Research on the Impact of China's Import and Export Trade on Carbon Emission under the Perspective of Carbon Emission Reduction ——Empirical Evidence Based on Provincial Panel Data

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Abstracts. With the development of economic globalization, China's import and export trade with other countries around the world has become increasingly frequent. However, the huge energy gap has led to serious environmental pollution problems in China, and how to realize sustainable development has become an important issue. Therefore, based on the research of scholars at home and abroad, this paper utilizes the panel data of 30 provinces and cities from 2012 to 2021 as well as the method of multiple stepwise regression to study the influencing factors of carbon emissions in China. The results show that China has achieved some success in improving the level of regional economic development, transitioning from traditional finance to green finance, and improving the level of scientific and technological development, which can effectively curb the growth of carbon emissions; however, the total amount of import and export trade, the level of advanced industrial structure, and the energy structure are still the key factors hindering the cause of carbon emission reduction.

Keywords: Import and export trade, Carbon emissions, Provincial panel data, Multiple stepwise regression, Sustainable development.

1. Introduction

With the advancement of industrialization and urbanization, the excessive use of fossil fuels has led to the emission of large quantities of greenhouse gases, such as carbon dioxide and methane, and has caused climate change on a global scale. Based on this, scientists and environmental activists in various countries are very concerned about the impact of people's production and life on atmospheric carbon dioxide. From 1957 to 1958, the United States established atmospheric composition observing systems in the Monaroa Mountains and Antarctica. The United States scientist Charles David Keeling raised the famous Keeling curve through the observation of the Antarctic and the Monaroa station data study. In the 2020s, an increasing number of countries and businesses announced 'carbon neutral' targets, which means to achieve net-zero carbon emissions at a specific point in time in the future.

During the early period of reform and opening up, rapid economic growth was accompanied by serious environmental problems, such as soil erosion, water pollution, and air pollution, and Chinese society began to pay more attention to environmental issues. The *Law of the People's Republic of China on the Prevention and Control of Air Pollution* was adopted at the twenty-second meeting of the Standing Committee of the Sixth National People's Congress on September 5, 1987, demonstrating that China attaches sufficient importance to the prevention and control of air pollution. In March 1994, the State Council adopted *China's Agenda 21*, which determined the implementation of the sustainable development strategy, marking the beginning of China's integration of environmental protection into the overall framework of economic and social development. In 2013, the State Council issued the *Air Pollution Prevention and Control Action Plan*, emphasizing the reduction of air pollution and the strengthening of air environment management. China has been striving to balance the relationship between economic development and environmental protection

over the past decades and has adopted a series of policies and measures to address environmental challenges, reflecting its increasing environmental awareness and responsibility.

With the internationalization of production and consumption, large-scale logistics and transportation increase carbon footprints and environmental burdens. Globalization has accelerated the cross-border flow of goods and services and has also given rise to a series of issues related to the environment and carbon emissions. The scale of China's import and export trade is growing, with the total import and export of goods amounting to 244,160,021,000,000 yuan in 2012 and 420,678,816,000,000 yuan in 2022, an increase of 72.30%, according to the National Bureau of Statistics. Except for some fluctuations in 2015-2016, China's total import and export trade has been growing steadily in the past ten years and ushered in an explosive period in 2021, as shown in Figure 1. Therefore, the development of import and export trade is one of the important influencing factors of China's carbon emissions.

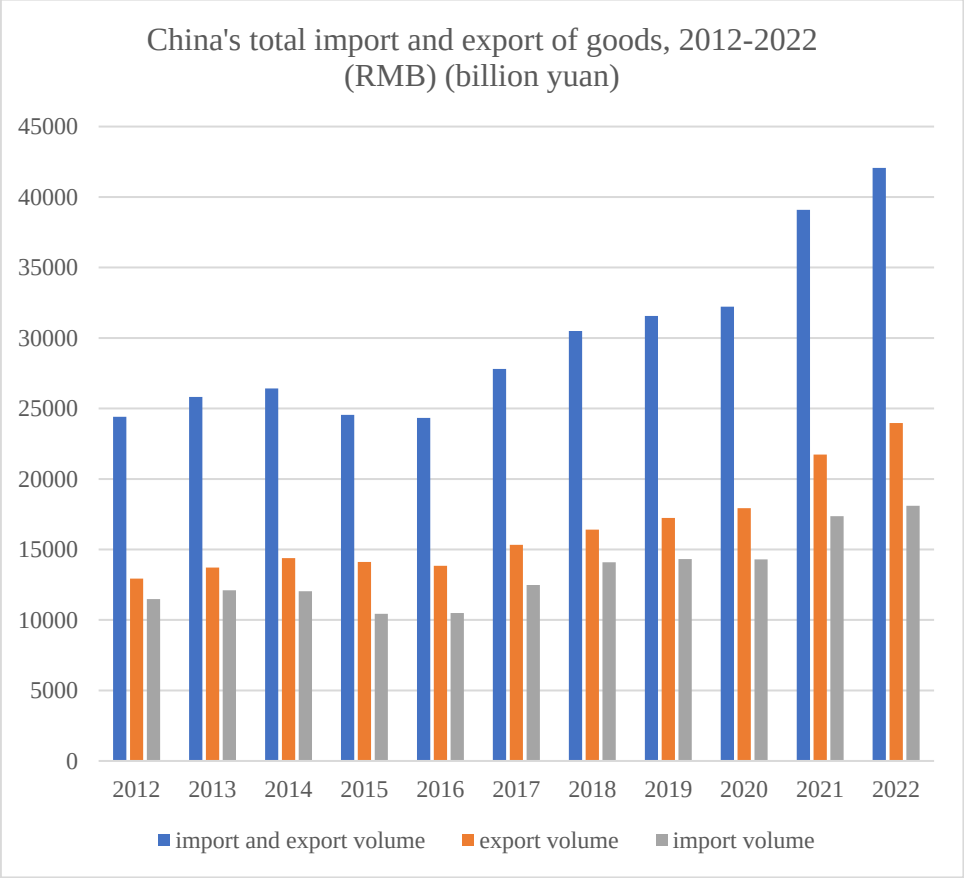

Figure 1. China's total import and export of goods, 2012-2022

Source: National Statistical Office

China faces a serious environmental pollution problem because of rapid economic growth and the huge energy gap in corporate production and people's lives. At present, China's industrialized production is not technologically advanced enough and has a low resource utilization rate, and the large-scale import and export trade of industrial products has further exacerbated the problem of air pollution. The carbon emission problem brought about by the import and export trade has attracted extensive attention from the government and academia. Given the above problems, exploring the impact of China's import and export trade on carbon emissions will be conducive to China's formulation of effective policies and management mechanisms to guide foreign trade in the direction of low-carbon, environmentally friendly development, and of practical emission reduction policies to achieve the goal of sustainable development.

2. Literature Review

With the steady implementation of the carbon peaking and carbon neutrality goals, scholars have further thought and explored the factors influencing carbon emissions. At this stage, the influencing factors of carbon emissions are mainly the following four points: First, the economic level. The economic development level of a country is mainly reflected in the industrial structure, per capita income, and urbanization level and so on. Li Jian and Zhou Hui (2012) found that the secondary industry is the main factor affecting regional carbon emission intensity, and the primary industry has the least impact on carbon emission intensity. Second, energy structure. Carbon emissions mainly come from the consumption of fossil energy, and a country's energy structure greatly affects carbon emissions. Wang Shaohua and other scholars (2015) analyzed the role of energy structure on carbon intensity and proposed that the main influence factor of carbon intensity is the structure of energy consumption. Third, the level of science and technology. Technological progress can slow down and reduce greenhouse gas emissions such as carbon dioxide. Lin Guiquan and Wang Yanan (2022) suggested that low-carbon technologies can optimize the proportion of factor inputs in the production and operation process, reducing carbon dioxide gas emissions. Fourth, consumption pattern. Carbon emissions are essentially affected by the consumption behavior of groups. Wei Guoqiang (2017) suggested that with increase of the proportion of material consumption such as technical products and public tools, the unreasonable consumption structure accelerates resource depletion and increases carbon emissions.

The subject of the impact of import and export trade on carbon emissions has also been widely discussed in the academic community who utilizing different research methods to provide solutions to the corresponding practical problems.

Foreign scholars favor the use of empirical methods to study the impact of import and export trade on carbon emissions. Hassan T and other scholars (2022) used empirical analysis to explore the role of imports, exports, renewable energy supply, and per capita GDP on carbon dioxide emissions with the RCEP economies as the object of study. Fan and other scholars (2021) conducted an empirical study on the carbon efficiency of international trade by using the carbon trading data of 14 major economies from 1995 to 2009, and the results showed that the characteristics of the carbon trading of the developing economies are different from those of the developed economies, and the countries with higher carbon intensity are generally developing countries and economies in transition.

Domestic scholars favor studying the mechanism and degree of the impact of import and export trade on carbon emissions. Zang Xin and Tang Qi (2019) adopted the IPCC carbon footprint calculation method and the data envelopment approach (DEA) to measure the efficiency of goods transportation and carbon emissions in 30 provinces, constructed a theoretical model of the impact of trade on carbon emissions in the freight industry, and found that the import and export trade significantly increases the carbon emissions of goods transportation. Wei Guangtong (2021) pointed out that the import trade can reduce carbon emissions through the technology spillover effect and the environmental regulation effect, while the export trade reduces carbon emissions through the structural effect and the scale effect. Li Mengfan (2020) used the panel smooth transition model (PSTR) to analyze the economic threshold effect and technological threshold effect of import and export trade on environmental pollution and found that the scale of import and export trade has a single threshold characteristic on implied carbon emissions with the level of technology as the transfer variable.

To summarize, current research on the relationship between import and export trade and carbon emissions focuses on the impact of trade on carbon emissions with energy-consuming industries as the main body, but there is still a lack of research on the impact of import and export trade on carbon emissions at the provincial level. Based on this, this paper uses the panel data of 30 provinces and cities in China from 2012 to 2021 to examine the impact of total import and export trade, regional economic development level, financial development level, industrial structure advanced level, science and technology development level, and energy structure on China's carbon emissions, to provide more empirical evidence for research in related fields.

3. Research Design

3.1 Model Setup

By studying the mechanism of import and export trade on carbon emissions, this paper sets the following panel model as the influence factor of carbon emissions, as shown in equation (1):

$$carb_{it} = \alpha_0 + \alpha_1 exim_{it} + \alpha_2 gdp_{it} + \alpha_3 fin_{it} + \alpha_4 indu_{it} + \alpha_5 tech_{it} + \alpha_6 ener_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them, $carb_{it}$ is carbon emissions, reflecting regional greenhouse gas emissions. The main reason for global warming is that human beings have been using fossil fuels (e.g., coal, oil, etc.) in large quantities for nearly a century, releasing a large amount of carbon dioxide and other greenhouse gases. $exim_{it}$ is the total amount of China's import and export trade, and this paper adopts the total amount of import and export of the domestic destinations and places of origin of the goods. gdp_{it} is the ratio of the regional gross domestic product to the national gross domestic product. Theoretically, raising the level of regional economic development and lowering the consumption of resources and waste emissions in the process of economic development can reduce the total amount of carbon emissions and thus lower the intensity of carbon emissions. fin_{it} denotes the level of financial development, which is the ratio of the balance of deposits and loans of financial institutions to the regional gross domestic product at the end of the year. $indu_{it}$ denotes the level of industrial structure advancement, which is the ratio of the tertiary industry output to the secondary industry output in the region. Since it does not involve large-scale material manufacturing or heavy industrial production, carbon emissions from the tertiary industry are usually relatively low, and whether the growth of a country's or region's service sector contributes to the reduction of overall carbon emissions requires further analysis of the region's specific service and production modes. $tech_{it}$ denotes the level of scientific and technological development, which is the ratio of the government's budgetary expenditure on science and technology to the government's expenditure on the general public budget, which to a certain extent indicates the region's tech represents the level of scientific and technological development, education and innovation. $ener_{it}$ represents the energy structure which is the ratio of provincial electricity consumption to the national total electricity consumption, which to a certain extent can represent the efficiency of electricity utilization in the province. μ_i represents the regional effect, λ_t is the time effect, and ε_{it} is the random perturbation term.

3.2 Variable Selection

This paper selects carbon emissions as predicted variable, total import and export trade as core explanatory variable, and several control variables.

3.2.1 Predicted Variable

The predicted variable of this paper is the carbon emissions constructed by Tsinghua University's Multiscale Emission Inventory Model (MEIC) platform. The model uses multi-source big data intelligent fusion and modeling technology and a new method of high spatial and temporal resolution emission dynamics characterization based on big data to construct a long time-series, high spatial and temporal resolution, dynamically updated global multi-scale atmospheric component emission database, which provides basic emission data for the study of global climate change and atmospheric pollution. Currently, the data cover the Chinese mainland and span the period 1990-2021.

3.2.2 Core Explanatory Variables

The total import and export trade, also known as the total import and export of goods, is the total amount of all actual imports and exports of goods of a country or region within a certain period expressed in monetary terms, which is the sum of the total imports and exports of goods in the same

period. Total import of goods is the total amount of goods imported from abroad within a certain period; total exports of goods are the total amount of goods exported abroad within a certain period.

3.2.3 Controlled Variable

In this paper, the following controlled variables are selected for the auxiliary regression:

Level of regional economic development (gdp): Ratio of Gross Regional Product to National Gross Regional Product.

Level of financial development (fin): Ratio of year-end deposit and loan balances of financial institutions to gross regional product.

Level of advanced industrial structure (indu): Ratio of tertiary sector output to secondary sector output.

Level of scientific and technological development (tech): Ratio of government budget expenditure on science and technology to general government public budget expenditure.

Energy structure (ener): Ratio of provincial electricity consumption to total national electricity consumption.

Table 1. Descriptive statistics for variables

Variables	Obs	Min	Max	Mean	Std.Dev.
Exim	310	282377	1.47e+09	1.42e+08	2.49e+08
carb	310	396.1	93635.5	31414.08	21249.72
gdp	310	0.0013187	0.1101499	0.0323026	0.0258732
fin	310	1.804857	7.578336	3.518367	1.120996
indu	310	0.558407	5.24401	1.355811	0.7410184
tech	310	1.09e-06	0.0675685	0.0211181	0.0151041
ener	310	0.0005587	0.0928287	0.0314534	0.0227868

3.3 Data Sources

In this paper, 31 provinces and cities in China (excluding data missing areas including Hong Kong, Macao, and Taiwan) are selected as the research object, and the panel data from 2012-2021 is used to test and analyze the influencing factors of carbon emissions. The main variables are from the National Bureau of Statistics, statistical yearbooks of each province, the MEIC platform, and the Wind database.

4. Empirical Testing

4.1 Baseline Regression Results

In this paper, Stata software was used to regress the model on fixed and random effects. Since the Hausman test results show acceptance of the original hypothesis, the random effects model results are chosen as the baseline regression results. To eliminate possible multicollinearity between variables, this paper adopts the method of adding explanatory variables one by one for regression. The results are shown in Table 2.

Table 2. Random effects model stepwise regression results

VARIABLES	(1) carb	(2) carb	(3) carb	(4) carb	(5) carb	(6) carb
exim	0.277***	0.272***	0.253***	0.245***	0.252***	0.151**
	(0.0695)	(0.0702)	(0.0737)	(0.0740)	(0.0761)	(0.0643)
gdp		0.159*	0.190*	0.198**	0.218**	-0.257***
		(0.0958)	(0.0997)	(0.0996)	(0.1043)	(0.0849)
fin			0.026	0.003	0.004	0.012
			(0.0313)	(0.0378)	(0.0381)	(0.0331)
indu				0.051	0.055	0.068*
				(0.0460)	(0.0470)	(0.0406)
tech					-0.013	0.008
					(0.0285)	(0.0246)
ener						0.791***
						(0.0611)
Constant	0.306***	0.261***	0.246***	0.243***	0.240***	0.109***
	(0.0392)	(0.0417)	(0.0440)	(0.0439)	(0.0436)	(0.0282)
R-squared	0.1464	0.2638	0.2558	0.2499	0.2612	0.6986
Observations	310	310	310	310	310	310
Number of id	30	30	30	30	30	30

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

From Table 2, the following conclusions are drawn:

First, total import and export trade significantly increases carbon emissions. First, industries involved in import and export trade are likely to be mostly high-carbon-emission industries, and the main export commodities are likely to be energy-intensive or carbon-intensive. Second, cross-border transportation and logistics lead to many transportation activities, including petroleum-fueled means of transport, which increase carbon emissions. China is currently emphasizing environmental and social responsibility, and actively promoting structural upgrading of its foreign trade. However, according to the current stage of China's carbon emissions management and the process of carbon emission reduction, there is still some room for Chinese enterprises to make progress in green production.

Secondly, an increase in the level of regional economic development can curb the increase in carbon emissions. A high level of economic development is usually accompanied by optimization of the energy structure, more efficient production technologies, the introduction of clean energy technologies, and the optimization of production processes, which can improve the efficiency of energy use and thus reduce carbon emissions. Countries with a high level of economic development also have the ability and willingness to implement strict environmental regulations and policies to promote enterprises to adopt more environmentally friendly production methods and reduce carbon emissions.

Third, the level of financial development has no significant effect on carbon emissions, which reflects the development of China's financial sector from traditional finance to green finance. As the Chinese government has introduced a series of policies to support the development of green finance and increased financial support for green finance programs, the development of green finance has been effective. Green finance can guide the flow of funds to resource-saving and ecological environmental protection industries, guide enterprises to focus on green production and consumers to form green consumption concepts, thereby promoting environmental protection and governance, and guide the flow of resources from high-energy-consumption industries to sectors with advanced concepts and technologies. Green finance fits in with the ESG concept, focusing on investment opportunities that support green and environmentally friendly tracks, and guiding the flow of capital to environmentally friendly enterprises.

Fourth, although China has launched a series of policies to promote the transformation and upgrading of its industrial structure, this is still one of the factors that cannot be ignored in hindering the cause of carbon emission reduction. In the past decade, the rise of new service industries, such as online retailing, electronic payments, and the sharing economy, has become a new engine for the transformation of industrial structure into a tertiary sector. However, China's industrial structure is still in the transition phase from a traditional manufacturing economy to a service economy. It is only by promoting more enterprises to develop in the direction of high-value-added and high-tech industrial chains, and reducing excessive reliance on traditional manufacturing, heavy industry, and other low-value-added and resource-intensive industries that carbon emissions in the process of production or services can be reduced.

Fifth, the level of technological development has no significant effect on carbon emissions. The Chinese government strongly supports the electric and new energy vehicle industry, which produces no tailpipe emissions and has a battery-driven system with higher energy conversion efficiency than the internal combustion engine used in traditional oil vehicles. The Chinese government promotes the construction of smart cities, applies advanced technology to improve urban planning and resource utilization, and strengthens the monitoring and management of environmental pollution through sensing technology and big data analysis. In addition, Chinese enterprises adopt cleaner production technologies in the industrial production process to reduce carbon emissions.

Sixth, the energy structure is an important factor contributing to the increase in carbon emissions. Currently, China's electricity comes mainly from energy sources with high-carbon emissions, such as coal or natural gas power plants. The process of burning coal or natural gas releases large amounts of greenhouse gases such as carbon dioxide. Secondly, less efficient power generation technologies result in less efficient energy conversion. Inefficient power generation processes usually require more fuel to produce the same amount of electricity, leading to increased carbon emissions. In addition, an increase in the demand for electricity for transportation and building facilities in a particular region will also bring about an increase in carbon emissions if these facilities are equipped with energy-intensive and emission-intensive technologies. Although the government has taken a series of measures in recent years, including the use of hydro, wind, and solar to generate electricity, coal and natural gas are still the main sources of energy for generating electricity due to the large shortage of electrical energy.

4.2 Robustness Check

To verify the robustness of the baseline regression results, this paper replaces the explanatory variables, which replacing the total import and export of domestic destinations and places of origin with the total import of domestic destinations. Then, it regresses this group of influencing factors again. The results are shown in Table 3, and the coefficients of all the influencing factors have not changed significantly in direction and value, indicating that the results of the baseline regression are relatively robust.

Table 3. Robustness check results

VARIABLES	(1) carb	(2) carb	(3) carb	(4) carb	(5) carb	(6) carb
imp	0.183***	0.188***	0.171***	0.162***	0.162***	0.137***
	(0.0573)	(0.0575)	(0.0591)	(0.0596)	(0.0602)	(0.0501)
gdp		0.193**	0.233**	0.236**	0.242**	-0.246***
		(0.0958)	(0.0986)	(0.0989)	(0.1047)	(0.0860)
fin			0.038	0.016	0.016	0.020
			(0.0309)	(0.0375)	(0.0379)	(0.0322)
indu				0.049	0.049	0.060
				(0.0465)	(0.0474)	(0.0402)
tech					-0.0003	0.015
					(0.0281)	(0.0239)
ener						0.781***
						(0.0606)
Constant	0.312***	0.257***	0.236***	0.234***	0.233***	0.105***
	(0.0397)	(0.0424)	(0.0444)	(0.0446)	(0.0443)	(0.0296)
R-squared	0.1254	0.2896	0.2699	0.2611	0.2641	0.6952
Observations	310	310	310	310	310	310
Number of id	30	30	30	30	30	30

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Conclusions and Recommendations

This paper uses panel data from 30 provinces and cities to test the influence mechanisms of total import and export trade, regional economic development level, financial development level, industrial structure advanced level, science and technology development level, and energy structure on carbon emissions. The study finds that, firstly, China has made great efforts in carbon emission reduction, and with the target of 'carbon neutrality', all industries have paid more attention to sustainable development, but there is still room for strengthening the upgrading of the foreign trade structure, the advanced industrial structure, and the optimization of the energy structure. Secondly, China has achieved some success in transforming traditional finance into green finance and has actively applied advanced science and technology to reduce carbon emissions in transportation, production and living processes. Thirdly, the increase in the level of regional economic development has curbed the growth of carbon emissions, reflecting the effectiveness of China's transformation of its economic structure into a tertiary industry.

Based on this, this paper puts forward the following suggestions for the development of China's carbon emission reduction program:

First, measures to reduce carbon emissions in the import and export trade process should be taken at the supply chain, transportation, production, policy, and consumer levels. For supply chain optimization, select raw materials and production materials with low carbon footprints, and give preference to suppliers that meet environmental standards and are socially responsible. For transportation and logistics optimization, adopt multimodal transportation, such as container transportation and railroad transportation, to reduce reliance on high-carbon emission modes of transportation. For the policy, promote the market-based management of carbon emissions, implement 'carbon neutrality' targets, formulate and promote carbon emission standards, and encourage enterprises to adopt low-carbon production and transportation modes. For the consumer education, add information on carbon footprints on product labels and raise consumers' awareness of sustainable products, to enable consumers to make more environmentally friendly shopping decisions.

Secondly, promote the upgrading of the industrial structure, to shift the economy from traditional manufacturing to more advanced, efficient, and sustainable industries. At first, promote the development of sustainable industries, invest and develop green industries, use renewable energy, environmental protection technology, and clean production technology. Guide enterprises to adopt a circular economy model to improve resource utilization efficiency. In addition, promote the development of the service industry. Develop the financial service industry, so that enterprises can better obtain financial support to carry out green production. Cultivate the cultural industry and increase the proportion of the service industry in the economy. Finally, promote environmental management and monitoring in the process of optimizing industrial structure, formulate strict environmental protection regulations and standards, and encourage enterprises to carry out green production. Establish a sound industrial monitoring system to keep abreast of the dynamics of emission reduction implementation in industrial development and adjust policies and support promptly.

Thirdly, optimize the energy structure, improve energy efficiency, reduce carbon emissions, and achieve sustainable energy development. At first, promote the development of renewable energy, increase investment in renewable energy sources such as solar and wind power, and build more solar power stations and wind farms. In addition, improve energy efficiency and promote the application of energy-efficient technologies, such as efficient lighting and smart homes, and set and enforce stricter energy-efficiency standards. What is more, use clean energy and low-carbon technologies, promote the development of electric vehicles and electric public transportation to reduce reliance on traditional fuel vehicles. Develop clean energy technologies, such as hydrogen energy and bioenergy, to reduce reliance on coal and oil. Finally, use smart grid and energy storage technologies. Build smart grids to better integrate renewable energy sources. Develop energy storage technologies, such as battery storage systems, to balance the intermittent output of renewable energy sources.

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