Pol. J. Environ. Stud. Vol. 32, No. 4 (2023), 3653-3662
DOI: *10.15244/pjoes/163568* ONLINE PUBLICATION DATE: 2023-05-18

Original Research

How Does Export Behavior Affect Carbon Emissions? Multivariate Heterogeneous Data Based on Chinese Enterprises

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Received: 19 January 2023
Accepted: 24 April 2023

Abstract

Given global warming, carbon peaking and carbon neutrality strategies have become imperative. Based on the multivariate heterogeneous data of China's industrial enterprises, enterprise pollution emissions and customs databases, this study uses a two-way fixed effects panel model to examine the impact of exports on carbon emission reduction and the mechanism of this effect from the enterprise perspective. The results show that with the increase in enterprise exports, carbon emission intensity decreases; that is, exports can promote carbon emission reduction among enterprises. Heterogeneity analysis shows that as far as enterprise characteristics are concerned, the exports of those enterprises with domestic funding and low energy consumption lead to a higher level of carbon emission reduction. In terms of product characteristics, the exports of those enterprises with a high concentration of products in the domestic market and low product prices abroad lead to a higher level of carbon emission reduction. Mechanism analysis shows that a decline in the use intensity of high carbon energy, the improvement of enterprise productivity and the increase in investment in emission reduction equipment are important channels through which enterprise exports can reduce carbon emission intensity. This study provides policy inspiration for improving sustainable trade development and achieving the goals of carbon peaking and carbon neutrality.

Keywords: enterprise export, carbon emission, energy intensity, enterprise productivity, equipment investment

Introduction

Since the beginning of its reform and opening up period, China's economy has been growing rapidly, and thus, environmental problems have become increasingly prominent [1, 2]. The demand for fossil energy for human activities has generated a large amount of carbon emissions, which have led to global warming with the threat of irreversible disasters occurring on the planet [3]. The sixth Intergovernmental Panel on Climate Change (IPCC) assessment report (2022) pointed out that the average annual global greenhouse gas emissions

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from 2010 to 2019 were at their highest level in human history; the related number of climate-sensitive infectious diseases, chronic noninfectious diseases and mental health threats were increasing; and future risks would be further exacerbated by global warming[1]. At present, global warming and carbon emission reduction have attracted a great deal of attention from all countries. For example, General Secretary Xi Jinping announced at more than 10 major international and domestic conferences, including the 75th "UN General Assembly", "Climate Ambition Summit", "Davos Agenda", "Leaders' Climate Summit", and "Central Economic Work Conference", that China will strive to achieve carbon peaking by 2030 and carbon neutrality by 2060, thus putting forward a higher degree of requirements for China's sustainable economic and social development and energy structure transformation.

Although its position and voice in the international trade supply chain have improved in recent years, China still faces tremendous pressure to reduce its carbon emissions. As early as 2010, China surpassed the United States to become the country with the largest rates of energy consumption in the world. In this context, it is particularly necessary to discuss how exports affect carbon emissions while stimulating economic growth. At present, research on international trade and carbon emissions is based mainly at the national or regional macro level, while research from the micro perspective is relatively scarce, and the research process rarely involves the analysis of enterprise heterogeneity and the discussion of internal mechanisms. In this context, the aim of the present study is to investigate the degree to which enterprise exports influence carbon emissions, the mechanism of that influence, and the heterogeneity effect of enterprise and product characteristics, providing a scientific basis and micro evidence to support the sustainable development of international trade.

Compared with previous studies, the possible contributions of this study are as follows. In terms of the research perspective, this work expands on previous studies on the relationship between international trade and carbon emissions by using enterprises as its starting point and examining the effects of export behavior on carbon emissions, thus avoiding the synthesis fallacy of macrolevel research. In terms of research content, this study introduces characteristics to differentiate among enterprises and products and discusses the internal mechanism by which enterprise exports affect carbon emission reduction, broadening the research framework for international trade and carbon emissions. In terms of research data, this work is based on multivariate heterogeneous data from China's industrial enterprises, enterprise pollution emissions and customs databases, which provide the largest sample of micro data available for studying international trade and environmental issues and make the research conclusions more generalizable and credible.

The remainder of this article is arranged as follows. The second part reviews the relevant literature and proposes the research hypotheses. The third part introduces the research design, which includes the econometric model constructed and the data sources. The fourth part is the empirical results and discussion, which analyzes the impact of enterprise exports on carbon emissions and carries out robustness checks and endogeneity tests. The fifth part is an expanded analysis, including heterogeneity analysis and an analysis for an internal mechanism. The final part provides the conclusions and policy implications.

Literature Review and Research Hypotheses

The relationship between trade and the environment has become the focus of academia and government departments [4-6]. However, the conclusions of recent studies on how trade affects the environment are inconsistent, as there are two main views. Some studies believe that trade will lead to environmental degradation [7-9]. Due to the differences in the intensity of environmental governance across regions, some enterprises will transfer the relatively polluting steps in the production process to regions with weak environmental regulations to avoid strict environmental standards [10-12]. With the rapid development of foreign trade, the progress of emission reduction technology lags behind the growth rate of foreign trade, which increases carbon emissions and carbon use intensity. Another stream of the literature believes that the "pollution haven" has not been established because developed countries have transferred not only polluting industries but also clean industries to developing countries [13-15]. The comprehensive environmental effect of trade is positive because trade can give developing countries the opportunity to learn foreign advanced technology through technology spillover and export learning effects to reduce their own pollution emissions. Related studies have confirmed that foreign trade can compete in the import and export markets through technology spillovers [16, 17], which improves process and management efficiency to reduce carbon emissions. Based on the literature, this study proposes the following hypothesis on international trade and carbon emissions from a micro perspective:

Hypothesis 1: Enterprise exports can affect carbon emissions in China.

Since the introduction of the theory of heterogeneous enterprises [18], an increasing number of studies have included heterogeneous enterprises in their analysis, and the recorded differences in enterprise-level environmental performance are an important aspect of related research [19-21]. Some studies have verified that the impact of enterprise exports on emissions are significantly different due to differing enterprise

[1] https://www.ipcc.ch/assessment-report/ar6/

characteristics [22-24]. In addition, some studies have verified that the relationship between enterprise exports and pollution emissions changes with product characteristics [25]. Therefore, the following hypothesis is proposed:

Hypothesis 2: The impact of enterprise exports on carbon emissions shows heterogeneity due to differences in enterprise and product characteristics.

Recent research has attempted to analyze the impact of international trade on carbon emissions from energy consumption intensity, production efficiency and emission reduction investments [26, 27]. First, exporting enterprises often have greater market demand and a larger production scale, improving the probability of enterprises using clean energy and reducing high carbon energy use to positively affect carbon emissions [28, 29]. Second, relevant studies have verified that the production efficiency of exporting enterprises is higher than that of domestically oriented enterprises. High-productivity enterprises are more inclined to upgrade their technology and improve their production processes to improve carbon emissions than are low-productivity enterprises [30]. Third, to meet the environmental standards of foreign markets, export enterprises have stronger incentives and more financial support to invest in emission reduction equipment [31]. Therefore, the following hypothesis is proposed:

Hypothesis 3: Enterprise exports can affect carbon emissions by reducing the intensity of use of high carbon energy, improving productivity and increasing investments in emission reduction equipment.

Material and Methods

Data Source

The multivariate heterogeneous data in this paper are matched based on the databases of China's industrial enterprises, enterprise pollution emissions and customs. The database of China's industrial enterprises reports yearly data, including those on all state- and nonstate-owned industrial firms above a designated size, and is run by the National Bureau of Statistics. The database of China's enterprise pollution emissions reports quarterly survey data of major polluting enterprises and is run by the Ministry of Ecology and Environment of China. The database of China's customs reports monthly data, including those on all transactions in and out of the customs area, and is run by Chinese Customs. The sample interval is 2000-2010[2]. The specific matching process was as follows. First, the database of China's industrial enterprises was processed according to the method used by Brandt, Van Biesebroeck [32] to form panel data with Chinese industrial enterprises, and similar methods were used to build panel data with enterprise pollution emissions. In addition, since the China Customs database provides monthly records, annual data can be obtained by summarizing the import and export data of enterprises based on the destination market and Harmonized System (HS) 8-quantile coding of product imports and exports. Second, according to the unique identification code assigned to each enterprise, the databases of China's industrial enterprises, enterprise pollution emissions and customs were combined. Finally, referring to the existing research [33, 34] and the General Accounting Standards, the data with statistical problems and missing key indicators in the combined data were eliminated.

Econometric Model

To investigate the impact of exports on the carbon emissions of enterprises, a two-way fixed effects panel model is constructed as follows:

$$lnCO2_{it} = \beta_0 + \beta_1 lnExport_{it} + X_{it} + \delta_i + \gamma_t + \varepsilon_{it} \quad (1)$$

CO_2 is the carbon emission intensity of enterprise i in year t. The core explanatory variable $Export_{it}$ is the export scale of enterprise i in year t, and ε_{it} represents the stochastic error term. To control for the interference of other factors on the estimation results, a series of control variables, X_{it}, is added to the model. In addition, to control for the interference of unobservable factors that do not change across individuals and time, variables for individual fixed effects δ_i and time fixed effects γ_t are further introduced.

Indicator Construction

Explained Variable

Carbon emission intensity $CO2_{it}$. Carbon emissions at the enterprise level cannot be obtained directly. The energy consumed by enterprises in production take the form of mainly primary energy, such as coal, oil and natural gas. China's enterprise pollution emission database provides data on the classified consumption of coal, oil and natural gas. Therefore, when measuring the carbon emissions of enterprises, this study mainly converts coal, oil, natural gas and other different measurement units into standard coal using the following formula for carbon emission calculation:

$$CO_2 = \sum_{j=1}^{3} Emission_j * \theta_j \text{ (j=Coal; Oil; Natural gas)} \quad (2)$$

where $Emission_j$ is the quantity of energy consumption and θ_j is the carbon emission coefficient of each energy

[2] This sample period was selected based largely on two factors: (1) the availability of key indicators and the quality of the data samples and (2) the absence of significant changes in China's export market since 2010 that would have affected the reliability of the study's findings.

Table 1. Carbon emission coefficient of each energy source.

Energy	Carbon emission coefficient
Coal	1.89 tCO_2/t
Oil	3.02 tCO_2/t
Natural gas	0.00209 tCO_2/m^3

source. The amount of carbon dioxide emitted by the enterprise is calculated according to the estimation method and parameter selection of carbon dioxide emission reduction issued by the National Development and Reform Commission of China. The carbon emission factors of the three kinds of energy sources are manually sorted in Table 1.

Core Explanatory Variable

Enterprise export, $Export_{it}$. This study uses the export volume of enterprises as the index of enterprise exports. The unit of enterprise exports in the China Customs database is US dollars. This work uses the annual average exchange rate to convert US dollars into RMB yuan, which is convenient for comparison and analysis with enterprise production and operation variables. The exchange rate data for each year are from the China Statistical Yearbook.

Control Variables

1) Enterprise scale, $Scale_{it}$. Different enterprise sizes can affect enterprises' investment in emission reduction and, thus, their carbon emissions. This study uses the logarithm of the total fixed assets of the enterprise. 2) Capital intensity, Ck_{it}. The carbon intensity of capital-intensive enterprises is significantly different from that of labor-intensive enterprises [34]. This study uses the logarithm of the ratio of actual total fixed assets to the number of employees. 3) Enterprise age, Age_{it}. The length of an enterprise's operating life has a certain impact on its production experience and efficiency, thus also affecting its carbon emissions. This study uses the logarithm of the year for which data on the enterprise are used minus the year when the enterprise started doing business plus 1. 4) Environmental regulation, $Regulation_{it}$. The literature shows that the degree of regional environmental governance may affect carbon emissions to some extent [35]. Based on the comprehensive index method, this study uses the removal rates of waste gas, wastewater, sulfur dioxide, smoke and dust in various regions to measure environmental regulation intensity.

Table 2. Benchmark regression.

	Carbon dioxide emission intensity				
	(1)	(2)	(3)	(4)	(5)
Export	-0.0012***	-0.0011***	-0.0010***	-0.0010***	-0.0010***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Scale		-0.0132***	-0.0292***	-0.0292***	-0.0293***
		(0.0011)	(0.0016)	(0.0016)	(0.0016)
Ck			0.0247***	0.0246***	0.0250***
			(0.0018)	(0.0018)	(0.0018)
Age				-0.0016	-0.0017
				(0.0023)	(0.0023)
Regulation					0.0225***
					(0.0044)
Constant	0.0321***	0.1667***	0.2209***	0.2246***	0.2043***
	(0.0033)	(0.0114)	(0.0120)	(0.0128)	(0.0134)
Time effect	Yes	Yes	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes	Yes	Yes
Observations	57,507	57,507	57,499	57,463	57,463
R^2	0.0339	0.0382	0.0435	0.0435	0.0442

Note: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Numbers in parentheses indicate standard errors.

Table 3. Robustness analysis.

	Winsorized		Indicator replacement
	(1) Five percent	(2) Ten percent	(3) Export intensity
Export	-0.0010***	-0.0010***	-0.0041***
	(0.0002)	(0.0002)	(0.0014)
Control variable	Yes	Yes	Yes
Individual effect	Yes	Yes	Yes
Time effect	Yes	Yes	Yes
Observations	57,463	57,463	57,463
R^2	0.0442	0.0442	0.0437

Note: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Numbers in parentheses indicate standard errors.

Results and Discussion

Benchmark Analysis

A two-way fixed effects panel model is used for regression analysis to examine the relationship between enterprise exports and carbon emissions. The benchmark analysis results are reported in Table 2. Column (1) considers only the impact of exports on the carbon emissions of enterprises, the results of which show that the impact of exports on carbon emissions is significantly negative. After the control variables are added, the impact of exports on carbon emissions is still negative at the 1% significance level. The results show that a 1% increase in exports will reduce the carbon emission intensity of enterprises by 0.001%.

Continuing to observe the regression results of the control variables in Table 2, it can be seen that the coefficients of enterprise scale are significantly negative at a level of 1%, indicating that the larger the enterprise's scale is, the lower its carbon emission intensity. The coefficients of enterprise capital intensity are significantly positive, indicating that the higher the capital intensity is, the higher the carbon emission intensity of enterprises. The coefficients of environmental regulation are positive, which shows that the government's environmental intervention did not significantly reduce carbon emissions.

Robustness Analysis

The results of the benchmark analysis show that enterprise exports can reduce carbon emissions. To ensure the reliability of the above conclusions, robustness checks are conducted through sample processing and indicator replacement. Considering that outliers have a certain impact on the estimation results, this study winsorizes the data on carbon emissions intensity by 5% and 10% to exclude the impact of extreme values on the estimation results. The results are shown in columns (1) and (2) of Table 3. After winsorization, the coefficients of enterprise exports are still significantly negative, which verifies the robustness of the benchmark regression results to a certain extent.

In addition, another robustness test is carried out by replacing the enterprise export indicators. In column (3) of Table 3, the export intensity of enterprises is used to measure enterprise exports. The results show that the export variable is significantly negative, indicating that with the increase in exports, the carbon emission intensity of enterprises decreases significantly, which is consistent with the benchmark results, verifying the robustness of the results again.

Endogeneity Analysis

Compared to other enterprises, those enterprises that can enter the export market have higher production efficiency and may also have better environmental performance, which may cause endogeneity problems of reverse causation. Instrumental variables (IVs) are powerful measurement tools for solving this problem and should satisfy the assumption of correlation and exogeneity. That is, we find IVs that are related to enterprise exports in corresponding years but not to carbon emission intensity. Columns (1) and (3) use a lag of one period on the enterprise's exports as the IV. An enterprise's current export amount is closely related to the next export amount and is not affected by current carbon emissions. In addition, columns (2) and (4) use the distance from the coastline multiplied by the real effective exchange rate as an IV. The proximity of foreign markets is closely related to exports; however, the distance between the enterprise and the coastline is not affected by carbon emissions[3].

The regression results of the first stage of the IVs are presented in columns (1) and (2) of Table 4 and show that there is a significantly positive relationship between the lag of exports and current exports and a significantly

[3] Distance from the coastline does not change with time, and thus, this study introduces the change in the real effective exchange rate per year as a product item.

Table 4. Endogeneity analysis.

	Export		Carbon emissions	
	(1)	(2)	(3)	(4)
Export lag one period	0.2384***			
	(0.0068)			
Approach degree of foreign markets		-0.0003**		
		(0.0001)		
Export			-0.0032***	-0.0554**
			(0.0011)	(0.0279)
Control variables	YES	YES	YES	YES
Individual effect	YES	YES	YES	YES
Time effect	YES	YES	YES	YES
Observation	27,423	47,399	27,423	47,399
Sargan			0.00	0.00
LM			1,158.537	5.803
			(0.00)	(0.016)

Note: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Numbers in parentheses indicate standard errors.

negative correlation between the enterprise's proximity to the overseas market and its exports. The coefficient of the IVs is in line with expectations. The regression results of the second stage of the IVs are presented in columns (3) and (4) of Table 4 and are consistent with the benchmark regression results. The coefficient of enterprise exports is still significantly negative at the 1% level, that is, that enterprise exports reduce carbon emissions, which proves the benchmark analysis conclusions when endogeneity is controlled. Table 4 reports that the results of *LM* and *Sargan* statistics significantly reject the original hypothesis of the insufficient and excessive identification of IVs, which indicates that the selection of the two IVs is reasonable.

Expanded Analysis

Heterogeneity Analysis

It has been verified that enterprise exports can reduce carbon emission intensity; however, since China has such a vast territory, there are significant differences between enterprise characteristics and product status. Will the above conclusions be heterogeneous for samples with different enterprise and product characteristics? This study analyzes the heterogeneity of the carbon emission reduction effects of enterprise exports.

There may be significant differences between domestically and foreign-funded enterprises in terms of export policies and constraints. According to the characteristics of enterprise ownership, enterprises in the sample are divided into domestically and foreign-funded enterprises. The left side of Fig. 1 reports the impact of exports on the carbon emission intensity of enterprises of different ownership types. The results show that a 1% increase in exports by domestically funded enterprises will reduce carbon emission intensity by 0.0018%, which is significant at the 1% level, while on the whole, foreign-funded enterprises do not show a significant carbon emission reduction effect in association with increased exports.

In addition, there are obvious differences in carbon emissions between high- and low-energy-consuming enterprises [36], and thus, the impact of exports on their carbon emission intensity may also be different. According to the Classification Standard of the Statistical Report on National Economic and Social Development, samples are defined as either high- or low-energy-consumption enterprises[4]. The right side of Fig. 1 displays the impact of exports on the carbon emissions of low- and high-energy-consuming enterprises. The regression results show that the exports of low-energy-consuming enterprises significantly

[4] According to the classification standard of the statistical report on national economic and social development, the chemical raw materials and chemical products manufacturing industry, nonmetallic mineral products industry, nonferrous metal smelting and rolling processing industry, petroleum processing and coking and nuclear fuel processing industry, power and heat production and supply industry, and ferrous metal smelting and rolling processing industry are defined as being in the high-energy-consumption group, and others are defined as being in the low-energy-consumption group.

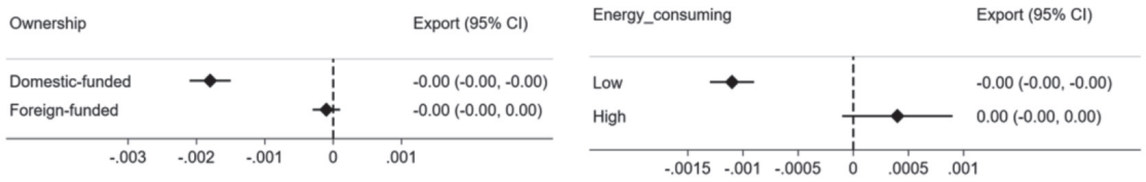

Fig. 1. Heterogeneity analysis I: introducing enterprise characteristics.
Note: An invalid vertical line is one with an abscissa scale of 0. The figure's diamond and two-sided line, which represent the effect size and 95% confidence interval, are used to illustrate these concepts. The coefficient of the variable is not significant at the 5% level when the *CI* horizontal line crosses the invalid vertical line.

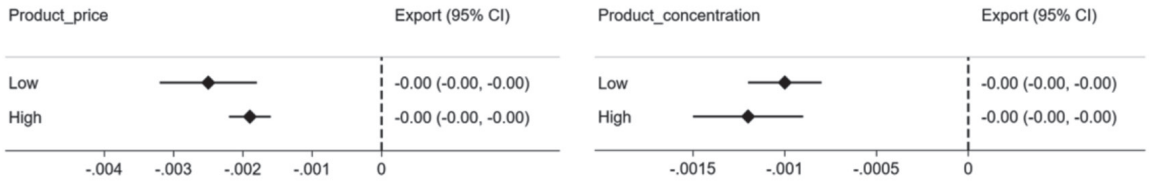

Fig. 2. Heterogeneity analysis II: Introducing product characteristics.
Note: An invalid vertical line is one with an abscissa scale of 0. The figure's diamond and two-sided line, which represent the effect's size and 95% confidence interval, are used to illustrate these concepts. The coefficient of the variable is not significant at the 5% level when the *CI* horizontal line crosses the invalid vertical line.

reduce carbon emissions. For every 1% increase in exports, the carbon emission intensity decreases by 0.0011%; however, there is no obvious carbon emission reduction effect in the exports of high-energy-consumption enterprises. A possible explanation for this is that high-energy-consuming enterprises consume more energy in scale and intensity than do low-energy-consuming enterprises, and thus, their exports will not lead to carbon emission reduction.

The differences in the product characteristics of enterprise exports may also directly or indirectly affect the relationship between enterprise exports and carbon emissions. There are differences in the production process and complexity of products with different prices, which may have different effects on enterprise carbon emissions. Therefore, the unit value of export products is used as a measure of the product price characteristics of enterprises. Enterprises whose export unit value is above the average value are regarded as enterprises with high-price product exports, and vice versa. The left side of Fig. 2 displays the impact of product price differences on the relationship between enterprise exports and carbon emissions. The results show that the exports of both high- enterprises and low-price-product enterprises will significantly reduce the carbon emissions of enterprises. However, when the export of low-price products increases by 1%, the carbon emission intensity of enterprises decreases by 0.0025%, while when the export of high-price products increases by 1%, the carbon emission intensity of enterprises decreases by only 0.0019%. A possible explanation for this is that the production mode of enterprises engaged in exporting low-price products is simple, with relatively few production processes, making it easier for them to increase their mass production to form economies of scale; thus, the carbon emission reduction effect of enterprise exports is more obvious for those enterprises exporting low-priced products.

In addition, product concentration reflects the competitive environment faced by an enterprise's products and the enterprise's ability to deploy products in the market. According to the difference in the market concentration of enterprises' products, enterprises above the average are defined as having a high product concentration, and vice versa. The right side of Fig. 2 shows the impact of product concentration differences on the relationship between enterprise exports and carbon emissions. The results show that the exports of enterprises with high product concentration have a greater inhibition of carbon emissions than do those of enterprises with low market concentration. A possible explanation for this is that enterprises with high market concentration have a stronger ability to allocate resources and dominate the product market and, thus, can produce and export more efficiently, reducing carbon emissions in both the production and export processes.

Internal Mechanism Analysis

One of the main findings of this paper is that the exports of Chinese enterprises help reduce carbon emission intensity. Then, the key question becomes the following: why do the exports of enterprises reduce carbon emission intensity, and what is the internal mechanism? This section introduces the variables of high carbon energy intensity, enterprise productivity and emission reduction equipment investment to

Table 5. Internal mechanism analysis.

	Energy use intensity	Productivity	Equipment investment
Export	-0.5121***	0.0118***	0.0010*
	(0.1120)	(0.0007)	(0.0006)
Control variables	YES	YES	YES
Individual effect	YES	YES	YES
Time effect	YES	YES	YES
Observation	57,412	65,577	65,577
R^2	0.0032	0.2959	0.0115

Note: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively. Numbers in parentheses indicate standard errors.

examine the internal mechanism of how enterprise exports reduce carbon emissions.

First, China's energy resource endowment is dominated by coal, and a high proportion of coal means large carbon emissions. In addition, each ton of oil can release up to 3 tons of carbon dioxide in energy mainly consumed by enterprises. Therefore, reducing the use structure of high carbon energy such as coal and oil may be an important channel through which to reduce carbon emissions. To verify this mechanism, this study takes the intensity of high-carbon energy as the explained variable to examine the impact of enterprise exports on enterprises' high-carbon energy consumption. The regression results in column (1) of Table 5 show that the coefficient of export variables is significantly negative, indicating that the increase in exports can effectively reduce the intensity of enterprise use of high carbon energy, verifying that reducing the intensity of high carbon energy use is the channel through which exports can encourage enterprises to achieve carbon emission reduction.

Second, export enterprises have lower carbon emission intensity, which may also be due to technology spillovers from trade development, providing conditions for such enterprises to learn advanced production technology or introduce advanced production equipment from abroad and reduce carbon emissions by improving enterprise productivity. To verify this mechanism, this study introduces enterprise productivity as the explained variable. The regression results in column (2) of Table 5 show that the coefficient of export variables is significantly positive at the 1% level, indicating that an increase in exports will improve the productivity of enterprises and verifying that an increase in enterprise productivity is the channel through which exports can promote carbon emission reduction.

Finally, with the increase in enterprise exports, to cope with the stricter environmental standards in the international market, enterprises may have a stronger incentive to increase their investment in emission reduction equipment, thus reducing their carbon emission intensity. In this paper, the investment in the emission reduction equipment of enterprises is introduced as the explained variable. The regression results in column (3) of Table 5 show that the coefficient of the export variables is significantly positive, indicating that the increase in enterprise exports can encourage enterprises to increase their investment in emission reduction equipment, which verifies that the increase in enterprise investment in emission reduction equipment is also the channel through which exports can promote carbon emission reduction.

Conclusions

Based on multivariate heterogeneous data from the databases of Chinese industrial enterprises, enterprise pollution emissions and customs, this study systematically analyzes the impact and mechanism of enterprise exports on carbon emissions. The main conclusions are as follows. First, the increase in exports reduces the carbon emissions of enterprises, and robustness and endogeneity analyses support the above conclusion. Second, the carbon emission reduction effects of enterprise exports are heterogeneous, with differences in enterprise and product characteristics. Specifically, on the one hand, the exports of domestically funded and low-energy-consuming enterprises can inhibit carbon emissions, while the carbon emission reduction effect of foreign-funded and high-energy-consuming enterprises is not obvious. On the other hand, compared with those of other enterprises, the exports of enterprises with low-priced products and a high product concentration can inhibit the carbon emissions of enterprises more than can other enterprises. Third, reducing the intensity of enterprise use of high carbon energy, improving enterprise productivity, and increasing investment in emission reduction equipment are internal mechanisms for how enterprise exports reduce carbon emission intensity.

According to the above research conclusions, the following policy implications are presented. First, the government should encourage enterprises to actively explore overseas markets and effectively use export trade to promote carbon emission reduction among enterprises. Second, classified supervision and incentives should be implemented for export enterprises with different characteristics. Pollution-intensive export enterprises should be guided to carry out low-carbon and clean production, and the proportion of high-carbon-emission enterprises in exports should be reduced. Finally, export enterprises should be encouraged to use clean energy, increase their investment in pollution control and improve production efficiency in the production link to achieve low-carbon transformation.

This study also has certain limitations that should be addressed in future research. This study examines

the effect of the internal mechanism of export behavior on carbon emissions using enterprise energy intensity, productivity, and equipment investment. However, some factors, such as enterprise environmental protection investment and pollution control technologies, have an unclear internal process. Future research should investigate how to effectively design and assess enterprise-level environmental characteristic variables and consider the other internal mechanisms of enterprise export behavior on carbon emissions. Furthermore, this study focuses on the static influence of export behavior on the carbon emissions of incumbent firms while ignoring the dynamic impact of export enterprise entry and exit. Future studies should address the dynamic changes in the entry and exit of export enterprises to compensate for the understated carbon emission effect of export behavior.

Acknowledgments

This research is sponsored by the National Natural Science Foundation of China (72274112, 71803102), Taishan Scholars Project Funding (tsqn202211237), Shandong Provincial Natural Science Foundation (ZR2020QG041) and China Postdoctoral Science Foundation (2021M690018).

Conflict of Interest

The authors declare no conflict of interest.

References

1. LI M.J., DU W.J. The impact of environmental regulation on the employment of enterprises: An empirical analysis based on scale and structure effects. Environmental Science and Pollution Research, **29**, 21705, **2022**.
2. WANG G.Y., SHEN Y.Z., HU P., YING Z.Y. Research on the supervision mechanism and effect of environmental regulation – re-estimation based on china's corn planting fertilizer pollution. Polish Journal of Environmental Studies, **31**, 4313, **2022**.
3. MALLAPATY S. China lays out plans for reducing carbon emissions. Nature, **600**, 19, **2021**.
4. CHERNIWCHAN J. Trade liberalization and the environment: Evidence from nafta and us manufacturing. Journal of International Economics, **105**, 130, **2017**.
5. SHAPIRO J.S., WALKER R. Why is pollution from us manufacturing declining? The roles of environmental regulation, productivity, and trade. American Economic Review, **108**, 3814, **2018**.
6. MAHMOOD H. Consumption and territory based CO_2 emissions, renewable energy consumption, exports and imports nexus in South America: Spatial analyses. Polish Journal of Environmental Studies, **31**, 1183, **2022**.
7. BOUTABBA M.A. The impact of financial development, income, energy and trade on carbon emissions: Evidence from the indian economy. Economic Modelling, **40**, 33, **2014**.
8. AL-MULALI U., OZTURK I. The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the mena (middle east and north African) region. Energy, **84**, 382, **2015**.
9. ASCENSAO F., FAHRIG L., CLEVENGER A.P., CORLETT R.T., JAEGER J.A.G., LAURANCE W.F., PEREIRA H.M. Environmental challenges for the belt and road initiative. Nature Sustainability, **1**, 206, **2018**.
10. COPELAND B.R., TAYLOR M.S. North-south trade and the environment. The Quarterly Journal of Economics, **109**, 755, **1994**.
11. LE T.H., CHANG Y., PARK D. Trade openness and environmental quality: International evidence. Energy Policy, **92**, 45, **2016**.
12. LI M.J., DU W.J., TANG S.L. Assessing the impact of environmental regulation and environmental co-governance on pollution transfer: Micro-evidence from China. Environmental Impact Assessment Review, **86**, 106467, **2021**.
13. SHAHBAZ M., HYE Q.M.A., TIWARI A.K., LEITAO N.C. Economic growth, energy consumption, financial development, international trade and CO_2 emissions in indonesia. Renewable & Sustainable Energy Reviews, **25**, 109, **2013**.
14. HUANG Q.B., XIA X.X., LIANG X.H., LIU Y., LI Y. Is China's equipment manufacturing export carbon emissions decoupled from export growth? Polish Journal of Environmental Studies, **31**, 85, **2022**.
15. HE L.Y., ZHANG Y.M., YUAN E.Y., WANG F., MA Q.S., CHAI X.K. Free trade zone policy and carbon dioxide emissions: A synthetic control group approach. Polish Journal of Environmental Studies, **31**, 3573, **2021**.
16. MORROW P.M., TRE D. How do endowments determine trade? Quantifying the output mix, factor price, and skill-biased technology channels*. Journal of International Economics, **137**, **2022**.
17. AUTOR D.H., DORN D., HANSON G.H. Untangling trade and technology: Evidence from local labour markets. Economic Journal, **125**, 621, **2015**.
18. MELITZ M.J. The impact of trade on intra-industry reallocations and aggregate industry productivity. Econometrica, **71**, 1695, **2003**.
19. DU W.J., LI M.J. Influence of environmental regulation on promoting the low-carbon transformation of china's foreign trade: Based on the dual margin of export enterprise. Journal of Cleaner Production, **244**, 118687, **2020**.
20. LI M., LI Z.B. Industry and regional environmental regulations: Policy heterogeneity and firm performance. Polish Journal of Environmental Studies, **31**, 2665, **2022**.
21. MA Y., MEN J.Z. The drivers of firms' environmental management: Soft environmental management vs. Hard environmental management. Polish Journal of Environmental Studies, **31**, 749, **2022**.
22. JIANG X.M., GUAN D.B., ZHANG J., ZHU K.F., GREEN C. Firm ownership, china's export related emissions, and the responsibility issue. Energy Economics, **51**, 466, **2015**.
23. ROKHMAWATI A. The nexus among green investment, foreign ownership, export, greenhouse gas emissions, and competitiveness. Energy Strategy Reviews, **37**, **2021**.
24. XIN D.L., YI Y.Z., DU J.J. Does digital finance promote corporate social responsibility of pollution-intensive industry? Evidence from chinese listed companies. Environmental Science and Pollution Research, **2022**.

25. BARROWS G., OLLIVIER H. Foreign demand, developing country exports, and co2 emissions: Firm-level evidence from india*. Journal of Development Economics, **149**, 27, **2021**.
26. AL-MULALI U., SHEAU-TING L. Econometric analysis of trade, exports, imports, energy consumption and CO_2 emission in six regions. Renewable & Sustainable Energy Reviews, **33**, 484, **2014**.
27. LIU Y., MENG B., HUBACEK K., XUE J.J., FENG K.S., GAO Y.N. 'Made in China': A reevaluation of embodied CO_2 emissions in Chinese exports using firm heterogeneity information. Applied Energy, **184**, 1106, **2016**.
28. BARROWS G., OLLIVIER H. Emission intensity and firm dynamics: Reallocation, product mix, and technology in India. Grantham Research Institute on Climate Change and the Environment; **2016**.
29. LEE C.C., HO S.J. Impacts of export diversification on energy intensity, renewable energy, and waste energy in 121 countries: Do environmental regulations matter?*. Renewable Energy, **199**, 1510, **2022**.
30. YU Y., YAMAGUCHI K., KITTNER N. How do imports and exports affect green productivity? New evidence from partially linear functional-coefficient models. Journal of Environmental Management, **308**, **2022**.
31. LIU D.H., REN S.G., LI W.M. SO_2 emissions trading and firm exports in China. Energy Economics, **109**, **2022**.
32. BRANDT L., VAN BIESEBROECK J., ZHANG Y.F. Creative accounting or creative destruction? Firm-level productivity growth in chinese manufacturing. Journal of Development Economics, **97**, 339, **2012**.
33. CAI H.B., LIU Q. Competition and corporate tax avoidance: Evidence from Chinese industrial firms. Economic Journal, **119**, 764, **2009**.
34. DU W., LI M. The impact of land resource mismatch and land marketization on pollution emissions of industrial enterprises in China. Journal of Environmental Management, **299**, 113565, **2021**.
35. DU W.J., LI M.J. Assessing the impact of environmental regulation on pollution abatement and collaborative emissions reduction: Micro-evidence from Chinese industrial enterprises. Environmental Impact Assessment Review, **82**, 106382, **2020**.
36. LI M., DU W. Can internet development improve the energy efficiency of firms: Empirical evidence from China. Energy, **237**, 121590, **2021**.