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Study on Trade Effects of Green Maritime Transport Efficiency: An Empirical Test for China Based on Trade Decision Model

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Abstract: As the natural environment continues to deteriorate, countries have begun to shift their emphasis to sustainable development, and the study of green shipping—as the main realization of international trade—is an important prerequisite for global sustainable trade. This paper measures the green maritime transport efficiency considering greenhouse gas emissions using the Super-slacks-based measurement (Super-SBM) method, then extrapolates the theoretical model of trade decision covering maritime transport efficiency and maritime transport distance based on the transcendental logarithmic utility function. A panel econometric model based on this theoretical model was constructed, and then the trade effects of green maritime transport efficiency and its transmission mechanism were studied empirically based on the data of 60 sample countries (regions) in five continents from the years 2010 to 2020. The study shows that green maritime transport efficiency significantly promotes China's foreign trade through three channels: promoting technological progress, reducing trade costs and curbing environmental deterioration. Additionally, this effect tends to be stronger for countries that are IMO members and have higher incomes. This article's research helps to provide new empirical evidence to explain the growth of international trade.

Keywords: green maritime transport efficiency; Super-SBM; trade decision model; the mediating effect; greenhouse gas emissions

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1. Introduction

With the strengthening of global economic integration, international trade is becoming more and more frequent. Transportation, as a basic industry supporting international trade, is a key factor affecting the competitiveness of international trade [1]. Maritime transport is currently the most widely used mode of transportation worldwide. Especially after containers are used in maritime transportation, the dramatically reduced transportation cost has a huge impact on international trade. According to Clarkson's Research [2], the global trade volume in the year 2020 was 13 billion tons, of which, trade using maritime transportation accounted for 89%. The volume of China's foreign trade using maritime transportation increased by 6.7% to 3.46 billion tons in year 2020, and its share of global volume rose to 30% from 27.1% in the year 2019. It is evident that maritime transport, as a bridge and hub for global commodity flows, remains the most cost-effective mode of transportation for merchandise trade [3]. Thus, the efficiency of maritime transport, which is a barometer of global merchandise trade, has always played an important role in the growth of international trade.

At the same time, as the natural environment continues to deteriorate, and the Earth's climate is experiencing unprecedented rapid warming, transportation systems are facing increasing challenges. Globally, carbon emissions from transportation accounted for 37% of total emissions in the year 2021, or about 7.7 gigatonnes (Gt) of CO_2, an increase of 65% compared to the year 1990. The carbon emissions from transportation are growing at an average annual rate of nearly 1.7%, higher than any other end-use sector. International maritime transport, one of the transport sectors, accounts for about 2% of total carbon emissions and 11% of transport carbon emissions [4]. Although the share of international maritime transport in carbon emissions is not high, to reach the goal of net zero emissions by the year 2050, international maritime transport must reduce emissions by nearly 15% from the years 2021 to 2030. Since the carbon emissions of international maritime transport are a major part of international trade transport emissions, this sector's green and efficient development is closely related to the global sustainable trade process, in which global efforts are being made to promote the development of zero-emission maritime transport. For example, in June 2021, the International Maritime Organization (IMO) launched a series of measures to achieve the goal of reducing the carbon intensity of maritime transport by 40% by the year 2030. In July 2022, the U.S. House of Representatives introduced the Clean Shipping Act of 2022, which set high carbon intensity standards for marine vessel fuels, saying that by the year 2030, all ships anchored or berthed in U.S. ports will achieve zero greenhouse gas emissions and zero air pollutant emissions. The White Paper on China's Policies and Actions to Address Climate Change, released in the year 2021, is also trying to promote greenhouse gas emission reductions through strong policies to accomplish the goals of carbon peaking and carbon neutrality.

Under this context, the green and efficient development of maritime transport will be of great significance to the sustainable and high-quality development of China's foreign trade. So, how is green maritime transport efficiency measured? What will be the trade effects of green maritime efficiency and its inherent transmission mechanism? In order to answer the above questions, this paper will provide a new perspective to explore the typical facts of green maritime transport efficiency and provide fresh empirical evidence for reinterpreting international trade, which has important theoretical innovation value and practical guidance significance for China's sustainable development in transport and trade. Additionally, since China is an important trading partner for most countries in the world, China's success can spill over to other countries, and its experience will also have significant reference value for other countries around the world.

The rest of this paper is organized as follows. Section 2 discusses the relationship between transportation, trade and the environment through the literature review. Section 3 analyzes the impact mechanism of green maritime transport efficiency on international trade. Section 4 introduces the measurement of green maritime transport efficiency, deducing a theoretical trade decision model that includes maritime transport, based on which the econometric model was established to test it, with detailed introductions for the variables and data. Section 5 introduces the factual characteristics of green maritime transport efficiency and explains the impact of green maritime transport efficiency on trade obtained from the above econometric model; the impact mechanisms, including the technological progress, trade costs and environmental deterioration, are further analyzed. In Section 6, heterogeneity analysis is conducted to study the heterogeneity effect of green maritime transport efficiency on trade in different groups. Section 7 provides research conclusions and policy recommendations.

2. Literature Review

In the context of green and low-carbon sustainable development, green transportation is an effective way to cope with "green barriers" in international trade and achieve sustainable trade development [5]. Although green maritime transportation is a new trend of modern logistics development, there are relatively few studies on the impact of green maritime transport on trade. This paper will review the literature from the following three aspects: ship operations and the environment, overall green logistics efficiency on international trade and maritime transport performance on trade, respectively.

Firstly, some of the literature examined the green sustainability of maritime transport from the relationship between ship operations and the environment but ignored the importance of maritime efficiency in the context of the global trade division of labor. With soaring fuel prices and continued global climate degradation, researchers have found that sailing speed not only reduces fuel consumption but also greenhouse gas emissions. Lindstad et al. [6] found that greenhouse gas emissions and transportation costs would be reduced at lower speeds. Orsic and Faltinsen [7] estimated a corresponding reduction in CO_2 emissions in the North Atlantic route if there is a reduction in sailing speed. Khan et al. [8] also measured the reduction in greenhouse gases and criteria pollutants if there is a reduction in sailing speed between ports. Cariou and Cheaitou [9] studied the relationship between the speed limits on ships and CO_2 emissions in European ports. Olmer [10] found that the container ship fleet accounts for 23% of the total CO_2 emissions from maritime transport, which is the highest in the ship sector, and suggested focusing on reducing emissions from container ships. Ammar [11] proved that for RO-RO (roll-on/roll-off) cargo ships, a 10% and 40% reduction in ship speed would reduce CO_2 emissions by 27.05% and 78.39%, with cost benefits of USD 121.2/ton of CO_2 and USD 287.6/ton of CO_2, respectively.

Secondly, some of the literature analyzed the impact of overall green logistics efficiency on international trade, but not particularizing on maritime transport. For example, Zaman and Shamsuddin [12], by examining the relationship between green logistics and national economies in 27 European countries, found that logistics performance promotes economic development, and economic development ultimately promotes green logistics. Wang et al. [13] estimated the impact of green logistics on trade using logistics of CO_2 emission intensity and an environmental logistics performance index as green logistics proxy variables, based on research subjects from 113 countries and regions, and found that green logistics efficiency can promote one country's export trade. Aldakhi et al. [14], using data from BRICS countries from the years 1995 to 2015, studied the impact of green logistics on socio-economic and environmental factors and found a positive correlation between the green logistics index and national per capita income. Yu et al. [15] found that green logistics have a strong, positive impact on FDI inflow and trade openness. Khan et al. [16] discovered that green logistics can mitigate the harmful effects of logistics on environmental sustainability and stimulate economic activities that provide numerous export opportunities. Karaman et al. [17], based on signaling theory, proved that green logistics performance can enhance the competitiveness of a company in the market. Fan et al. [18] constructed a green logistics efficiency index by adding greenhouse gas emissions to the logistics performance index, using the entropy weight method, and argued that green logistics performance can significantly promote China's export trade to RCEP countries. Yang et al. [19] investigated the relationship between green logistics performance and service trade using Partial Least Squares Structural Equation Modeling (PLS-SEM), and the results showed that green logistics performance has a positive impact on service trade and the environment.

Thirdly, there is also the literature that assessed the impact of maritime transport performance on trade but ignored the importance of green development for maritime transport. Asturias and Petty [20] concluded that when two ports are connected by direct maritime services, the distance will no longer be statistically significant in the trade model. Helble [21], using a gravity model approach, found that constructing direct maritime connections would increase maritime transport performance, which in turn doubles the import of goods. Wilmsmeier [22] analyzed the impact of maritime transport performance on transport costs from different regions in South America, and the results showed that maritime transport performance has a negative effect on transport costs. Fugazza [23] found that in terms of maritime transport performance, the lack of direct maritime connections was highly associated with a decrease in export value, ranging from 42% to 55%. Hoffmann and Saeed [24] analyzed the short-term and long-term effects of maritime transport connectivity on South African trade flows using a dynamic panel data model estimated by quasi-likelihood estimation. The estimation results indicated that improving maritime connectivity has a positive effect on the maritime trade and logistics competitiveness, as well as helps boost bilateral trade in South Africa, and that the long-term effect on trade is greater than the short-term effect. Chang et al. [25] found that the improvement of maritime connectivity and logistics performance can significantly reduce transportation costs, which in turn has a positive impact on trade. Qiu and Qing [26] studied the relationship between the maritime connectivity and trade of 111 countries and found that global maritime connectivity significantly contributes to the growth of export and import trade volumes by reducing trade costs and enhancing market attraction.

In summary, there is rich literature related to maritime transport and international trade. However, in the research on the green sustainability of ship operations, it only focused on reducing the ship's sailing speed to reduce energy consumption and carbon emissions, thus reducing the operating cost, without considerations on the importance of cargo transportation efficiency in the context of global trade. And in the research on green logistics' impact on trade, it fails to focus on maritime transportation, the main mode of transportation for international trade. And in the research on the impact of maritime transport performance on trade, it ignores the importance of green development for maritime transport.

It was found that, based on the existing literature, there are few studies that assess the development of maritime transport in terms of both specific maritime transportation efficiency and maritime transportation sustainability at the same time. Therefore, this paper will construct a green maritime transport efficiency index to assess the development process of maritime transportation that takes into account both efficiency and sustainability. In addition, the question of the relationship between green maritime transport efficiency and trade is addressed through theoretical models and panel data econometric models.

3. Theoretical Analysis and Research Hypothesis

As an organic part of international trade, maritime transport links global production and trade activities. Green maritime transport efficiency, as an important factor of the green and efficient development of maritime logistics, has a profound impact on the global sustainable trade process. This paper illustrates the impact mechanism of green maritime transport efficiency on international trade in three dimensions, which are technological progress, trade costs and environmental deterioration, as Figure 1 shows.

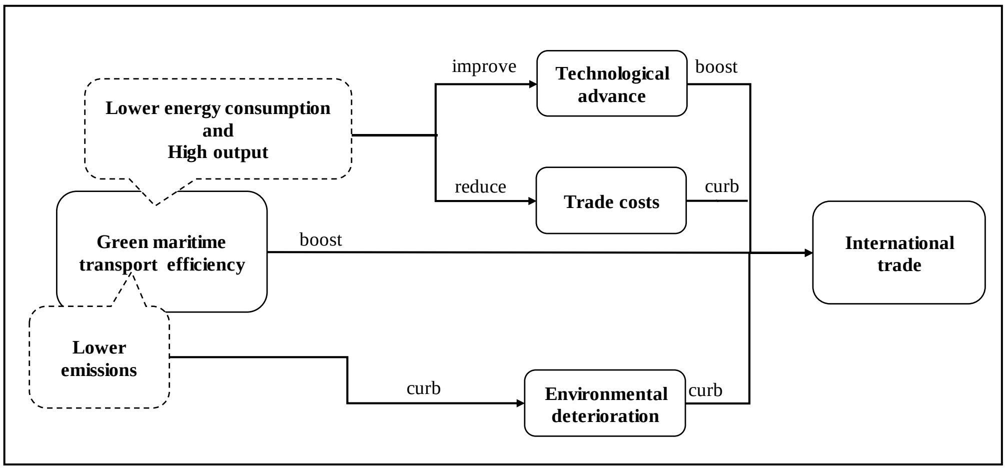

Figure 1. Theoretical framework of the trade effect from green maritime transport efficiency.

3.1. *Green Maritime Transport Efficiency Improvement Can Promote International Trade*

Firstly, green maritime transport efficiency improvement can directly promote international trade. Traditional logistics efficiency is more concerned with the low-cost and high-efficiency logistics services. But in the context of green sustainable development, logistics, as the "artery" of international trade, should pay more attention to the protection of the environment and resources in operation. As a new mode of modern logistics development, green logistics is the extension of traditional logistics in the background of a low-carbon era. China defines green logistics in the GB/T 37099-2018 standard as the process of using advanced logistics technology to reasonably plan and implement logistics activities such as transportation, storage, packaging, loading and unloading, distribution and processing with the goal of reducing environmental pollution and resource consumption. Lu et al. [27] believed that green logistics should give consideration to environmental protection based on the efficiency of logistics, and therefore, the author built an environmental logistics index to measure the development of green logistics by introducing CO_2 emissions and fossil energy consumption.

As an important branch of logistics, maritime transport's green and efficient development has two types of characteristics. Firstly, in terms of efficiency, as in traditional transport, it needs to pay attention to the input and output in the operation process of maritime transport, mainly in terms of lower cost and higher efficiency. Secondly, in terms of green development, compared with traditional logistics, green maritime transport efficiency focuses more on the harm caused to the environment in the operation process, which is mainly reflected in the lower energy consumption and lower greenhouse gas emissions in the transport process. Therefore, green maritime transport efficiency can better reflect the highly efficient and sustainable development process of maritime transport under the background of low-carbon economic development.

At least more than 70% of the world's international trade is delivered with international maritime transport [28]. *The Review of Maritime Transport*, a review of the maritime transport industry published by UNCTAD [29] in light of the global situation and future development trends, shows that the themes for the years 2015 and 2019 are maritime transport and sustainable development, respectively, thus showing that green and sustainable development of maritime transport, as a new driver of world maritime trade, can not only improve the climate environment but also reduce the frequency of trade disruptions caused by natural disasters, and further decrease trade uncertainty. For China, the great idea of the "21st Century Maritime Silk Road" was proposed in the year 2013, and the "Vision and Action for Promoting Energy Cooperation on the Silk Road Economic Belt and 21st Century Maritime Silk Road" was released in the year 2017. Additionally, for international maritime transport, Chinese ports are connected with more than 600 other major ports in more than 200 countries in the world, and China's maritime connectivity index remains the first in the world. This shows that China attaches great importance to international trade based on maritime transport, and in the context of the global promotion of sustainable development, green maritime transport efficiency will further promote China's trade with the world. Therefore, this paper proposes the first hypothesis.

H1. *A country's increased efficiency of green maritime transport can boost its bilateral trade with China.*

3.2. Green Maritime Transport Efficiency Improvement Can Boost Trade through Technological Progress

Secondly, green maritime transport efficiency improvement can boost trade through technological progress. The transport industry is featured with high energy consumption, high pollution and high emission, resulting in serious pollution problems. In order to solve these problems, the whole logistics industry is making continuous efforts. Li and Chen [30] selected 34 listed logistics enterprises as research subjects and verified that the enterprises obtained effective technological innovation by increasing the investment of resources, which eventually brought better profits. Chen and Wang [31] analyzed the development dilemma of logistics enterprises and pointed out that the logistics enterprises should start the innovation to green logistics, which could bring more capital and promote the enterprises to become industry giants. Then, the investment in low-carbon and environmental protection scientific research would increase, to create enterprise profits. Wei and Wang [32] took logistics enterprises as the research object, constructed an AHP research model and conducted a five-year follow-up study to verify the existence of correlation coupling between technological progress and green logistics.

Therefore, the green innovation of maritime transport enterprises to promote energy saving and emission reduction will push these enterprises to invest more funds into the technological progress, which will eventually obtain more efficient maritime transportation operations and expand the market share of the enterprises. Additionally, the technological breakthroughs in low-carbon and environmental protection in maritime transport will also spill over to the road ends and other transportation modes, thus promoting the technological progress of the whole transport and even logistics industry.

At the same time, the relationship between technological progress and trade has been discussed extensively. On one hand, technological progress creates new products through development and reasearch, generating more trade possibilities. The main representative theory is the technology gap theory from the 1960s, proposed by American economist M.A. Posner, which stated that due to the differences in R&D capabilities and technology, new products are first created in the innovating countries, which are available to other countries only through imports before they are able to master the production technology (namely the imitation time lag). So, the technology innovation brought by rapid constant technological progress makes international trade happen continuously. On the other hand, technological progress facilitates trade by making both sides of the trade more profitable. Cai et al. [33] argued that countries continuously increased the productivity of their comparatively inferior product through technological innovation, which not only contributed to the improvement of its own welfare but also likely led to a reversal in the direction of the international division of labor in the long run, making countries (including developed countries) gain more benefits from the new trade pattern.

As far as China is concerned, as the world situation is getting more and more complex and uncertain, China is emphasizing its scientific and technological revolution and development of industrial change. At the same time, with the continuous improvement of China's economic strength and soft power, the uncertainty of China's trade relations is also increasing, such as the Sino–U.S. trade war and other technical trade barriers adopted by various countries, which have dealt a heavy blow to China's foreign trade. Therefore, China proposed in its 14th Five-Year Plan that China has entered a new stage of development, and to open up new space for economic development in the profoundly complex and changing environment of development, it is particularly important to adhere to innovation-driven development, shape new advantages in development and fight the battle of key core technologies. It is clear that technological progress can strengthen China's ability to prevent risk from the complex international situation and promote China's bilateral trade and economic development. Based on the above analysis, this paper proposes hypothesis 2.

H2. *Green maritime transport efficiency improvement can boost bilateral trade with China through technological progress.*

3.3. Green Maritime Transport Efficiency Improvement Can Boost Trade by Reducing Trade Costs

Thirdly, green maritime transport efficiency improvement can boost trade by reducing trade costs. International maritime transport, as an important global integrated transport system, serves international trade through different technological means [34]. The rise and fall of international trade are closely related to international maritime transport, which acts as an important supporting demand for international trade. The cost of maritime transport mainly includes fuel prices, fleet cost, port operation fees, maritime environmental protection and transportation surcharges, which make up part of the international trade costs. Tran and Lam [35] studied the relationship between ship sailing speed, cost and carbon emission. They used a simulation of ship sailing at different sailing speeds and found that the increase in sailing speed accelerates the turnover of cargo, reducing the cargo transportation cost and capital operation cost. However, faster sailing speed will increase fuel consumption and CO_2 emissions, raising fuel and maritime environmental protection costs. So, maritime transport companies must reduce sailing speed, suffering a longer cargo cycle. Under this dilemma, green maritime transport can relieve these contradictions by significantly reducing trade costs through higher fuel conversion efficiency and lower greenhouse gas emissions, which in turn can reduce the environmental cost caused by higher sailing speeds.

Maritime transport costs, as the main cost in international trade, mainly covers time and expenses. On one hand, in the context of the commodities' international segmentation production, the length of sea transport time is not only related to the opportunity cost of goods but also affects the trade between countries. On the other hand, due to the sudden outbreak of public health events, the cost of maritime transport has increased significantly, and according to the Drewry World Container Index, the price of the same container on the same route has increased even up to 435%, causing a serious impact on the import and export trade worldwide. Zhou and Xu [36] studied 146 countries along the Belt and Road, using a gravity model approach, and discovered that the reduction in transportation time and transportation expenses could reduce the risk of currency exchange and multilateral resistance to trade and promote China's trade with countries along the Belt and Road. As China's maritime trade accounts for about 30% globally, the reduction in trade costs, especially the decrease in maritime trade costs, can significantly reduce the bilateral trade costs between China and other countries, facilitating China's bilateral trade. Based on the above analysis, this paper proposes hypothesis 3.

H3. *Green maritime transport efficiency can boost bilateral trade with China by reducing the trade costs.*

3.4. Green Maritime Transport Efficiency Improvement Can Boost Trade by Curbing Environment Deterioration

Fourthly, green maritime transport efficiency improvement can boost trade by curbing environmental deterioration. Maritime transport has seen significant growth over the last century and now accounts for the largest share of international trade transport. And the environmental impact of greenhouse gas emissions from ships is becoming increasingly significant. In the fourth greenhouse gas (GHG) study [37], the International Maritime Organization (IMO) presented an updated inventory of maritime-transport-related GHG emissions for the years 2012 to 2018 and developed emission projections for the years 2018 to 2050. According to the report, CO_2 emissions have increased by 8.4% from the years 2012 to 2018. In the face of growing climate concerns, there has been a global commitment to reduce greenhouse gas emissions. IMO introduced the International Convention for the Prevention of Pollution from Ships (MARPOL) and put the emphasis on further improving ocean energy efficiency and reducing ship emissions through technical and operational measures. Studies like Malchow [38] and Svindland [39] argued that large ships could lead to considerable economic gains and improve fuel efficiency through technological innovation, and the investment in green transport could greatly facilitate international trade, which in turn promoted breakthroughs in fuel-efficient technologies for ships. Antweileret et al. [40] found that trade would increase the scale of economic activity and GHG concentrations, but technological improvements would allow for sufficiently large reductions in GHG concentrations to produce more beneficial results. This study empirically verified that environmental protection could be achieved without negatively affecting international trade and maritime transport operations. It can be seen that if emphasis is placed on the green development of maritime transport, the government can give tax breaks or subsidies to ships using clean fuels in order to promote the transformation of the maritime industry to an environmentally friendly direction. At the same time, companies can also reduce fuel consumption by adopting energy-saving technologies, such as the hull drag reduction design and efficient navigation mode, or they can reduce nitrogen oxide (NOx) and sulfur oxide (SOx) emissions from ships using advanced emission control technologies, such as selective catalytic reduction (SCR) technology and flue gas desulfurization (FGD) technology, thereby reducing pollution in the environment. In this way, improving the efficiency of a country's green shipping will also greatly alleviate the deterioration of the environment.

At the same time, addressing environmental problems has become a global consensus, and the interaction between environmental change and international trade has also received more attention against the background of economic globalization. Since the Paris Agreement was reached in the year 2015, global climate governance has entered a comprehensive low-carbon transition phase. China has also pledged to strive to achieve carbon peaking by the year 2030 and carbon neutrality by the year 2060, demonstrating its commitment to sustainable development. Other countries have also introduced various environmental protection policies or raised environmental regulation standards and included environmental factors as a bargaining chip in international trade agreement negotiations, which have a significant impact on the total volume and structure of international trade. In the studies of the relationship between trade and the environment, the "pollution haven hypothesis" argues that environmental regulations directly impact the production cost of polluting industries, thus affecting comparative advantage, and eventually exports will be affected. Wang et al. [41] analyzed the European Commission's proposed Carbon Border Adjustment Mechanism (CBAM) legislation and calculated that if all listed goods were subject to carbon tariffs, China would have to pay up to EUR 760 million per year to the EU, which would inhibit bilateral trade flows. This proves that the continued deterioration of the environment will not only seriously endanger human security but will also hinder international trade. Therefore, this paper proposes the fourth hypothesis.

H4. *A country's increased efficiency of green maritime transport can boost bilateral trade with China by curbing its environmental deterioration.*

4. Study Design

The research of this paper focuses on the impact of green maritime transport efficiency on trade. Firstly, the paper constructs a Super-SBM model to assess green maritime transport efficiency. Then, the theoretical trade decision model based on Translog function is established, based on which the paper constructs the panel econometric model to verify this theoretical model. To ensure the correctness of a panel econometric model, the paper implements variable tests and explores the influence mechanism. Finally, the paper also further analyzes the heterogeneity problems. Figure 2 shows the whole process.

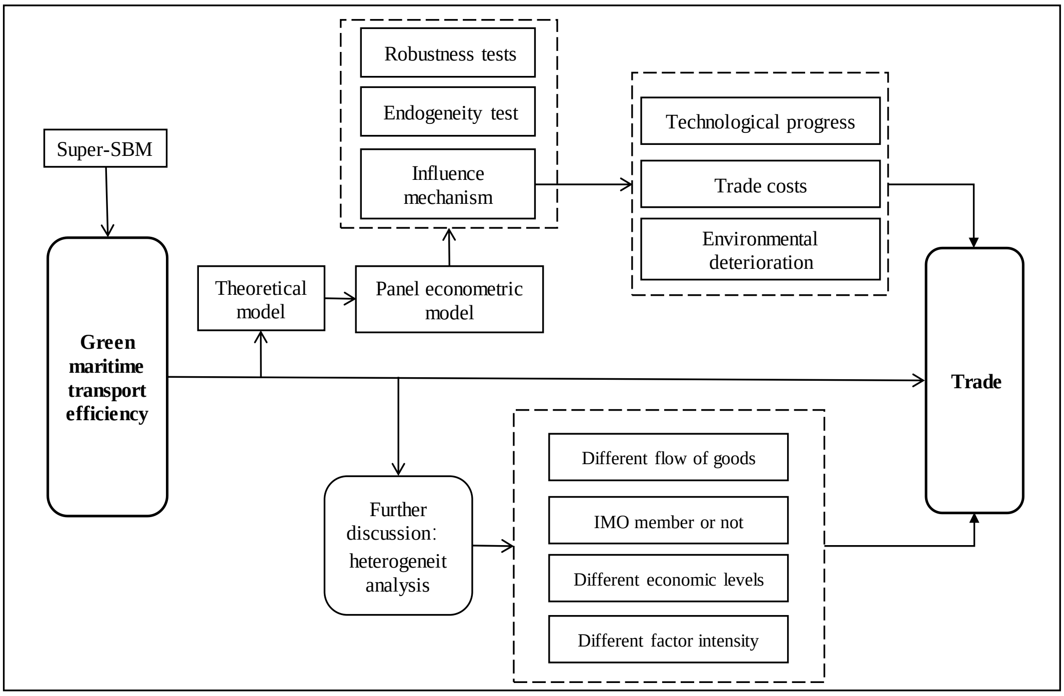

Figure 2. Chart flow of the research.

4.1. Super-SBM Model Construction

In the year 1978, Abraham Charnes, an American researcher, established the first CCR (Charnes–Cooper–Rhodes) model based on constant returns to scale (CRS), and then in 1984, Rajiv D. Banker and William W. Cooper proposed the BCC (Banker–Charnes–Cooper) model based on variable returns to scale (VRS), which set off a wave of DEA (Data Envelopment Analysis) research. The DEA is a data analysis tool to estimate the performance of decision-making units. It mainly uses the linear programming method to determine the effective frontier in a group of observation objects. Up to today, the DEA model has been widely used in many fields, such as various types of productivity, efficiency and performance evaluation. However, in the traditional DEA model, when there are too many input and output indicators, there are often multiple decision units in the frontier at the same time, and their efficiency values are all 1, so that it is impossible to make a further comparative analysis of the effective decision units with the efficiency value at 1. In order to solve this problem, Andersen and Petersen [42] proposed the Super Efficiency Model (SEM) in 1993, which is capable of comparing the efficiency of all decision units.

Meanwhile, in the traditional DEA model, due to the radial and input–output perspective, there is always factor slack leading to an overestimation of efficiency values. Additionally, based on the input or output perspective, different calculation results can be reached, leading to hard decisions. Therefore, Tone [43] proposed the slacks-based measurement (SBM) model containing undesirable output, which is a good solution to the problem of non-zero slack and non-desired output in the production process.

This paper combines the SEM with the SBM to get the Super-SBM model, which can fully consider the undesirable output of pollutants in the maritime transport operation process and can also improve convenience in comparing different countries in terms of green maritime transport efficiency. Therefore, the Super-SBM model is the best choice to accurately measure efficiency in this context, making full advantages of both the SEM and SBM methods. A possible flaw is the subjective selection of indicators, which to avoid, the paper will refer as much as possible to previous research for the indicator selection. Assuming that there are u inputs and r outputs, the Super-SBM model can be expressed as follows.

$$\ddot{O}^* = min\frac{\frac{1}{N}\sum_{u=1}^{N}\frac{\overline{q}_u}{q_{u0}}}{\frac{1}{\mathrm{V1+V2}}\left(\sum_{r=1}^{V1}\frac{\overline{h}_r^g}{h_{r0}^g}+\sum_{r=1}^{V2}\frac{\overline{h}_r^b}{h_{r0}^b}\right)},$$

$$\text{s.t.}\begin{cases}\overline{q} \geqslant \sum\limits_{j=1}^{n} ø_J q_J \\ \overline{h}^g \leqslant \sum\limits_{j=1}^{n} ø_J h_J^g \\ \overline{h}^b \geqslant \sum\limits_{j=1}^{n} ø_J h_J^b \\ \overline{q} \geqslant q_0, \overline{h}^g \leqslant h_0^g, \overline{h}^b \geqslant h_0^b, \overline{h}^g \geqslant 0, ø \geqslant 0\end{cases} \quad (1)$$

where the objective function value of $\ddot{O}^*$ denotes the efficiency value of the decision-making unit, and its value can exceed 1, while q, h^g and h^b denote input vector, desirable output vector and undesirable output vector, respectively. V_1 and V_2 indicate the number of elements; J = 1, 2,. . ., n denotes DMU (Decision Making Units); $ø_J$ denotes the traditional efficiency value of the J decision-making unit and N denotes total number of inputs.

The relevant indicators and their data source for the Super-SBM model used in this paper are shown in Table 1.

Table 1. Green maritime transport efficiency index system.

Indicator Type	Indicator Name	Unit	Data Source
Inputs	Number of Employees in the Maritime Transport Industry	Thousands of People	International Labor Organization
	Number of Ships	Ship	United Nations Conference on Trade and Development (UNCTAD)
	Maritime Transport Industry Energy Consumption	Terajoule	United Nations Statistics Division
Desirable Output	Container Throughput	20ft TEU	World Bank
Non-Desirable Outputs	CO_2 Generated by Shipping	Kiloton	Emissions Database for Global Atmospheric Research (EDGAR)
	N_2O Generated by Shipping	Kiloton	EDGAR
	CH_4 Generated by Shipping	Kiloton	EDGAR

In terms of input, this paper selects the number of employees related to the maritime transport industry in this country as the labor factor input index, and the data source is the International Labor Organization. For the capital factors, this paper mainly uses the number of ships as the input index of capital factors. In this paper, the place of flag registration is chosen as the statistical standard to measure the number of ships owned by a country. In terms of energy factors, this paper uses maritime transportation energy consumption to measure a country's energy consumption in the maritime transport industry.

In terms of desirable output, this paper focuses on container port throughput, measured in twenty-foot equivalent units (TEU), which is a good indicator of the total number of containers handled by the country and also reflects the extent of the country's trade in goods with the world.

For the non-desirable output, in this paper, CO_2, N_2O and CH_4 emitted during ship navigation are mainly used as non-desirable output indicators, which are chosen mainly because these three gases are not only the main greenhouse gases causing climate deterioration but are also more comprehensive than the measurement using a single greenhouse gas.

This paper proposes a study of the relationship between global green maritime transport and trade; however, it was found that data of key indicators were missing for some countries, or there were obvious extreme outliers during the data collection process. To reduce errors, a sample of 60 countries with continuous and stable data was finally selected for this study. In addition, considering the impact of the financial crisis in the year 2008, this study avoided this particular time and took the year 2010, when the economy began to recover, as the starting point of the study and examined the last 11 years. Therefore, the years from 2010 to 2020 were finally selected as the study period.

4.2. Constructing Trade Decision Model Based on Translog Function

This paper, based on the assumption of technological differences in supply proposed by Eaton and Kortum [44], tried to derive a model of international trade decision by introducing a utility function based on the Translog function, using the "price" variable as a bridge.

At first, for the Translog function, the expression is

$$G = f(x_1, \ldots, x_n) = A_0 \prod_{I=1}^{n} x_I^{A_I} \prod_{I=1}^{n} x_I^{1/2[\sum_{w=1}^{n} B_{Iw} lnx_w]} \quad (2)$$

where G is an output, A_0 is an efficiency parameter, x_w is an input w and A_I and B_{Iw} are unknown parameters [45].

Taking natural logarithms of both sides in the model:

$$lnG = lnA_0 + \sum_{I=1}^{n} A_I lnx_I + 1/2 \sum_{I=1}^{n} \sum_{w=1}^{n} B_{Iw} lnx_I lnx_w \quad (3)$$

The utility function was developed by Christensen et al. [46] based on Translog function, on the basis of which this paper uses x_i^j to denote the j commodity consumed in country i. Assuming that m kinds of commodities exist, the direct utility function for country i can be expressed as:

$$lnU_i = lnU_i\left(x_i^1, x_i^2, \cdots, x_i^m\right) \quad (4)$$

This country's maximization of utility subject to the budget constraint can be expressed as:

$$\sum p_i^j x_i^j = M_i \quad (5)$$

where p_i^j is the price of the j commodity in country i, and M_i is the value of total expenditures in country i. Thus, the first-order condition for utility maximization can be written as:

$$\frac{\partial lnU_i}{\partial lnx_i^j} = \mu_i \frac{p_i^j x_i^j}{U_i} (j = 1, 2, \cdots, m) \quad (6)$$

where μ_i is the marginal utility of income, and from the budget constraint, the function expression is as follows:

$$\frac{\mu_i}{U_i} = \frac{1}{M_i} \sum \frac{\partial lnU_i}{\partial lnx_i^j} \quad (7)$$

Then, it is possible to obtain:

$$\frac{\partial lnU_i}{\partial lnx_i^j} = \frac{p_i^j x_i^j}{M_i} \sum \frac{\partial lnU_i}{\partial lnx_i^j} (j = 1, 2, \cdots, m) \quad (8)$$

Referring to the treatment of Christensen et al., this paper approximates the negative of the logarithm of the utility function with a function quadratic in the logarithms of the quantities consumed and obtains the utility function similar to Translog function:

$$-lnU_i = \alpha_{0,i} + \sum \alpha_i^j lnx_i^j + \frac{1}{2} \sum \sum e_i^{jk} lnx_i^j lnx_i^k \quad (9)$$

Ui denotes the utility level of consumption of commodity j or commodity k in country i. α_i^j and e_i^{jk} are unknown parameters.

Using a utility function of this form yields:

$$\alpha_i^k + \sum e_i^{kj} lnx_i^j = \frac{p_i^k x_i^k}{M_i} \sum\left(a_i^l + \sum e_i^{lj} lnx_i^j\right)(k = 1, 2, \cdots, m) \quad (10)$$

For simplicity, the function can be written as follows:

$$a_i^M = \sum a_i^l \quad (11)$$

$$e_i^{Mj} = \sum e_i^{lj} (j = 1, 2, \cdots, m) \quad (12)$$

In turn, the share of the total consumption of a commodity in the country's total income can be obtained as:

$$\frac{p_i^k x_i^k}{M_i} = \frac{a_i^k + \sum e_i^{kj} lnx_i^j}{a_i^M + \sum e_i^{Mj} lnx_i^j} (k = 1, 2, \cdots, m) \quad (13)$$

Referring to the studies of Dornbusch et al. [47], Eaton and Kortum [44] assumed that there is a single factor (labor), labor factors are immobile between countries and the market structure is perfectly competitive. Similarly, this paper supposes there are technological differences across countries, resulting in various efficiencies with country and commodity. This paper assumes that the production efficiency of product k in country i is $z_i(k)$, and $k \in [0, 1]$. In the presence of only a single factor (labor), the input cost of producing different products in a country is the same, denoted as c_i. At the same time, assuming constant returns to scale, the unit production cost of producing commodity k in country i is $\frac{c_i}{z_i(k)}$.

Considering the geographical barriers to cross-border trade, this paper adopts the Samuelson "iceberg transportation cost" assumption, which is commonly recognized. When exporting one unit of a commodity from country i to country f, transportation cost is incurred. $d_{i:f}$ is the geographical distance factor, and the distance of transporting unit for commodity k from country i to country f is assumed to be $d_{i:f}^k$. While international trade is mainly delivered via sea transportation, the geographical distance factor will be gradually weakened as the efficiency of sea transportation increases. Assuming that the maritime transport efficiency of country i in the transportation of commodity k is $mat_i(k)$, and $k \in [0, 1]$, here, this paper considers the geographic distance $d_{i:f}^k$ to be the actual maritime transport distance in the transportation process and introduces the maritime transport efficiency per unit commodity as $mat_i(k)$, then the iceberg transportation cost of exporting unit commodity k produced in country i and exported to country f is $\frac{d_{i:f}^k}{mat_i(k)}$.

Thus, the unit price of commodity k exported from country i to country f consists of the production cost in country i and the iceberg transportation cost with country f:

$$p_{i:f}^k = \frac{c_i}{z_i(k)} \cdot \frac{d_{i:f}^k}{mat_i(k)} \tag{14}$$

Here, $p_{i:f}^k$ denotes the price of country i's commodity k in country f.

By calculating the price of the iceberg transportation cost, combined with the demand function of the country, this paper can get the consumption of country f for commodity k imported from country i as follows:

$$x_f^k = \frac{a_f^k + \sum e_f^{kj} lnx_f^j}{a_f^M + \sum e_f^{Mj} lnx_f^j} \cdot \frac{M_f z_i(k) mat_i(k)}{c_i d_{i:f}^k} \tag{15}$$

In summary, for country f whose final consumption of commodities may come from different regions, assuming that the "iceberg transportation cost" of the country's commodity transportation process does not vary with the type of commodity, if country f has R kinds of goods imported from country i, then this paper can get the import trade volume of country f from country i:

$$x_{f,i} = \sum x_{f,i}^k = \sum \frac{a_f^k + \sum e_f^{kj} lnx_f^j}{a_f^M + \sum e_f^{Mj} lnx_f^j} \cdot \frac{M_f z_i(k) mat_i(k)}{c_i d_{i:f}^k} \tag{16}$$

$$x_{f,i} = \sum x_{f,i}^k = \frac{M_f mat_i \sum \left[\left(a_f^k + \sum e_f^{kj} lnx_f^j \right) z_i(k) \right]}{d_{i:f} c_i \left(a_f^M + \sum e_f^{Mj} lnx_f^j \right)} \tag{17}$$

It follows that the volume of trade from one country to another is positively proportional to the country's nominal national income and maritime transport efficiency and inversely proportional to the production cost and maritime distance. In contrast to the final form of the gravity model derived by Eaton and Kortum [44], this paper retains maritime transport efficiency in the final form. Compared with the gravity model, this paper not only expands the geographical factor with the actual maritime transport distance but also introduces the maritime transport efficiency, which is closely related to international trade, to provide new ideas for the study of international trade from the perspective of international maritime transport.

4.3. Econometric Model Construction and Variables Explanation

To test the previous theoretical hypothesis on the impact of green maritime transport efficiency on trade, this study constructs a panel econometric model to conduct an empirical analysis. Regression models based on panel data combined with time series and cross-sectional observations, with more information and richer sources of variance, can reduce covariance between variables and yield more valid and reliable parameter estimates due to more degrees of freedom. In addition, this empirical model is based on the above theoretical trade decision model and iceberg trade costs assumption, which can improve the objectivity and stability of the study.

To facilitate the econometric analysis, Equation (17) can be simplified in this paper. The parts $\sum\left[\left(a_f^k + \sum e_f^{kj} lnx_f^j\right) z_i(k)\right]$ and $c_i\left(a_f^M + \sum e_f^{Mj} lnx_f^j\right)$ can be treated as constants, denoted as L_1 and L_2, respectively, in order to focus on the impact of international maritime transport factors on trade in depth. This paper takes the logarithm of both sides and obtains

$$lnx_{f,i} = lnL_1 - lnL_2 + lnM_f + lnmat_i - lnd_{i:f} \quad (18)$$

The $x_{f,i}$ can be deemed as the bilateral commodity trade, M_f can be deemed as the GDP of the country, mat_i can be deemed as green maritime transport efficiency, $d_{i:f}$ can be deemed as the maritime distance between two countries and some corresponding control variables will be added to enhance the validity of the model. Thus, the basic regression model of this paper is set as follows.

$$lntrade_{it} = \beta_0 + \beta_1 lnGmat_{it} + \beta_2 lndist_{it} + \beta_3 lngdp_{it} + \beta controls_{it} + \lambda_i + \theta_t + \varepsilon_{it} \quad (19)$$

The explanatory variable $trade_{it}$ represents the bilateral commodity import and export trade between China and the target country i in the year t. $Gmat_{it}$ is the core explanatory variable, representing the green maritime transport efficiency of the country i, and β_1 is the parameter to be estimated, which is expected to be positive. The geographical distance variable $dist_{it}$ is in accordance with Zhou and Xu [36], expressed in terms of the actual maritime sailing distance between China and the target trading country, which is more representative of the trade distance between the two countries than the traditional straight-line distance between the two capitals. The actual sailing distance of maritime transport is about 1.5 times of the straight-line distance between the two capitals. This paper uses the actual maritime sailing distance between China and the target country multiplied by the crude oil price in the current period to address the non-time-varying nature of the geographical distance. β_2 is the parameter to be estimated, which is expected to be negative. The variable gdp_{it} represents the economic scale of the country, and β_3 is the parameter to be estimated, which is expected to be positive. Controls represents a series of control variables. λ_i is the country-fixed effect, controlling for country-level influences that do not vary over time. θ_t is the year-fixed effect, controlling for time-level influences that do not vary with the country. ε_{it} is the error term. To reduce heteroskedasticity, all variables in the model are logarithmic, except for the dummy variables.

This paper uses panel data from 60 sample countries of five continents from the years 2010 to 2020. The data sources and description of the variables in this paper are shown in Table 2.

With reference to the existing literature, the following control variables are selected in this paper: openness to trade (*open*), population level (*pop*) and regional trade agreement (*rta*). Openness to trade (*open*), expressed as the sum of merchandise exports and imports divided by the value of GDP, is used to measure a country's openness to the outside world and is expected to be positive. Population level (*pop*), expressed as the number of people in a country, is expected to be positive. Regional trade agreement (*rta*), expressed as whether

China has signed a trade agreement with the target country, is taken as 1 if it has signed, and 0 if it has not, and is expected to be positive.

Table 2. Description of variables.

Variables	Name	Mean	Standard Error	Min	Max	Data Source
Bilateral Trade Volume	*lntrade*	23.221	1.821	18.537	27.177	UNCOMTRADE
Green Maritime Transport Efficiency	*lnGmat*	−1.707	1.347	−5.993	2.27	Calculated by Authors
Geographical Distance	*lndist*	13.811	0.632	11.321	14.801	Searates
Trade Openness	*lnopen*	4.174	0.152	3.661	4.493	World Bank
Economic Scale	*lngdp*	26.168	1.893	22.924	30.693	World Bank
Population Level	*lnpop*	16.852	1.763	12.67	21.068	World Bank
Regional Trade Agreements	*rta*	0.217	0.412	0	1	CEPII and WTO

In order to examine the influence mechanism of green maritime transport efficiency on trade, this paper applies the mediating effect model to explore the channels. Based on Wen et al. [48], this paper constructed the three-step mediating effect model.

$$lntrade_{it} = \beta_0 + \beta_1 lnGmat_{it} + \beta Controls_{it} + \lambda_i + \theta_t + \varepsilon_{it} \quad (20)$$

$$lnmediator_{it} = \beta_0 + \beta_1 lnGmat_{it} + \beta Controls_{it} + \lambda_i + \theta_t + \varepsilon_{it} \quad (21)$$

$$lntrade_{it} = \beta_0 + \beta_1 lnGmat_{it} + \beta_2 lnmediator_{it} + \beta Controls_{it} + \lambda_i + \theta_t + \varepsilon_{it} \quad (22)$$

In the first step, as Equation (20) shows, this paper tests how the core explanatory variable affects the dependent variable, which is the same with the baseline regression model. In the second step, as Equation (21) shows, this paper tests how the core explanatory variable affects the mediator variable. In the third step, as Equation (22) shows, this paper tests how the mediator variable and the core explanatory variable affect the dependent variable together.

To test whether the mediating effect exists, this paper draws on the method from Wen and Ye [49], using the Sobel test to determine the validity of the mediating effect. Usually when the absolute value of the Sobel statistic (Z) is greater than the critical value of 0.97 (5% significance level), it indicates that the mediating effect exists.

5. Empirical Results and Analysis

5.1. Analysis of Green Maritime Transport Efficiency

Based on the Super-SBM model, including non-desirable outputs, the green maritime transport efficiency is calculated using Max-DEA software, and the green maritime transport efficiency values of 60 countries are obtained for each year during 2010–2020, as shown in Table 3. Meanwhile, GIS technology is used to carry out the spatial analysis of green maritime transport efficiency, which is detailed in Figure 3.

From the overall perspective, the average green maritime transport efficiency is 0.544, which indicates that the sustainable development of maritime transport industry still needs to be solved by global efforts. From the economic development level (according to the World Bank by 2021 GNI income), countries with more moderate levels of economic development, such as Albania, Brazil, Colombia, etc., have the highest levels of efficiency (0.581). This is probably due to the fact that developed countries have shifted their production to the medium-development economies, which in turn sell globally, expanding their trade with the world and at the same time accelerating the development of the maritime transport industry as a supporting service. And since these medium-development countries have lower human inputs and relatively modest outputs, they have the highest average efficiency value. From the perspective of individual countries, the highest ranking is Costa Rica, for this country attaches great importance to environmental protection and is known as the ecological king of the Americas, where the implementation of the PES (payments for ecosystem services) program has made its achievements in ecological protection world-renowned. Therefore, it has the highest efficiency in green maritime transport efficiency considering energy consumption and greenhouse gas emissions. Singapore is in second place, mainly because it is one of the world's maritime centers and busiest ports with not only excellent port facilities but also highly qualified human resources, and has made great contributions to the safety of ship navigation and control of marine environmental pollution. Singapore's shipping fuel exhaust treatment system CSNOx (the full system where SO_2, CO_2 and NO_x are removed simultaneously in one system and one process) uses the electrolyte principle to significantly reduce greenhouse gas emissions without generating secondary emissions. Singapore's low-carbon development in the maritime transport industry has resulted in high values of green maritime transport efficiency.

Table 3. Average value of green maritime transport efficiency.

Ranking	Country	Green Maritime Transport Efficiency	Ranking	Country	Green Maritime Transport Efficiency
1	Costa Rica	8.700	33	Iceland	0.162
2	Singapore	7.100	34	Mauritius	0.157
3	Belgium	1.500	35	Turkey	0.152
4	Uruguay	1.140	36	Ireland	0.145
5	Sri Lanka	1.062	37	France	0.138
6	Poland	1.015	38	Brazil	0.127
7	South Africa	0.876	39	USA	0.126
8	Malta	0.729	40	Mozambique	0.116
9	Cyprus	0.696	41	Latvia	0.113
10	New Zealand	0.667	42	Italy	0.106
11	Colombia	0.604	43	Japan	0.104
12	Congo	0.531	44	United Kingdom	0.097
13	Canada	0.459	45	Finland	0.085
14	Korea	0.429	46	Russia	0.077
15	Namibia	0.414	47	Sweden	0.074
16	Spain	0.369	48	India	0.072
17	Germany	0.363	49	Estonia	0.062
18	China	0.347	50	Philippines	0.062
19	Vietnam	0.314	51	Cambodia	0.057
20	The Netherlands	0.299	52	Greece	0.054
21	Georgia	0.292	53	Romania	0.048
22	Thailand	0.289	54	Bangladesh	0.047
23	Angola	0.267	55	Indonesia	0.037
24	Australia	0.234	56	Denmark	0.036
25	Ghana	0.223	57	Madagascar	0.030
26	Chile	0.222	58	Norway	0.010
27	Egypt	0.204	59	Croatia	0.010
28	Mexico	0.199	60	Albania	0.009
29	Peru	0.199		Low-Development Countries	0.226
30	Portugal	0.199		Mid-Development Countries	0.581
31	Lithuania	0.189		High-Development Countries	0.543
32	Ecuador	0.178		Average	0.544

Compared with traditional transport efficiency, the green maritime transport efficiency value of a country may become lower when the input, desirable output and non-desirable output are all very large. While energy consumption and greenhouse gas emissions are becoming more and more serious problems that human society needs to face in development, green maritime transport efficiency is more reflective of a country's efforts for sustainable development.

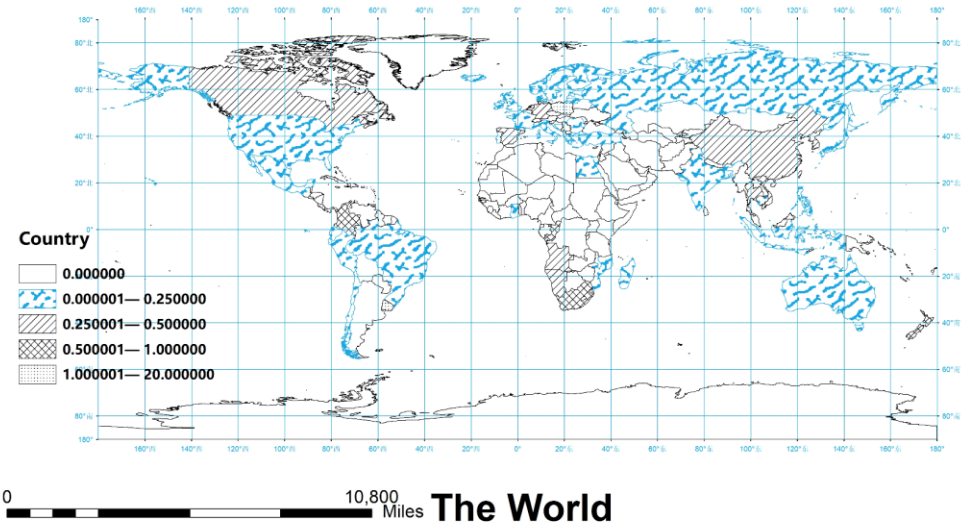

Figure 3. Spatial distribution of the average value of green maritime transport efficiency by country.

In order to analyze the dynamic information of the green maritime transport efficiency in more detail, this paper uses the kernel density estimation method to explore the dynamic characteristics of the distribution of green maritime transport efficiency in three aspects: distribution location, developing trend and polarization trend.

Figure 4 shows the overall kernel density of green maritime transport efficiency from the years 2010 to 2020, from which it can be seen that there is a "double peak" of green maritime transport efficiency, i.e., a main peak and a side peak, and the side peak is lower and has a thin right trailing feature. In terms of values, the overall global green maritime transport efficiency is mainly concentrated between 0 and 1.5, and the green maritime transport efficiency level of the main peak is mostly concentrated around 0.4, while the green maritime transport efficiency of the side peak is concentrated around 1.2. It indicates that the green maritime transport efficiency values in different economies have obvious spatial differences, and there is a bipolar or multi-polar divergence trend.

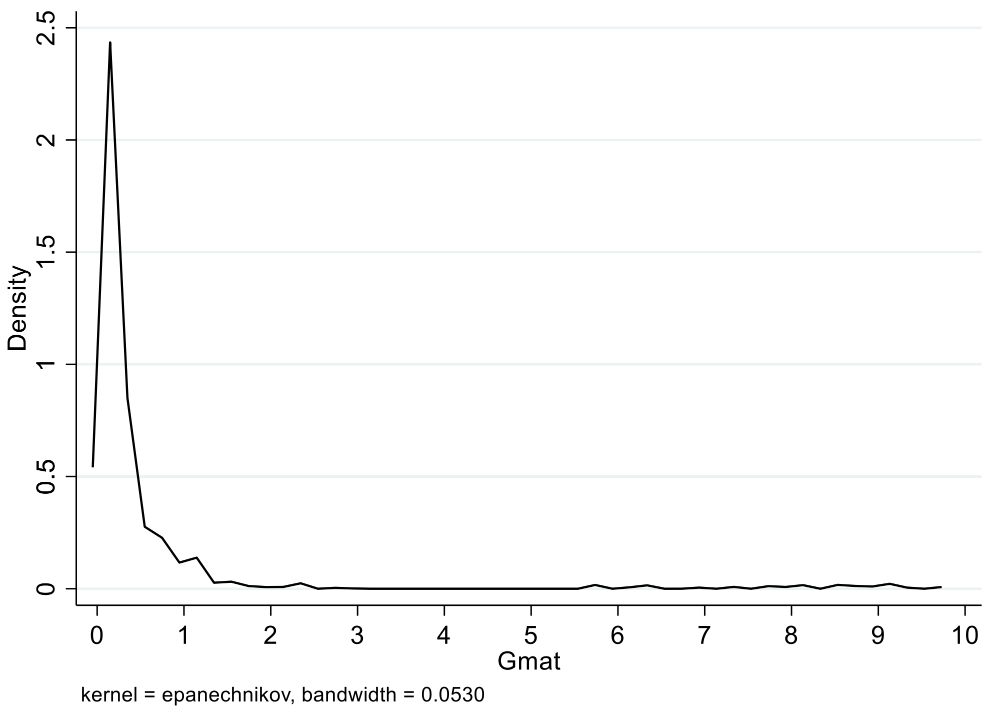

Figure 4. Overall kernel density estimation of green maritime transport efficiency.

In order to better capture the dynamic information of the differences, this paper further analyzes the green maritime transport efficiency kernel density in the years 2010, 2015 and 2020, as in Figure 5.

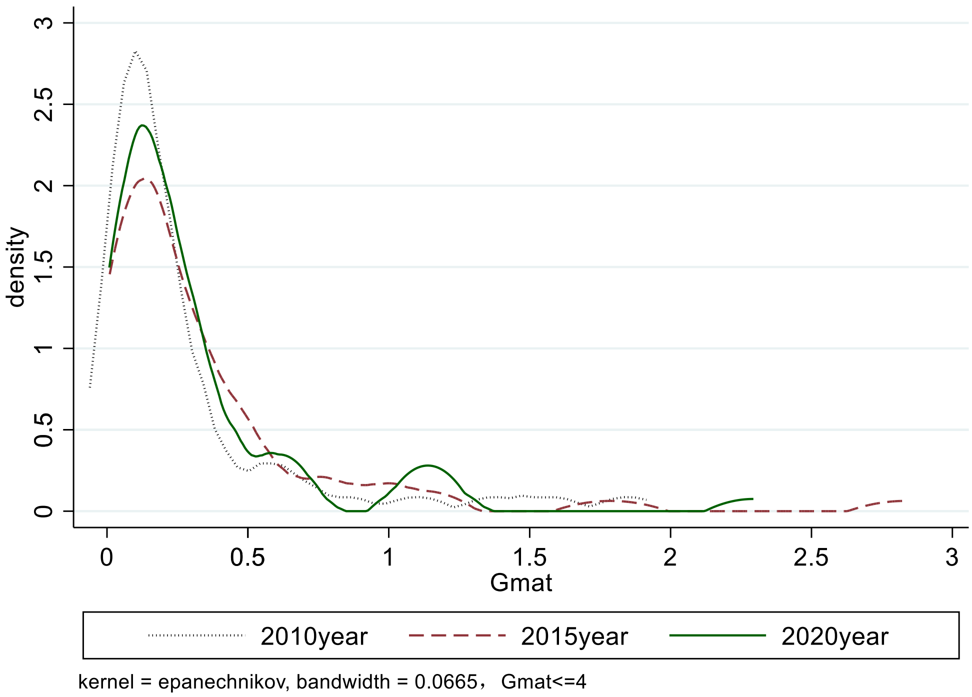

Figure 5. Dynamic kernel density estimation of green maritime transport efficiency.

Since a slimmer trailing feature appears from the efficiency values after 4 and the density is smaller, the green maritime efficiency values in the interval of 0–4 are further analyzed in Figure 5. Firstly, looking at the distribution position, the center of the distribution curve and the change interval are slightly shifted to the right from the years 2010 to 2020, which indicates that the green maritime transport efficiency tends to rise slowly. Secondly, looking at the distribution pattern, the green maritime transport efficiency shows an overall "first-down and then-up" trend in peak value and an increase in width during the observation period, which means that the absolute difference of green maritime transport efficiency tends to slightly expand in general. Finally, looking at the polarization phenomenon, the initial "double-peak" gradually evolves into the "triple-peak" over time; the peak on the right side gradually rises, and the two peaks on the right side are of equal height. In general, the overall green maritime transport efficiency grows slowly, and there are strong spatial differences; the bipolar or multi-polar trend continues to be prominent.

5.2. Baseline Regression Results

The Stata software was applied to estimate the impact of green maritime transport efficiency on bilateral trade, as shown in Table 4. In its column (1), the paper only examines the impact of green maritime transport efficiency on bilateral trade, showing that the coefficient of green maritime transport efficiency is significantly positive at the 1% level. In order to test the robustness of the result, this paper chooses to add control variables from column (2) to column (6) gradually, and the results show that the coefficient of green maritime transport efficiency is still significantly positive at the 1% level. According to column (6), the coefficient of green maritime transport efficiency is 0.116, which indicates that a country's green maritime transport efficiency considering greenhouse gas emissions has a positive effect on bilateral trade between this country and China, thus verifying the previous hypothesis 1. Therefore, the development of green maritime transport is an effective way to achieve sustainable trade development.

Table 4. Baseline regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
lnGmat	0.154 ***	0.154 ***	0.147 ***	0.116 ***	0.116 ***	0.116 ***
	(0.036)	(0.036)	(0.036)	(0.032)	(0.032)	(0.033)
lndist		−0.778 ***	−0.753 ***	−0.610 ***	−0.610 ***	−0.608 ***
		(0.072)	(0.072)	(0.068)	(0.068)	(0.072)
lnopen			0.718 ***	0.448 **	0.448 **	0.451 **
			(0.225)	(0.210)	(0.210)	(0.211)
lngdp				0.520 ***	0.520 ***	0.519 ***
				(0.074)	(0.074)	(0.071)
rta					0.880 ***	0.872 ***
					(0.252)	(0.311)
lnpop						0.018
						(0.338)
Cons	20.531 ***	31.519 ***	28.129 ***	15.062 ***	15.062 ***	14.775 **
	(0.182)	(1.002)	(1.458)	(2.272)	(2.272)	(6.030)
N	649.000	649.000	649.000	649.000	649.000	649.000
R-squared	0.989	0.989	0.989	0.990	0.990	0.990
Id	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; ** and *** indicate significance at the 5% and 1% levels, respectively.

In terms of control variables, it can be seen that the coefficient of geographical distance is −0.608 and is significant at the 1% level, indicating that a longer actual sailing distance by sea will inhibit bilateral trade, which is also consistent with the theory of the traditional gravity model. And the coefficient of trade openness is 0.451 and is significant at the 5% level, indicating that a higher degree of trade openness of a country will promote its bilateral trade with China. The regression coefficient of economic size is 0.519 and is significant at the 1% level, indicating that a GDP increase in a country will promote its bilateral trade with China, which is also consistent with the gravity model. And the coefficient of regional trade agreements is 0.872 and is significant at the 1% level, indicating that regional trade agreements promote bilateral trade by bringing lower tariffs and higher trade facilitation, thus reducing the costs of trade. Finally, the coefficient of the population is 0.018, but it is not significant, indirectly indicating that the population level does not have a significant effect on bilateral trade.

5.3. Robustness Tests

Firstly, this paper uses *LSCI* (Liner Shipping Connectivity Index) as a substitute for green maritime transport efficiency, as shown in column (1) of Table 5. For maritime transport, in the year 2006, UNCTAD published the *LSCI*, aiming to reflect the extent to which a country is integrated into the global liner maritime transport network, and the *LSCI* was updated and improved in the year 2019 to include a wider country coverage and additional component. The current version of the *LSCI* is composed of six components, including the number of liner services calling, number of liner companies providing those services, number of ships in those services, etc. Table 5 shows that the *LSCI* coefficient remains positive and significant, verifying the robustness.

Secondly, this paper uses the panel corrected standard errors (PCSE) method for estimation to deal with the complex panel error structure and test the sensitivity of the model results, for this paper uses panel data with short time and lots of countries. The PCSE method is able to estimate the panel data more accurately by substituting the residuals into the diagonal matrix and correcting their standard errors. It enhances the validity and robustness of regression and improves the accuracy and explanatory strength. As seen in column (2) of Table 5, the results using PCSE show that the green maritime transport efficiency remains significant, and the regression results converge with the benchmark regression, also verifying the robustness.

Table 5. Robustness tests.

Variables	(1) *LSCI*	(2) PCSE *lntrade*	(3) GMM *lntrade*
L.lntrade			0.834 *** (0.045)
lnLSCI	0.133 * (0.079)		
lnGmat		0.116 *** (0.037)	0.025 * (0.014)
lndist	−0.591 *** (0.082)	−0.608 *** (0.039)	−0.070 ** (0.031)
lnopen	0.490 ** (0.213)	0.451 ** (0.213)	0.236 * (0.135)
lngdp	0.531 *** (0.077)	0.519 *** (0.055)	0.098 *** (0.037)
rta	1.171 *** (0.269)	0.872 *** (0.233)	0.071(0.055)
lnpop	−0.080 (0.341)	0.018 (0.257)	0.062 *** (0.021)
Cons	14.797 ** (6.038)	14.775 *** (4.739)	0.283 (0.681)
Observations	649	649	590
R-squared	0.990	0.990	
Id	YES	YES	YES
Year	YES	YES	YES
Hansen			0.581
Ar1			0.000584
Ar2			0.826

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Thirdly, considering that the bilateral trade volume of the previous period affects the current period, in order to reflect the dynamic time-series characteristics, this paper will use the systematic GMM (generalized method of moments) method for testing. As can be seen from column (3) of Table 5, the AR (1) test is significant, while AR (2) is not significant, indicating that there is no second-order auto-correlation in the residual series of the model. And the green maritime transport efficiency is still significantly positive and thus supports the benchmark results.

In addition, Koenker and Bassett [50] proposed quantile regression using the weighted average of the absolute values of the residuals as the minimization objective function, which is less susceptible to extreme values than the traditional mean regression and does not require assumptions about the distribution of the series. The paper, by generating 10,000 seeds under the Bayesian framework, uses the parameter inference method based on the Markov chain Monte Carlo method (mcmc) for five quantile points of 0.1, 0.3, 0.5, 0.7 and 0.9, and the results are shown in Table 6.

Table 6. Regression based on different quartiles.

Variables	(1) q.1	(2) q.3	(3) q.5	(4) q.7	(5) q.9
lnGmat	0.054 ***	0.057 ***	0.148 ***	0.119 ***	0.244 ***
	(0.002)	(0.013)	(0.007)	(0.017)	(0.057)
lndist	−0.404 ***	−0.388 ***	−0.301 ***	−0.251 ***	−0.208 ***
	(0.025)	(0.036)	(0.029)	(0.035)	(0.066)
lnopen	1.972 ***	1.216 ***	0.891 ***	0.167	1.262 ***
	(0.102)	(0.103)	(0.069)	(0.204)	(0.161)
lngdp	0.701 ***	0.725 ***	0.690 ***	0.664 ***	0.543 ***
	(0.016)	(0.009)	(0.007)	(0.021)	(0.031)
rta	0.191 ***	0.382 ***	0.550 ***	0.714 ***	0.374 ***
	(0.063)	(0.039)	(0.037)	(0.053)	(0.143)
lnpop	0.295 ***	0.279 ***	0.271 ***	0.170 ***	0.270 ***
	(0.018)	(0.016)	(0.012)	(0.035)	(0.051)
N	649.000	649.000	649.000	649.000	649.000
Id	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; *** indicate significance at the 1% levels.

It can be seen that the green maritime transport efficiency is significant at all different quantile points, and the coefficients are always positive. This strongly indicates that the benchmark results have good robustness.

5.4. Endogeneity Test

The main endogeneity risk may originate from the two-way causality between the explanatory variable and the explanatory variable. To solve this problem, this paper will use the instrumental variables method, with the help of the GMM2S (two-stage GMM) method, TSLS method (two-stage least squares), LIML method (limited information maximum likelihood) and IGMM (iterative GMM) method to estimate the results to enhance the credibility, so as to effectively reduce the endogeneity risk.

Firstly, the green maritime transport efficiency of the previous period is used as an instrumental variable, due to the fact that the green maritime transport efficiency of the previous period can influence the green maritime transport efficiency of the current period and thus have an impact on bilateral trade in the current period. While bilateral trade in the current period cannot have an impact on the green maritime transport efficiency of the previous period, which has already occurred and has become history, effectively avoiding endogeneity.

The regression results are shown in Table 7. The Kleibergen–Paap Wald rk F statistic is 26.56, which is much higher than the critical value (16.38) at the 10% level in the Stock–Yogo test, rejecting the original hypothesis that the instrumental variable is weakly identified. And the coefficients of green maritime transport efficiency are always significantly positive and converge (0.182) among the four different methods of estimation, indicating that the model is still robust after overcoming the endogeneity problem.

Table 7. Endogenous problem treatment 1.

Variables	**(GMM2S)** ***lntrade***	**(TSLS)** ***lntrade***	**(LIML)** ***lntrade***	**(IGMM)** ***lntrade***
lnGmat	0.182 *** (0.057)	0.182 *** (0.057)	0.182 *** (0.057)	0.182 *** (0.057)
lndist	−0.316 *** (0.050)	−0.316 *** (0.050)	−0.052 (0.105)	−0.052 (0.105)
lnopen	0.358 * (0.195)	0.358 * (0.195)	0.358 * (0.195)	0.358 * (0.195)
lngdp	0.421 *** (0.073)	0.421 *** (0.073)	0.421 *** (0.073)	0.421 *** (0.073)
rta	1.053 *** (0.368)	1.053 *** (0.368)	1.149 *** (0.378)	1.149 *** (0.378)
lnpop	−0.126 (0.371)	−0.126 (0.371)	−0.126 (0.371)	−0.126 (0.371)
Cons	16.002 ** (6.457)	16.002 ** (6.457)	12.461 ** (6.274)	12.462 ** (6.274)
Observations	590	590	590	590
R-squared	0.991	0.991	0.991	0.991
Id	YES	YES	YES	YES
Year	YES	YES	YES	YES
Under-identification test	31	31		
p-value	2.58×10^{-8}	2.58×10^{-8}		
Weak-identification test	26.56	26.56		

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Secondly, with reference to Fisman and Sevensson [51], this paper uses another instrumental variable, which is the mean of the regional group in which the trade country is located, by which way, the green maritime transport efficiency can be decomposed into two components, i.e., *Gmat* = *GmatA* + *GmatD*, in which the *GmatA* is the the mean of the region in which the trade country is located, and *GmatD* is the difference (In this paper, regions are divided into five groups (respectively, five continents). For example, China's annual green maritime transport efficiency = annual Asiana verage group + (China's annual green maritime transport efficiency – annual Asian average group)). The *GmatA* is clearly correlated with the green maritime transport efficiency but not with the disturbances, satisfying the exogeneity requirement for the instrumental variable. The instrumental variable is suitable for the reason that countries in the same geographical region usually have similar geographical characteristics, external environment and economic development levels, and thus, their international maritime transport would also show close features. It is justified to use *GmatA* as the instrumental variable for green maritime transport efficiency of a sample country. Additionally, in terms of exogeneity, the overall green maritime transport efficiency level in the region where the trade country is located is closely related to the maritime transport status of this trade country but hardly affects the trade activities of this country directly. Therefore, this instrumental variable satisfies the exogeneity requirement.

The regression results are presented in Table 8, from which it is clear that the Kleibergen–Paap rk LM tests strongly reject the original hypothesis that the instrumental variables are under-identified, and the Kleibergen–Paap Wald rk F statistics are both 21.45, so the instrumental variables are valid. At the same time, the coefficient of green maritime transport efficiency is always significantly positive and convergent (0.395) in the four different methods, indicating that the model remains robust after overcoming the endogeneity problem.

Table 8. Endogenous problem treatment 2.

Variables	(GMM2S) *lntrade*	(TSLS) *lntrade*	(LIML) *lntrade*	(IGMM) *lntrade*
lnGmat	0.395 ** (0.179)	0.395 ** (0.179)	0.395 ** (0.179)	0.395 ** (0.179)
lndist	−0.522 *** (0.088)	−0.522 *** (0.088)	−0.522 *** (0.088)	−0.522 *** (0.088)
lnopen	0.376 * (0.224)	0.376 * (0.224)	0.376 * (0.224)	0.376 * (0.224)
lngdp	0.434 *** (0.085)	0.434 *** (0.085)	0.434 *** (0.085)	0.434 *** (0.085)
rta	−0.201 (0.725)	−0.201 (0.725)	−0.202 (0.725)	−0.201 (0.725)
lnpop	0.270 (0.350)	0.270 (0.350)	0.270 (0.350)	0.270 (0.350)
Cons	13.489 ** (6.185)	13.489 ** (6.185)	13.488 ** (6.185)	13.489 ** (6.185)
Observations	649	649	649	649
R-squared	0.989	0.989	0.989	0.989
Id	YES	YES	YES	YES
Year	YES	YES	YES	YES
Under-identification test	22.02	22.02		
p-Value	2.69×10^{-6}	2.69×10^{-6}		
Weak-identification test	21.45	21.45		

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

5.5. Influence Mechanism Exploration

Based on Equations (21) and (22), the article here explores the channels of trade effect from the green maritime transport efficiency.

Firstly, the paper tests the mechanism of technology-progress promotion. The technological progress brought by the increase in green maritime transport efficiency, through technological spillover, leads to the development of road transport and other modes of transport and thus promotes the green and efficient development of the entire transport industry. In order to demonstrate that green maritime transport efficiency promotes bilateral trade through promoting technological progress, this paper uses the Frontier Technology Readiness Index, from the Technology and Innovation Report published by the United Nations Conference on Trade and Development [52], as the mediating variable. This index fully evaluates countries' progress in the use of frontier technologies, which is particularly important for the future development of the world after the epidemic (UNCTAD, 2021). Due to the missing data of the sample country Angola, the paper excludes it from the whole sample in this regression.

The regression results are shown in Table 9, where *lntech* represents the Frontier Technology Readiness Index. Column (2) shows that the coefficient of green maritime transport efficiency is significantly positive at the 1% level, which indicates that green maritime transport efficiency promotes technological progress. Column (3) proves that both green maritime transport efficiency and technological progress are significantly positive. The Z-statistic in Sobel test is 1.742, which indicates that the mediating effect of the technology-progress promotion is effective; it is a partial mediating effect, and the proportion of this mediating effect in the total effect is 8.2%. The results show that the green maritime transport efficiency promotes bilateral trade through promoting technological progress, thus verifying the previous hypothesis 2.

Table 9. Test on mechanism of technology-progress promotion.

Variables	(1) *lntrade*	(2) *lntech*	(3) *lntrade*
lntech			0.202 ** (0.092)
lnGmat	0.117 *** (0.033)	0.048 *** (0.017)	0.107 *** (0.033)
lndist	−0.605 *** (0.072)	−0.072 ** (0.034)	−0.590 *** (0.071)
lnopen	0.582 *** (0.209)	0.156 (0.170)	0.551 ** (0.215)
lngdp	0.435 *** (0.076)	0.171 *** (0.051)	0.401 *** (0.077)
rta	0.901 *** (0.319)	−0.136 (0.207)	0.928 *** (0.317)
lnpop	0.357 (0.371)	0.678 *** (0.249)	0.220 (0.383)
Cons	11.095 * (6.393)	−14.604 *** (3.913)	14.038 ** (6.635)
N	638.000	638.000	638.000
R-squared	0.990	0.970	0.990
Id	Yes	Yes	Yes
Year	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Secondly, the paper tests the mechanism of trade-costs reduction. Trade costs are all the costs that must be paid to obtain goods, except for the production costs of goods. Although traditional international trade theory rarely deals with trade costs, trade costs are more and more outstanding in today's trade. In order to examine if green maritime transport efficiency would affect trade through the mechanism of trade-costs reduction, the specific value of trade costs need to be measured. This paper refers to Anderson and Wincoop [53] and Novy [54], and it uses iceberg-type cost to calculate the costs of trade. The equation is as follows

$$\tau_{EO} = \left(\frac{W_{EE}W_{OO}}{W_{EO}W_{OE}}\right)^{\frac{1}{2(\sigma-1)}} - 1 \tag{23}$$

where τ_{EO} is the costs of bilateral trade between country O, namely, China and country O. And W_{EE} is China's domestic trade, which equals to China's GDP minus China's total exports, and W_{OO} is domestic trade of the China's trading partners, which equals to the GDP of trading partners minus their total exports. W_{EO} and W_{OE} represent the mutual exports between China and its trading partners, respectively. The elasticity of substitution σ is difficult to determine, and Anderson and Wincoop (2003) suggested that the elasticity of substitution σ should be between 5 and 10, based on estimation results from other studies. In this paper, the value of the elasticity of substitution σ is taken as 9. It is noted that the value of W_{OO} for Ireland and Singapore is negative, which makes Equation (23) impossible, and this paper would exclude them from the whole sample in this regression. This paper uses the calculated cost of trade (*lncb*) as the mediating variable.

The regression results are shown in Table 10. Column (2) shows that the coefficient of green maritime transport efficiency is significantly negative at the 1% level, indicating that the green maritime transport efficiency significantly suppresses the increase in the costs of trade. In column (3), the coefficient of trade costs is significantly negative. The Z-statistic in Sobel test is 3.064, which indicates that the mediating effect of reducing trade costs is effective. It can be seen that there is a partial mediating effect, and the proportion of this mediating effect in the total effect is 75.8%. The results demonstrate that green maritime transport efficiency promotes bilateral trade through reducing the costs of trade, thus verifying the previous hypothesis 3.

Table 10. Test on mechanism of trade-costs reduction.

Variables	(1) *ln*	(2) *lncb*	(3) *lntrade*
lncb			−8.077 *** (0.595)
lnGmat	0.109 *** (0.032)	−0.008 *** (0.002)	0.049 * (0.026)
lndist	−0.576 *** (0.070)	0.086 *** (0.005)	0.119 * (0.072)
lnopen	0.460 ** (0.207)	−0.079 *** (0.016)	−0.176 (0.202)
lngdp	0.555 *** (0.073)	0.063 *** (0.006)	1.064 *** (0.066)
rta	0.672 ** (0.299)	−0.279 *** (0.026)	−1.584 *** (0.227)
lnpop	0.322 (0.318)	0.040 (0.025)	0.647 ** (0.279)
Cons	8.913 (5.588)	−2.446 *** (0.466)	−10.839 ** (4.605)
N	627.000	627.000	627.000
R-squared	0.991	0.995	0.995
Id	Yes	Yes	Yes
Year	Yes	Yes	Yes

The numbers in parentheses in the table are standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Thirdly, the paper tests the mechanism of environment-deterioration hinderance. To verify the environment-related mechanism of the effect from green maritime transport efficiency on trade, this paper uses the Climate Deterioration Index (*lncch*) from the report on Environmental Performance Index jointly published by Yale University and Columbia University as a mediating variable, to test whether green maritime transport efficiency promotes bilateral trade by curbing environment deterioration. This Climate Deterioration Index is calculated based on the growth rates of various pollutants with different weights, such as CO_2, CH_4, NxO, etc., reflecting the degree of climate deterioration.

The regression results are shown in Table 11, where column (2) shows that the coefficient of green maritime transport efficiency is significantly negative at the 5% level, which indicates that the improvement of green maritime transport efficiency suppresses environmental deterioration. The results in column (3) show that the green maritime transport efficiency remains positive, and environment deterioration is significantly negative. The Z-statistic in the Sobel test is 2.051, which indicates that the mediating effect of environment-deterioration hinderance is effective; it is a partial mediating effect, and the proportion of this mediating effect in the total effect is 10.6%. The results indicate that green maritime transport efficiency promotes bilateral trade by suppressing environment deterioration, which verifies the previous hypothesis 4.

Table 11. Test on mechanism of environment-deterioration hinderance.

Variables	(1) *lntrade*	(2) *lncch*	(3) *lntrade*
lncch			−0.102 *** (0.029)
lnGmat	0.116 *** (0.033)	−0.120 ** (0.047)	0.104 *** (0.032)
lndist	−0.608 *** (0.072)	−0.663 *** (0.098)	−0.676 *** (0.072)
lnopen	0.451 ** (0.211)	−0.432 (0.397)	0.408 ** (0.200)
lngdp	0.519 *** (0.071)	−0.297 *** (0.090)	0.488 *** (0.072)
rta	0.872 *** (0.311)	2.353 *** (0.358)	1.116 *** (0.311)
lnpop	0.018 (0.338)	−3.065 *** (0.425)	−0.298 (0.341)
Cons	14.775 ** (6.030)	67.228 *** (7.373)	21.690 *** (6.162)
N	649.000	648.000	648.000
R-squared	0.990	0.345	0.990
Id	Yes	Yes	Yes
Year	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; ** and *** indicate significance at the 5% and 1% levels, respectively.

6. Further Discussion

The last part has proved that green maritime transport efficiency promotes trade based on the overall sample. However, what are the trade effects of green maritime efficiency for different countries and products with different characteristics? In this part, the paper will go further to discuss the heterogeneity problem according to different groups of samples, in order to analyze, in detail, the impact of green maritime transport efficiency on trade under different subgroups and to obtain more targeted conclusions

6.1. Heterogeneity Analysis for Different Flow of Goods

If grouping is based on the flow of goods, the bilateral trade can be further differentiated into two dimensions: import and export, and this paper will examine the difference of trade effects from green maritime transport efficiency under these two dimensions. The regression results are shown in Table 12. From columns (1) and (2), it can be seen that green maritime transport efficiency is significantly positive for both China's import and export trade and more remarkable in trade effects of import. This may be due to the fact that the higher the efficiency level of green maritime transport in one country, the more focused the country is on the development of green technologies. In the context of internationalization, there are two main sources of one country's technological progress. One is independent research and development, and the other is the absorption of international technology spillover. As one of the channels of international technology spillover, import trade can improve the country's technological progress to a certain extent. Therefore, the higher the efficiency level of green maritime transport, the stronger the effect on import trade in international trade.

Table 12. Heterogeneity test based on import/export and membership in IMO.

Variables	(1) imp	(2) exp	(3) IMO	(4) NO-IMO
lnGmat	0.139 *** (0.050)	0.113 *** (0.034)	0.140 ** (0.063)	0.065 * (0.038)
lndist	−0.895 *** (0.121)	−0.564 *** (0.075)	−0.704 *** (0.095)	−0.534 *** (0.118)
lnopen	0.642 ** (0.312)	0.367 * (0.216)	0.219 (0.239)	1.046 ** (0.425)
lngdp	0.527 *** (0.117)	0.644 *** (0.067)	0.249 ** (0.097)	0.678 *** (0.103)
rta	2.123 *** (0.510)	−0.072 (0.296)	1.978 ** (0.933)	0.314 (0.390)
lnpop	−1.261 ** (0.489)	0.001 (0.346)	−0.897 (0.710)	0.533 (0.390)
Cons	35.473 *** (9.155)	11.523 * (6.172)	40.648 *** (12.763)	−0.361 (7.616)
N	649.000	649.000	330.000	308.000
R-squared	0.983	0.990	0.990	0.973
Id	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

6.2. Heterogeneity Analysis for Different Countries: IMO Member or Not

Based on whether a country serves as an IMO council member, another heterogeneity analysis is conducted. The International Maritime Organization (IMO) is a specialized agency under the United Nations, responsible for the safety of maritime navigation and the prevention of marine pollution from ships, to promote the safe, environmentally friendly, efficient and sustainable development of maritime transport through cooperation. The regression results are shown in Table 12.

From columns (3) and (4), it can be seen that the green maritime transport efficiency is significantly positive for both being a council member (Council members: China, Greece, Italy, Japan, Norway, Korea, Russia, United, Kingdom, USA, Australia, Brazil, Canada, France, Germany, India, The Netherlands, Spain, Belgium, Chile, Cyprus, Denmark, Egypt, Indonesia, Malta, Mexico, Peru, Philippines, Singapore, South Africa, Thailand and Turkey) and not being a council member (Non-Council members: Albania, Angola, Bangladesh, Cambodia, Colombia, Congo, Costa Rica, Croatia, Ecuador, Estonia, Finland, Georgia, Ghana, Iceland, Ireland, Latvia, Lithuania, Madagascar, Mauritius, Mozambique, Namibia, Poland, Portugal, Romania, Sri Lanka, Sweden, Uruguay, Vietnam, New Zealand), with coefficients of 0.140 and 0.065, respectively. However, being a council member has a comparatively stronger impact on bilateral trade. Take Singapore as an example. Singapore is a member of the council, and it places high importance on greening international maritime transport. At the same time, China's trade flows with Singapore increase by about 18% from the years 2017 to 2021. This is because both Singapore and China are members of IMO council, and both tend to place more emphasis on green and sustainable development, which in turn boosts China's bilateral trade with Singapore.

6.3. Heterogeneity Analysis for Countries of Different Economic Levels

The paper further classifies the sample countries into low, middle and high economic development categories based on the World Bank 2020 criteria for classifying economies by gross national income (GNI) per capita. Those low-income and lower-middle-income countries are classified as "low economic development" countries (Angola, Bangladesh, Cambodia, Congo, Egypt, Ghana, India, Indonesia, Ireland, Madagascar, Mozambique, Philippines, Sri Lanka, and Vietnam), upper-middle-income countries are classified as "medium economic development" countries (Albania, Brazil, Colombia, Costa Rica, Ecuador, Georgia, Mauritius, Mexico, Namibia, Peru, Thailand, Turkey, China, Russia and South Africa), and high-income countries are classified as "high economic development" countries (Belgium, Chile, Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Italy, Japan, Latvia, Lithuania, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Singapore, Spain, Sweden, United Kingdom, USA, Uruguay, Korea, Canada, Australia and New Zealand). The regression results are shown in Table 13.

Table 13. Heterogeneity test based on different levels of economic development.

Variables	(1) High	(2) Med	(3) Low
lnGmat	0.127 ** (0.050)	0.107 *** (0.040)	0.036 (0.097)
lndist	−0.539 *** (0.085)	−1.077 *** (0.148)	−1.092 *** (0.355)
lnopen	0.774 *** (0.249)	−0.344 (0.491)	0.203 (0.415)
lngdp	0.293 ** (0.134)	−0.135 (0.213)	0.613 *** (0.132)
rta	−1.645 *** (0.594)	8.265 *** (2.938)	0.562 (0.933)
lnpop	−0.951 * (0.571)	−1.374 (0.849)	−1.263 (1.035)
Cons	35.723 *** (11.439)	60.382 *** (16.545)	44.504 * (25.132)
N	341.000	154.000	154.000
R-squared	0.994	0.990	0.982
Id	Yes	Yes	Yes
Year	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

From the results in columns (1) and (2), it can be seen that the green maritime transport efficiency is significant for countries with high- and medium-economic development levels, and the trade effect is better for countries with high economic development. The results in column (3) show that the coefficient of green maritime transport efficiency is positive (0.036) in countries with a low-economic development level, but the result is not significant. According to Staffan B. Linder's demand similarity theory, the magnitude of trade flows in two countries is determined by the demand preference similarity of the two countries, while the demand preference of a country is determined by its average income level. For example. Although the green maritime transport efficiency values of Sri Lanka and Congo are above the level of 0.5, they are among the countries with low economic development. According to Linder's theory, China's trade flows with these two countries are not outstanding, which may be due to the large difference in the average income levels of the countries. Therefore, for those poorer countries, the green maritime transport efficiency fails to influence trade.

6.4. Heterogeneity Analysis for Products with Different Factor-Intensity

The paper further explores the heterogeneous impact of green maritime transport efficiency on trade based on different products' factor-intensity. The Standard International Trade Classification of Goods (SITC) offers 10 classifications, and this paper refers to some related studies [55] and takes SITC_0-SITC_4 as primary products, SITC_5 and SITC_7 as capital-intensive products and SITC_6 and SITC_8 as labor-intensive products. The number of SITC_9 is neglected here for small values. The regression results are shown in Table 14, from which it can be seen that green maritime transport efficiency is significantly positive for all kinds of products but with slightly different strengths. The strongest trade effect happens in the labor-intensive products.

Table 14. Heterogeneity based on factor-intensity of products.

Variables	(1) Primary Products	(2) Capital-Intensive	(3) Labor-Intensive
lnGmat	0.079 * (0.042)	0.078 ** (0.039)	0.136 *** (0.038)
lndist	−0.606 *** (0.107)	−0.660 *** (0.089)	−0.573 *** (0.075)
lnopen	0.371 (0.247)	0.545 * (0.290)	0.271 (0.185)
lngdp	0.567 *** (0.096)	0.554 *** (0.090)	0.639 *** (0.071)
rta	1.599 *** (0.385)	0.997 *** (0.374)	−0.396 (0.279)
lnpop	0.396 (0.448)	−0.714 * (0.382)	0.306 (0.341)
Cons	6.782 (7.694)	23.600 *** (7.018)	7.273 (6.083)
N	649.000	649.000	649.000
R-squared	0.985	0.986	0.990
Id	Yes	Yes	Yes
Year	Yes	Yes	Yes

The numbers in parentheses in the table are robust standard errors; *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively.

This may be due to the fact that the traditional labor-intensive industries tend to have greater pollution in the environment in the process of production. With the rapid development of national economies, the global value chain division of labor is deeply adjusted. Due to the energy consumption characteristics of labor-intensive industries, countries with high levels of economic development pay more attention to green and sustainable development. Therefore, they strive to transform their industrial structure from traditional labor-intensive industries to capital-intensive industries, and their original labor-intensive industries will be transferred outside, and those countries with cheap labor and land resource elements will undertake these labor-intensive industries in large numbers to promote economic development. As a result, countries with high levels of economic development will rely mainly on international trade to meet the demand of their consumers for labor-intensive products, and thus, their trade with countries with slightly lower levels of economic development in labor-intensive products will become more frequent. Therefore, the higher the efficiency of green maritime transport, the stronger the trade effect on labor-intensive products.

7. Conclusions and Recommendations

7.1. Research Conclusions

Using the data of 60 sample economies in five continents from the years 2010 to 2020, this paper uses the Super-SBM method to measure their green maritime transport efficiency reflecting greenhouse gas emissions, then extrapolates the theoretical model of trade decision considering maritime transport efficiency and maritime transport distance based on the transcendental logarithmic function, based on which, empirical models are constructed to examine the trade effect of green maritime transport efficiency and the possible influence mechanisms.

It is found that, firstly, there are obvious regional differences in the spatial and temporal characteristics of green maritime transport efficiency among countries, and the trend is polarized. Secondly, green maritime transport efficiency significantly promotes bilateral trade between these countries and China. Thirdly, in terms of influence mechanism, a country's green maritime transport efficiency improvement can promote its trade with China through three channels: technology-progress promotion, trade-costs reduction and environment-deterioration hinderance, in which the trade-costs reduction plays the biggest role. Fourthly, in terms of the countries' heterogeneity, green maritime transport efficiency has a greater trade growth effect for countries that are IMO council members and have higher per capita income. Fifthly, in terms of trade heterogeneity, green maritime transport efficiency has a greater trade promotion effect on labor-intensive product trades and import trades.

7.2. Countermeasures and Suggestions

Based on the above findings, this paper makes the following policy recommendations for China.

Firstly, China should continue to promote the development of green maritime transport, thus realizing the high-quality and sustainable development of foreign trade. China can set up a green maritime transport research fund and lay a solid foundation for basic research through industry–academia research linkages, and at the same time, carry out multi-sectoral joint research on core technologies to improve environmental protection technologies in the maritime transport field. China should also formulate and improve regulations on carbon emission limits for the maritime transport industry, establish a sound monitoring and enforcement mechanism for ship emissions and increase the regulation of pollution emissions. However, it is also important to note that the investment in the research and development of green technology, as well as strict government regulations on environmental protection will increase the input costs of enterprises. Therefore, relevant incentive policies should be introduced to subsidize the enterprises of green technology research and development and application to ensure the smooth transformation of China's s maritime transport to be green and sustainable.

Secondly, China ought to actively participate in the cooperation of IMO Council members to accelerate the transformation and upgrading of the global international maritime transport industry. China should play its role as the world's largest maritime transport trading country, dedicated to improving international economic and trade cooperation and enhancing political communication with IMO Council members to gain more support; China should actively participate in IMO meetings and various decision-making processes, fully express its views and suggestions and promote and develop sustainable development policies and regulations for maritime transport that are suitable for the world. At the same time, China can share its technical, policy and management experience with other member countries, advocate for enhanced international cooperation through the IMO platform and promote cooperation projects in the field, thus promoting the transformation and upgrade of the global international maritime industry.

Thirdly, China should accelerate industrial upgrading and reduce the production of highly polluting and labor-intensive products. China should fully connect domestic and international market resources, replace the demand for highly polluting labor-intensive products with international trade and increase the international flow of labor-intensive products to release the trade growth effect of green maritime transport efficiency. However, it may lead to a decrease in the market share of local labor-intensive enterprises and an increase in unemployment. Therefore, before the completion of industrial transformation and upgrading, China should enhance its transnational production docking capacity with other countries under the international division of labor in global value chains (GVC) and absorb advanced technologies from other countries through the learning-by-doing effect, as well as establish strategic partnerships with other enterprises and institutions to help enterprises transform and upgrade. At the same time, the training and education of talents will be strengthened to improve the quality of the workforce, so that China can carry out industrial upgrading smoothly.

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