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The Empirical Analysis of Carbon Border Adjustment Mechanism's Impact on China's Foreign Trade and the Multidimensional Impact Assessment

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Abstract. The European Union's CBAM entered its transitional phase in October 2023 and is scheduled to formally require importers to surrender CBAM certificates corresponding to the embedded emissions of covered goods starting in 2026. While most existing studies rely on macro-level assumptions, the actual compliance cost for firms critically depends on emissions accounting boundaries, default values, and on-site data reporting strategies. This study constructs a reproducible "industry-product-factor" empirical framework to bridge this gap based on an analysis of the relevant policies. It mainly comprises two parts: first, identifing the risk exposure for steel, aluminum and their downstream sectors (e.g., automotive); second, utilizing default values from internal research materials and on-site data verification cases, this study conducts comparative calculations to quantify the increase in border carbon costs attributable to the omission of China-specific emission factors or verified on-site data. Based on these findings, the study proposes a response strategy centered on building the real factor system and data governance.

Keywords: CBAM, China-EU trade, Embodied carbon, Emission factors, Cost differential

1. Introduction

Global climate governance is shifting from "domestic marginal emissions reductions" to a new paradigm emphasizing cross-border carbon cost comparability. Against this backdrop, the EU introduced CBAM via Regulation (EU) 2023/956 to mitigate carbon leakage as ETS free allowances are phased down and to ensure imported products bear equivalent explicit carbon costs [1]. In practice, CBAM integrates embedded emissions, ETS carbon prices, free allowance phase-out, and crediting of third-country carbon prices [1, 2]. Steel, aluminium, and their derived products—high-carbon-intensity, high-value-added segments in China's exports to Europe—reached millions of tons and tens of billions of dollars in 2023, far exceeding cement and fertilizers, making them among the first to experience salient cost impacts [3]. Studies based on GTAP-E indicate that the marginal decline in China's total exports to Europe may be limited in the short run [4]. For China's foreign trade, the CBAM will raise landed costs, order uncertainty, and fixed costs related to data management, accounting, verification, and compliance. More importantly, the EU's "verifiable data system" requirements may reshape global supply chain comparative advantage.

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This study combines literature review, quantitative analysis, and comparative analysis to interpret the mechanism, assess impacts, and explore policy responses, offering two main contributions. First, rather than reiterating limited existing conclusions, it provides reproducible product-level empirical comparisons based on computational logic and case parameters from internal materials. Second, it highlights the cost differential between "default values/penalty coefficients" and "on-site data/specific emission factors," using this disparity as the foundation for an analytical framework explaining China's data infrastructure and industrial response challenges.

2. Empirical analysis of CBAM impact

2.1. Core quantification logic

The impact of CBAM on trade cannot be reduced to a simple "tax multiplier," but rather unfolds through an integrated chain: the EU carbon price determines the marginal cost of emissions; this combines with the product's embedded carbon to define the number of certificates required; border adjustment adds this cost to delivered goods; and the resulting price change feeds back into demand, market share, output, and ultimately, provincial emissions and welfare. For rigorous empirical analysis, four key boundaries must be specified: product coverage and its mapping to CN codes; emissions accounting scope (direct, indirect, and upstream precursor emissions); carbon price trajectories and the free allowance phase-out schedule; and the crediting of explicit carbon prices paid in third countries [1, 2]. In the Chinese context, provincial heterogeneity in energy structures and electricity emission factors also generates a phenomenon of "homogeneous products with heterogeneous embodied carbon" [3, 5].

At the firm level, the effective CBAM liability can be expressed as follows:

$$\text{EffectiveCBAMcost} = (\text{E}_{\text{embedded}} - \text{E}_{\text{freeallowance}}) \times \text{P}_{\text{EUETS}} - \text{C}_{\text{paid}} \quad (1)$$

where $E_{embedded}$ represents the product's verified or default embedded emissions (tCO_2 per tonne of product), $E_{freeallowance}$ is the volume of free allowances per product under EU ETS phase-out rules, P_{EUETS} is the EU carbon market price, and C_{paid} denotes any explicit carbon cost already paid in the producing country and eligible for crediting [1]. Among these variables, $E_{embedded}$ offers firms the greatest flexibility and exerts the most direct leverage on total cost. Critically, if a firm relies on EU-prescribed default values, the process is procedurally simple but the reported emissions are often inflated and subject to annual penalty markups (10% in 2026, 20% in 2027, and 30% from 2028 onwards). If, on the other hand, the firm uses on-site measured data, which is verified by an accredited third party before annual declaration, the reported emissions are far closer to actual production levels, but the fixed costs of data management, monitoring, and verification are substantially higher. The resulting cost gap between the two approaches can, according to recent industry analysis, reach two to four times. This underscores a decisive insight: under CBAM, a firm's "data capability" directly determines its cost advantage or disadvantage, making the choice between reporting pathways a strategic rather than a merely technical matter.

2.2. Research methodology and empirical framework

Existing studies offer three complementary types of evidence. Global multi-regional input-output (MRIO) models combined with China's provincial modules reconstruct embodied carbon from trade flows and are well-suited to characterising the cost distribution across the "province-sector-EU

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market" nexus [3, 5]. Computable general equilibrium (CGE/GTAP-E) models compare static equilibrium outcomes across scenarios, identifying structural shifts in trade diversion, output, and GDP over the medium to long term. Industry-level price pass-through and cost elasticity studies provide supplementary evidence on how border carbon costs translate into per-tonne burdens for steel, aluminium, and other high-trade-intensity sectors [6].

However, these approaches share a common limitation when applied to the empirical assessment of CBAM's impact at the micro level: they abstract away from the discrete choice of data-reporting methods that individual firms face. MRIO and CGE models rely on national or sectoral average emission intensities and therefore cannot capture firm-level or production-line heterogeneity in emissions for the same product, yet CBAM compliance costs are ultimately determined by each firm's reported data. Moreover, these models generally assume a uniform cost structure across exporters, whereas under the CBAM regime, firms lacking data capabilities face a "default-value trap" with punitive costs that cannot be captured by macro-level parameters.

To address this gap, this study therefore proposes an empirical methodology based on comparative calculation and scenario simulation. The core approach is as follows: drawing on process-level data and energy/material activity levels available to comparable Chinese enterprises, the carbon emissions embedded in products are calculated under two distinct accounting frameworks and then converted into border carbon costs.

This method offers three distinct advantages over the existing literature. First, it has strong micro-level operational feasibility: by aligning directly with actual production processes and accounting practices, its results can be verified at the individual plant level. Second, it is policy-sensitive: the analytical framework clearly separates the "default penalty effect" from the "on-site data dividend," providing quantifiable targets for the development of China's MRV system and national product carbon footprint databases. Third, it makes the results comparable and actionable: the cost wedge explicitly illustrates what is at stake for China between "passively accepting EU-imposed rules" versus "actively providing verifiable evidence" under the CBAM regime, thereby informing both enterprise strategy and national policy response.

2.3. Empirical result and cost estimates

Applying the "comparative calculation plus scenario simulation" framework to steel and aluminium, which are key sectors in China's EU exports, this section integrates macro- and micro-level cost estimates to identify the "cost wedge" between different data reporting pathways, thereby providing quantitative evidence for China's MRV system development and policy responses.

2.3.1. Benchmark macro-level cost estimates

Existing studies using MRIO, CGE, and sectoral models have quantified potential CBAM trade costs. In 2023, China's exports of steel, aluminium, and related products to the EU amounted to approximately 7.43 Mt, with a total value of around €13 billion—far exceeding other initial coverage categories such as cement and fertilisers [3]. On emissions and monetised costs, one study linking provincial data from China with a global industry-energy model provides indicative future estimates. Under a 2034 scenario considering only direct emissions from exports to Europe, the total is estimated at roughly 5.4 $MtCO_2$, with a monetised cost of about €1.157 billion. Including electricity use raises both emissions and costs accordingly. When embodied emissions from the broader supply chain are incorporated, total emissions may reach approximately 15.8 $MtCO_2$, with associated costs rising to about €3.378 billion. Provinces such as Hebei, Jiangsu, Shanxi, Liaoning,

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and Zhejiang are likely to bear the majority (over 65%) of these monetised costs, highlighting pronounced interprovincial heterogeneity [3]. At the per-tonne border carbon cost level, third-party studies provide reference orders of magnitude. For steel products under a medium carbon price scenario for 2030, the simulated marginal cost per tonne of steel is approximately 72–83; by2034, under the same analytical framework, costs could rise to roughly 210–243 per tonne [6]. It should be noted that these figures represent scenario-based ranges derived from research assumptions and do not correspond to actual firm payments. Final costs depend on reported emissions, the application of default values, and offset rules [1, 2].

A multi-scenario MRIO-based study found that different combinations of carbon pricing and industry expansion pathways can cause annual incremental costs in affected industries to fluctuate in the range of tens of billions of US dollars, with steel, aluminium, and their downstream sectors being particularly sensitive to price competitiveness [5]. GTAP-E-based analyses suggest that while the marginal impact on exports to Europe may be limited in the short term, trade diversion effects may gradually emerge in the medium to long term; if the accounting scope is extended to include indirect emissions, the aluminium sector may experience a significantly greater negative impact than the steel sector [4]. In summary, macro-level findings indicate that aggregate shocks may not be the earliest to manifest, but cost concentration in high-carbon metal sectors and certain provinces appears more certain; medium- to long-term trade shifts and output structure adjustments warrant attention; and indirect emissions and scope extrapolation are the primary sources of scenario uncertainty [3-5]. However, these findings cannot illuminate a critical issue: the cost disparities arising from different corporate data reporting pathways for the same product—specifically, the comparison between using EU default values and using on-site emission factors. The following section addresses this gap through micro-level estimates based on domestic case studies.

2.3.2. Micro-level cost discrepancy: 9-fold difference

Under the EU's CBAM regulations, exporters who cannot provide verified on-site emissions data are required to report by using default values published by the EU for their declarations. However, estimates by Chinese research institutions indicate that the default values set by the EU to Chinese products are significantly inflated, which constitutes an implicit "punitive" cost.

A more significant issue to note is that the choice between reporting based on default values and reporting based on firm field emission factors can lead to differences in the resulting carbon tariff on the order of magnitude. Taking steel products under HS code 72071111 as an example, and assuming an EU carbon price of €100 per ton and a gradual phase-out of free allowances.

The estimates show that for the same ton of steel, if Chinese companies are unable to provide verified on-site data and are therefore compelled to rely on the EU's default values, the carbon tariff costs they incur will be nearly nine times higher than under a reporting pathway based on actual data, amounting to a difference of roughly €190 per ton of steel. Moreover, as the EU increases the penalty factor for default values each year, the gap is likely to widen. The policy implication of this finding is that, for enterprises, the choice of whether to use actual factors and on-site data is a strategic variable with direct impacts on cash flow, rather than merely a matter of compliance formality.

2.3.3. Supply chain cost spillover: automobile sector

The CBAM impact extends from raw materials (steel, aluminium) to downstream products, with the automotive sector warranting particular attention [6, 7]. Under a given policy scenario, export costs

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increase by approximately €250 per vehicle and by €5–50 per component. This demonstrates that carbon prices embedded in basic materials are passed down the supply chain through the bill of materials, shifting competitive pressure from raw material exports to finished manufactured goods. The empirical finding is that CBAM's impact on China's foreign trade is not a single "tax rate" but a range of costs dictated by "data capabilities". Enterprises with strong data capabilities minimise cost impacts by reporting on-site factors, while those with weak capabilities are forced to bear the high "data tax" imposed by EU default values. This cost disparity is key to understanding CBAM's real impact.

3. Multidimensional impact and systemic issue

From a policy perspective, the CBAM is gradually aligning with the EU's industrial and trade policies, and its "border carbon cost" will be dynamically adjusted after 2026 based on institutional parameters such as the phase-out of free allowances and default penalty factors [7, 8]. In terms of industries, carbon-intensive basic materials such as steel and aluminium remain the sectors most directly affected. As the scope of the mechanism expands, downstream and more complex products, including automobiles, components, and machinery, are likely to follow as the next group of impacted industries. Looking at cost structures, in addition to explicit certificate costs, firms must also bear fixed expenditures related to MRV system development, third-party verification, information disclosure, contract terms, and legal compliance—all of which will directly influence firms' order-taking strategies and the composition of their client base [9-11].

As illustrated by the case study in this paper, when default values are set too high and combined with penalty coefficients, the tax burden can increase by multiples. At the macro level, the core systemic issue lies in the "discursive power" and "verifiability" of the data system [11, 12]. If Chinese enterprises are unable to provide verifiable emission factors and process data, they will be forced to accept the EU's default value framework. As a result, discrepancies in emissions that could have been reduced through management and technological upgrades are effectively transformed into a non-negotiable cost disadvantage in landed costs. This underscores that the real challenge is not merely the level of carbon pricing, but the structural gap in data credibility and verification capacity—a gap that, if left unaddressed, will systematically erode the competitiveness of Chinese exports across multiple industries.

4. Policy implications and recommendations

The practical challenge lies in the insufficient process-level measurement and data traceability, which makes it difficult for emission factors to be recognized by verification; at the same time, a short-term shortage of verification resources and expertise further drives up fixed compliance costs. Faced with these fixed costs, small and medium-sized enterprises are more likely to be squeezed out of EU markets, leading to an asymmetric contraction in market share.

Building on the empirical findings identified in this study, it is recommended that a "real-factor-first" principle be adopted as the core response strategy. Specifically, three policy directions are proposed. First, we should promote the development of process-level data templates, tiered emission factor classifications, and evidentiary chain requirements for export-oriented products. Second, prioritize the establishment of a replicable accounting-verification closed-loop within the supply chains of steel, aluminum, and their complex downstream products. Third, at the enterprise level, institutionalize a dual-track calculation approach—combining "default values" with "on-site data"—

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as a business decision-making tool to evaluate the border cost elasticities across different customers and product lines under various policy scenarios [13-15].

5. Conclusion

The impact of the CBAM on China's foreign trade cannot be reduced to a simple "tax rate"; the crux lies in the choice of emissions accounting boundaries and the credibility of data that firms can provide. Moving beyond macro-level averages from MRIO and CGE models—which obscure firm-level heterogeneity—this study introduces a micro-level "comparative calculation plus scenario simulation" framework that directly contrasts EU default values (with penalty coefficients) against on-site verified data. Using case-specific parameters from internal materials, the empirical analysis reveals that the disparity in effective CBAM tax burdens between these two pathways can reach nearly ninefold for comparable products. The study also identifies a downstream cost spillover risk: carbon prices embedded in steel and aluminium propagate through the bill of materials to automobiles and components, shifting competitive pressure from raw material exports to finished manufactured goods. The main contribution is twofold: first, making explicit how a firm's "data capability" directly translates into a cost advantage or disadvantage—an insight that macro models cannot capture; second, providing quantifiable targets for the development of China's MRV system and national product carbon footprint database. Limitations include a limited product sample (steel and aluminium) and static assumptions regarding EU carbon price trajectories and free allowance phase-out schedules. Future research should expand sectoral coverage to machinery and electronics, incorporate dynamic policy uncertainty, and explore optimal designs for China's domestic MRV infrastructure and bilateral crediting arrangements to mitigate the adverse "data tax" effect.

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