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Quantitative Assessment of the Carbon Border Adjustment Mechanism: Impacts on China–EU Trade and Provincial-Level Vulnerabilities

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Abstract: The implementation of the Carbon Border Adjustment Mechanism (CBAM) carries profound implications for China's export trade with the EU. However, a comprehensive analysis of CBAM's impact on provincial export trade, particularly one grounded in industrial linkages and incorporating diverse policy scenarios, remains limited. To address this gap, this study develops a mechanistic framework based on industrial linkage theory and dynamically integrates key factors such as the scope of industries covered by CBAM, carbon emission accounting boundaries, and carbon pricing into a multi-scenario quantitative model. Leveraging a refined multi-region input–output (MRIO) model, we quantitatively assess the effects of CBAM on China's provincial exports to the EU under various scenarios. The findings show that CBAM significantly raises export costs, leading to a pronounced decline in the competitiveness of five highly vulnerable industries. As CBAM expands to include sectors covered by the EU Emissions Trading System (EU ETS), the total levies on affected industries increase considerably, ranging from USD 0.07 billion to USD 2.25 billion depending on the scenario. Conversely, seven provincial industries, such as the chemical industry in Shanxi, experience only limited impacts due to their low direct carbon intensity and minimal overall increases in carbon tariffs. Then, the study underscores the pivotal role of China's domestic carbon pricing mechanism in mitigating the effects of CBAM. Higher domestic carbon prices enhance China's capacity to respond effectively, thereby reducing the overall impact of the mechanism. By adopting an inter-industry linkage perspective, this study provides new insights into assessing the multidimensional impacts of CBAM on China's exports to the EU across provinces under different policy design scenarios, providing lessons for different categories of provinces on how to cope with CBAM.

Keywords: Carbon Border Adjustment Mechanism; provincial-level vulnerabilities; China–EU trade; quantitative assessment; multi-regional inputs and outputs model

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Academic Editor: Sajid Anwar

Received: 14 January 2025
Revised: 12 February 2025
Accepted: 14 February 2025
Published: 18 February 2025

Citation: Ren, L.; Wang, J.; Zhang, L.; Hu, X.; Ning, Y.; Cong, J.; Li, Y.; Zhang, W.; Xu, T.; Shi, X. Quantitative Assessment of the Carbon Border Adjustment Mechanism: Impacts on China–EU Trade and Provincial-Level Vulnerabilities. *Sustainability* **2025**, *17*, 1699. https://doi.org/10.3390/su17041699

1. Introduction

In order to mitigate the risk of carbon leakage and safeguard the competitiveness of domestic industries, the EU formally proposed and adopted the Carbon Border Adjustment Mechanism (CBAM) bill [1]. The bill stipulates that CBAM will be implemented on a trial basis from 2023 to 2025 and will become effective in 2026. It will be applicable to six major industries: iron and steel, aluminum, fertilizers, cement, electricity, and hydrogen. The carbon price differential between the two countries serves as the tax base.

However, the implementation of CBAM will have an impact on the exports of the EU's trading partners. Small developing countries, such as Mozambique, which have a high share of high-carbon products in their exports, and major suppliers of industries related to CBAM, such as China, are found to have a greater impact on their exports to the EU. In addition, some developed countries that enjoy carbon price exemptions or mainly import high-carbon products will benefit from CBAM [2–6]. China is the EU's second-largest trading partner and the largest source of implied carbon emissions from imported goods [7]. Therefore, it is very important to quantify the impact of CBAM on China's exports to the EU under different policy designs.

The extant literature is largely in agreement that CBAM has a deleterious effect on China's export trade [8,9]. Zhai and Wu [10] posit that should the EU implement CBAM, it would have a significant adverse impact on the exports of China's carbon-intensive industries. Xu and Li [11] posit that should the EU implement a CBAM of USD 60/tonne, exports to the EU from China's CBAM-involved industries will incur an additional USD 0.65 billion in export costs on an annual basis. Among them, CBAM has more influence on the price advantage of steel and aluminum and their downstream products [12–15]. Considering the increasing number of industries involved in CBAM in the future, some scholars believe that once CBAM covers steel and aluminum extension industries, the export cost of related products will increase significantly, which will weaken their competitiveness in the EU market [16–19].

Furthermore, in order to accurately assess the economic impact of CBAM on countries outside the region under different policy backgrounds and identify optimal coping strategies, the extant literature employs a multi-scenario quantitative evaluation methodology for research purposes. Zhong and Pei [20] examine the carbon pricing response of exporting countries by taxing the implied carbon emissions of industries participating in the EU Emissions Trading System (EU ETS) under varying CBAM prices. Mörsdorf [21] does not examine the impact of carbon pricing on exporting countries by assessing the taxation of direct and indirect carbon emissions from industries participating in CBAM at varying CBAM rates. Sun et al. [22] examine the carbon pricing response of an exporting country by taxing direct and implied carbon emissions from industries involved in the EU ETS under varying CBAM prices. Gu et al. [23] consider the carbon pricing response of exporting countries by taxing direct emissions from industries covered by CBAM under different CBAM prices. In contrast, Bellora and Fontagné [24] do not consider the carbon pricing response of exporting countries by taxing direct emissions from industries covered by the EU ETS under different CBAM prices.

Overall, while existing studies have examined CBAM from various perspectives and enhanced our understanding of its economic impacts on non-EU countries, certain limitations remain. First, the mechanisms through which CBAM affects the export trade of industries in different provinces of China, particularly from the perspective of systemic inter-industry linkages, have not been thoroughly explored. Second, there is a relative scarcity of provincial-level research, and quantitative analyses addressing the heterogeneous impacts of CBAM on provincial exports through inter-industry connections are lacking. Third, limited attention has been paid to the dynamic interplay of key factors such as carbon emission scopes, industry coverage, and CBAM pricing. This has hindered a comprehensive identification of CBAM's effects on export trade to the EU, and few studies have considered the optimization of carbon pricing mechanisms as a strategic response to CBAM.

To address these gaps, this study makes several contributions. It integrates input–output theory and the trade deterioration effect to develop a new framework for analyzing the impact mechanisms of CBAM on China's export trade, emphasizing inter-provincial industrial linkages. By employing an input–output model, the research investigates the heterogeneity of CBAM's effects on export costs and competitiveness across provinces, taking into account variations in inter-industry connections. This approach identifies the provinces and industries most affected by declines in competitiveness and export profits due to CBAM. Additionally, the study dynamically incorporates three critical factors—the scope of industries covered by CBAM, carbon emission accounting boundaries, and carbon pricing—into a multi-scenario simulation framework. This enables a more comprehensive assessment of the potential impacts of the current CBAM policy on China–Europe trade, as well as its implications under possible future scenarios, such as increases in carbon pricing, expansions in sectoral coverage, or changes to carbon accounting boundaries. By doing so, the study provides a clearer distinction between short-term and long-term impacts. Furthermore, it evaluates the effectiveness of adopting a more robust carbon pricing mechanism as a response to CBAM and compares the increases in carbon tariff rates and revenues under different scenarios. Through this comprehensive approach, the study assesses the multidimensional impacts of CBAM on China's provincial exports to the EU across various policy scenarios.

The remainder of the paper is organized as follows. Section 2 describes the mechanism of CBAM's impact on Chinese provincial industries' exports to the EU. The third section describes the data, model construction, and the design of the multi-scenario quantitative assessment. The fourth section presents the empirical results. Section 5 presents the discussion, and Section 6 presents the conclusions and policy recommendations.

2. CBAM Impact Mechanisms on China's Provincial Industries' Exports to the EU

In accordance with the input–output-related theory, the impact mechanism of this paper is designed as follows (see Figure 1): It is assumed that industries A, B, and C represent the upstream and downstream industries of the same industrial chain and serve as the pillar industries in provinces 1, 2, and 3, respectively. It should be noted that Industry A is the CBAM-involved industry and would be directly impacted by CBAM. Therefore, firstly, the realization path of Industry A being directly affected by CBAM is constructed. Secondly, considering the correlation between industries, the implementation of CBAM will lead to industries in the same industry chain being indirectly affected (e.g., by affecting Industry A and then Industry B). On this basis, the single-layer industry-linked indirect impact path and the multi-layer industry-linked indirect impact path are constructed.

The implementation of the CBAM has significant implications for Industry A, which falls within the scope of CBAM-involved sectors. As a pillar industry in Province 1, the introduction of CBAM increases the tax burden for Industry A on exports to the EU, thereby altering its trade competitiveness in the EU market. If the trade competitiveness remains relatively unchanged, Industry A's export volume to the EU will either remain stable or increase. However, as CBAM prices gradually rise, the competitive advantage of Industry A in the EU market diminishes, prompting partial trade diversion as Industry A redirects some of its market share to other countries. Consequently, its trade competitiveness in the EU market declines, leading to a reduction in export volume [25,26]. If CBAM prices continue to escalate, the trade competitiveness of Industry A in the EU market will eventually disappear, driving its export volume to the EU to zero.

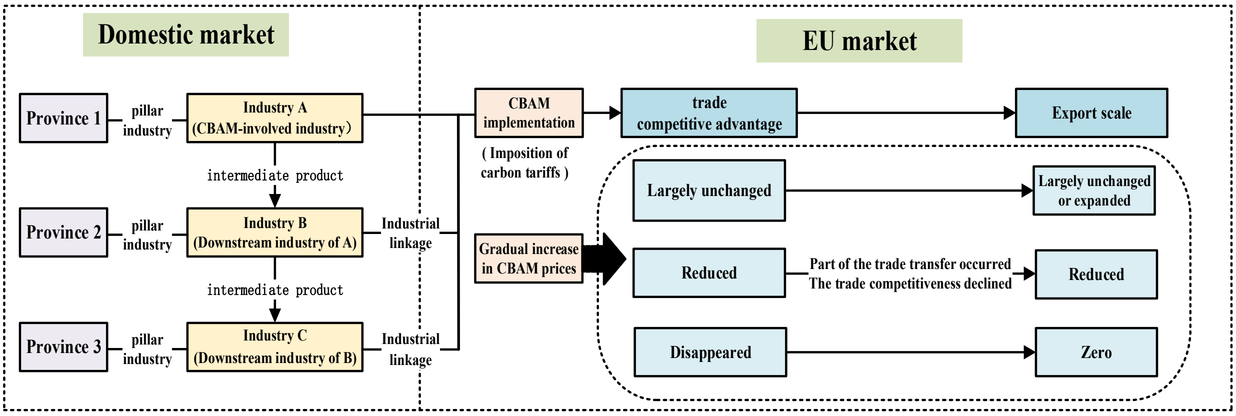

Figure 1. CBAM impact mechanisms on China's provincial industries' exports to the EU.

Industry B, as the downstream sector of Industry A, is also affected by CBAM. Changes in the trade competitiveness of Industry A in the EU market, driven by CBAM, have a cascading effect on Industry B in Province 2 due to the interconnected nature of the industries. If Industry B's trade competitiveness in the EU market remains largely unaffected, its export volume to the EU will either remain stable or expand. However, as CBAM prices increase, Industry B's competitive advantage in the EU market narrows, leading to a partial shift of its market share to other countries and resulting in trade diversion. This reduction in competitiveness ultimately decreases Industry B's export volume to the EU [27,28]. As CBAM prices rise further, Industry B's competitiveness in the EU market is completely eroded, making exports to the EU unprofitable and leading to the cessation of its exports.

Industry C, as the downstream sector of Industry B, is similarly influenced by the cascading effects of CBAM. The implementation of CBAM alters the trade competitiveness of Industry A in Province 1 and Industry B in Province 2, which, in turn, affects the trade competitiveness of Industry C in Province 3 within the EU market. If Industry C's trade competitiveness remains relatively stable, its export volume to the EU will either remain unchanged or increase. However, as CBAM prices escalate, Industry C's competitive advantage in the EU market diminishes, prompting a partial shift of its market share to other countries and leading to trade diversion. This decline in competitiveness reduces Industry C's export volume to the EU [29,30]. If CBAM prices continue to rise, Industry C's trade competitiveness in the EU market will disappear entirely, causing it to cease exports to the EU.

3. Data and Models

3.1. Data Sources and Data Processing

In order to construct the Embedded Inter-Provincial Input–Output (EMIIO) table, this paper uses the latest China Muti-Region Input–Output (CMRIO) table and World Input–Output Table (WIOT). Among them, the 2017 CMRIO table comes from the China Emission Accounts and Datasets (CEADs); in 2014, WIOT came from the World Input–Output Database (WIOD); in 2017, the bilateral trade data at the provincial industry level in China came from the Economy Prediction System (EPS); the carbon emission data of China's provinces and countries used for export carbon emission measurement come from CEADs and environmental accounts published by Exiobase, respectively; and EU import tariff data come from the Integrated Tariff of the European Union (TARIC) database. Based on the purpose of the study, the data we selected represent the most recent and authoritative information currently available from publicly published sources, covering multiple dimensions, with sufficient data volume and accurate data. Given the relatively stable economic structures across provinces, the data and methods employed in this research are sufficient to capture the impact of CBAM on the direction and structure of export trade to the EU across various provincial industries.

The classification of industries is based on two principles: Firstly, it highlights the industries that are directly affected by CBAM, i.e., the industries covered by CBAM (CBAM covers three major industries: metal smelting and products, non-metallic mineral products, and chemicals) and EU ETS (EU ETS covers nine major industries: extractive industries; the textile and garment industry; the wood processing products industry; the paper, printing, and stationery manufacturing industry; the food manufacturing and tobacco processing industry; the petroleum processing industry; the coking and chemical industry; the non-metallic mineral products industry; and the metal smelting and products industry). Secondly, industries that may be indirectly affected by CBAM are categorized according to their industrial linkages, which will be indirectly involved in international trade and usually serve as upstream and downstream industries of related energy-intensive and trade-exposed (EITE) industries (e.g., extractive industries and other service industries with large carbon emissions transfer). Meanwhile, this paper summarizes the 42 industries into 18 industries based on the 2011 Standard Industrial Classification of the National Economy (GB/T 4754-2011) and the International Standard Industrial Classification (ISIC Rev*4), as well as referring to the industry classifications of the CMRIO table, WIOT, and other databases (see Table 1). Restricted by the existing multi-region input–output table, industry classification is relatively rough; this paper cannot highlight the six CBAM-involved industries but can only categorize them into the broad categories to which they belong for subsequent analysis.

Table 1. Industry match between the MRIO table and WIOT table.

	MRIO–WIOT 18 Sector	GB/T 4754-2011	ISIC rev4		MRIO–WIOT 18 Sector	GB/T 4754-2011	ISIC rev4
1	Agriculture, forestry, animal husbandry, and fisheries	A01–A05	A01–A03	10	Metal smelting and products industry	C31–C33	C24–C25
2	Extractive industry	B06–B12	B05–B09	11	Transportation equipment manufacturing	C36–C37	C29–C30
3	Textile and clothing industry	C17–C19	C13–C15	12	High-tech manufacturing	C39–C40	C26
4	Wood processing products industry	C20–C21	C16	13	Electricity and heat supply	D44–D45	D35
5	Manufacture of paper, printing, and stationery	C22–C24	C17–C18	14	Water production, collection, treatment, and supply	D46	E36
6	Food manufacturing and tobacco processing	C13–C16	C10–C12	15	Building industry	E47–E50	F41–F43
7	Petroleum processing and coking	C25	C19	16	Transportation, storage, and postal services	G53–G60	H49–H53
8	Chemical industry	C26–C29	C20–C22	17	Other manufacturing	C34, etc.	C27, etc.
9	Non-metallic mineral products industry	C30	C23	18	Other services	F51, etc.	E37, etc.

Using country-level bilateral trade data from the UN Comtrade database, along with industry-level data from the EPS database on China's total exports to global economies, we categorized the 43 countries in the WIOT table into 19 major regions. These regions include the United Kingdom, Italy, the United States, France, Russia, Germany, the Netherlands, Australia, Poland, Japan, Spain, India, Belgium, Indonesia, South Korea, Mexico, Canada, Brazil, and a collective group labeled as "the rest of the world". This classification encompasses the world's leading economies, the top seven EU countries with which China maintains the largest trade volumes (accounting for 80.2% of its total exports to the 27 EU member states), as well as several developing nations, such as Russia, India, and Brazil, which are expected to be more significantly impacted by CBAM.

3.2. Modeling

3.2.1. Construction of EMIIO Forms

In this paper, we refer to Meng [31] to construct the EMIIO table, using WIOT data as the control volume. Taking two countries, two regions, and two sectors as examples, the EMIIO table intermediate flows, end uses, and value added are calculated as follows:

$$\hat{xe}_{ij}^{rs} = \sum_i \sum_j x_{ij}^{C_t C_t} \cdot \frac{xd_{ij}^{rs}}{\sum_r \sum_s \sum_i \sum_j xd_{ij}^{rs}} \tag{1}$$

$$\hat{ye}_{ik}^{rs} = \sum_i \sum_k y_{ik}^{C_t C_t} \cdot \frac{yd_{ik}^{rs}}{\sum_r \sum_s \sum_i \sum_k yd_{ik}^{rs}} \tag{2}$$

$$\hat{XE}_i^r = \sum_i X_i^{Ct} \cdot \frac{XD_i^r}{\sum_r \sum_i XD_i^r} \tag{3}$$

$$\hat{VE}_j^r = \sum_j V_j^{Ct} \cdot \frac{VD_j^r}{\sum_r \sum_j VD_j^r} \tag{4}$$

$$\hat{YE}_k^s = \sum_k Y_k^{Ct} \cdot \frac{YD_k^r}{\sum_r \sum_k YD_k^r} \tag{5}$$

where R and S denote countries, r and s denote subregions of the target country C_t, and i and j denote sectoral proxies. xe and ye denote estimates of intermediate and final use, respectively, and XE, YE, and VE denote estimates of total output, final use plus, and value added. xd and yd are intermediate and final use in the CMRIO table, x and y are intermediate use and end use in the WIOT table, x, y, and v are total output, end use plus, and value added in the WIOT table, and xd, yd, and vd are total output, end use plus, and value added in the CMRIO table.

The calculation method of the initial value of regional imports by country of origin of the target countries in the EMIIO table is as follows:

$$\hat{xe}_{ig,j}^{Rs} = \left(\sum_j x_{ig,j}^{RCt} \cdot \frac{mx_{ig}^{Rs}}{\sum_s mx_{ig}^{Rs}} \right) \cdot \frac{\sum_r xd_{ig,j}^{rs}}{\sum_r \sum_j xd_{ig,j}^{rs}} (R \neq C_t, ig = good) \tag{6}$$

$$\hat{xe}_{is,j}^{Rs} = \left(\sum_j x_{is,j}^{RCt} \cdot \frac{\sum_{ig} mx_{ig}^{Rs}}{\sum_s \sum_{ig} mx_{ig}^{Rs}} \right) \cdot \frac{\sum_r xd_{is,j}^{rs}}{\sum_r \sum_j xd_{is,j}^{rs}} (R \neq C_t, is = service) \tag{7}$$

$$\hat{ye}_{ig,k}^{Rs} = \left(\sum_k y_{ig,k}^{RCt} \cdot \frac{my_{ig}^{Rs}}{\sum_s my_{ig}^{Rs}} \right) \cdot \frac{\sum_r yd_{ig,k}^{rs}}{\sum_r \sum_k yd_{ig,k}^{rs}} (R \neq C_t, ig = good) \tag{8}$$

$$\hat{ye}_{is,k}^{Rs} = \left(\sum_k y_{is,k}^{RCt} \cdot \frac{\sum_{ig} my_{ig}^{Rs}}{\sum_s \sum_{ig} my_{ig}^{Rs}} \right) \cdot \frac{\sum_r yd_{is,k}^{rs}}{\sum_r \sum_k yd_{is,k}^{rs}} (R \neq C_t, is = service) \tag{9}$$

The initial value of regional exports of target countries for each destination country in the EMIIO table is calculated as follows:

$$\hat{ye}_{is,k}^{rS} = y_{is,k}^{CtS} \cdot \frac{\sum_{ig} ey_{ig}^{rS}}{\sum_{r} \sum_{ig} ey_{ig}^{rS}} (S \neq C_t, is = service) \tag{10}$$

$$\hat{ye}_{ig,k}^{rS} = y_{ig,k}^{CtS} \cdot \frac{ey_{ig}^{rS}}{\sum_{r} ey_{ig}^{rS}} (S \neq C_t, ig = good) \tag{11}$$

where *ex* and *ey* are data on exports of intermediate goods and exports of final goods from the target country, and mx and my are data on imports of intermediate goods and imports of final goods from the target country.

It should be noted that in the absence of regional statistics on imports of services by country of origin versus regional statistics on exports of services by country of destination, the structure of regional statistics on imports/exports of goods was used as a proxy to estimate the initial value of services.

3.2.2. Accounting for Carbon Emissions from Exports

This paper presents two scenarios of EU taxation on direct and implied carbon emissions and calculates the direct and implied carbon emissions of China's provincial industries exported to the EU. Based on these calculations, the paper determines the lower and upper limits of the carbon tariff tax and tax rate for provincial industries and the scope of CBAM's influence on the export of provincial industries.

First, we determine the direct carbon emissions from China's provincial industries exporting to EU. In this paper, the direct carbon emissions at the level of China's provincial industries caused by EU unit consumption are taken as the object of accounting, and the calculation expression is as follows:

$$C^d = E^d \cdot Y_e \tag{12}$$

where $ei = Ei/Xi$. Xi is the total output of the *i*th sector; E_i is the total direct production of CO_2 emitted by the *i*th sector; e_i is the CO_2 emitted per unit of output produced in the *i*th sector, also known as the direct carbon intensity coefficients; the matrix consisting of all the $1 \times n$ e_i is the matrix of the carbon intensity coefficients, which is set to be E^d; and Y_e is a vector of columns of the final foreign demand.

Second, the implied carbon emissions from China's provincial industries' exports to the EU are accounted for. Since the implied carbon emissions from export trade include direct and indirect emissions [32], this paper therefore calculates the implied carbon emissions of China's provincial industries' exports to the EU (the main seven countries) by applying the MRIO model on the basis of the EMIIO table.

The basic input–output model structure is as follows:

$$AX + Y = X \tag{13}$$

where A is the matrix of direct consumption coefficients, X is a vector of aggregate output columns, and Y is a vector of aggregate demand columns. Further:

$$X = (I - A)^{-1} Y \tag{14}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix. Therefore, the implied carbon emissions are given by the following formula:

$$C^i = E^d (I - A)^{-1} Y \tag{15}$$

where Y is a vector of aggregate demand columns divided into Chinese domestic demand Y_d and foreign demand Y_e. Therefore, the final formula for calculating trade implied carbon produced and exported in China is as follows:

$$C^e = E^d(I - A)^{-1}Y_e \quad (16)$$

3.2.3. Measuring the Carbon Intensity of Trade

Referring to the method of Fu [33] for calculating the carbon intensity of trade, this paper measures both the direct production carbon intensity and the implied carbon intensity of the industries in each province of China, and the calculation expressions are as follows [33]:

$$E^i = E^d(I - A)^{-1} \quad (17)$$

where E^d is the direct carbon intensity coefficient matrix and E^i is the implied carbon intensity coefficients matrix.

3.3. Policy Scenario Simulations

The current CBAM taxes six industries. However, the latest CBAM text indicates that by 2030, CBAM will extend the scope of applicable industries to EU ETS-covered industries. Therefore, this paper assumes two applicable industry scopes, CBAM and EU ETS. In addition, the CBAM implementation program mentions that exemptions and reductions will be applied to non-EU countries that already have carbon pricing in their countries. Based on the above, this paper designs multiple scenarios for China–EU carbon pricing in order to find the optimal response strategy for China's carbon pricing under different implementation scenarios of CBAM.

In light of the aforementioned considerations, this paper integrates the CBAM-involved industries (2), the carbon emission accounting scopes (2), and carbon price design in Sino-EU trade (1 + 12) to develop a multi-scenario policy scheme. This is with a view to identifying the optimal carbon pricing strategy in China under different CBAM implementation scenarios (see Table 2).

Table 2. Sino-EU climate policy scenario simulation.

Scenario Grouping	Scenario Number	EU Carbon Price (USD/Tonne)	China Carbon Price (USD/Tonne)	Carbon Emission Accounting Ranges	CBAM Prices (USD/Tonne)
Group I (Baseline scenario)	S1	95/105/170	0		0
Group II China has no domestic climate policy	S2-1	95	0	Direct emission	95
	S2-2	95	0	Direct + indirect emission	95
	S3-1	105	0	Direct emission	105
	S3-2	105	0	Direct + indirect emission	105
	S4-1	170	0	Direct emission	170
	S4-2	170	0	Direct + indirect emission	170
Group III China has a domestic climate policy (incomplete response)	S5/6-1	95	10/18	Direct emission	85/77
	S5/6-2	95	10/18	Direct + indirect emission	85/77
	S7/8-1	105	10/18	Direct emission	95/87
	S7/8-2	105	10/18	Direct + indirect emission	95/87
	S9/10-1	170	10/18	Direct emission	160/152
	S9/10-2	170	10/18	Direct + indirect emission	160/152

Table 2. *Cont.*

Scenario Grouping	Scenario Number	EU Carbon Price (USD/Tonne)	China Carbon Price (USD/Tonne)	Carbon Emission Accounting Ranges	CBAM Prices (USD/Tonne)
Group IV	S11	95	95		0
China has a domestic	S12	105	105		0
climate policy	S13	170	170		0
(complete response)	S13	170	170		0

Note: The EU carbon price is based on the following. According to the CBAM proposal: EU Carbon Tariff Rate = EU ETS Weekly Average Price − Carbon Price Paid by Country of Origin − EU Free Allowance. For the EU carbon price: In 2022, the EU average carbon price is EUR 81/tonne; in 2023, the average carbon price is expected to be EUR 97.66/tonne, and by 2030, it is expected to reach EUR 160/tonne. For China's carbon price: The median price of the national carbon emission allowance (CEA) in December 2023 is expected to be 64.10 CNY/tonne. According to the China Carbon Price Survey Report 2022 (2023), the national carbon market expects the carbon price to rise to CNY 87 per tonne by 2025 and to reach CNY 130 per tonne by 2030.

4. Empirical Results

This paper measures the degree of trade competitiveness damage by changes in carbon tariff rates, quantifies the increase in export costs by changes in the amount of carbon tariffs, and conducts an empirical analysis based on a multi-scenario design with two CBAM-involved industries, two types of carbon emission accounting scopes, and nine types of CBAM prices. The results are as follows:

4.1. Trade Carbon Intensity of China's Provincial Industries Under Different Carbon Emission Accounting Ranges

From the direct carbon intensity (see Table 3), the average production carbon intensity in China was 0.66 kg/USD in 2017, with Inner Mongolia, Xinjiang, and Ningxia having the largest carbon intensity coefficients, with industry averages of 1.83 kg/USD, 1.36 kg/USD, and 1.21 kg/USD, respectively. At the industry level, the carbon intensity of products from the CBAM-involved industries of China ranked high, with average values of 6.51 kg/USD, 2.06 kg/USD, and 0.80 kg/USD, respectively (since China does not export electricity to the EU and hydrogen exports to the EU are negligible, electricity and hydrogen are not analyzed in this paper). The industries involved in CBAM are viewed in terms of different provinces. First, in the non-metallic mineral products industry, Inner Mongolia, Yunnan, and Guizhou have the highest carbon intensity, reaching 13.32 kg/USD, 5.62 kg/USD, and 5.59 kg/USD, respectively, which is much higher than the average level of the same industry and other industries; second, in the metal smelting and products industry, Liaoning, Shanxi, and Heilongjiang have the largest carbon intensity, which is 2–3 times the national average level.

In terms of implied carbon intensity, China's average implied carbon intensity is 1.43 kg/USD, much higher than the direct carbon intensity of 0.66 kg/USD and the EU average of 0.55 kg/USD. At the provincial level, the provinces with the highest implied carbon intensities are Inner Mongolia, Shanxi, and Hebei; as with direct carbon intensities, Inner Mongolia, Shanxi, and Guizhou still have the highest implied carbon intensities in the cement and steel and aluminum sectors.

For CBAM-covered industries and high-carbon industries such as extractive industries, the discrepancy between direct and implied carbon intensity is typically 2–4 times. At the provincial level, in some provinces such as Inner Mongolia, Shanxi, Hebei, and others, the discrepancy between direct and implied carbon intensity is predominantly 1–3 times, and the gap multiple is not substantial, yet the absolute value is considerably disparate.

Table 3. Average carbon intensity of production by province with different industry coverage (kg/USD).

	Province	CBAM-Covered Industries			Province	EU ETS-Covered Industries	
		Direct Carbon Intensity	Embodied Carbon Intensity			Direct Carbon Intensity	Embodied Carbon Intensity
1	Inner Mongolia	4.76	8.23 (1.73)	1	Inner Mongolia	1.77	3.68 (2.08)
2	Yunnan	2.54	2.80 (1.10)	2	Yunnan	1.15	1.27 (1.10)
3	Guizhou	2.00	2.25 (1.13)	3	Ningxia	0.91	1.00 (1.10)
4	Ningxia	1.79	1.97 (1.10)	4	Guizhou	0.91	1.03 (1.13)
5	Qinghai	1.79	1.92 (1.07)	5	Shanxi	0.85	2.45 (2.88)
6	Shanxi	1.61	4.14 (2.57)	6	Tibet	0.84	0.89 (1.06)
7	Tibet	1.60	1.69 (1.06)	7	Xinjiang	0.84	0.97 (1.15)
8	Xinjiang	1.60	1.87 (1.17)	8	Qinghai	0.75	0.81 (1.08)
9	Liaoning	1.19	3.11 (2.61)	9	Heilongjiang	0.60	1.72 (2.87)
10	Gansu	1.18	1.34 (1.14)	10	Sichuan	0.51	0.77 (1.51)
11	Guangxi	1.16	1.48 (1.28)	11	Gansu	0.50	0.56 (1.12)
12	Heilongjiang	1.15	2.77 (2.41)	12	Liaoning	0.49	1.71 (3.49)
13	Hainan	1.08	1.16 (1.07)	13	Guangxi	0.46	0.76 (1.65)
14	Hebei	0.87	2.75 (3.16)	14	Hainan	0.45	0.49 (1.09)
15	Sichuan	0.87	1.33 (1.53)	15	Chongqing	0.44	0.55 (1.25)
16	Chongqing	0.69	0.92 (1.33)	16	Hebei	0.42	1.91 (4.55)
17	Jilin	0.68	2.02 (2.97)	17	Shaanxi	0.33	0.46 (1.39)
18	Hubei	0.64	1.75 (2.73)	18	Jilin	0.32	1.42 (4.44)
19	Shaanxi	0.61	0.81 (1.33)	19	Hunan	0.31	1.22 (3.94)
20	Jiangxi	0.51	2.18 (4.27)	20	Jiangxi	0.30	1.71 (5.70)
21	Hunan	0.51	1.71 (3.35)	21	Jiangsu	0.26	1.32 (5.08)
22	Jiangsu	0.49	2.03 (4.14)	22	Hubei	0.25	1.05 (4.20)
23	Anhui	0.47	2.25 (4.79)	23	Anhui	0.24	1.57 (6.54)
24	Zhejiang	0.42	1.59 (3.79)	24	Zhejiang	0.18	1.10 (6.11)
25	Fujian	0.38	1.14 (3.00)	25	Henan	0.18	1.29 (7.17)
26	Tianjin	0.33	1.41 (4.27)	26	Fujian	0.18	0.70 (3.89)
27	Guangdong	0.33	1.61 (4.88)	27	Shanghai	0.17	0.82 (4.82)
28	Shandong	0.30	1.59 (5.30)	28	Shandong	0.16	1.15 (7.19)
29	Shanghai	0.30	1.05 (3.50)	29	Tianjin	0.15	0.94 (6.27)
30	Henan	0.28	1.80 (6.43)	30	Guangdong	0.14	0.97 (6.93)
31	Beijing	0.03	0.93 (31.00)	31	Beijing	0.06	0.73 (12.17)

4.2. Export Carbon Emissions from China's Provincial Industries Under Different Carbon Emission Accounting Ranges

In terms of direct carbon emissions, the direct carbon emissions from China's exports to the seven major EU countries amounted to 7.47 MT. Among them, the carbon emissions from the industries belonging to four types of products, namely iron and steel, aluminum, fertilizer, and cement, amounted to 3.81 MT, accounting for 51.1% of the total amount exported to the seven EU countries; meanwhile, those of the industries covered by the EU ETS amounted to 4.77 MT, accounting for 63.9% of the total amount of exported carbon emissions.

In terms of different provinces (see Table 4), coastal provinces such as Guangdong, Jiangsu, and Zhejiang have the largest direct carbon emissions from exports to the EU, but inland high-carbon provinces such as Inner Mongolia, Xinjiang, and Yunnan ranked lower. For the metal and non-metallic mineral products industry, the provinces with higher carbon emissions from exports are coastal provinces such as Jiangsu, Shanghai, and Zhejiang and inland provinces with higher carbon intensity such as Shanxi. Provinces such as Qinghai and Yunnan, due to their lower trade intensity, have relatively small carbon emissions from their exports, despite their higher carbon intensity and larger increases in carbon tariff rates. In addition, the chemical industry covered by CBAM has lower export carbon emissions overall, with inland high-carbon provinces such as Ningxia and Shanxi having the highest export carbon emissions, followed by coastal provinces such as Jiangsu, Shanghai, and Zhejiang.

Table 4. Carbon emissions from selected high-carbon sectors' exports to the EU under different carbon emission ranges (MT).

	Province	Metal Smelting and Products Industry		Non-Metallic Mineral Products Industry		Chemical Industry		Extractive Industry		Petroleum Processing and Coking	
		S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2	S-1	S-2
1	Beijing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.09
2	Tianjin	0.10	1.66	0.00	0.03	0.00	0.02	0.00	0.03	0.00	0.10
3	Anhui	0.43	9.76	0.05	0.31	0.00	0.13	0.02	1.19	0.00	0.12
4	Shanxi	0.28	2.96	0.03	0.19	0.00	0.09	0.01	0.41	0.07	1.15
5	Inner Mongolia	0.00	0.79	0.02	0.32	0.00	0.07	0.00	0.27	0.00	0.20
6	Liaoning	0.30	5.03	0.06	0.27	0.00	0.05	0.07	0.33	0.00	0.28
7	Jilin	0.01	0.37	0.01	0.11	0.00	0.09	0.00	0.06	0.00	0.01
8	Heilongjiang	0.01	0.13	0.00	0.02	0.00	0.03	0.00	0.22	0.00	0.19
9	Shanghai	0.23	1.65	0.01	0.03	0.00	0.07	0.00	0.00	0.06	0.35
10	Jiangsu	0.50	9.01	0.09	1.27	0.01	0.40	0.01	0.24	0.00	0.15
11	Zhejiang	0.18	1.15	0.11	0.76	0.00	0.12	0.00	0.01	0.00	0.16
12	Anhui	0.01	1.03	0.01	0.49	0.00	0.00	0.00	0.40	0.00	0.02
13	Fujian	0.05	1.32	0.08	0.60	0.00	0.04	0.00	0.02	0.00	0.15
14	Jiangxi	0.02	1.09	0.03	0.34	0.00	0.06	0.00	0.07	0.00	0.11
15	Shandong	0.14	3.72	0.05	0.78	0.00	0.17	0.05	1.09	0.00	0.27
16	Henan	0.02	1.97	0.01	0.44	0.00	0.03	0.02	0.74	0.00	0.07
17	Hubei	0.04	0.68	0.01	0.17	0.00	0.18	0.00	0.03	0.00	0.02
18	Hunan	0.01	0.36	0.03	0.26	0.00	0.06	0.00	0.21	0.00	0.02
19	Guangdong	0.29	3.29	0.30	1.99	0.00	0.04	0.00	0.07	0.00	0.13
20	Guangxi	0.02	1.02	0.05	0.31	0.00	0.03	0.00	0.01	0.00	0.02
21	Hainan	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.04
22	Chongqing	0.01	0.22	0.01	0.17	0.00	0.09	0.00	0.16	0.00	0.00
23	Sichuan	0.03	0.44	0.01	0.15	0.00	0.24	0.00	0.08	0.00	0.17
24	Guizhou	0.00	0.18	0.00	0.06	0.00	0.02	0.01	0.13	0.00	0.00
25	Yunnan	0.01	0.52	0.00	0.03	0.01	0.21	0.00	0.15	0.00	0.01
26	Tibet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Shaanxi	0.02	0.37	0.01	0.08	0.00	0.05	0.00	0.49	0.00	0.13
28	Gansu	0.00	0.38	0.00	0.03	0.00	0.01	0.00	0.00	0.00	0.04
29	Qinghai	0.00	0.04	0.00	0.00	0.00	0.01	0.00	0.10	0.00	0.00
30	Ningxia	0.02	0.25	0.01	0.06	0.00	0.12	0.00	0.17	0.00	0.02
31	Xinjiang	0.00	0.52	0.00	0.03	0.01	0.23	0.00	0.17	0.00	0.07

Note: S-1 and S-2 represent two different scenarios of taxing direct production carbon emissions and implied carbon emissions, respectively. In addition, the five emission-intensive and trade-exposed (EITE) industries defined in this paper are shown in the table.

In terms of implied carbon emissions, China exported 204.4 MT of implied carbon emissions to the seven major EU countries, of which the industries involved in CBAM accounted for 61.89 MT, or 30.3% of the total, while the industries involved in EU ETS accounted for 75.15 MT, or 36.8% of the total. In terms of different provinces, coastal provinces such as Jiangsu and Guangdong led the carbon exports, followed by high-carbon provinces such as Shanxi and Inner Mongolia. The implied carbon emissions of metal and non-metal mineral products industries are similar to those of direct carbon emissions.

4.3. Changes in CBAM Tax Rates of China's Provincial Industries Under Different CBAM Prices and Carbon Emission Accounting Ranges

As can be seen from the results of the calculations (see Table 5), the average carbon tariff rates for the industries covered by CBAM rise by 7.99–34.89% under the different simulation scenarios, which is significantly higher than that of the industries covered by the EU ETS, which ranges from 3.76 to 20.28%. Within the scope of these two applicable industries, the S4-2 scenario has the largest increase in tariff rates, followed by the S9-2 scenario. This result suggests that the tariff rate increase is greater for implied carbon emissions compared to direct emissions. In addition, under both applicable industries, changes in tariff rates are more prominent in Inner Mongolia, Shanxi, and Liaoning, with the cement, iron and steel, and aluminum sectors experiencing the largest changes in carbon tariff rates.

Table 5. Changes in average carbon tariff rates across provinces under different scenarios (%).

	Province	**CBAM-Covered Industries**							**Province**	**EU ETS-Covered Industries**					
		S2-1	**S5-1**	**S6-1**	**S4-2**	**S9-2**	**S10-2**			**S2-1**	**S5-1**	**S6-1**	**S4-2**	**S9-2**	**S10-2**
1	Inner Mongolia	45.17	40.43	36.63	139.85	131.61	125.03	1	Inner Mongolia	16.84	15.08	13.65	62.52	58.83	55.89
2	Yunnan	24.15	21.63	19.58	47.62	44.82	42.58	2	Yunnan	10.90	9.75	8.83	21.51	20.24	19.24
3	Guizhou	19.02	17.03	15.43	38.31	36.04	34.24	3	Ningxia	8.67	7.75	7.03	17.02	16.02	15.22
4	Ningxia	17.01	15.23	13.78	33.51	31.55	29.97	4	Guizhou	8.65	7.73	7.01	17.45	16.43	15.61
5	Qinghai	16.98	15.18	13.76	32.56	30.64	29.12	5	Shanxi	8.12	7.28	6.57	41.65	39.20	37.24
6	Shanxi	15.32	13.70	12.42	70.36	66.21	62.91	6	Tibet	8.03	7.18	6.49	15.17	14.27	13.55
7	Tibet	15.20	13.60	12.32	28.73	27.03	25.69	7	Xinjiang	8.03	7.18	6.49	16.51	15.52	14.77
8	Xinjiang	15.20	13.60	12.32	31.73	29.86	28.38	8	Qinghai	7.15	6.40	5.80	13.71	12.91	12.27
9	Liaoning	11.28	10.10	9.14	52.91	49.79	47.32	9	Heilongjiang	5.72	5.13	4.65	29.18	27.46	26.10
10	Gansu	11.19	10.03	9.06	22.78	21.45	20.37	10	Sichuan	4.82	4.30	3.90	13.09	12.30	11.70
11	Guangxi	11.04	9.88	8.93	25.14	23.65	22.47	11	Gansu	4.73	4.23	3.82	9.58	9.02	8.58
12	Heilongjiang	10.93	9.78	8.86	47.11	44.35	42.13	12	Liaoning	4.70	4.20	3.80	29.13	27.42	26.04
13	Hainan	10.26	9.18	8.32	19.72	18.55	17.63	13	Guangxi	4.42	3.95	3.57	12.98	12.22	11.60
14	Anhui	8.27	7.40	6.70	46.77	44.02	41.82	14	Hainan	4.28	3.83	3.47	8.27	7.78	7.38
15	Sichuan	8.27	7.40	6.70	22.55	21.21	20.15	15	Chongqing	4.16	3.73	3.39	9.37	8.82	8.38
16	Chongqing	6.58	5.90	5.34	15.66	14.75	14.01	16	Anhui	3.99	3.58	3.23	32.47	30.57	29.03
17	Jilin	6.51	5.83	5.26	34.30	32.28	30.66	17	Shaanxi	3.14	2.80	2.54	7.84	7.37	6.99
18	Hubei	6.03	5.40	4.90	29.81	28.06	26.67	18	Jilin	3.09	2.75	2.49	24.16	22.75	21.61
19	Shaanxi	5.77	5.18	4.70	13.83	13.04	12.38	19	Hunan	2.97	2.68	2.41	20.74	19.52	18.54
20	Jiangxi	4.87	4.35	3.95	37.12	34.94	33.20	20	Jiangxi	2.83	2.53	2.28	29.03	27.33	25.95
21	Hunan	4.85	4.35	3.93	29.16	27.44	26.06	21	Jiangsu	2.42	2.18	1.98	22.38	21.06	20.00
22	Jiangsu	4.66	4.18	3.77	34.53	32.50	30.88	22	Hubei	2.42	2.18	1.95	17.77	16.74	15.89
23	Anhui	4.44	3.98	3.62	38.27	36.02	34.22	23	Anhui	2.30	2.05	1.87	26.63	25.06	23.80
24	Zhejiang	3.99	3.58	3.23	26.95	25.36	24.10	24	Zhejiang	1.71	1.53	1.39	18.64	17.54	16.65
25	Fujian	3.59	3.20	2.90	19.38	18.23	17.33	25	Henan	1.69	1.50	1.36	21.93	20.65	19.61
26	Tianjin	3.14	2.80	2.54	24.01	22.59	21.48	26	Fujian	1.66	1.50	1.36	11.88	11.18	10.62
27	Guangdong	3.09	2.78	2.52	27.37	25.77	24.47	27	Shanghai	1.62	1.45	1.31	13.90	13.08	12.44
28	Shandong	2.90	2.60	2.34	27.09	25.49	24.21	28	Shandong	1.57	1.40	1.26	19.49	18.34	17.41
29	Shanghai	2.80	2.53	2.28	17.89	16.84	16.00	29	Tianjin	1.40	1.25	1.13	15.92	14.98	14.22
30	Henan	2.66	2.38	2.16	30.62	28.82	27.38	30	Guangdong	1.33	1.20	1.08	16.47	15.50	14.72
31	Beijing	0.26	0.25	0.21	15.81	14.88	14.14	31	Beijing	0.59	0.55	0.49	12.43	11.70	11.12

Source: Based on the authors' own calculations.

For both direct and implied emissions, for the fertilizer, iron and steel, and aluminum industries, the tax rate increases were the largest in Inner Mongolia, Shanxi, and Hebei provinces, especially for the non-metal industry in Inner Mongolia, followed by the metal industry in Shanxi. However, the overall carbon tax rate increase for the chemical industry is not prominent, but there are large differences in the tax rate changes under different carbon emission accounting scopes in various provinces, especially in Shanxi, Hebei, and Liaoning.

In addition, the provincial and industry heterogeneity of tax rate changes under different carbon emission accounting scopes is analyzed, and the results are consistent with carbon intensity. Assuming a carbon price of USD 170/tonne, the largest changes in tax rates are still in the metal, non-metal, and chemical industries, with average tax rate changes of 20.44%, 19.06%, and 12.24%, respectively. Distinguishing between different provinces, the biggest changes in tax rates are in the provinces with the highest carbon intensity, such as Inner Mongolia, Shanxi, and Hebei, where taxing implied carbon emissions will result in tax rate increases of 32.39%, 27.12%, and 25.35%. Therefore, regardless of the carbon emission accounting methodology adopted by CBAM, the provinces and industries with the highest carbon intensity will bear the brunt of the direct or indirect impact of CBAM.

4.4. Changes in CBAM Tax Amounts of China's Provincial Industries Under Different CBAM Prices and Carbon Emission Accounting Ranges

First, from a national perspective, the carbon price of USD 77–170/tonne results in a carbon tariff of USD 0.29–10.52 billion for the industries involved in CBAM, accounting for 0.42–18.22% of the industry's exports. Included among these, the damage under the S4-2 scenario (USD 170/tonne, implied carbon emissions) is the most serious. Should CBAM be extended to encompass all products within the EU ETS, the resulting carbon tariffs imposed on this industry would total USD 0.37–12.78 billion. Meanwhile, the carbon tariffs of the industries involved in CBAM account for 79.90–82.36% of the industries involved in EU ETS. Therefore, irrespective of whether CBAM expands its application industries in the future, the steel, aluminum, cement, and fertilizer industries will be most seriously affected by trade.

Therefore, this paper examines the industries involved in CBAM in different provinces (see Table 6). From the perspective of different industries, due to high carbon emissions, the iron and steel and aluminum industries are subject to the largest carbon tariffs, accounting for 72.43–80.62% of the total tariffs of the CBAM industries under different carbon emission accounting ranges, followed by the non-metallic mineral products industry and the chemical industry. In the metal industry, the three major provinces of Jiangsu, Hebei, and Liaoning led the way, with taxes amounting to USD 0.10–0.44 billion. For the non-metallic mineral products industry, coastal provinces such as Jiangsu are more directly affected by CBAM, while developed coastal provinces such as Guangdong and Zhejiang are more seriously affected by CBAM indirectly due to inter-industry correlation, resulting in higher carbon tariffs for these two types of provinces. It can be seen that under different scenarios (especially the S4-2 scenario), coastal provinces led by Jiangsu, Hebei, and Liaoning and inland high-carbon provinces led by Shanxi will bear the brunt of the direct or indirect impact of CBAM. Developed coastal provinces such as Guangdong and Zhejiang's CBAM-involved industries and their upstream and downstream industries will also be affected by higher carbon tariffs due to their higher trade intensity.

Analyzing the different carbon price response scenarios for China, a higher Chinese carbon price response would mitigate the increase in carbon tariffs to a greater extent (e.g., higher carbon tariff collection in S9-2 than in S10-2), whereas the same Chinese carbon price response to a higher level of the EU carbon price would result in a greater tariff reduction, making the response more effective (e.g., higher carbon tariff collection in S10-1 than in S6-1). In addition, by industry, with a carbon price of USD 170/tonne, the direct and implied carbon taxes for metal smelting and manufacturing average USD 0.02 billion and USD 0.27 billion, respectively, a difference of USD 0.26 billion, followed by the non-metallic mineral products industry with a difference of USD 0.05 billion. Distinguishing between different provinces, provinces with higher implied carbon emissions from exports have larger tax changes under different carbon emission accounting ranges, and these provinces will be directly or indirectly affected by CBAM based on inter-industry linkages. Also, based on a carbon price of USD 170/tonne, Jiangsu and Hebei have the largest industry average tax differentials of USD 0.57 billion and USD 0.55 billion, respectively, followed by Liaoning and Guangdong with tax differentials of USD 0.28 billion and USD 0.27 billion, respectively.

Table 6. Amount of carbon tariffs imposed on China's provinces under different scenarios (million USD).

	Province	CBAM-Covered Industries							Province	EU ETS-Covered Industries					
		S2-1	S5-1	S6-1	S4-2	S9-2	S10-2			S2-1	S5-1	S6-1	S4-2	S9-2	S10-2
1	Beijing	0.14	0.27	0.13	1.42	1.34	1.28	1	Beijing	2.80	2.50	2.26	17.74	16.71	15.87
2	Tianjin	9.93	19.32	8.03	292.19	275.03	261.22	2	Tianjin	10.47	9.38	8.50	316.84	298.16	283.37
3	Anhui	46.00	89.56	37.27	1733.36	1631.35	1549.75	3	Anhui	48.93	43.78	39.66	1969.24	1853.19	1760.59
4	Shanxi	29.55	57.51	23.95	551.01	518.49	492.70	4	Shanxi	36.81	32.95	29.85	816.64	768.43	730.03
5	Inner Mongolia	2.45	4.79	1.98	200.13	188.35	178.93	5	Inner Mongolia	2.87	2.58	2.34	281.35	264.86	251.67
6	Liaoning	34.11	66.44	27.64	909.50	856.00	813.20	6	Liaoning	42.89	38.38	34.75	1018.73	958.70	910.91
7	Jilin	1.69	3.26	1.36	97.71	91.96	87.36	7	Jilin	2.23	2.00	1.80	127.52	120.02	114.02
8	Heilongjiang	0.71	1.41	0.59	30.32	28.54	27.12	8	Heilongjiang	1.69	1.50	1.36	108.25	101.88	96.78
9	Shanghai	22.30	43.42	18.07	296.86	279.57	265.57	9	Shanghai	37.00	33.13	30.00	382.93	360.22	342.22
10	Jiangsu	56.74	110.46	45.99	1816.45	1709.62	1624.01	10	Jiangsu	66.05	59.08	53.52	1942.25	1827.89	1736.49
11	Zhejiang	27.95	54.47	22.66	345.31	324.97	308.78	11	Zhejiang	42.85	38.33	34.73	433.71	408.22	387.82
12	Anhui	1.83	3.54	1.49	257.76	242.59	230.39	12	Anhui	2.04	1.83	1.64	332.56	313.08	297.27
13	Fujian	12.14	23.67	9.83	334.26	314.59	299.01	13	Fujian	15.13	13.53	12.27	385.69	363.03	344.82
14	Jiangxi	4.96	9.63	4.00	251.60	236.76	224.96	14	Jiangxi	5.46	4.90	4.44	288.79	271.78	258.18
15	Shandong	18.83	36.67	15.27	792.84	746.38	708.97	15	Shandong	27.79	24.88	22.54	1084.81	1020.76	969.98
16	Henan	3.16	6.15	2.57	414.80	390.49	370.88	16	Henan	5.25	4.70	4.26	556.11	523.46	497.26
17	Hubei	4.87	9.47	3.95	174.53	164.26	156.06	17	Hubei	5.20	4.68	4.24	188.47	177.38	168.50
18	Hunan	4.32	8.43	3.52	115.64	108.84	103.40	18	Hunan	4.99	4.48	4.06	158.78	149.45	141.97
19	Guangdong	56.12	109.31	45.48	904.19	851.03	808.42	19	Guangdong	64.98	58.13	52.67	991.95	933.62	886.81
20	Guangxi	7.36	14.36	5.98	232.26	218.59	207.65	20	Guangxi	7.81	6.98	6.34	244.80	230.49	218.88
21	Hainan	0.02	0.00	0.00	1.42	1.34	1.28	21	Hainan	0.40	0.38	0.33	10.92	10.27	9.77
22	Chongqing	2.30	4.46	1.87	83.07	78.18	74.26	22	Chongqing	2.66	2.38	2.16	113.69	107.01	101.64
23	Sichuan	3.54	6.86	2.85	141.23	132.91	126.27	23	Sichuan	4.16	3.73	3.36	202.85	190.92	181.38
24	Guizhou	0.45	0.93	0.39	44.52	41.90	39.80	24	Guizhou	1.47	1.30	1.18	67.98	63.98	60.78
25	Yunnan	2.07	4.03	1.67	128.24	120.71	114.67	25	Yunnan	2.21	1.98	1.80	157.06	147.83	140.43
26	Tibet	0.00	0.00	0.00	0.36	0.35	0.33	26	Tibet	0.00	0.00	0.00	0.81	0.76	0.72
27	Shaanxi	2.76	5.39	2.23	84.02	79.07	75.11	27	Shaanxi	2.95	2.63	2.39	190.63	179.42	170.46
28	Gansu	0.33	0.65	0.28	71.21	67.03	63.67	28	Gansu	0.40	0.35	0.33	78.73	74.10	70.40
29	Qinghai	0.07	0.16	0.05	10.29	9.69	9.21	29	Qinghai	0.12	0.10	0.10	27.20	25.60	24.32
30	Ningxia	3.82	7.40	3.08	72.42	68.17	64.75	30	Ningxia	3.90	3.48	3.16	103.89	97.77	92.89
31	Xinjiang	1.85	3.59	1.51	132.41	124.63	118.41	31	Xinjiang	2.09	1.88	1.69	174.08	163.85	155.65

Note: The sectoral definitions of CBAM-covered industries in relation to the EU ETS and the scenarios for S2-1, S5-1, S6-1, S4-2, S9-2, and S10-2 are the same as above. The taxed amounts in scenarios S6-1 and S4-2 are the ranges that could be affected by CBAM as a result of this simulation.

4.5. Comparative Analysis of Changes in CBAM Tax Rates and Tax Amounts in China's Provincial Industries Under Different Scenarios

The analysis revealed that the change range of the carbon tariff rate and tax amount exhibited significant inter-provincial heterogeneity, regardless of whether CBAM adopted direct or implicit emission. This implies that the carbon tariff tax levied by provinces with substantial tax rate alterations is not inherently high. This is because the export carbon emissions and carbon tariff tax levied are not solely contingent on carbon intensity but also contingent on trade intensity.

Based on the considerations outlined above, and to ensure the broad coverage of the selected indicators within the classification framework, this study proposes a multidimensional classification framework encompassing "pillar industry relevance to CBAM-covered sectors–carbon intensity–trade intensity". Using this framework, the 31 provinces are classified into four categories (see Table 7). We believe that these indicators, to some extent, encompass other relevant factors such as economic development levels, industrial structure, and technological capabilities, thereby providing a more comprehensive reflection of inter-provincial heterogeneity. The first category is the provinces with industries involved in CBAM as the pillar industries, which have high carbon intensity and trade intensity, so they are most directly influenced by CBAM. The second category is the provinces with relatively high carbon intensity and trade intensity, which are based on the upstream and downstream industries involved in CBAM. These provinces are indirectly influenced by CBAM. The third category is the provinces whose pillar industries have nothing to do with CBAM and whose trade intensity is high but their carbon intensity is low. The fourth category is the provinces with high carbon intensity but low trade intensity, although CBAM-related industries are the pillar industries.

Table 7. Criteria for the delineation and determination of the scope of the 31 provinces.

Delineation Criteria	Scope Determination
Provinces that are directly affected by CBAM have high carbon and trade intensities	Jiangsu, Hebei, Liaoning, Guangxi, and Henan
Provinces that are indirectly affected by CBAM have high carbon and trade intensities	Shanxi, Shaanxi, Anhui, Jiangxi, Hunan, Sichuan, and Shandong
Pillar industries that are not CBAM-related industries have high trade intensity but low carbon intensity	Guangdong, Zhejiang, Shanghai, Fujian, Jiangxi, Tianjin, Beijing, Hubei, Chongqing, and Hainan
Pillar industries that are CBAM-related industries have high trade intensity but low carbon intensity	Yunnan, Xinjiang, Ningxia, Heilongjiang, Qinghai, Inner Mongolia, Gansu, Jilin, Tibet, and Guizhou

Moreover, this paper categorizes five vulnerable industries with high trade carbon intensity and export carbon emissions under various scenarios, including the non-metallic mineral products industry, the metal products smelting and products industry, the mining industry, the petroleum processing industry, and the coking and chemical industry. These industries are particularly susceptible to a significant increase in export costs and a consequent decline in competitiveness.

5. Discussion

Compared with Gao's [34] study, this paper examines the impact of carbon pricing policies on the export costs and trade competitiveness of industries in each province [34]. To this end, the analysis employs a comparative approach, investigating the carbon intensity of trade and carbon emissions in each province under different policy designs of CBAM. This paper employs an inter-provincial industrial linkage perspective to construct a multi-dimensional classification framework, comprising four categories of provinces and five categories of vulnerable industries. It posits that CBAM will directly impact China's first two categories of provinces and the five most vulnerable industries, including extractive and oil-processing industries, resulting in a notable rise in export costs and a significant decline in competitiveness. It further proposes targeted recommendations for different provinces. Compared with the studies of George and Cecilia [21,24], this paper examines the varying impacts of CBAM on the export trade of industries in different provinces in response to different carbon pricing mechanisms in China. It is demonstrated that the carbon pricing mechanism of exporting countries can effectively respond to CBAM and that its response efficiency increases in accordance with the rise in carbon price in exporting countries. In conclusion, based on the perspective of inter-industry linkages, this paper presents a novel perspective for assessing the impact of CBAM on China's exports to the EU under different policy design scenarios and offers insights for different types of provinces in China to effectively respond to CBAM.

This study acknowledges several limitations. First, the timeliness of the data used in this study presents certain limitations. Although the selected data represent the most recent and authoritative information currently available, and the study focuses on analyzing the impact of CBAM on the direction and structure of export trade to the EU across various provincial industries—where interprovincial economic structures have remained relatively stable—data timeliness remains a key constraint. Moving forward, we will closely monitor updates to relevant databases and strive to optimize and expand data sources. This will enable us to improve the timeliness and accuracy of our findings in future research.

Second, the study primarily focuses on Sino-EU carbon price differentials and emission accounting scope, while other critical factors—such as technological advancements and market demand dynamics—remain underexplored. Although carbon intensity serves as an indirect proxy for technological progress, more direct and granular assessments are needed. Similarly, the interaction between carbon tariff amounts and market demand warrants further investigation to provide a more comprehensive understanding of the economic impact of CBAM.

Third, the provincial-level analysis, which relies on indicators such as carbon intensity, trade intensity, and pillar industry relevance to CBAM-covered industries, may not fully capture the complexity of provincial-level heterogeneity. Factors such as economic development, industrial structure, and technological capacity are only partially reflected in the selected indicators. A more comprehensive framework that integrates these dimensions is necessary to better assess how different provinces may adapt to CBAM and its associated challenges. Future research should address this gap to provide a more nuanced understanding of regional disparities.

Furthermore, this study examines CBAM's static impacts but does not account for dynamic processes such as carbon price fluctuations, technological progress, and policy adjustments. For instance, China's rising carbon prices and the role of provincial participation in carbon trading pilots are not fully analyzed. Likewise, the implications of carbon quota allocations and potential domestic carbon taxes remain unexplored. A dynamic framework would be valuable for capturing these evolving factors and their implications for China's export trade and industrial adjustment over time.

Additionally, this study clearly distinguishes between the short- and long-term impacts of CBAM as insufficient, especially in addressing possible industrial restructuring and changes in international trade relations in the long term. Although we have dynamically incorporated key elements (e.g., industry coverage, carbon accounting boundaries, and pricing mechanisms) into the multi-scenario assessment framework to account for both short- and long-term impacts, the limited scope of the article and the existing technical constraints do not allow us to provide an in-depth analysis of the structural changes that may be induced by CBAM. In our future research, we will improve our technology and focus on exploring long-term impacts through specialized studies, thus filling this gap.

Finally, this study does not sufficiently address the influence of geopolitical dynamics, domestic political shifts, and other unpredictable factors on carbon pricing mechanisms in China and the EU. While these aspects were partially considered, analytical and methodological constraints limited their depth. Future research should refine analytical tools to better examine these dimensions.

6. Conclusions and Policy Recommendations

6.1. Conclusions

The impact of varying carbon emission accounting frameworks on trade competitiveness and export costs differs across provinces. Accordingly, this paper proposes a multidimensional categorization framework based on three key factors: "CBAM impact mode and magnitude", "carbon intensity", and "trade intensity". Using this framework, provinces are classified into four distinct types. The first category includes provinces that are directly affected by the CBAM, characterized by both high carbon intensity and high trade intensity. The second category consists of provinces that are indirectly impacted by CBAM and still exhibit considerable carbon and trade intensities. The third category encompasses provinces whose key industries are not subject to CBAM; these provinces display high trade volumes but relatively low carbon intensities. Finally, the fourth category includes provinces with relatively low trade intensities, even though their leading industries fall within the scope of CBAM.

Additionally, the five industries most vulnerable to CBAM—non-metallic mineral products, metal smelting and products, extractive industries, petroleum processing and coking, and chemicals—are particularly prone to significant increases in export costs and a sharp decline in trade competitiveness due to their high carbon intensity in both trade and emissions. In contrast, seven provincial industries, such as the chemical sectors in Inner Mongolia and Shanxi, were initially affected by CBAM only to a limited degree. These regions have relatively low direct carbon intensity, and the overall carbon tariff increase for their industries was not significant enough to drastically affect competitiveness. However, as the price of the CBAM rises, these industries may face higher export costs, further eroding their competitiveness.

The trade competitiveness of provinces in the first two categories, along with the most vulnerable industries, is expected to decline under various scenarios. As the carbon price gap between China and the EU widens and the carbon emission accounting scope expands, the negative impact on these provinces and industries will be aggravated.

Lastly, China's carbon pricing mechanism shows promise in responding effectively to CBAM. As China's carbon price increases, the effectiveness of this response improves, helping to mitigate some of the challenges posed by CBAM.

6.2. Policy Recommendations

It is essential to differentiate between the various categories of provinces and implement more precise CBAM response programs. In the case of the fourth category of provinces, it is recommended that investment in low-carbon technologies be increased and that the carbon intensity of vulnerable industries be adjusted. With regard to Category 3 provinces, it is advised that the trade structure of high-carbon industry exports to the EU be adjusted and that upstream inputs continue to be optimized. In the case of provinces in the first two categories, it is recommended that export restructuring and green low-carbon transformation of high-carbon industries be carried out concurrently.

Focus should be directed to the provincial industries that are easily overlooked, with a view to making appropriate impact assessments and production adjustments. While the short-term impact of CBAM is limited, such indicators should provide an effective means of assessing the impact of the CBAM policy, as well as adjusting the product mix of upstream inputs included in the scope of accounting in order to reduce the implied carbon intensity of products.

The carbon pricing mechanism in China should also be improved, both at the national level and in each of the country's provinces. Furthermore, the process of introducing a carbon tax in China should be accelerated. Given the significant discrepancies in industrial carbon intensity and carbon tax rates across different provinces, implementing differential carbon pricing among provincial industries will prove more effective in addressing the challenges posed by the CBAM.

Author Contributions: Conceptualization: L.R.; methodology: L.R. and J.C.; software: T.X.; validation: Y.L. and X.S.; formal analysis: J.W.; investigation: Y.N. and W.Z.; resources: W.Z.; data curation: J.W. and X.S.; writing—original draft preparation: J.W. and L.Z.; writing—review and editing: X.H., J.C., and T.X.; visualization: L.Z. and Y.L.; supervision: Y.N.; project administration: X.H.; funding acquisition: L.R. and J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Philosophy and Social Science Planning Project of Shanxi Province (Grant Number 2023YJ012, 2024ZK014), the Key Research Base Project of Humanities and Social Sciences of Shanxi Provincial Colleges and Universities (Grant Number 2022J011), and the

Philosophy and Social Science Project of Shanxi Provincial Colleges and Universities (Grant Number 2023W087).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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