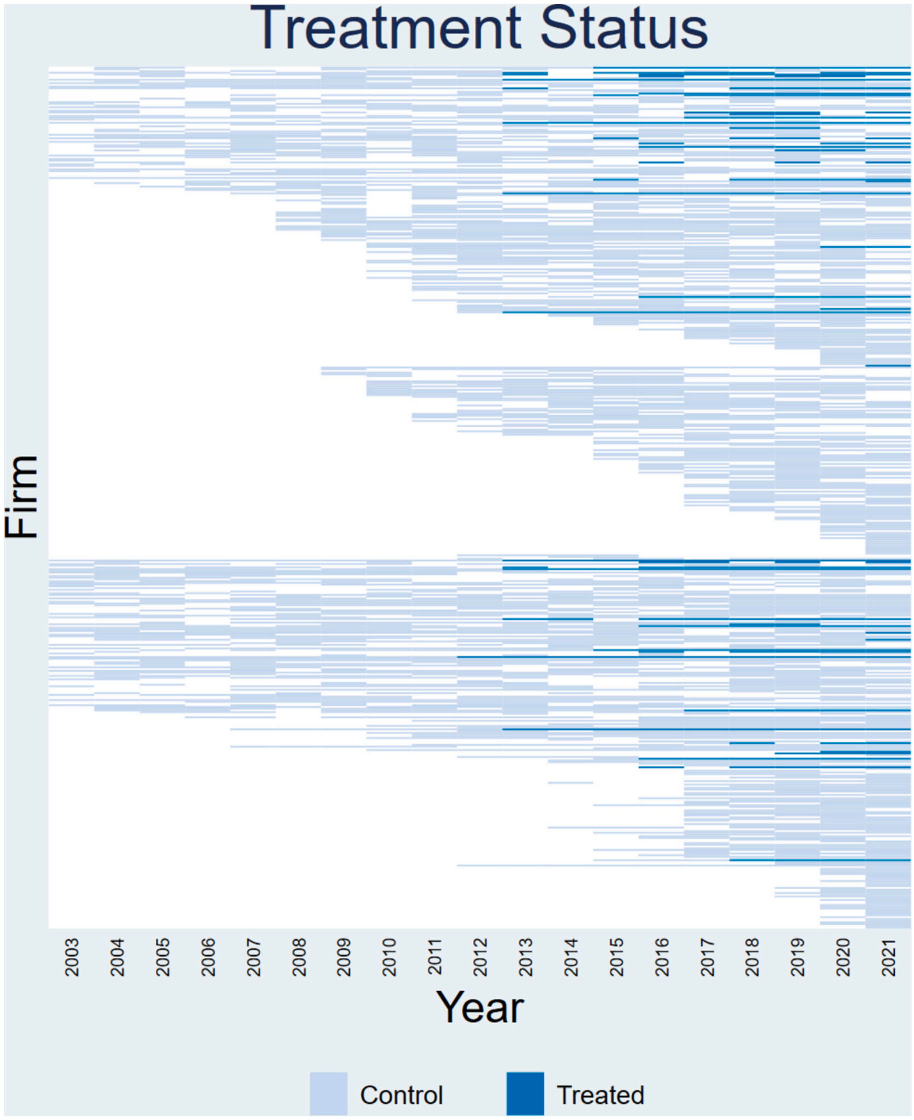

Fig. 5. Treatment status of each regulated firm.

4. Conclusions and policy implications

Investment leakage happens when regulated firms adjust their investment pattern by setting up more subsidiaries outside the pilot area than inside. In this paper, the investment leakage among the regulated firms induced by the China ETS is observed, which, to the best of our knowledge, is the first direct empirical econometric evidence of the domestic investment leakage accompanying the gradual ETS policy implementation in China.

The driver of the investment leakage could be the lifted compliance cost caused by the ETS, which motivates them to transfer investment outside the pilot area. The regulation intensity is a moderator, considering that the more restricted a firm is, the severer its investment leakage tend to be. Social responsibility also affects the investment leakage tendency significantly, given that the regulated firms with higher levels of social responsibility report lower levels of investment leakage, which complements the PHH theory by highlighting the moderating role of social responsibility.

The policy effects demonstrate vast heterogeneity across different sectors. Carbon-intensive and labor-intensive regulated firms are the two groups reporting the most significant investment leakage. We also find that the investment redistribution can happen not only through the direct channel but also through the indirect channel, particularly by involving more related transactions with subsidiaries outside the pilot area. In this way, regulated firms can achieve lower operating costs by avoiding the incremental cost induced by the ETS inside the pilot area, which explicitly illustrates how the uneven regulation alters regulated firms' investment and operating behavior.

Investment leakage to unregulated areas may result in relative employment loss and a decline in other economic activities, entailing long-term economic erosion within the regulated regions. Additionally, while focusing on investment leakage, this study may also imply the existence of long-lasting carbon leakage under China ETS, consistent with Gao et al. (2020), which undermines the environmental efficacy of ETS. Therefore, it illustrates the need for swift countermeasures, such as covering more carbon-intensive sectors into the national ETS market and compensating specific sectors at high risk of relocating with free allowances, to eliminate any negative effect of investment leakage.

However, this study also suffers from data limitations that might undermine the results' credibility. Hindered by data availability, we use a 2-digit industry classification code in our data processing, which is not precise enough to identify different businesses accurately. Therefore, as more detailed and comprehensive data accumulates, more firm-level econometric empirical research from different ETSs is encouraged to shed light on the investment leakage induced by ETS.

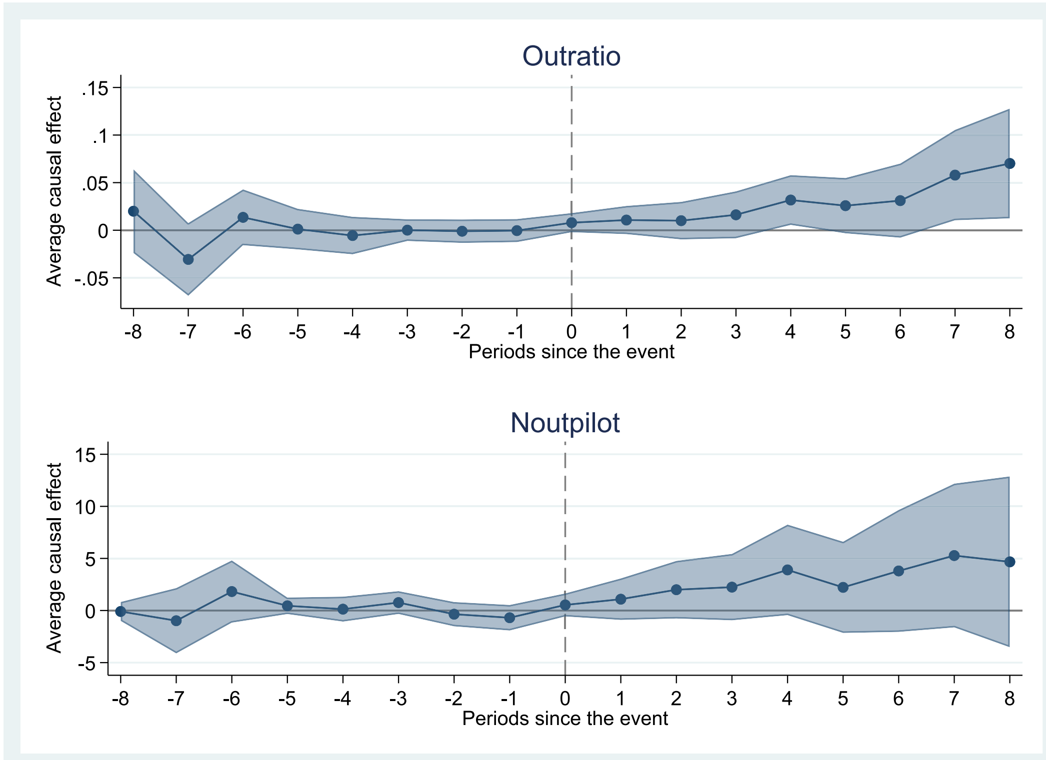

Fig. 6. HRE-de Chaisemartin and D'Haultfœuille, 2020.

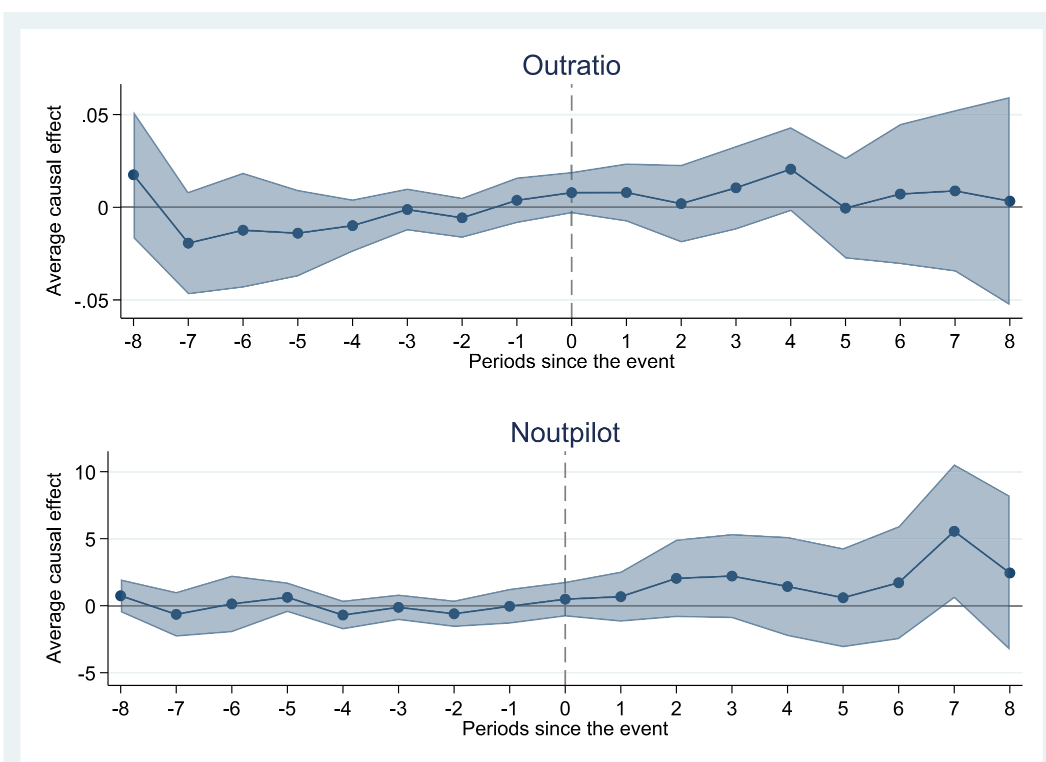

Fig. 7. HRE- Callaway and Sant'Anna, 2021.

CRediT authorship contribution statement

Ying Huang: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Kai Fang:** Writing – review & editing, Supervision, Conceptualization. **Gengyuan Liu:** Writing – review & editing, Supervision, Conceptualization. **Sujian Guo:** Writing – review & editing, Supervision, Conceptualization.

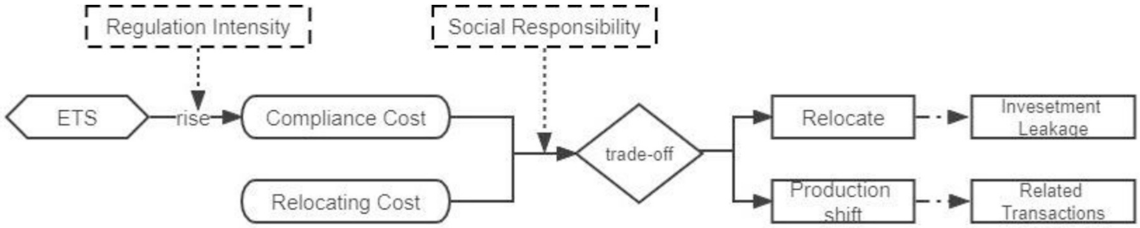

Fig. 8. Mechanism of investment leakage induced by ETS.

Table 5
Mechanism analysis.

	(1)	(2)	(3)	(4)
VARIABLES	OperatingCost	Noutpilot	Noutpilot	Noutpilot
post_ETS	0.034***	−1.652	−8.306***	11.396**
	(2.76)	(−1.44)	(−3.97)	(2.38)
post_ETS*Npilotsubsidiary		0.982***		
		(7.89)		
post_ETS*NpilotMarket			7.158***	
			(5.36)	
post_ETS*ESG				−6.999***
				(−2.73)
Constant	−0.323	−77.406***	−73.504***	−120.706
	(−0.86)	(−2.93)	(−2.83)	(−1.15)
Observations	30,026	30,026	30,026	3953
R-squared	0.974	0.289	0.289	0.324
Number of ID	4480	4480	4480	409
Control Variables	YES	YES	YES	YES
Company FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Robust t-statistics in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6
Heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)
GROUP	Non-carbon-intensive	Carbon-intensive	Capital-intensive	Labor-intensive	Tech-intensive
VARIABLES	Noutpilot	Noutpilot	Noutpilot	Noutpilot	Noutpilot
post_ETS	0.414	5.148**	1.495	3.941*	−0.586
	(1.321)	(2.026)	(1.800)	(2.195)	(1.648)
Constant	−77.69***	−95.40	−114.7**	−99.98*	−37.03
	(28.79)	(71.64)	(52.44)	(53.63)	(36.86)
Observations	24,700	5326	8428	8379	13,219
R-squared	0.270	0.318	0.313	0.293	0.265
Number of ID	3810	670	1232	1009	2239
Control Variables	YES	YES	YES	YES	YES
Company FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

Robust standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Detailed data processing description

The data used in this study comprises three parts: pilot firm list, financial statements, and subsidiary data. The pilot firm list is manually compiled by collecting information scattered on the official websites of each pilot province's development and reform commission and the department of ecology and environment. The firm-level financial data and information on subsidiaries are acquired from the CSMAR database.[4]

Detailed data processing is conducted in three steps. The first step is identifying the parent companies of the pilot firms by matching the pilot firm list and the subsidiary inventory.[5] Altogether, from 2012 to 2021, the pilot firm list of the eight pilots comprises 6008 entities, 837 of which are subsidiaries to 394 A-share listed firms (hereafter the regulated firms). It is these 394 companies that are referred to as the regulated firms in our study. The reasons for it are twofold.

On the one hand, the pilot firm list consists of more than 2000 entities, among which only 78 are A-share listed firms, meaning that very little publicly available firm-level data could be acquired for further empirical analysis. Therefore, to avoid the data limitations confronting the previous firm-level works, we reasonably extended the treated group to the A-share-listed parent companies of the pilot firms in the original inventory, enabling us to construct an unbalanced panel with 30,026 observations.

On the other hand, when a firm is announced as a pilot firm under ETS, it is reasonable to assume that its parent company receives the carbon price signal simultaneously. The parent company, as the biggest shareholder, determines the strategic decisions of subsidiaries. Under the rational-economic man hypothesis, just like its regulated subsidiary, the parent company is also inherently motivated to lower the operation cost through different pathways, including transferring investment to environmentally lenient areas. Eventually, there are 4480 A-share listed firms in our sample, with 394 firms deemed as regulated firms, and the left 4086 firms seen as unregulated.

The second step is calculating the number of subsidiaries in the pilot and non-pilot areas by recognizing each subsidiary's registered location.[6] Before 2016, the pilot area covered seven pilots: Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen; after 2016, the pilot area was expanded to include eight pilots by integrating Fujian. The non-pilot area corresponds to the left part of China mainland except the pilot area.

The third step is computing the dependent variables based on the number of subsidiaries.

Appendix B. Supplement content to section 3.5.1

Intuitively, the cost-boosting mechanism of the ETS on the investment leakage ought to be explored by examining whether the ETS boosts the direct compliance cost of the regulated firms. However, as indicated by the field survey on the accounting information disclosure under the China ETS (Cui and Zhou, 2017), most of the regulated firms choose to exclude the information on carbon allowance transactions from their financial reports, which severely impedes our attempt to acquire the financial data on the direct compliance cost with the ETS.

The compliance cost lifted by the ETS could be direct or indirect. First, the direct compliance cost comprises two categories: the cost for the carbon allowance transaction and surrender; the cost for emission abatement through technological innovation and equipment upgrading, usually recorded in the *Fixed Assets* account. Second, the indirect compliance cost refers to the related administrative expenses accompanying the carbon allowance transaction and technological innovation and upgrading.

Appendix C. Further descriptive statistics

Table A1
Difference between the treatment group and the control group.

Two-sample	*t*-test with equal variances				
Variables	G1(0)	Mean1	G2(1)	Mean2	MeanDiff
Outratio	25,954	0.668	4072	0.468	0.200***
Noutpilot	25,954	9.745	4072	14.456	−4.711***
LnLargestHolder	25,954	3.460	4072	3.566	−0.105***
LnTopTenHolders	25,954	4.049	4072	4.076	−0.027***
LnPER	25,954	3.742	4072	3.396	0.346***
LnPCFR	25,954	3.422	4072	2.863	0.559***
LnTobin's Q	25,954	0.579	4072	0.386	0.193***
LnEBIT	25,954	3.051	4072	2.808	0.243***
LnMainRevenue	25,954	21.279	4072	22.595	−1.316***
LnCapexp	25,954	18.530	4072	19.958	−1.428***
LnAge	25,954	2.722	4072	2.726	−0.005
Leverage	25,954	0.403	4072	0.499	−0.097***
EPS	25,954	0.519	4072	0.590	−0.071***
SecondindustryGDPratio	25,954	42.809	4072	39.637	3.172***
Lnavesalary	25,954	11.035	4072	11.035	0.000
CPI	25,954	102.322	4072	102.345	−0.023
Marketization	25,954	9.245	4072	9.354	−0.109***

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. G1(0) and G2(1) correspond to unregulated and regulated firms.

Table A1 reports the t-test results of all variables in baseline model, indicating that significant differences exist between the regulated and unregulated firms across most variables. Generally, compared with the unregulated firms, the regulated firms have relatively more subsidiaries outside the pilot area but with lower share in total investment, have more concentrated ownership structure, generate more revenue and EPS, but bear higher leverage.

[4] The financial data used in this study are the consolidated financial statements.

[5] The pilot firms solely participating in the national ETS market are excluded from the identification considering that the nation-wide ETS would make the relocation be meaningless and in vain.

[6] The subsidiaries we focus on in this paper are those registered in China mainland.

Table A2
Correlation coefficients.

	Outratio	Noutpilot	LnLargest Holder	LnTopTen Holders	LnPER	LnPCFR	LnTobin's Q	LnEBIT	LnMain Revenue	LnCapexp	LnAge	Leverage	EPS	Secondindustry GDPratio	Lnave salary	CPI	Marke tization
Outratio	1.000																
Noutpilot	0.259***	1.000															
	(0.000)																
LnLargestHolder	0.044***	−0.004	1.000														
	(0.000)	(0.492)															
LnTopTenHolders	0.004	−0.011*	0.622***	1.000													
	(0.529)	(0.068)	(0.000)														
LnPER	−0.042***	−0.193***	−0.144***	−0.158***	1.000												
	(0.000)	(0.000)	(0.000)	(0.000)													
LnPCFR	−0.082***	−0.193***	−0.123***	−0.017***	0.470***	1.000											
	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)												
LnTobin's Q	−0.072***	−0.148***	−0.155***	−0.106***	0.425***	0.496***	1.000										
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)											
LnEBIT	−0.129***	−0.101***	−0.205***	−0.220***	0.717***	0.462***	0.552***	1.000									
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)										
LnMainRevenue	0.037***	0.431***	0.154***	0.100***	−0.438***	−0.434***	−0.334***	−0.319***	1.000								
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)									
LnCapexp	0.095***	0.331***	0.130***	0.153***	−0.345***	−0.324***	−0.282***	−0.362***	0.683***	1.000							
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)								
LnAge	−0.034***	0.161***	−0.170***	−0.194***	−0.038***	−0.087***	0.052***	0.102***	0.198***	0.034***	1.000						
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)							
Leverage	0.066***	0.247***	0.044***	−0.114***	−0.112***	−0.364***	−0.338***	−0.043***	0.476***	0.286***	0.096***	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
EPS	0.008	0.131***	0.087***	0.221***	−0.449***	−0.085***	0.089***	−0.335***	0.299***	0.256***	0.045***	−0.075***	1.000				
	(0.176)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
Secondin dustryGDPratio	0.249***	−0.068***	0.016***	−0.058***	0.011*	−0.019***	−0.051***	−0.112***	−0.131***	−0.044***	−0.205***	0.051***	−0.076***	1.000			
	(0.000)	(0.000)	(0.005)	(0.000)	(0.065)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)				
Lnavesalary	−0.182***	0.135***	−0.088***	0.070***	−0.034***	0.071***	0.139***	0.143***	0.194***	0.088***	0.495***	−0.142***	0.183***	−0.635***	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
CPI	0.025***	−0.053***	0.018***	−0.023***	−0.080***	−0.048***	−0.108***	−0.124***	−0.045***	0.003	−0.143***	0.028***	−0.033***	0.180***	−0.240***	1.000	
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.594)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
Marketization	−0.255***	0.034***	−0.074***	0.074***	−0.035***	0.083***	0.108***	0.082***	0.075***	0.011*	0.286***	−0.147***	0.148***	−0.183***	0.649***	−0.155***	1.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.052)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

Notes: p-value in paratheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table A2 demonstrates the correlation coefficients for all variables in baseline model. It can be seen that most of the coefficients between the covariates and the dependent variables are statistically significant, indicating the effectiveness of the covariate selection.

Appendix D. Further robustness check: Proof from the related transaction with subsidiaries

Table A3
Further robustness check- Related transactions with subsidiaries.

	(1)	(2)	(3)	(4)
VARIABLES	Ntransac_outpilot	PSM-Ntransac_outpilot	Ntransac_inpilot	PSM-Ntransac_inpilot
post_ETS	−0.658	−0.417	4.225***	4.504***
	(−0.70)	(−0.41)	(8.15)	(8.08)
post_ETS*Carbonintensive	4.039***	4.235***	−1.806***	−1.866***
	(3.87)	(3.78)	(−3.14)	(−3.02)
Constant	−5807.696	−5546.824	−4306.946**	−3875.709*
	(−1.55)	(−1.48)	(−2.09)	(−1.88)
Observations	26,663	26,663	26,663	26,663
R-squared	0.228	0.228	0.191	0.191
Number of ID	3217	3217	3217	3217
Company FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Robust t-statistics in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The comprehensive perspective regarding the reallocation of resources by regulated firms in response to the ETS could be supplemented through an examination of the alterations in their related transaction behavior. Eq. (A.1) and Eq. (A.2) are estimated based on a new dataset combining the pilot firm list with a comprehensive dataset on the related transaction behavior of the A-share listed firms, where *Ntransac_outpilot* and *Ntransac_inpilot* correspond to the number of subsidiaries located outside and inside the pilot area that have related transactions with the parent company, *Carbon-intensive* denotes the eight carbon-intensive sectors mentioned in 3.6.

$$Ntransac_{outpilot_{it}} = \alpha_0 + \beta post_{ETS_{it}} + \delta post_{ETS_{it}}{*}Carbon-intensive_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{A.1}$$

$$Ntransac_{inpilot_{it}} = \alpha_0 + \beta post_{ETS_{it}} + \delta post_{ETS_{it}}{*}Carbon-intensive_{it} + \gamma X_{it} + u_i + v_t + \varepsilon_{it} \tag{A.2}$$

The results are shown in Table A3 where the regulated firms in the eight carbon-intensive sectors are significantly involved in more related transactions with subsidiaries outside the pilot area and fewer related transactions with subsidiaries inside the pilot area, which could be interpreted as another pathway to lower the overall compliance cost induced by the ETS besides directly transferring investment from the pilot area to the non-pilot area. This phenomenon is in line with the evidence provided by He and Chen (2023), who discovered that the ETS provoked production transfer from the pilot entities to non-pilot entities under the same conglomerate, which to some extent echoes the so-called *operational leakage* defined by Branger and Quirion (2014).

Appendix E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.108091.

References

Beck, T., Levine, R., Levkov, A., 2010. Big bad banks? The winners and Losers from Bank deregulation in the United States. J. Financ. 65, 1637–1667. https://doi.org/10.1111/j.1540-6261.2010.01589.x.

Böhringer, C., Balistreri, E.J., Rutherford, T.F., 2012. The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). In: Energy Econ., The Role of Border Carbon Adjustment in Unilateral Climate Policy: Results from EMF 29 34, pp. S97–S110. https://doi.org/10.1016/j.eneco.2012.10.003.

Böhringer, C., Schneider, J., Asane-Otoo, E., 2021. Trade in carbon and carbon tariffs. Environ. Resour. Econ. 78, 669–708. https://doi.org/10.1007/s10640-021-00548-y.

Böhringer, C., Fischer, C., Rosendahl, K.E., Rutherford, T.F., 2022. Potential impacts and challenges of border carbon adjustments. Nat. Clim. Chang. 12, 22–29. https://doi.org/10.1038/s41558-021-01250-z.

Branger, F., Quirion, P., 2014. Climate policy and the 'carbon haven' effect. WIREs Clim. Change 5, 53–71. https://doi.org/10.1002/wcc.245.

Brouwer, A.E., Mariotti, I., van Ommeren, J.N., 2004. The firm relocation decision: an empirical investigation. Ann. Reg. Sci. 38, 335–347. https://doi.org/10.1007/s00168-004-0198-5.

Callaway, B., Sant'Anna, P.H.C., 2021. Difference-in-differences with multiple time periods. J. Econ., Themed Issue: Treatment Effect 1 225, 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001.

Cui, Y.G., Zhou, C., 2017. Study on the current situation of carbon emissions trading and the accounting treatment in Beijing-Tianjin-Hebei region (in Chinese). Account. Res. 3-10+96.

Dam, L., Scholtens, B., 2008. Environmental regulation and MNEs location: does CSR matter? Ecol. Econ. 67, 55–65. https://doi.org/10.1016/j.ecolecon.2007.11.007.

de Chaisemartin, C., D'Haultfœuille, X., 2020. Two-way fixed effects estimators with heterogeneous treatment effects. Am. Econ. Rev. 110, 2964–2996. https://doi.org/10.1257/aer.20181169.

Dechezleprêtre, A., Nachtigall, D., Venmans, F., 2023. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. J. Environ. Econ. Manag. 118, 102758. https://doi.org/10.1016/j.jeem.2022.102758.

Dong, H., Liu, W., Liu, Y., Xiong, Z., 2022. Fixed asset changes with carbon regulation: the cases of China. J. Environ. Manag. 306, 114494. https://doi.org/10.1016/j.jenvman.2022.114494.

Du, H., Matthew, Q., Zhang, Y., Chen, W., 2023. Does emission trading system lead to reverse investment leakage: evidence from Chinese listed firms. Sustain. Prod. Consum. S2352550923000295. https://doi.org/10.1016/j.spc.2023.02.006.

Elliott, J., Foster, I., Kortum, S., Munson, T., Pérez Cervantes, F., Weisbach, D., 2010. Trade and carbon taxes. Am. Econ. Rev. 100, 465–469. https://doi.org/10.1257/aer.100.2.465.

Fischer, C., Fox, A.K., 2012. Comparing policies to combat emissions leakage: border carbon adjustments versus rebates. J. Environ. Econ. Manag. 64, 199–216. https://doi.org/10.1016/j.jeem.2012.01.005.

Freyaldenhoven, S., Hansen, C., Pérez, J.P., Shapiro, J.M., 2021. Visualization, Identification, and Estimation in the Linear Panel Event-Study Design.

Gao, Y., Li, M., Xue, J., Liu, Y., 2020. Evaluation of effectiveness of China's carbon emissions trading scheme in carbon mitigation. Energy Econ. 90, 104872. https://doi.org/10.1016/j.eneco.2020.104872.

Gerlagh, R., Kuik, O., 2014. Spill or leak? Carbon leakage with international technology spillovers: a CGE analysis. Energy Econ. 45, 381–388. https://doi.org/10.1016/j.eneco.2014.07.017.

He, L.-Y., Chen, K.-X., 2023. Does China's regional emission trading scheme lead to carbon leakage? Evidence from conglomerates. Energy Policy 175, 113481. https://doi.org/10.1016/j.enpol.2023.113481.

Huang, W., Zhang, Z.Y., Liu, A.R., 2022. From difference-in-differences to event study (in Chinese). Rev. Indust. Econ. 17–36. https://doi.org/10.19313/j.cnki.cn10-1223/f.20211227.002.

Kapitsinis, N., 2017. Firm relocation in times of economic crisis: evidence from Greek small and medium enterprises' movement to Bulgaria, 2007-2014. Eur. Plan. Stud. 25, 703–725. https://doi.org/10.1080/09654313.2017.1288703.

Koch, N., Basse Mama, H., 2019. Does the EU emissions trading system induce investment leakage? Evidence from German multinational firms. Energy Econ. 81, 479–492. https://doi.org/10.1016/j.eneco.2019.04.018.

Kronenberg, K., 2013. Firm relocations in the Netherlands: why do firms move, and where do they go? Pap. Reg. Sci. 92, 691–714. https://doi.org/10.1111/j.1435-5957.2012.00443.x.

Levinson, A., Taylor, M.S., 2008. Unmasking the pollution haven effect*. Int. Econ. Rev. 49, 223–254. https://doi.org/10.1111/j.1468-2354.2008.00478.x.

Liu, C., Sha, X.K., Zhang, Y., 2022. Staggered difference-in-differences method: heterogeneous Treatement effects and choice of estimation (in Chinese). J. Quant. Technol. Econ. 1–28. https://doi.org/10.13653/j.cnki.jqte.20220805.001.

Mattoo, A., Subramanian, A., Van Der Mensbrugghe, D., He, J., 2009. Reconciling climate change and trade policy. SSRN Electron. J. https://doi.org/10.2139/ssrn.1516053.

Meyfroidt, P., Lambin, E.F., 2009. Forest transition in Vietnam and displacement of deforestation abroad. Proc. Natl. Acad. Sci. 106, 16139–16144. https://doi.org/10.1073/pnas.0904942106.

Mou, H., Xu, Y., 2023. PANELVIEW: Stata module to visualize panel data. In: Stat. Softw. Compon.

Naegele, H., Zaklan, A., 2019. Does the EU ETS cause carbon leakage in European manufacturing? J. Environ. Econ. Manag. 93, 125–147. https://doi.org/10.1016/j.jeem.2018.11.004.

Pan, X., Yu, L., 2024. Do China's pilot emissions trading schemes lead to domestic carbon leakage? Perspective from the firm relocation. Energy Econ. 132, 107334. https://doi.org/10.1016/j.eneco.2024.107334.

Pennings, E., Sleuwaegen, L., 2000. International relocation: firm and industry determinants. Econ. Lett. 67, 179–186. https://doi.org/10.1016/S0165-1765(99)00269-4.

Peters, G.P., Hertwich, E.G., 2008. CO2 embodied in international trade with implications for global climate policy. Environ. Sci. Technol. 42, 1401–1407. https://doi.org/10.1021/es072023k.

Peters, G.P., Minx, J.C., Weber, C.L., Edenhofer, O., 2011. Growth in emission transfers via international trade from 1990 to 2008. Proc. Natl. Acad. Sci. 108, 8903–8908. https://doi.org/10.1073/pnas.1006388108.

Porter, M.E., 1991. America' green strategy. Sci. Am. 264, 168. https://doi.org/10.1038/scientificamerican0491-168.

Sleuwaegen, L., Pennings, E., 2006. International relocation of production: where do firms go? Scott. J. Polit. Econ. 53, 430–446. https://doi.org/10.1111/j.1467-9485.2006.00388.x.

Tan, X., Liu, Y., Cui, J., Su, B., 2018. Assessment of carbon leakage by channels: an approach combining CGE model and decomposition analysis. Energy Econ. 74, 535–545. https://doi.org/10.1016/j.eneco.2018.07.003.

The State Council Information Office of the People''s Republic of China, 2021. Responding to Climate Change: China's Policies and Actions. Beijing. http://english.scio.gov.cn/whitepapers/2021-10/27/content_77836502.htm.

Verde, S.F., 2020. The impact of the EU emissions trading system on competitiveness and carbon leakage: the econometric evidence. J. Econ. Surv. 34, 320–343. https://doi.org/10.1111/joes.12356.

Wang, F., Xia, J., Xu, J., 2020. To upgrade or to relocate? Explaining heterogeneous responses of Chinese light manufacturing firms to rising labor costs. China Econ. Rev. 60, 101333. https://doi.org/10.1016/j.chieco.2019.101333.

World Bank, 2022. State and Trends of Carbon Pricing 2022. World Bank, Washington, DC. http://hdl.handle.net/10986/37455.

Yu, P., Cai, Z., Sun, Y., 2021. Does the emissions trading system in developing countries accelerate carbon leakage through OFDI? Evidence from China. Energy Econ. 101, 105397. https://doi.org/10.1016/j.eneco.2021.105397.

Zhang, Y.-J., Wang, W., 2021. How does China's carbon emissions trading (CET) policy affect the investment of CET-covered enterprises? Energy Econ. 98, 105224. https://doi.org/10.1016/j.eneco.2021.105224.