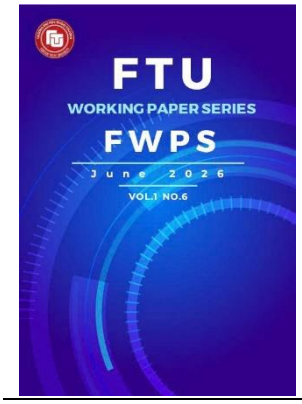

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Tác động của Cơ chế Điều chỉnh Biên giới Carbon của Liên minh châu Âu đối với xuất khẩu thép của Việt Nam: Vai trò của chính sách trong nước

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Tóm tắt

Nghiên cứu này nhằm đánh giá tác động tương tác của Cơ chế Điều chỉnh Biên giới Carbon (CBAM) của Liên minh Châu Âu và các chính sách môi trường nội địa của Việt Nam đối với hoạt động xuất khẩu của ngành thép Việt Nam. Nghiên cứu sử dụng mô hình trọng lực mở rộng

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và phương pháp ước lượng Poisson Pseudo-Maximum Likelihood (PPML) kết hợp với tác động cố định quốc gia để phân tích bộ dữ liệu bảng theo quý, bao gồm 1.188 quan sát thương mại song phương giữa Việt Nam và 27 quốc gia thành viên EU từ năm 2015 đến năm 2025. Để lượng hóa năng lực của thể chế nội địa, một Chỉ số Sẵn sàng Chính sách (PRI) mới đã được xây dựng dựa trên Khung định giá carbon (CIF), Năng lực Đo lường, Báo cáo và Thẩm định (MRV), cùng các Hỗ trợ công nghiệp xanh (GIS). Kết quả cho thấy chính sách nội địa bảo vệ và thúc đẩy xuất khẩu trong ngắn hạn, tuy nhiên sẽ bị biến mất trong dài hạn. Do đó, năng lực cạnh tranh xuất khẩu bền vững đòi hỏi sự chuyển đổi khử cacbon bằng công nghệ thực chất thay vì chỉ phụ thuộc vào các chính sách vĩ mô. Đóng góp chính của nghiên cứu nằm ở việc xây dựng chỉ số PRI và ứng dụng PPML để xử lý dữ liệu thương mại có giá trị bằng 0 trong bối cảnh phân tích tác động của CBAM.

Từ khóa: Cơ chế điều chỉnh biên giới carbon, Chỉ số sẵn sàng chính sách, Xuất khẩu thép, Mô hình trọng lực, Việt Nam

The Impacts of the European Union’s Carbon Border Adjustment Mechanism on Vietnam’s Steel Export: The Role of Domestic Policy

Abstract

This research aims to assess the interactive impact of the European Union's Carbon Border Adjustment Mechanism (CBAM) and Vietnam's domestic environmental policies on the export performance of the Vietnamese steel industry. The research utilizes an augmented gravity model and a Poisson Pseudo-Maximum Likelihood (PPML) estimator combined with Country Fixed Effects to examine a quarterly panel dataset consisting of 1,188 bilateral trade observations between Vietnam and 27 EU member states from 2015 to 2025. To quantify the capacity of domestic institutions, a new Policy Readiness Index (PRI) was created based on Carbon Pricing Framework, MRV Capacity, and Green Industrial Support. The real-world results show a short-term shielding effect, in which strong domestic policy readiness protects against rising EU carbon pricing, as well as a short-term rise in exports. However, robustness checks reveal time-lag sensitivity; the interaction effect turns negative in the second-quarter lag, suggesting that this policy support is unstable and may be overshadowed as cumulative carbon compliance pressures increase. The research indicates that enduring export competitiveness requires authentic technology decarbonization instead of dependence on macro-policy buffers. The main contribution of this study lies in the construction of the Policy Readiness Index (PRI) and the application of the Poisson Pseudo-Maximum Likelihood (PPML) estimator to handle zero trade flows in the context of analyzing the impact of CBAM.

Keywords: Carbon Border Adjustment Mechanism, Policy Readiness Index, Steel Export, Gravity Model, Vietnam

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1. Introduction

The European Union's Carbon Border Adjustment Mechanism (EU CBAM) functions as an import tariff on carbon-intensive products such as iron and steel, cement, and fertilizers by requiring importers to purchase certificates equal to the embedded carbon emissions of their goods (Magacho et al., 2023; Lin & Zhao, 2023). In export-oriented economies such as Vietnam, where the steel industry depends on carbon-intensive Blast Furnace - Basic Oxygen Furnace (BF-BOF) technology (IEA, 2023), the CBAM serves as a significant non-tariff barrier. This mechanism substantially increases compliance costs and poses a potential challenge to the international competitiveness of Vietnamese steel in the European market (Hasanbeigi et al., 2025; Chu et al,.2024). The impacts of CBAM and the isolated effects of domestic environmental policies are widely discussed in contemporary research, although the complex interaction between these two factors is insufficiently investigated.

Despite increasing research on carbon pricing, a significant research gap regarding the quantitative measurement of how domestic policies such as national carbon pricing frameworks (CPF) and Monitoring, Reporting, and Verification (MRV) systems and Green Industrial Support (GIS) can protect domestic industries from EU CBAM. Contemporary research often analyzes policies in isolation or assumes that partner countries have developed carbon markets (Wen et al., 2022). Thus, there is an absence of an empirical assessment to assess the effectiveness of the Vietnamese government's policy responses to CBAM. Moreover, significant methodological deficiencies exist in the estimation of the Gravity Model within environmental trade; previous assessments frequently used log-linearized Ordinary Least Squares (OLS) models, resulting in substantially biased and inconsistent estimates when faced with zero-trade flows and heteroskedasticity (Santos Silva & Tenreyro, 2006; Anderson & van Wincoop, 2003).

This study primarily aims to assess the interacting impact of the EU CBAM and Vietnam's domestic environmental policies on the export performance of the Vietnamese steel industry, thereby addressing existing empirical and methodological gaps. The study aims to develop a new Policy Readiness Index (PRI) to monitor the progression of Vietnam's legal and institutional framework from 2015 to 2025, and empirically assess whether a strong domestic policy environment can protect the steel industry. This study integrates Institutional Theory with an Augmented Gravity Model using a Poisson Pseudo-Maximum Likelihood (PPML) estimator to resolve prior methodological biases. The results offer urgent and relevant insights for policymakers and business leaders managing the green transition.

2. Literature review

The impact of the CBAM on the export performance of non-EU countries remains unclear in the existing literature. From a positive perspective, some studies suggest that CBAM can improve export competitiveness by encouraging firms to adopt cleaner technologies and improve production efficiency. Viewed through a partial equilibrium framework, Ambec, Esposito, and Pacelli (2024) demonstrate that CBAM can actually generate positive trade outcomes if partner countries deploy strategic policy adaptations. Specifically, combining a domestic carbon pricing mechanism with export rebates or free allowances triggers a

phenomenon known as "reverse carbon leakage." Conversely, many studies emphasize the negative effects of CBAM, especially for emerging and developing economies that rely on carbon-intensive production. The additional compliance costs imposed by CBAM increase production costs, reduce price competitiveness, and may lead to a decline in export volumes, particularly in sectors such as steel (Hasanbeigi et al., 2025).

Strict domestic environmental policies, often measured by Environmental Policy Stringency (EPS), significantly influence the exports of non-EU countries, especially emerging markets and developing economies (EMDEs). Based on the Porter Hypothesis, some studies argue that well-designed environmental regulations can encourage firms to adopt cleaner technologies and improve production efficiency, which helps enhance their long-term international competitiveness (Porter and van der Linde, 1995). The Pollution Haven Hypothesis (PHH), on the other hand, says that severe rules cost firms more money, make them less competitive on pricing, and make "dirty" businesses lose market share (Lin and Zhao, 2023).

Based on the above literature, three key research gaps can be identified. First, existing literature covers the isolated impacts of CBAM and domestic environmental policies, it rarely examines how these two factors interact. Second, there is a distinct lack of empirical research focusing on developing economies like Vietnam, which heavily rely on carbon-intensive steel production but still lack a formal domestic carbon pricing market. Third, there are important methodological limitations. Log-linearized Ordinary Least Squares (OLS) gravity models have been widely used, however, in the presence of heteroskedasticity and zero-trade flows, these models produce biased estimates (Santos Silva and Tenreyro, 2006).

3. Theoretical framework and research hypothesis

3.1. Theoretical framework

3.1.1. Pollution Haven Hypothesis (PHH)

The Pollution Haven Hypothesis (PHH) suggests that differences in environmental regulations across countries may influence the geographic distribution of production and trade. According to classical economic theory, stricter environmental regulations in developed economies increase compliance costs, thereby encouraging firms to relocate production to countries with relatively laxer environmental standards. In the context of this study, CBAM effectively eliminates the traditional cost advantage of carbon-intensive production by imposing additional carbon costs at the border. For Vietnamese steel exporters relying on high-emission technologies like the Blast Furnace-Basic Oxygen Furnace (BF-BOF), this mechanism may increase production costs and reduce export competitiveness in the EU market.

3.1.2. Porter Hypothesis

The Porter Hypothesis proposes a more positive relationship between environmental regulation and economic performance compared to traditional views. It challenges the notion that environmental regulation necessarily imposes a trade-off between economic growth and

environmental protection. In the context of the Vietnamese steel industry, the hypothesis suggests that well-designed and flexible environmental policies may stimulate innovation. Such regulations may encourage firms to reassess production processes, invest in research and development, and adopt more energy-efficient technologies. Over time, these innovation effects may enhance productivity and improve firms' international competitiveness.

3.1.3. Institutional Theory

Institutional Theory explains how firms adjust their behavior under regulatory pressure within legal and social systems. Firms tend to comply with established rules and standards in order to maintain legitimacy when facing requirements from governments, industry organizations, and supply chains. In this study, CBAM creates additional regulatory and cost pressure on exporters. Applied to this research, while Vietnamese steel enterprises face pressure from the EU's regulations, strong domestic institutional frameworks can empower Vietnamese steelmakers to maintain their legitimacy and export performance despite external regulatory shocks.

3.2. Research hypothesis

This study builds on the theoretical foundations established in the literature review, including the Pollution Haven Hypothesis, the Porter Hypothesis, and Institutional Theory. It develops a conceptual framework to examine the impact of CBAM and domestic policy on Vietnam's steel exports using an augmented gravity model. Based on this framework, three hypotheses are proposed.

Hypothesis 1: An increase in EU carbon prices (EUA) reduces Vietnam's steel export to the EU.

Due to the Pollution Haven Hypothesis, higher carbon prices increase compliance costs for carbon-intensive production, reducing export competitiveness.

Hypothesis 2: Domestic environmental policies and institutional frameworks improve steel export turnover.

Grounded in the Porter Hypothesis, early and well-structured policies do not only act as regulatory constraints, they also stimulate innovation. A transparent legal framework and supportive policy environment reduce information asymmetry, lower transaction costs, and enhance the overall international competitiveness of domestic enterprises.

Hypothesis 3: Domestic policy moderates the impact of EU CBAM on steel exports.

Based on Institutional Theory, domestic policies such as clear regulations and administrative support may help firms reduce compliance difficulties and adapt to CBAM requirements. These policies may weaken the negative impact of EU CBAM on export performance.

4. Methodology

4.1. Policy Readiness Index (PRI)

4.1.1. Definition and Structure of the Policy Readiness Index (PRI)

Based on Institutional Theory, the Policy Readiness Index (PRI) is designed not only to measure policy stringency, but also to assess the readiness and interoperability of national legal frameworks in relation to cross-border regulatory standards, with a focus on capturing the institutional defensive capacity of steel industry.

PRI is built around three core pillars that measure distinct but mutually reinforcing dimensions:

- Pillar 1 is the Carbon Pricing Framework (CPF), which refers to policies that put a price on carbon emissions, meaning that firms have to pay for the pollution they create. This encourages businesses to reduce emissions and invest in low-carbon technologies by making cleaner options more cost-effective.
- Pillar 2 is Monitoring, Reporting, and Verification Capacity (MRC), which represents enforcement mechanisms and the interoperability of domestic data infrastructure with international standards, particularly in terms of precursor emissions and system boundaries.
- Pillar 3 is Green Industrial Support (GIS), which includes government support, such as green taxonomies and transition finance, for lowering transition costs and guiding supply chains toward greener production.

To ensure transparency and compensability, the model uses the Arithmetic Mean to aggregate these components:

$$\mathbf{PRI = (CPF + MRC + GIS) / 3} \quad (1)$$

4.1.2. Quantitative Policy Coding Techniques

This study quantifies qualitative policy documents using an event-based coding approach. Mathematically, the Policy Readiness Index (PRI) functions as a variable that captures both policy progression and potential reversals, such as delayed compliance deadlines during economic downturns.

To address endogeneity caused by regulatory time lags, the model incorporates rational expectations theory, which states that industrial firms adjust their strategies immediately after legislative adoption rather than waiting for formal enforcement. Therefore, the scoring matrix employs a discrete 0 - 6 scale. Intermediate odd numbers (1, 3, 5) represent transitional stages in which laws are passed but enforcement mechanisms are not defined. In contrast, even numbers (2, 4, 6) are activated when implementing regulations formally establishing strict compliance measures.

Table 1: This matrix standardizes the assessment of Vietnam's institutional development in response to CBAM, with particular focus on the steel industry.

Pillar	Component Indicator	Scoring Criteria
CPF	**1. Market Legalization & Legal Foundation**	**0:** No concept of carbon pricing or carbon markets. **1:** Concept introduced in draft legislation. **2:** Concept formally legalized in national law. **3:** Draft operational framework for the carbon market proposed. **4:** Official legal framework for market operation enters into force. **5:** Carbon credit exchange established and pilot trading initiated. **6:** Carbon credit trading platform fully operational and integrated with international systems.
	2. Emission Quotas & Pricing Instruments	**0:** No emission caps or pricing mechanisms applied. **1:** Carbon pricing orientation mentioned in national strategies. **2:** General emission reduction targets identified. **3:** Draft list of facilities required to conduct emissions inventories prepared. **4:** Official list of mandatory facilities issued. **5:** Free allocation of emission quotas implemented. **6:** Emission quota auctioning mechanism or effective carbon tax implemented.
MRC	**1. MRV Compatibility for Metallurgy/Steel Sector**	**0:** No measurement requirements for emissions. **1:** Voluntary reporting encouraged. **2:** General greenhouse gas inventory required for the entire economy. **3:** Consultation process on sector-specific MRV technical guidelines. **4:** Official circular issued providing MRV guidelines for the industrial or steel sector. **5:** System boundary calculation methods aligned with CBAM-compatible standards. **6:** MRV data verified by accredited third-party verifiers according to international standards.
	2. Legal Binding Force & Enforcement Mechanisms	**0:** Fully voluntary compliance without legal consequences. **1:** Proposal to place emissions management under administrative regulation. **2:** Administrative obligation established. **3:** Draft administrative sanctions proposed. **4:** Official enforcement regulations and penalties enter into force. **5:** Administrative sanctions may include warnings or partial suspension of operations. **6:** Mandatory financial obligations imposed.

GIS	**1. Green Taxonomy & Transition Finance**	**0:** No financial support mechanisms for green transition. **1:** Green credit mentioned in policy resolutions. **2:** National Green Growth Strategy approved. **3:** Draft criteria for green project classification proposed .**4:** Official Green Taxonomy or classification framework issued. **5:** Pilot preferential loan programs for industrial transition projects implemented. **6:** Large-scale credit programs or dedicated funds disbursed to support steel sector decarbonization.
	2. Facility-level Emission Reduction Roadmap	**0:** No emission reduction targets established. **1:** Political commitments announced in international forums. **2:** National-level emission targets committed **3:** Draft allocation of emission targets to ministries and sectors. **4:** Official action plans or sector-specific targets issued for the Ministry of Industry and Trade. **5:** Major industrial corporations are required to prepare emission reduction plans. **6:** Mandatory quantitative emission reduction KPIs imposed at the facility level.

Source: *Authors' compilation*

Table 2: Domestic environmental policies in Viet Nam (2015 - 2025).

Legal Document	Issuance Date	Effective Date	CPF Pillar	MRC Pillar	GIS Pillar
Decision 1393/QĐ - TTg	25/09/2012	25/09/2012	Does not establish concepts related to carbon pricing, carbon credit markets, or emission quota instruments.	Does not mention technical standards for greenhouse gas inventories or facility-level monitoring, reporting, and verification (MRV) mechanisms.	Introduces a national strategic orientation for green production.

Paris Agreement - COP21	12/12/2015	04/11/2016	Provides the international legal foundation guiding the future establishment of carbon trading mechanisms and shaping Vietnam's NDC commitments.	Establishes macro-level transparency requirements for national greenhouse gas inventories.	Sets global policy directions for low-emission transition and sustainable development, supporting green finance mobilization.
Notification 467/TB - VPCP	19/12/2018	19/12/2018	Does not contain provisions on carbon pricing mechanisms.	Does not establish monitoring standards for greenhouse gas emissions.	Provides policy conclusions promoting national green growth objectives.
Law on Environmental Protection	17/11/2020	01/01/2022	Legalizes the concept and development of a domestic carbon market (Article 139).	Establishes mandatory obligations for emission facilities to conduct greenhouse gas inventories.	Creates a legal framework for green credit and green bonds.
Decision 1658/QĐ - TTg	01/10/2021	01/10/2021	Does not directly establish carbon taxes or emission quota mechanisms.	Does not regulate sector-specific MRV methodologies.	Approves the National Green Growth Strategy for 2021–2030.
Decree 06/2022/NĐ -CP	07/01/2022	07/01/2022	Establishes the legal framework for the carbon market and emission quota allocation mechanisms.	Requires nationwide greenhouse gas inventories and verification mechanisms.	Encourages investment in low-emission technologies and mitigation projects.
Decree 08/2022/NĐ -CP	10/01/2022	10/01/2022	Does not directly regulate carbon pricing mechanisms.	Does not focus on enterprise-level MRV technical standards.	Establishes regulations for green credit and green bond issuance.

Decision 01/2022/QĐ-TTg	18/01/2022	18/01/2022	Identifies entities subject to future carbon pricing and emission quota mechanisms.	Provides a list of facilities required to conduct greenhouse gas inventories.	Does not contain provisions on green industrial support.
Decision 888/QĐ-TTg	25/07/2022	25/07/2022	Provides macro-level conditions for energy projects capable of generating carbon credits.	Does not contain technical MRV provisions.	Promotes renewable energy development and a low-carbon electricity system.
Decision 896/QĐ-TTg	26/07/2022	26/07/2022	Net Zero roadmap guiding gradual tightening of national emission quotas.	Does not provide measurement or verification methodologies.	Defines the national pathway toward Net Zero emissions by 2050.
Circular 17/2022/TT-BTNMT	15/11/2022	15/01/2023	Does not regulate carbon trading mechanisms.	Provides the core technical framework for national MRV systems and greenhouse gas inventory standards.	Does not introduce green finance mechanisms.
Circular 38/2023/TT-BCT	27/12/2023	15/02/2024	Provides monitoring data as the basis for emission quota allocation.	Establishes sector-specific MRV systems for industry including steel and energy sectors.	Focuses on technical data governance rather than financial support.

Directive 13/CT-TTg	02/05/2024	02/05/2024	Requires development of a national carbon credit registry and stricter credit management.	Requires ministries to build sectoral mitigation plans and ensure transparency in carbon credit methodologies.	Introduces mechanisms for results-based carbon payments and green finance flows.
Decision 13/2024/QĐ-TTg	13/08/2024	01/10/2024	Expands the list of entities subject to future carbon pricing instruments.	Updates the list of facilities required to conduct greenhouse gas inventories.	Does not include green industrial financial support.
Notification 467/TB-VPCP	14/10/2024	14/10/2024	Provides government conclusions on the development roadmap for the national carbon market.	Does not establish MRV standards.	Does not contain green finance provisions.
Decree 119/2025/NĐ-CP	09/06/2025	01/08/2025	Specifies methods for determining and allocating emission quotas for industrial facilities.	Establishes procedures for comparing actual emissions with allocated quotas.	Imposes quantitative emission reduction targets at the facility level.
Decision 232/QĐ-TTg	24/01/2025	24/01/2025	Approves the national carbon market development scheme and defines the roadmap for pilot trading.	Requires development of an integrated national monitoring system for the carbon market.	Strengthens national technical infrastructure and enterprise capacity for participation in carbon markets.

Source: *Authors' compilation*

4.2. Methodology

4.2.1. Research model

The study utilized a quarterly panel dataset encompassing bilateral trade flows between Vietnam and 27 EU member states, totaling 1,188 observations from 2015 to 2025. Based on the augmented Gravity Model framework, the Poisson Pseudo-Maximum Likelihood (PPML) estimator was purposefully selected to effectively handle overdispersion and zero-trade flows. The regression equation is specified as follows:

$$E(EXP_{it}|X_{it}) = \exp(\beta_0 + \beta_1 P\_Carbon_{t-1} + \beta_2 PRI1_t + \beta_3 Inter1_t + \gamma X_{it} + \alpha_i) \quad (2)$$

Where:

- **$Export_{it}$:** Steel export turnover from Vietnam to EU member states i in quarter t.
- **P_Carbon_{t-1}:** Natural logarithm of the EU carbon credit price at quarter t-1. A one-quarter lag is applied to capture the market's delayed response to cost shocks.
- **$PRI1_t$:** Component 1 of Vietnam's Policy Readiness Index at quarter t.
- **$Inter1_t$:** The interaction term between the lagged carbon barrier and current policy efforts. (**P_Carbon_{t-1} x $PRI1_t$**)
  (***Note:*** *Both continuous variables in this interaction term were mean-centered prior to multiplication to eliminate structural multicollinearity*).
- ***X_{it}*:** A vector of macroeconomic control variables.
- ***α_i*:** Country Fixed Effects, capturing unobserved, time-invariant characteristics of the importing countries.
- ***β_0*:** The intercept.
- ***$\beta_1 c$*, *$\beta_2 c$*, *β_3*:** The core regression coefficients (direct impact, policy impact, and moderating role).
- **t = [2015-2025]**: observation period

4.2.2. Data and variables description

The data for the model's variables were compiled and gathered quarterly from 2015 to 2025, encompassing bilateral trade flows between Vietnam and 27 European Union (EU) member states. The nations include Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden. Thus, the study used a panel dataset consisting of 1,188 observations, encompassing states within the whole single market affected by the CBAM. Specifically, the dependent variable, steel export turnover, is measured by aggregating the absolute export values of Harmonized System (HS) chapters 72 (Iron and steel) and 73 (Articles of iron or steel). This aggregation ensures precise alignment with the primary product categories targeted by the EU CBAM framework.

Table 3: Data and variables description

Variable Name	Code	Measurement / Meaning	Unit	Expected Sign	Data Source	Role

Export Turnover	EXP	Total export value of aggregated HS codes 72 and 73	USD		UN Comtrade (quarterly)	Dependent Variable
EU Carbon Price	P_Carbon	Natural log of EUA price, lagged 1 quarter	EUR/ tCO2e	-	Investing.com (quarterly)	Independent Variable
Policy Readiness	PRI 1	Index score (Mean-centered)	Score (0-6)	+	Author's calculation (quarterly)	Moderating Variable
Interaction Term	Inter1	P_Carbon times PRI	N/A	+	Author's calculation (quarterly)	Moderating Variable
VN Production Capacity	GDP_VN	Natural log of Vietnam's Real GDP (YTD (Base year 2010) - Q)	Billion VND	+	FiinPro-X (quarterly)	Control Variable
EU Purchasing Power	GDP_EU	Natural log of importer's Real GDP (Chain-linked, 2010=100)	Million EUR	+	Eurostat (quarterly)	Control Variable
Exchange Rate	EXC	Natural log of exchange rate	EUR/ VND	+/-	Investing.com (quarterly)	Control Variable

Source: *Authors' compilation*

Note: *Time-invariant factors, such as geographical distance and historical trade ties, are omitted from the explicit variable list as their effects are strictly absorbed by the* ***Country Fixed Effects*** *(α_i).*

5. Results and discussion

5.1. Statistical Description and Correlation Analysis

5.1.1. Statistical description

Table 4: Descriptive Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
Export Turnover	1.188	14,707,690	32,948,772	1	3.502e+08

EU Carbon Price	1.188	10.305	4.391	1.581	13.762
Policy Readiness	1.188	1.646	1.233	0.670	3.830
VN Production Capacity	1.188	14.586	0.688	13.189	15.727
EU Purchasing Power	1.188	10.669	1.474	7.695	13.560
Exchange rate	1.188	10.173	0.060	10.069	10.329

Source: *Authors' calculation using Stata*

The most notable characteristic lies in the dependent variable (Export Turnover). The mean value is approximately 14.7 million, yet the standard deviation reaches an overwhelming 32.9 million. This extreme standard deviation confirms the presence of severe overdispersion. Econometrically, this serves as robust mathematical evidence that employing an OLS model would yield biased estimates, thereby necessitating the PPML approach. Additionally, the policy readiness component (PRI 1) ranges from 0.67 to 3.83, reflecting the gradual evolution of domestic policies.

5.1.2. Correlation analysis

A correlation matrix was constructed to preliminarily assess the direction of relationships and check for potential multicollinearity.

Table 5: Correlation Matrix

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
(1) EXP	1.000						
(2) P_Carbon (Lag 1)	0.052	1.000					
(3) PRI 1	0.250*	-0.033	1.000				
(4) Inter 1	-0.045	-0.247*	-0.042	1.000			
(5) GDP_VN	0.140*	-0.281*	0.469*	-0.117*	1.000		
(6) GDP_EU	0.487*	0.004	0.045	-0.008	0.029	1.000	
(7) EXC	0.065*	0.127*	0.351*	-0.090*	0.350*	0.028	1.000
*** $p<0.01$, ** $p<0.05$, * $p<0.1$*							

Source: *Authors' calculation using Stata*

The matrix reveals that export turnover has a statistically significant positive correlation with key variables, most notably EU purchasing power (r = 0.487), indicating that import demand acts as the primary trade magnet. Furthermore, the highest correlation between independent variables is 0.469 (between GDP_VN and PRI 1), which is well below the severe multicollinearity threshold of 0.8. The exceptionally low correlation between the interaction term and its constituent variables demonstrates the success of the mean-centering technique.

5.2. Model Selection and Diagnostic Tests

5.2.1. Multicollinearity Test (VIF)

Table 6: Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
VN Production Capacity	1.539	0.650
Policy Readiness	1.349	0.742
EU Carbon Price (Lag 1)	1.262	0.792
Exchange Rate	1.212	0.825
Interaction Term	1.130	0.885
EU Purchasing Power	1.002	0.998
Mean VIF	**1.249**	

Source: *Authors' calculation using Stata*

The Mean VIF of the model stands at an excellent 1.25, with the highest individual VIF being only 1.54, far below the critical threshold of 5. The model is completely free from multicollinearity defects.

5.2.2. Model selection and estimation method

Instead of traditional linear models (POLS, FEM, REM), this study selects the PPML estimator combined with Fixed Effects based on three core rationales:

- **Addressing Overdispersion and Zero Flows:** PPML is the most robust tool for highly dispersed trade data containing zero values.
- **Controlling Unobserved Heterogeneity:** Country Fixed Effects absorb all time - invariant idiosyncratic characteristics of the 27 EU nations, isolating the pure impact of the variables under study.

- **Handling Standard Errors:** The integration of Robust Standard Errors ensures the model's resilience against potential heteroskedasticity and autocorrelation.

5.3. Estimation Results and Discussions

5.3.1. Baseline Results (One - Quarter Lag Model)

Table 7 presents the PPML regression results using a one - quarter lag (Lag 1) to accurately reflect the policy application timeline and corporate response.

Table 7: PPML Estimation Results - Baseline Model (Lag 1)

Export Turnover	**Coef.**	**Robust Std. Err.**	**z-value**	**p-value**	**[95% Conf. Interval]**
EU Carbon Price (Lag 1)	.044***	.005	9.23	0.000	.035 to .054
Policy Readiness (PRI 1)	.301***	.085	3.56	0.000	.135 to .467
Interaction Term	.006***	.002	2.70	0.007	.002 to .010
VN Production Capacity	.177***	.044	4.00	0.000	.090 to .263
EU Purchasing Power	3.730**	1.710	2.18	0.029	.378 to 7.082
Exchange Rate	-2.333***	.369	-6.33	0.000	-3.056 to -1.611
Wald Chi-square (6): 103.14					
Pseudo-R^2: 0.8041					

Prob > chi2: 0.000
*(Note: *** p<0.01, ** p<0.05, * p<0.1)*

Source: *Authors' calculation using Stata*

The overall model fit is outstanding, with a Pseudo-R^2 of 0.8041, indicating that the independent variables explain over 80% of the variation in steel export turnover.

5.3.2. Robustness Check

To verify stability, the model is re - estimated by extending the EU carbon price lag to two quarters (Lag 2).

Table 8: Robustness Check - Model with Two - Quarter Lag (Lag 2)

Export Turnover	Coef.	Robust Std. Err.	z-value	p-value	[95% Conf. Interval]
EU Carbon Price (Lag 2)	.017***	.006	2.85	0.004	.005 to .029
Policy Readiness (PRI)	.304***	.085	3.56	0.000	.136 to .471
Interaction Term	-.010***	.002	-4.59	0.000	-.015 to -.006
VN Production Capacity	.044	.037	1.18	0.237	-.029 to .116
EU Purchasing Power	3.841**	1.690	2.27	0.023	.529 to 7.154
Exchange Rate	-2.000***	.366	-5.47	0.000	-2.717 to - 1.284

Source: *Authors' calculation using Stata*

The Lag 2 model successfully passes the robustness check, maintaining overall statistical significance (p = 0.000). Core macroeconomic variables retain their directional impact, proving the fundamental structural stability of the baseline model.

5.3.3. Discussion

Evaluation of Hypothesis 1 (H1): The empirical results reject this hypothesis in the short term, as the coefficient for the EU carbon price in the one-quarter lag model is positive.

The short-term deviation reveals a limitation in traditional trade models, which assume that regulatory costs immediately reduce exports. These traditional models assume that regulatory costs immediately reduce trade volumes, but they fail to account for corporate behavior. In reality, firms may respond strategically to anticipated regulations. As CBAM implementation approaches, exporters engage in exporting before carbon costs are fully imposed.

However, the robustness check (Lag 2) shows that although the effect remains positive, its magnitude declines sharply (from +0.044 to +0.017), indicating that this behavior is temporary. As CBAM is fully implemented, export capacity begins to decline. Therefore, while H1 is not supported in the short term, the long-term results align with theoretical expectations that carbon pricing reduces exports.

Evaluation of Hypothesis 2 (H2): Hypothesis 2 is fully accepted.

This finding provides strong empirical evidence supporting the Porter Hypothesis. In the context of the steel industry, the implementation of a domestic legal framework does not act as an administrative burden on enterprises. Clear state regulations reduce information asymmetry, lower the transaction costs of understanding complex international rules, and provide a stable environment for businesses to operate. By preparing the legal groundwork early, the domestic government directly helps enterprises maintain their competitive edge in the global market.

Evaluation of Hypothesis 3 (H3): The result supports the hypothesis in the short term but rejects it in the long term.

The baseline model confirms this hypothesis, aligning with Institutional Theory. The positive interaction term in the short term demonstrates that proactive domestic policies effectively reduce the negative impact of the CBAM, helping enterprises manage initial regulatory pressures.

However, the robustness check reveals a critical practical implication: this moderating role has a strict time limit. In the two - quarter lag model, the interaction term reverses to a negative sign. This proves that while state administrative regulations are highly effective for short - term preparation, they cannot permanently reduce the actual financial costs of carbon emissions.

The core mechanism of CBAM taxes the actual carbon emitted during production. Currently, Vietnam's steel industry relies heavily on traditional, highly polluting blast furnace technology. State laws and reporting guidelines cannot physically reduce the carbon footprint of a blast furnace. Therefore, the steel industry cannot rely solely on the legal and administrative support of the government to survive in the European market long - term.

6. Conclusion and policy implications

To enhance long-term export competitiveness under CBAM, the government should focus on three key pillars. First, developing a domestic carbon pricing framework is essential to retain carbon-related revenues and reduce the net compliance burden for exporters.. Second, strengthening the MRV system in line with international standards is necessary to ensure credible emissions data and avoid the application of high default values. Third, expanding green industrial support through financial incentives, clear green taxonomies, and investment in R&D will facilitate technological upgrading in the steel sector. At the firm level, steel enterprises need to adopt a proactive strategy by improving emissions monitoring systems in the short term and gradually transitioning to low-carbon technologies such as electric arc furnaces in the long term. In addition, firms should shift toward higher value-added products, restructure supply chains, and integrate carbon costs into strategic and financial decision-making to remain competitive in an increasingly carbon-constrained global market.

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