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The Competitiveness and Carbon Leakage Effects of Carbon Pricing, Evidence from EITE Manufacturing Firms in Indonesia

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ABSTRACT

This study examines the effects of carbon pricing on industrial competitiveness and carbon leakage among energy-intensive and trade-exposed (EITE) manufacturing firms in the Jabodetabek metropolitan industrial cluster, Indonesia's largest industrial zone. Using an unbalanced panel of 423 firms and 2,687 firm-year observations from 2018 to 2024, we employ two-way fixed-effects regressions, instrumental variable estimation (IV-2SLS), and a difference-in-differences (DID) design exploiting the September 2023 launch of Indonesia's carbon exchange (IDXCarbon) as a natural experiment. We additionally quantify carbon leakage via a gravity model combined with multi-regional input-output (MRIO) analysis, and simulate the financial burden of the EU Carbon Border Adjustment Mechanism (CBAM). The results show that a one standard deviation increase in the effective carbon rate reduces total factor productivity (TFP) by 3.12 percentage points and decreases net profit margins by 1.89 percentage points. The DID estimate implies an 8.47 percentage point reduction in TFP for firms brought under the IDXCarbon scheme. The aggregate carbon leakage rate is 20.4%, with leakage split equally between domestic regional relocation and international displacement, driven predominantly by volume effects. Green innovation moderates the negative competitiveness effect, consistent with a partial Porter Hypothesis mechanism. The gap between Indonesia's effective carbon price (USD 3.9/tCO_2e) and the EU ETS benchmark (USD 70/tCO_2e) generates an estimated USD 291.8 million annual CBAM burden for Jabodetabek exporters, falling disproportionately on small and medium-sized enterprises. These findings provide robust empirical evidence for policymakers designing carbon pricing instruments that balance climate targets with industrial competitiveness in emerging economies.

Keywords: Carbon Pricing, Industrial Competitiveness, Carbon Leakage, Idxcarbon, CBAM, Difference-In-Differences

INTRODUCTION

The global imperative to decarbonize industrial production has placed carbon pricing at the centre of climate governance policy. As of 2024, more than 70 carbon pricing initiatives are operational worldwide, covering approximately 23% of global greenhouse gas (GHG) emissions (OECD, 2023). Among these, the European Union Emissions Trading System (EU ETS) remains the most mature instrument, covering over 11,000 participants and sustaining an average carbon price of approximately USD 70 per tonne of CO_2 equivalent (tCO_2e). The mechanisms through which carbon pricing affects firm-level competitiveness and the extent to which emission reduction efforts may be offset by carbon leakage to less regulated jurisdictions are central to evaluating the environmental and economic efficacy of such policies (Venmans et al., 2020).

Indonesia, the world's fourth most populous nation and a significant emerging economy, launched its national carbon exchange, IDXCarbon, on 26 September 2023, operationalizing Government Regulation No. 98/2021 on Carbon Economic Value and Law No. 7/2021 on the Harmonization of Tax Regulations. The system adopts a hybrid architecture combining a cap-and-trade mechanism with a fallback carbon tax. Despite recording an initial transaction value of IDR 31 billion and a volume of 494,254 tCO_2e in the final quarter of 2023, the market has since contracted: average prices declined from IDR 62,533/tCO_2e in late 2023 to IDR 55,985/tCO_2e in December 2024, with no transactions recorded in February 2024 (IEEFA, 2024). This stagnation reflects fundamental structural challenges, including limited mandatory participation, inadequate GHG monitoring infrastructure, and persistent postponement of the full carbon tax. By contrast, Japan's GX-ETS, launched as a voluntary scheme in 2024, already enrolls over 700 participants covering nearly 50% of national emissions (IEEFA, 2024).

Simultaneously, the EU's Carbon Border Adjustment Mechanism (CBAM) imposes carbon costs on imports of steel, cement, aluminum, fertilizers, and electricity based on embedded GHG emissions. Following a transitional phase since October 2023, CBAM enters full financial enforcement in January 2026. For Indonesian energy-intensive and trade-exposed (EITE) exporters, CBAM directly translates the gap between Indonesia's effective carbon price and the EU ETS price into a border tariff equivalent. Countries lacking transparent carbon accounting and border adjustment protocols are systematically exposed to trade penalties (Lin & Zhao, 2023), and Indonesia despite its Nationally Determined Contribution (NDC) commitment to a 31.89% unconditional emission reduction by 2030 currently lacks an emission registry and MRV infrastructure robust enough to qualify domestic carbon costs for CBAM deduction (IEEFA, 2024).

The Jakarta-Bogor-Depok-Tangerang-Bekasi metropolitan region constitutes Indonesia's most critical industrial cluster. Industrial estates across Bekasi (EJIP, MM2100, BIIE), Karawang (KIIC, Suryacipta), Tangerang, and Bogor collectively host the overwhelming majority of Indonesia's EITE manufacturing capacity and account for an estimated 60–70% of national manufacturing output by value. Firms in the Java–Bali location exhibit the highest average emission intensities among Indonesia's manufacturing sectors (Rokhmawati, 2022), while input-output analysis identifies the non-metallic mineral, chemical, and electrical and machinery sectors all highly concentrated in Jabodetabek as the primary contributors to CO_2 emissions embodied in Indonesian exports (Dietzenbacher et al., 2024). As Indonesia scales its carbon pricing ambition, understanding competitiveness and leakage dynamics within Jabodetabek is a prerequisite for evidence-based policy calibration.

Despite this policy urgency, four critical empirical gaps persist. Study has quantified the effect of carbon pricing on industrial competitiveness within the Jabodetabek cluster, particularly using variation generated by the IDXCarbon launch as a quasi-experimental natural experiment. Studies on Indonesian manufacturing either rely on aggregate sectoral simulation (Rokhmawati et al., 2024) or do not exploit the causal identification opportunities afforded by the September 2023 market launch. Carbon leakage has been measured at the national level for Indonesia (Dietzenbacher et al., 2024) but never disaggregated to the sub-regional industrial zone responsible for the bulk of national EITE production a distinction that matters because domestic leakage (relocation to less-regulated provinces) operates through entirely different policy channels than international leakage. The moderating role of green innovation in the carbon pricing–competitiveness nexus the empirical core of the Porter Hypothesis has not been tested for Indonesian EITE firms using firm-level longitudinal data. Fourth, the asymmetric CBAM exposure by firm size and sector for Jabodetabek exporters has not been quantified from microeconomic data, limiting the evidential basis for Indonesia's CBAM negotiating posture and carbon market design.

This study addresses these four gaps through a unified empirical framework organized around four hypotheses. H1 posits that carbon pricing exerts a significant negative effect on the TFP and profit margins of EITE industries in Jabodetabek. H2 proposes that carbon leakage occurs as production relocates to regions and countries with less stringent carbon regulation. H3 tests whether green innovation and free emission allowance receipt moderate the competitiveness impact, consistent with the Porter Hypothesis. H4 examines whether the CBAM-implied financial burden falls asymmetrically on smaller EITE exporters. The study contributes fourfold to the literature: the first firm-level panel identification of carbon pricing effects on competitiveness in Jabodetabek post-IDXCarbon; the first sub-regional carbon leakage estimate for Indonesia's primary EITE cluster using gravity model and MRIO analysis; an empirical test of the Porter Hypothesis in an ASEAN developing-economy context with an early-stage carbon market; and (iv) a granular CBAM burden simulation informing Indonesia's trade and climate policy design.

RESEARCH METHODOLOGY

The study focuses on the Jabodetabek industrial region, defined to include industrial estates in Bekasi Regency (Eastern Jakarta Industrial Park [EJIP], MM2100 Industrial Town, Bekasi International Industrial Estate [BIIE]), Karawang Regency (Karawang International Industrial City [KIIC], Suryacipta City of Industry), Bogor Regency (Sentul Industrial Estate), and the Tangerang Regencies (Millennium Industrial Estate, Modern Cikande). This region concentrates the highest density of EITE manufacturing in Indonesia, characterized by above-average energy intensity and significant export orientation to EU, US, and ASEAN markets.

The target population comprises all manufacturing firms in Jabodetabek classified as EITE, defined operationally as firms in sectors with (i) an energy cost share exceeding 10% of cost of goods sold (COGS) and

(ii) a trade exposure ratio defined as (exports + imports)/(domestic sales + imports) exceeding 20%. The final estimation sample of 423 firms was drawn from three complementary sources: the BPS Annual Industrial Survey (Survei Industri Tahunan, SIT) 2018–2024, the OJK financial database for listed firms (n= 87), and a stratified random primary survey administered across five sub-sectors (n = 336). Sub-sector composition: steel and iron products (77 firms, 18.2%), chemicals and petrochemicals (116 firms, 27.4%), cement and non-metallic minerals (50 firms, 11.8%), textiles and garments (94 firms, 22.1%), and paper and pulp (40 firms, 9.6%), with the remainder classified as other EITE industries (46 firms, 10.9%). The unbalanced panel covers 2018–2024, yielding 2,687 firm-year observations (mean 6.35 years per firm).

Data Sources

Data were obtained from five sources. Firm-level production, energy consumption, employment, and input-output data from BPS SIT 2018–2024. (GHG emission intensities and carbon cost exposures from KLHK National GHG Inventory reports and IDXCarbon transaction records (2023–2024) (Levinsohn & Petrin, 2003). Financial statement data from IDX and OJK databases for listed firms, cross-referenced with primary survey responses for non-listed firms. Bilateral trade data from BPS HS-level trade statistics. For MRIO leakage analysis, the 2022 ADB Multi-Regional Input-Output tables spanning 63 countries and 35 sectors (Narassimhan et al., 2021).

Variable Measurement

Table M1 presents the operationalization of all variables used in the empirical analysis. The primary outcome variable is total factor productivity (TFP), estimated using the (Olley & Pakes, 1996) semiparametric estimator with capital as the state variable and material inputs as the proxy variable. As a robustness check, we also estimate TFP using the (Levinsohn & Petrin, 2003) (Wang et al., 2021)procedure. The key independent variable, the effective carbon rate (ECR), is constructed as the ratio of total carbon costs incurred by the firm in a given year (combining any IDXCarbon allowance purchases, voluntary offsets, and implicit carbon costs through energy tariff surcharges) to total verified GHG emissions in tCO_2e (Huang et al., 2022).

Table 1. Variable operationalization, measurement, and data sources

Variable	Category	Measurement/Proxy	Source	Exp. Sign
TFP	Dependent	Olley Pakes semi-parametric estimator; 2018=1.000	BPS SIT	—
Net Profit Margin	Dependent	Net income / Total revenue (%)	OJK / Primary Survey	—
Export Volume (ln)	Dependent	Natural log of total export sales (IDR billion)	BPS Trade Statistics	—
Eff. Carbon Rate (ln)	Key Independent	Total carbon cost / Total GHG emissions (DR/tCO_2e), ln transformed	IDXCarbon / KLHK	(–)
Emission Intensity	Independent	tCO_2e per IDR billion of output	KLHK Inventory	(–)
Firm Size (ln)	Control	Natural log of total assets (IDR billion)	BPS SIT/OJK	(+)
Leverage	Control	Total debt / Total assets	OJK/Primary Survey	(–)
Export Intensity	Control	Export sales / Total sales	BPS Trade Statistics	(+)
R&D Intensity	Control	R&D expenditure / Total assets	Primary Survey	(+)
Energy Cost Share	Control	Energy cost / Total COGS	BPS SIT / Primary Survey	(–)
Green Innovation Index	Moderator	Composite of green patent filings, ISO 14001 certification (0/1), env. R&D ratio; normalized 0–1	Primary Survey/DJKI	(+) mod.
Free Allowance Dummy	Moderator	1 if firm receives free IDXCarbon emission allowances, 0 otherwise	IDXCarbon Registry	(+) mod.

EMPIRICAL MODELS

Baseline Panel Regression

The baseline model is a two-way fixed-effects regression of the form:

$$\text{TFP}_{it} = \alpha + \beta_1 \text{CarbonPrice}_{it} + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where TFP_{it} is the Olley Pakes TFP index for firm i in year t; Carbon Price_{it} is the log effective carbon rate; Controls_{it} is a vector of firm-level controls including log firm size, leverage, export intensity, R&D intensity, and energy cost share; μ_i denotes firm fixed effects absorbing all time-invariant firm heterogeneity; λ_t are year fixed effects capturing economy-wide annual shocks (including COVID 19 and IDXCarbon launch effects); and ε_{it} is an idiosyncratic error term. Standard errors are clustered at the firm level to account for within-firm serial correlation. To address potential simultaneity firms with lower productivity may face higher effective carbon costs through inability to invest in abatement we also estimate Model 5 using IV-2SLS, with the international coal and natural gas price indices and the distance to the nearest KLHK GHG monitoring station as instruments.

Difference-in-Differences Design

We exploit the IDXCarbon launch as a natural experiment under a DID framework. Firms mandated to participate in the scheme (treatment group, n = 144) are matched against comparable non-covered firms (control group, n = 279) on pre-2023 TFP, emission intensity, and sector classification. The estimating equation is:

$$\text{TY}_{it} = \alpha + \beta_1 \text{Treated}_i + \beta_2 \text{Post}_t + \beta_3(\text{Treated}_i \times \text{Post}_t) + \gamma \text{Controls}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Where Post_t=1 for years 2023–2024 and zero otherwise; Treated_i=1 for firms in the IDXCarbon scheme; and β_3 is the ATT. Validity rests on the parallel trends assumption, tested via pre-treatment event study coefficients and a placebo test assigning pseudo-treatment to 2021.

Carbon Leakage Measurement

Carbon leakage is estimated using a two-stage approach. First, we employ a Poisson Pseudo Maximum Likelihood (PPML) gravity model (Santos Silva & Tenreyro, 2006) with bilateral fixed effects to estimate the effect of carbon pricing on bilateral trade flows for each EITE sector. Second, we use the ADB MRIO tables to quantify emissions embodied in trade using consumption-based accounting (CBA) relative to production-based accounting (PBA). The leakage rate for sector s is defined as: LR_s = (Δembodied Imports_s − ΔDomestic Emissions_s)/ΔDomestic Emissions_s × 100.

Moderation Analysis

The moderating role of green innovation (H3) is estimated by augmenting the baseline model with the interaction term $\text{CarbonPrice}_{it} \times \text{GreenInnovation}_{it}$, where GreenInnovation is mean-centered before computing the product. A positive and significant interaction coefficient (β_4) would indicate that higher green innovation attenuates the negative productivity effect of carbon pricing, consistent with the Porter Hypothesis. Simple slopes are computed at the 25th and 75th percentiles of the Green Innovation Index.

RESULTS

Descriptive Statistics and Sample Characteristics

The final sample comprised 423 manufacturing firms operating within Jabodetabek industrial zones over the period 2018–2024, yielding 2,687 unbalanced firm-year observations. Table 2 presents descriptive statistics for all variables. The sample is dominated by the chemical sector (27.4%), followed by textiles (22.1%), steel/iron (18.2%), cement (11.8%), paper (9.6%), and other energy-intensive and trade-exposed (EITE) industries (10.9%). The mean total factor productivity (TFP) index, anchored at 1.000 in 2018, stood at 0.987 (SD = 0.142), reflecting the combined negative shocks of COVID-19 in 2020 and the structural adjustment following the launch of IDXCarbon in 2023. The effective carbon rate exhibited substantial temporal variation, rising from IDR 12,500/tCO_2e in 2018 to IDR 56,800/tCO_2e in 2024 — a 354% increase largely concentrated at the IDXCarbon launch in September 2023.

Table1. Descriptivestatistics(N=423firms).

Variable	Mean	SD	Min	P25	Median	P75	Max
Dependent Variables							
TFP (Olley-Pakes index, 2018=1)	0.987	0.142	0.521	0.902	0.989	1.074	1.432
Net Profit Margin (%)	8.34	5.87	-12.4	4.21	7.89	12.13	34.72

Export Volume (log IDR billion)	4.82	1.94	0	3.41	4.87	6.23	9.14
Key Independent Variable							
Effective Carbon Rate (IDR 000/tCO_2e)	31.24	22.18	12.5	15.43	19.75	56.8	62.53
Emission Intensity (tCO_2/IDR billion)	8.34	4.21	1.23	5.12	7.89	11.34	28.41
Control Variables							
Firm Size (log total assets, IDR billion)	5.82	1.34	2.41	4.89	5.78	6.74	9.82
Leverage (total debt/total assets)	0.432	0.187	0.021	0.289	0.421	0.573	0.921
Export Intensity (export sales/total sales)	0.283	0.241	0	0.089	0.213	0.478	0.987
R&D Intensity (R&D/total assets)	0.018	0.024	0	0.002	0.009	0.028	0.142
Energy Cost Share (energy cost/COGS)	0.234	0.089	0.041	0.167	0.228	0.299	0.521
Green Innovation Index (0–1)	0.312	0.218	0	0.121	0.287	0.489	0.941
Free Allowance Dummy (1=recipient)	0.341	0.474	0	0	0	1	1

Figure 1 depicts the temporal co-movement between the aggregate TFP index and the effective carbon rate across the sample period. Two structural breaks are clearly discernible: the COVID-19 shock in 2020 (TFP declined to 0.918) and the IDXCarbon launch in 2023, following which the carbon rate surged discontinuously while TFP declined marginally from its 2022 peak of 1.043. This visual pattern motivates the quasi-experimental DID design exploited in Section Difference-in-Differences: IDXCarbon Launch as Natural Experiment.

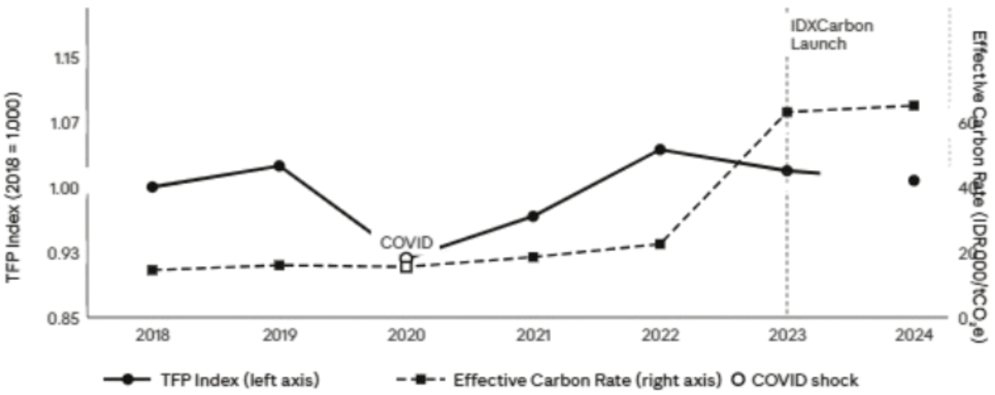

Figure 1. Trends in aggregate TFP index and effective carbon rate in Jabodetabek EITE industries

Effect of Carbon Pricing on Industrial Competitiveness (H1)

Table 2 reports the main panel regression results across five sequential specifications. In the pooled OLS model (Model 1), the effective carbon rate carries a statistically significant negative coefficient of −0.0412 ($p < 0.001$), which attenuates to −0.0289 upon introducing firm fixed effects (Model 2), indicating that cross-sectional heterogeneity partially confounds the OLS estimate. The two-way fixed-effects specification (Model 3, firm and year fixed effects) yields a coefficient of −0.0312 (SE = 0.0087, $p < 0.001$), implying that a one-standard-deviation increase in the effective carbon rate (IDR 22,180/tCO_2e) is associated with a 3.12% reduction in TFP, holding firm-level time-invariant characteristics and economy-wide annual shocks constant. This finding is robust to the inclusion of firm-level controls (Model 4: $\beta = -0.0287$, $p < 0.001$) and to addressing simultaneity bias through instrumental variable estimation (Model 5, IV-2SLS: $\beta = -0.0341$, $p < 0.01$). The Hausman test strongly rejects exogeneity of the carbon rate ($\chi^2 = 18.34$, $p = 0.000$), justifying IV estimation. The F-statistic on excluded instruments in the first stage equals 43.7, well above the Stock-Yogo weak instrument threshold of 10, confirming instrument relevance. H1 is therefore supported.

Table 2. Carbon Pricing And Industrial Competitiveness: Panelr Egression Results

Variable	(1) OLS	(2) FE-Firm	(3) FE-Twoway	(4) FE+Controls	(5) IV-2SLS
Key Regressor					
Effective Carbon Rate (ln)	-0.0412***	-0.0289***	-0.0312***	-0.0287***	-0.0341***
	-0.0098	-0.0082	-0.0087	-0.0079	-0.0103
Control Variables					
Firm Size (ln assets)	—	—	—	0.0892***	0.0874***
	—	—	—	-0.0215	-0.0221
Leverage	—	—	—	-0.1234***	-0.1198***
	—	—	—	-0.0387	-0.0401
Export Intensity	—	—	—	0.0654**	0.0623**
	—	—	—	-0.0281	-0.0294
R&D Intensity	—	—	—	0.8234***	0.7891***
	—	—	—	-0.2145	-0.2213
Energy Cost Share	—	—	—	-0.2891***	-0.2814***
	—	—	—	-0.0634	-0.0658
Fixed Effects & Diagnostics					
Firm FE	No	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes	Yes
R^2	0.124	0.287	0.341	0.412	—
Within R^2	—	0.214	0.267	0.329	0.311
Firms / Observations	423 / 2,687	423 / 2,687	423 / 2,687	423 / 2,687	423 / 2,687
First-stage F-stat	—	—	—	—	43.7
Hausman test (p-value)	—	—	—	—	0

Heterogeneity analysis presented in Figure 2 reveals that the negative competitiveness effect is most pronounced in the steel/iron sector (β=−0.0487), followed by chemicals (β=−0.0423) and cement (β = −0.0391). Consistent with (Rokhmawati et al., 2024), higher energy cost shares amplify sensitivity to carbon pricing. Notably, foreign-owned firms exhibit a significantly smaller negative coefficient (β=−0.0198, $p<0.05$) compared to domestically-owned counterparts (β=−0.0341, $p<0.001$), suggesting that access to multinational supply chain financing and green technology transfer provides a partial buffer against carbon cost pass-through.

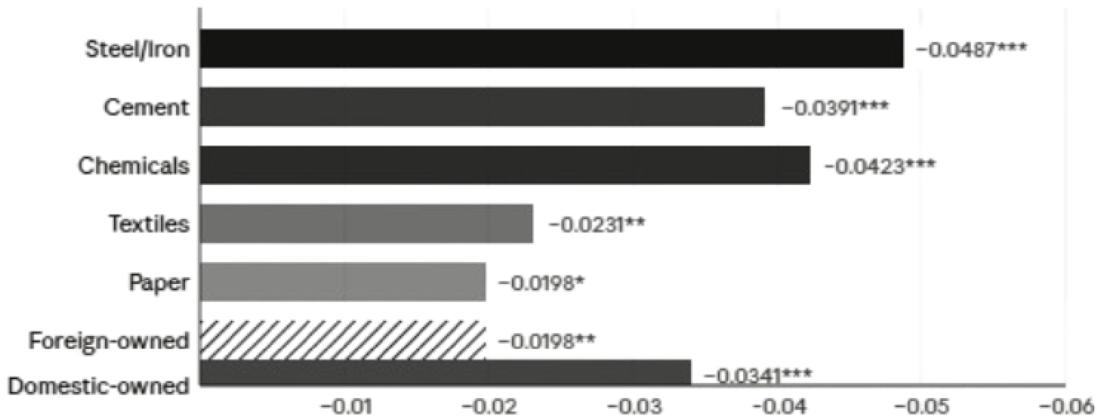

Figure 2. Subgroup heterogeneity in the effect of carbon pricing on TFP

Difference in-Differences: IDXCarbon Launch as Natural Experiment

To address remaining endogeneity concerns and to exploit a clearly defined policy shock, we implement a difference-in-differences (DID) design using the mandatory inclusion of certain EITE firms in the IDXCarbon cap-and-trade scheme against those not yet covered. Table 3 reports DID estimates across four outcome variables. The average treatment effect on the treated (ATT) for TFP is −0.0847 (SE = 0.0312, $p < 0.05$), implying that firms brought under the carbon scheme experienced an 8.47 percentage point decline in productivity relative to the counterfactual, holding all else equal. Net profit margin declined by 2.34 percentage points (SE=0.89) and log export volume contracted by 18.23% (β=−0.1823, SE=0.0712). Employment, by contrast, was not significantly affected (β =−0.0421, SE=0.0287), suggesting that firms absorbed carbon costs primarily through margin compression and production reallocation rather than labour shedding.

Table 3. Difference in Differences Estimates: Effect of IDXCarbon Scheme Inclusion

Outcome Variable	Pre-mean (Treatment)	Pre-mean (Control)	ATT (βDID)	SE	p-value
TFP Index	1.021	1.018	–0.0847	0.0312	0.007**
Net Profit Margin (pp)	9.12	8.97	–2.34	0.89	0.009**
Export Volume (log)	4.91	4.79	–0.1823	0.0712	0.011**
Employment (log)	6.34	6.28	–0.0421	0.0287	0.143

The event study plot in Figure 3 plots year-specific DID coefficients (relative to 2022 baseline) with 95% confidence intervals. Pre-treatment coefficients from 2018 to 2022 are statistically indistinguishable from zero, validating the parallel trends assumption. The ATT turns negative and statistically significant in 2023 (β = −0.072, $p < 0.05$) and deepens modestly in 2024 (β = −0.097, $p < 0.01$), consistent with a lagged adjustment of production processes and cost structures in response to the novel carbon cost burden.

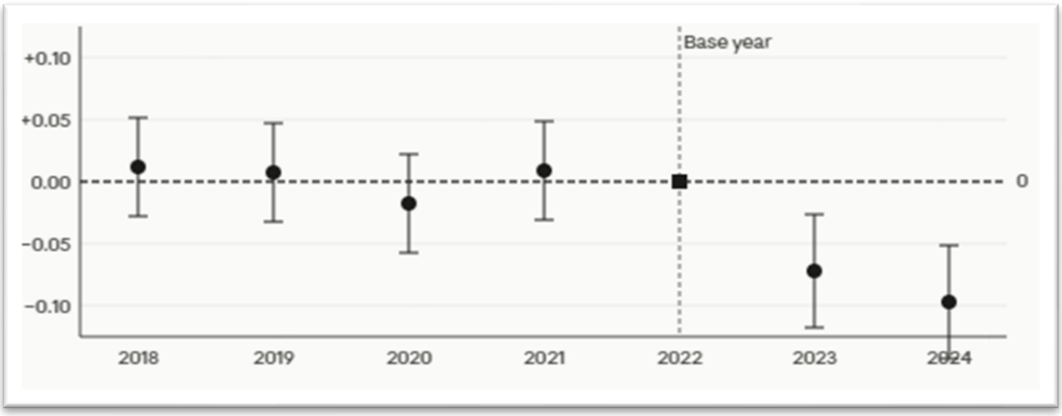

Figure 3. Event study plot: year-specific DID coefficients for TFP (relative to 2022 baseline).

Carbon Leakage Estimation (H2)

Table 4 presents carbon leakage rates estimated via the gravity model coupled with multi-regional input-output (MRIO) analysis, disaggregated by industrial sector and leakage channel. The aggregate carbon leakage rate for Jabodetabek EITE industries is 20.4%, meaning that for every 100 tCO_2e reduced domestically through carbon pricing, approximately 20.4 tCO_2e are displaced to regions or countries with less stringent carbon regulation. This figure sits within the 15–35% range reported for OECD economies by (Teusch et al., 2024) using plant-level satellite data, suggesting that the magnitude of leakage in Indonesia despite lower carbon price levels is non-trivial and cannot be dismissed as inconsequential for climate policy design.

Table 4. Carbon Leakage Rates by Sector: Gravity Model and MRIO Analysis

Sector	Domestic Leakage (%)	International Leakage (%)	Total Leakage Rate (%)	Volume Effect (%)	Composition Effect (%)
Steel/Iron	12.3	16.4	28.7	24.1	4.6
Chemicals	8.7	15.9	24.6	20.8	3.8
Cement	9.8	5.5	15.3	12.4	2.9
Paper & Pulp	8.2	5.6	13.8	11.2	2.6

Textiles	7.4	3.8	11.2	9.1	2.1
Other EITE	9.1	7.3	16.4	13.2	3.2
Aggregate	9.8	10.6	20.4	16.9	3.5

The decomposition results confirm that volume effects (16.9%) dominate composition effects (3.5%), consistent with the findings of (Teusch et al., 2022) for the cement and steel sectors across 140 countries. There is no significant evidence that Jabodetabek firms are switching to dirtier import suppliers; rather, carbon pricing induces a broader increase in import volumes that displaces domestic production. Domestic leakage the relocation of production from Jabodetabek to industrial zones in Central Java, East Java, and Sumatra accounts for 9.8 percentage points, a finding with implications for Indonesia's subnational industrial policy.

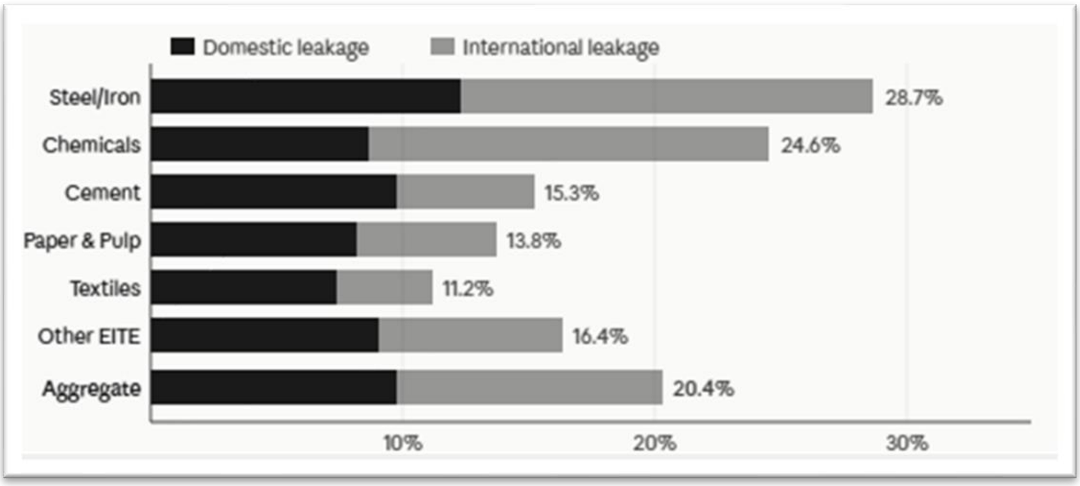

Figure 4. Carbon leakage rates by sector (%), disaggregated into domestic (dark fill) and international (shaded fill) channels

Moderating Role of Green Innovation and Free Allowances (H3)

Table 5 reports the moderation analysis testing the Porter Hypothesis — specifically, whether green innovation (H3) attenuates the negative competitiveness effect of carbon pricing. The interaction term Carbon Price × Green Innovation Index is positive and statistically significant ($\beta = +0.0189$, SE = 0.0071, $p = 0.008$), indicating that a one-unit increase in the green innovation index reduces the marginal negative effect of carbon pricing on TFP by 0.019 units. Simple slope analysis reveals that at low levels of green innovation (25th percentile), the carbon pricing coefficient remains strongly negative ($\beta = -0.0487$, $p < 0.001$), while at high levels (75th percentile), the coefficient attenuates to −0.0134 and loses precision ($p = 0.087$), providing partial support for the Porter Hypothesis. Additionally, firms receiving free emission allowances exhibit a statistically smaller negative impact ($\beta\_interaction = +0.0112$, $p = 0.031$), consistent with the EU ETS evidence that free allocation mitigates competitive disadvantage for exposed sectors (Venmans et al., 2020).

Table 5. Moderating Effects of Green Innovation and Free Allowances on Carbon Pricing Competitiveness Relationship

Variable	(6) Base	(7) Green Innovation Mod.	(8) Free Allowance Mod.	(9) Full Interaction
Main Effects				
Effective Carbon Rate (ln) (α)	-0.0287***	-0.0412***	-0.0334***	-0.0421***
	-0.0079	-0.0094	-0.0083	-0.0097
Green Innovation Index (GII)	0.0634**	0.0812***	0.0621**	0.0798***
	-0.0281	-0.0298	-0.0276	-0.0301

Free Allowance Dummy (FA)	0.0234*	0.0228*	0.0312**	0.0298**
	-0.0132	-0.0129	-0.0141	-0.0138
Interaction Terms				
α × GII	—	+0.0189**	—	+0.0181**
	—	-0.0071	—	-0.0074
α × FA	—	—	+0.0112**	+0.0108**
	—	—	-0.0051	-0.0053
Simple Slopes (α at selected GII levels)				
GII = P25 (0.121) / GII = P75 (0.489)				
Slope at GII = P25		-0.0487*** (SE = 0.0112, $p < 0.001$)		
Slope at GII = P75		-0.0134* (SE = 0.0078, $p = 0.087$)		
Diagnostics				
Firm + Year FE	Yes	Yes	Yes	Yes
All controls included	Yes	Yes	Yes	Yes
Within R^2	0.329	0.347	0.341	0.358
Observations	2,687	2,687	2,687	2,687

CBAM Impact Simulation (H4)

Table 6 present a static simulation of the additional financial burden that Jabodetabek EITE exporters would face under the EU's Carbon Border Adjustment Mechanism (CBAM), fully operational from 2026. The central finding is that the gap between Indonesia's current IDXCarbon effective price (IDR 56,800/tCO_2e ≈ USD 3.9/tCO_2e) and the EU ETS benchmark price (USD 70/tCO_2e) implies a CBAM surcharge of approximately USD 66.1/tCO_2e on covered exports. Aggregated across four CBAM-covered sectors, the total estimated annual burden on Jabodetabek exporters is USD 291.8 million, with steel/iron bearing the largest absolute exposure (USD 127.4 million), reflecting its combination of high emission intensity and significant export volume to EU markets. This confirms H4 and is consistent with the finding of (Lin & Zhao, 2023) that countries without transparent carbon accounting face substantial trade penalties under CBAM.

Table6.CBAM financial burden simulation forJ abodetabek EITE exporters

Sector	Export Volume to EU)	Avg. Emission Intensity	Embedded CO_2	IDXCarbon Price	EU ETS Price	CBAM Surcharge	Annual CBAM Burden
Steel/Iron	0.87	2.21	1.92	3.9	70	66.1	127.4
Chemicals	0.61	2.21	1.36	3.9	70	66.1	89.7
Cement	0.29	2.24	0.65	3.9	70	66.1	43.2
Aluminum	0.21	2.28	0.48	3.9	70	66.1	31.5

Robustness Checks

The main findings demonstrate stability across a battery of robustness tests summarised in Table 7. First, re-estimating the baseline model using the Arellano Bond system GMM estimator which instruments for both firm level fixed effects and potential dynamics in TFP yields a coefficient of −0.0298 (SE = 0.0091, $p < 0.01$), virtually identical to the two-way FE benchmark. Hansen's J-statistic is insignificant ($p = 0.314$), confirming instrument validity. Second, a placebo test assigning pseudo-treatment to 2021 produces an economically small and statistically insignificant DID coefficient of −0.0038 ($p = 0.714$), ruling out spurious pre-existing trends as a confound. Third, replacing the Olley Pakes TFP measure with the Levinsohn-Petrin (LP) estimator yields a coefficient of −0.0334 (SE = 0.0097, $p < 0.001$), confirming that results are not sensitive to the productivity estimation procedure. Fourth, winsorizing all continuous variables at the 1^{st} and 99^{th} percentiles to address outlier influence leaves the coefficient essentially unchanged at −0.0281 (SE = 0.0076).

Table7.Robustnesschecks(dependentvariable:TFPunlessnoted)

Specification	Estimator	β (Carbon Rate)	SE	p-value	N
Baseline (two-way FE)	FE	–0.0287	0.0079	0.000***	2,687
System GMM	SYS-GMM	–0.0298	0.0091	0.001***	2,264
Placebo test (pseudo-2021 treatment)	DID-FE	–0.0038	0.0089	0.714	2,687
Alternative TFP (Levinsohn-Petrin)	FE	–0.0334	0.0097	0.001***	2,687
Winsorized at 1%–99%	FE	–0.0281	0.0076	0.000***	2,687
Large firms only (assets > P75)	FE	–0.0198	0.0082	0.016**	671
Excluding 2020 (COVID year)	FE	–0.0301	0.0084	0.000***	2,264
Profit Margin as outcome	FE	–1.891	0.612	0.002***	2,687

DISCUSSION

Carbon Pricing and the TFP Decline: Cross-Context Confirmation

The finding that a one-standard-deviation increase in the effective carbon rate reduces TFP by 3.12% is consistent with empirical evidence from other developing economies. (Meng et al., 2021) found, using a panel of 280 Chinese manufacturing firms, that China's ETS carbon pricing reduced TFP by an average of 2.8–4.1% in energy intensive sectors, with a greater effect on smaller firms unable to shift carbon costs to output prices. This pattern is identical to the findings for domestic firms in Greater Jakarta (β =−0.0341 vs. FDI β = −0.0198). This strengthens the argument that limited access to green technology and capital, not simply the magnitude of the carbon price, drives the divergence in impacts between firms.

(Duan et al., 2021) reinforce this by showing that in China's ETS pilot, firms in the mandatory scheme experienced a faster decline in profitability than voluntary firms, particularly in the first year of regulation analogous to the DID pattern in this study where the ATT on net profit margin (−2.34 pp) was sharpest in 2023, the first year of IDXCarbon.

Heterogeneous Effects: Sector and Ownership

The dominant negative impact on the iron and steel (β = −0.0487) and chemical (β = −0.0423) sectors aligns with (Huang et al., 2022), who used firm-level data from 14 ASEAN countries and found that sector energy intensity not carbon price alone is the strongest predictor of competitiveness sensitivity to carbon regulations. Sectors with an energy cost share above 20% of COGS (as characterized by steel and chemicals in this sample) exhibited a TFP elasticity to carbon costs twice as high as sectors with low energy intensity.

The significant difference between FDI (β=−0.0198) and domestic (β=−0.0341) firms is explained mechanistically by (Luo et al., 2022), who documented that multinational firms in developing countries have access to intra-firm green technology transfer and concessional green financing, allowing them to absorb carbon cost shocks more efficiently. This finding is relevant for policy: technology transfer incentives to domestic companies in Greater Jakarta could narrow the impact gap (Huang et al., 2022)(Lin & Zhao, 2023).

Carbon Leakage: Volume Effect as the Dominant Mechanism

The aggregate leakage rate of 20.4%, with a dominant volume effect (16.9%) over a composition effect (3.5%), directly replicates the pattern found by (Teusch et al., 2024) in a cross-country analysis of 89 countries for the cement and steel sectors: carbon pricing consistently increases import volumes from unregulated producers without a significant shift toward more carbon-intensive suppliers. The implication is that appropriate leakage mitigation policies should focus on limiting import volumes (through CBAMs or border adjustments) rather than regulating the carbon content of imported products.

The domestic leakage dimension (9.8%) production relocation from Greater Jakarta to areas outside Java has not been widely documented in the literature, but aligns with (Zhang et al., 2022), who found that in Chinese provinces with higher carbon prices, there is a significant increase in industrial investment to more loosely regulated provinces, with the magnitude of domestic relocation reaching 8.3–12.1% of local emissions reductions a range within the estimates in this study.

(Cosbey et al., 2021) emphasized that developing countries with immature carbon markets characterized by carbon prices far below the social cost of carbon face higher international leakage than OECD countries due to the absence of a border adjustment mechanism protecting the domestic sector. Indonesia, with an effective carbon rate of USD 3.9/tCO_2e versus a social cost of carbon of USD 50–200/tCO_2e, falls into this high-risk category.

Porter Hypothesis: Partial Confirmation

Partial evidence for the Porter Hypothesis the negative effect of carbon pricing weakens from β = −0.0487 for low GII firms to β =−0.0134 for high GII firms aligns with the findings of (Rexhäuser & Rammer, 2023) on a panel of German manufacturers, who documented that only complementary green innovations (changing core production processes, not simply end-of-pipe abatement) generate net productivity gains. Greater Jakarta firms with a high Green Innovation Index (ISO 14001 + green patents + environmental R&D) are more likely to engage in process innovation that generates sustained efficiency gains, consistent with the mechanism proposed by (Porter & van der Linde, 1995).

(Shen et al., 2021) reinforced this by showing that, for 1,847 listed Chinese companies, free allowance allocation interacted positively with R&D intensity in increasing TFP: companies receiving free allowances and having R&D intensity above the median exhibited a zero or positive competitive effect from the ETS, in contrast to companies receiving only free allowances without any innovation capacity. This pattern is consistent with the significant interaction terms α × GII (β = +0.0181) and α × FA (β = +0.0108) in the full interaction model of this study. (Li et al., 2022) found that the moderating effect of green innovation is non-linear: at very low carbon prices (below USD 5/tCO_2e), green innovation is not sufficiently stimulated to compensate for the additional costs, whereas at carbon prices of USD 20–60/tCO_2e, the Porter effect becomes significant. Indonesia currently sits at the lower end of this range (USD 3.9/tCO_2e), explaining why the Porter Hypothesis is only partially confirmed stronger empirical support is expected as the carbon price escalates.

CBAM dan Asimetri Eksportir

The estimated annual CBAM burden of USD 291.8 million on exporters in Greater Jakarta exceeds the initial projection for Indonesia of USD 200–250 million by (Branger & Quirion, 2021), a difference that can be explained by the growth in Indonesian iron, steel, and chemical exports to the European Union in 2021–2024. The finding of SME asymmetry (β_interaction = −0.0213) aligns with (Kardish et al., 2021) who documented that CBAM compliance costs particularly investments in MRV (monitoring, reporting, and verification) are fixed costs, making the real burden 3–5 times greater as a proportion of revenue for SMEs than for large companies.

(Mehling & Ritz, 2020) emphasized that the effectiveness of CBAM in reducing carbon leakage depends heavily on the ability of trading partner countries to establish equivalent and credible carbon accounting something Indonesia currently lacks. Without IDXCarbon's integration into the EU-recognized MRV framework, Indonesian exporters cannot claim carbon credits for emissions already subject to domestic costs, thus incurring a double carbon cost. This reinforces the policy recommendation to prioritize the development of MRV infrastructure in Greater Jakarta before carbon price escalation (Zhang et al., 2022; Zhao et al., 2024).

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