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Impacts of Shipping Carbon Tax on Dry Bulk Shipping Costs and Maritime Trades—The Case of China

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Abstract: Greenhouse gas (GHG) emissions in shipping have been receiving growing concerns in the maritime industry. Recently, the International Maritime Organization (IMO) is considering the introduction of a global shipping carbon tax, which has become the most talked-about topic in both industry and academia. To assess the potential impact of the carbon tax on maritime trades, a trade-volume-based model of shipping carbon emissions was developed. Considering that bulk shipping is the second-largest carbon emitter in the maritime industry and the low value-to-weight nature of bulk cargoes, the model was applied to analyze the dry bulk trade in China, one of the leading countries in the global dry bulk trade. The results show that the introduction of the carbon tax could have significant impacts on freight rates and commodity prices. Depending on the trading regions and the carbon charges, shipping freight rates would increase by 10–30%, which is equivalent to 1–4% of the trading prices. Additionally, since shorter shipping distances may have less emission per trading tonnage, the shipping carbon tax may significantly change the dry bulk trade patterns, resulting in China's increasing reliance on nearby countries, e.g., India and Australia, for the import of key commodities. These findings can help shipping companies and sectors make better carbon reduction responses, such as redeploying their fleets, promoting the development of low-carbon shipping technologies, and increasing investments in Australia, as well as South and Southeast Asia.

Keywords: decarbonization of shipping; shipping carbon tax; dry bulk trade; maritime industry

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1. Introduction

Shipping is the primary mode of transportation for international trade, carrying more than 80% of the international commodity trade by volume and over 70% of the global trade by value [1]. With the growth of trade activities, decarbonization of shipping has become an ongoing concern for the maritime industry, even though shipping is often considered to be the most energy-efficient way to transport large quantities of goods. Excluding the impact of the COVID-19 pandemic, it is estimated that the share of carbon emissions from shipping activities in global anthropogenic emissions has been increasing over the past decade, with annual carbon emissions exceeding 1000 million tons, accounting for 3% of the total GHG emissions [2]. Considering future economic and energy developments, as well as the improvements in the carbon efficiency of ships, these emissions are projected to be 90–130% of 2008 emissions by 2050 [3]. If the climate change impact of shipping activities grows as projected, the Paris Agreement's goal of limiting global warming to well below 2 °C and pursuing efforts to limit it to 1.5 °C would be greatly threatened [4].

The Initial IMO Strategy on Reduction in GHG Emissions from Ships was developed as early as 2018, which calls for a carbon reduction of at least 50% by 2050 compared to 2008, and pursues efforts toward phasing them out entirely [5,6]. To comply with the IMO GHG reduction target in 2050, IMO has initially developed several short- (2018–2023), medium- (2023–2030), and long-term (beyond 2030) measures. In brief, these measures can be divided into four categories: technical measures, operational measures, market-based measures (MBMs), and alternative fuels. Technical measures include the development and installation of greening technologies on ships, such as energy-saving engines and propulsion. Operational measures are mainly related to the optimization of sailing routes and speeds, as well as other logistics-based measures. MBMs may be divided into two main types, namely, emissions trading systems (ETS) and carbon taxation. Lastly, alternative fuels refer to the ultimate path to zero carbon emissions in the long term.

Given the importance and urgency of the maritime carbon emissions issue, a large number of studies have been conducted to explore the decarbonization pathways of maritime transport. Bouman et al. [7] investigated the carbon reduction potential of shipping technologies and operational measures in the published literature, and noted that the current technology combinations could reduce GHG emissions per freight unit by a factor of 4–6 by 2050. Schwartz et al. [8] developed a scenario-based simulation approach to evaluate carbon emission reductions and investment costs for various technologies and operational measures. It was found that more than 50% of emissions could be reduced through profitable investments, such as operational solutions, cold scalding, and slender hulls. In the case of MBMs, Psaraftis et al. [9] conducted a comprehensive assessment of three types of measures: bunker levy, ETS, and other MBMs. The study concluded that a tax-based MBM has advantages over the ETS in terms of GHG reduction effectiveness, administrative burden, practical feasibility, and avoidance of split incentives. Similarly, Garcia et al. [10] came to the conclusion that the carbon tax is more feasible than the ETS in terms of complexity, but that low- or zero-carbon fuels are the only way to achieve decarbonization of shipping. Although LNG is a well-liked alternative fuel with favorable economic and environmental effects, it is still not enough to achieve 50% decarbonization and often needs to be used in combination with multiple options [11]. As a result, researchers are now focusing more on methanol [12], hydrogen energy [13], ammonia energy [14], and other renewable energy sources [15,16]. In addition, several studies designed decarbonization pathways in the form of scenario simulations based on the above measures to achieve long-term carbon emission targets, and thoroughly discussed the potential difficulties and the support required from policymakers [17–19].

In recent years, newly approved technical and operational measures at the IMO have not been sufficient to curb GHG emissions from international shipping in the long term. As a result, IMO is considering the introduction of a market-based measure, the global shipping carbon tax, which would be paid on the basis of the amount of carbon emissions from ships in global trade. The tax imposed could be used to fund research and development of low-carbon technologies and zero-carbon fuels for shipping. The IMO originally planned to discuss and implement MBMs in 2023–2030, but the carbon tax proposal still did not reach a consensus at the latest May 2022 meeting [20]. Therefore, there is no specific timeline for the tax at this time, although it has generated extensive discussion within the industry. For example, Trafigura, a global commodity trading company, proposed a carbon tax of 250–300 USD per ton of CO_2 in September 2020 to make zero- and low-carbon fuels more economically viable and competitive [21]. In June 2021, the Marshall Islands and the Solomon Islands, which are most threatened by sea-level rise and other climate impacts, submitted a new request to the IMO to impose a levy of 100 USD per ton of CO_2 emitted by ships starting in 2025 [22]. Moreover, the levy would increase by 30% or 100% annually or every 5 years. Meanwhile, Maersk, the world's largest container shipping company, also called in early June for a carbon tax of 150 USD per ton of CO_2 (equivalent to 450 USD per ton of fuel) to help the maritime industry move away from fossil fuels [23]. In May 2022, Japan also proposed a financial incentive that the maritime industry would be required to pay 56 USD per ton of CO_2 starting in 2025 under the proposed global carbon tax. The tax, if implemented, is expected to raise more than 50 billion USD annually [24].

However, some other IMO members seem to be opposed to the idea of the measure, arguing that it could cause considerable economic disruption (i.e., loss of profits) for industry stakeholders, particularly ship owners, shipbuilders, shipping service providers, and national governments. This is because the regulation of maritime carbon emissions would not only affect the competitiveness of shipping companies but could also have a significant impact on the world economy through higher freight rates and changes in the trade patterns of individual countries (i.e., imports and exports). Therefore, the potential impact of this measure on countries, especially the economic impact on developing countries, should be reasonably assessed and considered before it is formally implemented.

Some assessments of the impact of the carbon tax on the maritime industry do exist in the literature, but the majority of them focus on three areas: GHG reduction effective, freight modal shift, and the impact on shipowners' operations optimization. Mundaca et al. [25] estimated that a global tax of 40 USD per ton of CO_2 would result in a 7.65% reduction in CO_2 emissions from the heaviest traded products transported by sea. This study found that commodities with relatively low value-to-weight ratios, such as fossil fuels and ores, would experience greater reductions in carbon emissions. Psaraftis [26] found that an increase in fuel price from 100 to 500 USD per ton would result in a 17% to 50% CO_2 reduction for the basic container ship scenario, taking into account the CO_2 emissions of additional ships deployed to compensate for the loss of throughput. Lagouvardou et al. [27] concluded that a bunker levy can reduce CO_2 emissions from tankers up to 43% in the short term by inducing speed reduction. Avetisyan [28] and IFT [29] studied the modal shift in the transportation of goods traded in different regions, noting that increased transport costs or longer shipping times in the context of a carbon tax on shipping may drive a modal shift from maritime to rail or road transport, especially in the case of trade in valuable or perishable goods. Pomaska et al. [30] studied the impact of carbon taxes on shipowners' decisions to invest in hydrogen fuels. Only a high carbon tax could drive shipowners' investments and accelerate the uptake of new technologies. In addition, some studies also focused on the operational optimization of shipping companies under the carbon tax scenario, such as route selection [31], ship energy system configuration [32], fleet planning, and sailing speed optimization [33–36]. To our knowledge, only a few studies have assessed the potential economic impact of a carbon tax on the countries. Among them, Rojon et al. [37] showed that the introduction of a carbon price would have a limited impact on the total costs of maritime transport for the average country. However, Small Island Developing States (SIDS) and Least Developed Countries (LDCs) are more likely to be adversely affected by such measure in terms of maritime transport costs. Lee et al. [38] assessed the economic impact of a carbon tax on international container shipping and found that the implementation of the measure would not have a significant economic impact unless the price of carbon charges is very high. Of these, China could experience the highest real GDP loss of all countries with a reduction of roughly 0.02% (assuming a carbon charge of 90 USD per ton). Halim et al. [39] concluded that the introduction of a carbon price of 10 to 50 USD per ton of CO_2 for bunker fuel could increase the cost of shipping by 0.4% to 16%. However, this would only slightly increase the import price of goods (less than 1%), and the impact on the national economy was expected to be small (−0.002% to 0.5% of GDP).

The literature review above shows that the assessment of the impact of the carbon tax on countries is still lacking at present, especially in China. As the world's second-largest economy, China is a major player in international maritime trades, especially in the global dry bulk shipping trade. The dry bulk shipping is the most important transportation model of bulk commodities, carrying cargoes such as iron ore, coal, and grain, often with relatively low value-to-weight ratios. It is reported that China is the world's largest importer of iron ore and coal, accounting for 76% and 20% of global imports, respectively [40]. According to BIMCO, the global dry bulk shipping industry carried a total volume of 5.49 billion tons in 2020. Of this, China dominated the dry bulk shipping market with its imports accounting for just shy of 50% of the market when measured in ton-miles [41]. In addition, according to the Fourth IMO GHG Study 2020, dry bulk shipping is also the second largest source of GHG emissions from the maritime industry [3]. Therefore, the implementation of a carbon tax will have a more significant impact on the bulk goods, which have high logistic costs relative to their value. Accordingly, the purpose of this paper was to examine the impact of the global shipping carbon tax on China's shipping trade with a focus on dry bulk trade. Specifically, a trade-volume-based shipping carbon emissions model was developed to analyze the carbon emissions in China's dry bulk trade and the carbon costs under different carbon charges. Furthermore, we analyzed the impact of the introduction of the carbon tax on shipping costs and China's dry bulk shipping trade activities, using iron ore and coal (the main dry bulk cargoes) as examples. The results show the current carbon emissions of shipping and the changing pattern of the dry bulk shipping trade in China, which can be used to help shipping companies and shipping sectors to adjust their carbon reduction strategies for ships.

The remainder of this paper is organized as follows: Section 2 describes the methodology used and the data collected. The detailed results are presented in Section 3. Section 4 provides an in-depth discussion and analysis of the results. Lastly, Section 5 presents the main conclusions of this work.

2. Methods and Materials

2.1. Shipping Carbon Emissions Model

In the current literature, there are two main approaches to assessing CO_2 emissions from maritime transport: top-down (based on fuel consumption) and bottom-up (activity-based) approaches [42–45]. However, it is very difficult to obtain accurate fuel consumption for shipping, and there may be some risk of uncertainty or inconsistent data, which poses a great challenge to the application of the top-down approach [46]. Therefore, to better assess the carbon emissions of shipping activities in a specific region or country, we referred to the global carbon emissions estimation methodology in the Fourth IMO GHG Study 2020, which uses Energy Efficiency Operational Indicator (EEOI) as a carbon intensity metric for ships [3]. Specifically, the EEOI represents the CO_2 emissions per actual cargo ton-mile traveled by a given type and size of ship. This metric can better reflect the impact of the ship technology improvements or operation-related factors on carbon emissions, as the actual cargo deadweight and differences between ship types are taken into account in the calculation. Therefore, we developed a new shipping carbon emissions estimation model on the basis of the shipping trades of a country in combination with the latest EEOI carbon intensity metric reported by the IMO. The following formula underlies the main methodology of this paper:

$$Carbon\ Emissions = \sum_{i \in VesselType} \sum_{j \in VesselSize} \sum_{k \in Region} EEOI_{ij} \times D_{ijk} \times CargoWeight_{ijk}, \quad (1)$$

where $VeselType$ indicates the type of vessel (including bulk carrier, container vessel, tanker, and other vessels), $VesselSize$ indicates the size of the vessel, $Region$ denotes the set of shipping trade areas, $EEOI_{ij}$ represents the carbon intensity metric for the vessel of type i with size j, and $D_{ijk} \times CargoWeight_{ijk}$ refers to the cargo turnover by the vessel of type i with size j in a given region k. On the basis of the historical shipping data, approximate estimations of shipping carbon emissions in a given region or country can be made.

Of course, in order to reduce the complexity of the calculation and improve the applicability of the model, we can also use the cargo turnover of specific types of vessels traveling to and from different regions to approximate the total carbon emissions. The main components of the simplified model are as follows: (1) the average vessel size for each type in each region, (2) the carbon intensity metric EEOI, (3) the average sailing distance with the key trading countries in each region for each type, and (4) the weight of cargo carried by different regions and vessel types. The carbon emissions from vessels of type i can be estimated using the four components above, as follows:

$$Carbon\ Emissions_i = \sum_{k \in Region} \overline{EEOI_{ik}} \times \overline{D_{ik}} \times CargoWeight_{ik}, \quad (2)$$

where $\overline{EEOI_{ik}}$ indicates the average carbon intensity metric for vessels of type i trading with region k, and $\overline{D_{ik}}$ is the average sailing distance to region k. Noting that different types of vessels may have significantly different sailing routes to the same region, the subscript i is used for identification. $CargoWeight_{ik}$ represents the total amount of shipping freight occurring with region k through vessels of type i.

Lastly, the total carbon emissions from shipping can be obtained by summing up the carbon emissions of different types of vessels. It should be noted that the EEOI metric estimated by IMO is calculated by dividing the total emissions from shipping by the total tonnage miles of shipping. Thus, the EEOI value already considers both the laden trips and the empty trips (if any) of the ships. Therefore, the carbon emission estimates based on the EEOI metric could reflect the total carbon emissions for all the vessel voyages for carrying a particular trade, including both head-haul and back-haul trade.

2.2. Data Collection

2.2.1. China's Dry Bulk Shipping Trade

The COVID-19 pandemic greatly disrupted the global shipping trade; however, as the global economy gradually recovered, the demand for commodity shipments rebounded, leading to further growth in the global dry bulk shipping market. A very important reason for this was that the rapid recovery of the Chinese economy stimulated demand for imports of dry bulk cargoes such as iron ore and grains, which sustained the flow of international maritime trade to some extent [40].

As shown in Table 1, COSCO, China's largest shipping company and one of the world's largest maritime companies, estimated China's dry bulk shipping trade in 2021. Overall, China's international dry bulk shipping volume was estimated at 2011 million tons. Specifically, the largest volume of freight occurred between with Pacific, followed by Latin and South America and Asia (excluding South Asia). In terms of the types of commodities traded, we compiled the latest dry bulk throughput of China's coastal ports published by China's National Bureau of Statistics (2020) [47] (see Figure 1). As a large industrial country, China's trade in iron ore and coal dominates the overall dry bulk trade with a share of over 60% and is dominated by import trade.

Table 1. China's dry bulk shipping trade by trading partner region in 2021.

Region	Cargo Weight (million tons)	Average Vessel Size (dwt)	EEOI (gCO_2/t·nm)	Average Sailing Distance (nm)	Sailing Route
Europe	136.0	86,000	7.9	10,857	Qingdao to Rotterdam (via Suez)
Asia (excluding South Asia)	290.0	60,000	7.9	1458	Shanghai to Vanino
North America	96.5	86,000	7.9	15,135	Shanghai to New Orleans
Latin and South America	340.0	325,000	4.7	11,156	Qingdao to Tubarao
Middle East	132.0	56,000	9.4	5656	Shanghai to Jebel Ali
Pacific	689.0	185,000	5.3	3256	Shanghai to Hedland
South Asia	131.5	63,000	7.9	3127	Shanghai to Padang
Africa	196.0	215,000	4.7	11,235	Qingdao to Boffa
Average	251.4	134,500	7	7735	-

Source: The columns of 'cargo weight', 'average vessel size', 'average sailing distance', and 'sailing route' were provided by COSCO, and the EEOI values for ships are based on the Fourth Greenhouse Gas Study published in 2020 by IMO.

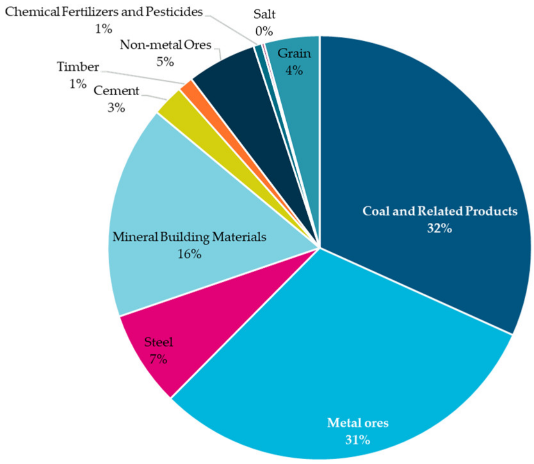

Figure 1. Share of dry bulk cargoes handled in coastal ports by type of commodities (2020). Source: National Bureau of Statistics of China.

2.2.2. China's Dry Bulk Trade Vessel Sizes and Sailing Distances

Due to geographic limitations and the volume of trade, the capacity of dry bulk carriers may vary depending on the trading partner region. Therefore, the dry bulk fleet data provided by COSCO was used to provide an indication of vessel capacity/size. The Four IMO GHG Study 2020 report displays the latest estimates of carbon intensity for various types and sizes of ships, and the average values were adopted [3]. In general, larger ships typically have lower carbon intensity rates per ton of cargo. Additionally, the distance between China's major ports and those of its key trading partners in each region served as a rough guide for the sailing distances. Table 1 also displays the average size and sailing distance traveled by bulk carriers engaged in trade with each region.

3. Results

3.1. Carbon Emissions Estimation

Using the shipping carbon emissions estimation model developed in Section 2.1. and the data collected in Section 2.2., the carbon emissions for China's dry bulk shipping were estimated, as shown in Table 2. According to the IMO, global maritime carbon emissions in 2018 were 1056 million tons [3]. Comparatively, China's dry bulk trade was roughly 76.88 million tons in 2021, about 7.3% of the global total. The majority of the carbon emissions were generated by trading with Latin and South America (23.2%), followed by Pacific (15.5%).

Table 2. Estimated carbon emissions from dry bulk shipping trade in China, 2021.

Region	Cargo Weight (million tons)	Cargo Weight (%)	Carbon Emission (tons)	Carbon Emission (%)	Carbon Emission/Cargo Weight
Europe	136.0	6.8%	11,664,761	15.2%	0.09
Asia (excluding South Asia)	290.0	14.4%	3,340,278	4.3%	0.01
North America	96.5	4.8%	11,540,559	15.0%	0.12
Latin and South America	340.0	16.9%	17,827,288	23.2%	0.05
Middle East	132.0	6.6%	7,017,965	9.1%	0.05
Pacific	689.0	34.3%	11,889,935	15.5%	0.02
South Asia	131.5	6.5%	3,248,484	4.2%	0.02
Africa	196.0	9.7%	10,349,682	13.5%	0.05
Total	2011.0	100%	76,878,951	100%	-

Source: The column of 'cargo weight' was estimated by COSCO, and the column of 'cargo Emission' was calculated using the shipping carbon emissions model in Section 2.1.

As shown in Figure 2, it is noteworthy that China's dry bulk trade with the Pacific region amounted to 34.3%, but the share of overall carbon emissions was not high, which was comparable to that of Europe and North America, at around 15%. This may be due to the fact that larger dry bulk carriers are more carbon-efficient per ton of cargo compared with other regions, in addition to the shorter sailing distances between China and Australia, the major trading partner in Pacific. Moreover, China's dry bulk trade volume (by net weight) was only 13.2% of the global total in 2021 (15,200 million tons, estimated by IHS Markit [48]). This means that China's dry bulk maritime trade on average created fewer emissions than the global average. This is because of the relatively short sailing distances between China and its trading partners (almost 60% of China's dry bulk trade is with Asia and the Pacific).

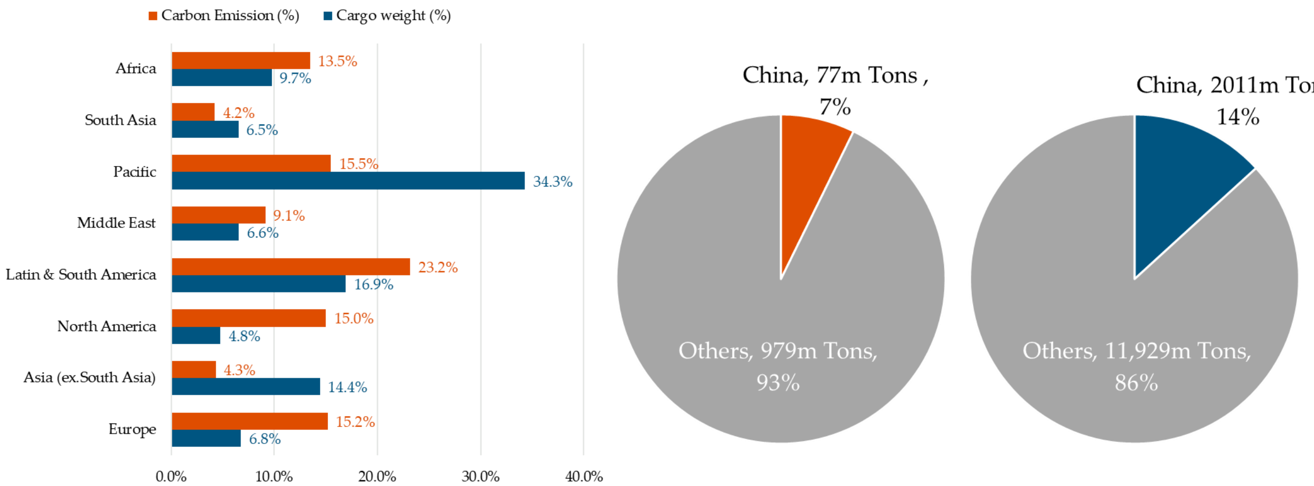

Figure 2. Comparison of China's dry bulk trade volumes and carbon emissions in different trading regions (**left**) and global international shipping (**right**). Source: Four IMO GHG Study 2020; IHS Markit.

3.2. Carbon Costs Estimation

On the basis of the shipping carbon emissions estimates above, the carbon emissions costs for China's dry bulk shipping in 2021 were estimated, assuming the carbon charges by IMO ranging from 100 to 300 USD per ton (see Table 3). The total carbon costs were estimated at 7.7–23.1 billion USD or 0.1–0.4% of the total import trade in 2021 (6050 billion USD, as estimated by the General Administration of Customs of China [49]). The distribution of carbon costs is comparable to the distribution of carbon emissions by trading partners. Additionally, the cost of carbon emissions to the amount of weight transported in each trading region might provide an estimate of the region's carbon efficiency. As shown in Table 3, assuming carbon charges of 100, 200, and 300 USD per ton, the carbon costs associated with shipping a ton of bulk cargo were estimated as 8.58, 17.15, and 25.73 USD per ton between China and European regions, respectively, with similar interpretations for other regions. Among them, we could find that China's dry bulk trade with North America had the lowest carbon efficiency per unit of products; in contrast, trade with Asia (excluding South Asia) and the Pacific region had a carbon efficiency that was almost 7–10 times greater than that of the former.

Table 3. Estimated carbon costs from dry bulk trade shipping in China, 2021.

Region	Carbon Charge = 100 USD/ton (Low)		Carbon Charge = 200 USD/ton (Medium)		Carbon Charge = 300 USD/ton (High)	
	Carbon Cost (million USD)	Cost/Weight (USD/ton)	Carbon Cost (million USD)	Cost/Weight (USD/ton)	Carbon Cost (million USD)	Cost/Weight (USD/ton)
Europe	1166	8.58	2333	17.15	3499	25.73
Asia (excluding South Asia)	334	1.15	668	2.30	1002	3.46
North America	1154	11.90	2308	23.79	3462	35.69
Latin and South America	1783	5.24	3565	10.49	5348	15.73
Middle East	702	5.32	1404	10.63	2105	15.95
Pacific	1189	1.73	2378	3.45	3567	5.18
South Asia	325	2.46	650	4.92	975	7.38
Africa	1035	5.28	2070	10.56	3105	15.84
Total	7688	-	15,376	-	23,064	-

The carbon cost of shipping is displayed by region in Table 4 as a percentage of total import and export trade, which was compiled by the General Administration of Customs of China [49]. We can find that the carbon cost as a percentage of trade volume did not appear to be large, at most about 0.4% to 1.3%, of course only taking the carbon cost of dry bulk shipping into consideration. Latin and South America, the Pacific, and Africa were the three trading regions that are most affected, while Latin and South America's overall import and export trade was substantially bigger than that of the other two. This may have also accounted for the better carbon efficiency of the latter.

Table 4. Carbon costs as a share of total import and export trade, 2021.

Region	Trade Value (%)	Carbon Cost/Trade Value		
		Low	Medium	High
Europe	19.5%	0.1%	0.2%	0.3%
Asia (excluding South Asia)	41.7%	0.0%	0.0%	0.0%
North America	13.9%	0.1%	0.3%	0.4%
Latin and South America	7.5%	0.4%	0.8%	1.2%
Middle East	5.8%	0.2%	0.4%	0.6%
Pacific	4.4%	0.4%	0.9%	1.3%
South Asia	3.1%	0.2%	0.3%	0.5%
Africa	4.2%	0.4%	0.8%	1.2%
Total	100.0%	Carbon Cost: USD 7.7–23.1 Billion		

Source: The total value of China's imports and exports of goods by regions in 2021 compiled by the General Administration of Customs, P.R.China.

4. Discussion

4.1. Impact of the Carbon Tax on Freight Rates and Trading Prices

The implementation of the carbon tax will raise the operational expenses for shipping companies, which may result in an increase in freight rates and trade prices for commodities. However, the elasticity of demand varies across products; hence, the impact of a carbon tax on each product may be quite different. Given the significance of the import trade in coal and iron ore for China's dry bulk shipping, we used these two essential dry bulk commodities as examples in the section below to assess the potential economic effects of the carbon tax.

4.1.1. Iron Ore

China is a major producer and consumer of steel, but iron ore, the primary raw material for the steel industry, is relatively scarce and mostly dependent on imports. Figure 3 displays China's top trading partners for iron ore imports in 2020 and 2021. In comparison to 2020, the overall structure of China's iron ore import trade remained stable, with imports from Australia continuing to completely dominate (more than 60% of the total), followed by Brazil (around 20%).

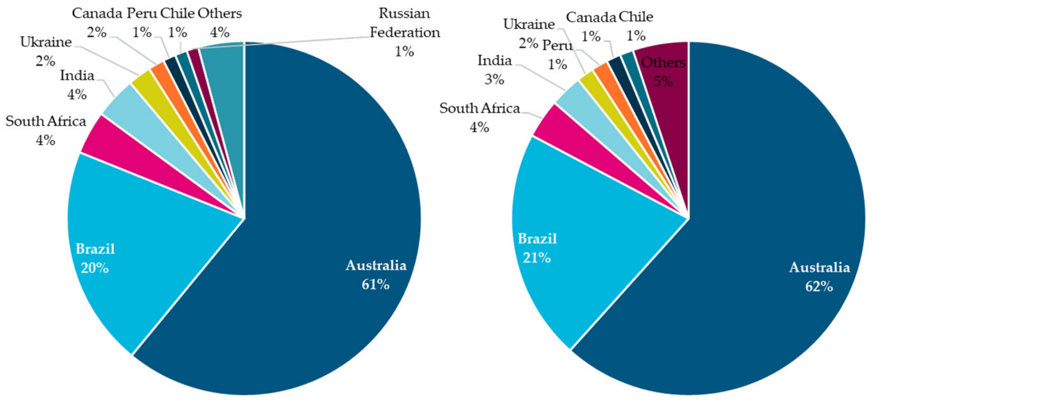

Figure 3. Major trading partners for China's imports of iron ore in 2020 (**left**) and 2021 (**right**). Source: General Administration of Customs, P.R.China.

Figure 4 displays the latest freight rates for importing iron ore from Australia and Brazil, respectively. As freight prices in October 2021 were much higher than they were before COVID-19, we used them as the foundation for our research. In the future when overall freight rates are lower, the impact of the carbon tax on freight rates would be more significant than what we predicted. The freight rate, trading price, and carbon charge for imported iron ore from Australia to China are shown in Figure 5, assuming the carbon charges of 100, 200, and 300 USD per ton. The cost of carbon per unit of bulk shipping from China to the Pacific, according to our estimate in Section 3.2, is 1.73, 3.45, and 5.18 USD per ton, respectively. These amounts represent 8%, 15%, and 23% of the freight rate, and nearly 1%, 2%, and 4% of the trading price for iron ore.

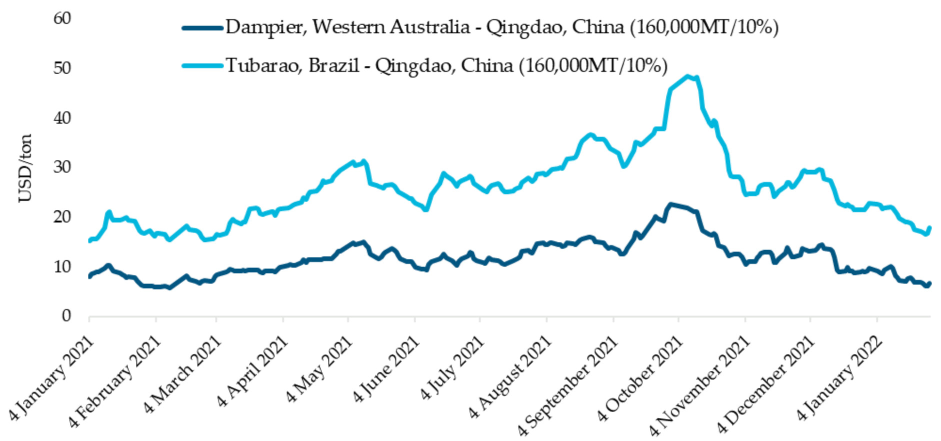

Figure 4. Freight rates for importing iron ore from Australia and Brazil to China in 2021. Source: Shanghai Shipping Exchange.

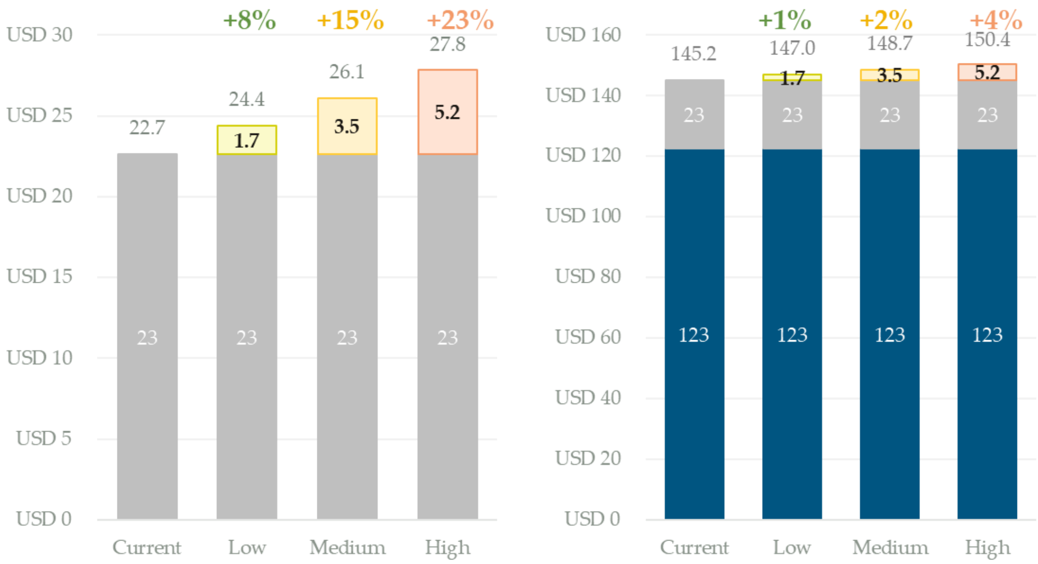

Figure 5. The impact of the carbon tax under various charging levels on freight rate (**left**) and trading price (**right**) for iron ore (assuming trades from Port Dampier, Australia to Qingdao, China). Notes: In October 2021, the highest freight rate and the average trading price for iron ore from Australia to China were 22.66 USD/ton and 122.58 USD/ton, respectively. Source: Shanghai Shipping Exchange.

4.1.2. Coal

China is also a global leader in coal imports. The major trading partners for China's coal imports in 2020 and 2021 are shown in Figure 6. We found a significant change in China's coal import trade pattern, with Indonesia controlling 46% to 60% of imports. Conversely, Australia's coal imports fell from 26% to 4% as a result of the COVID-19 pandemic and tensions between China and Australia.

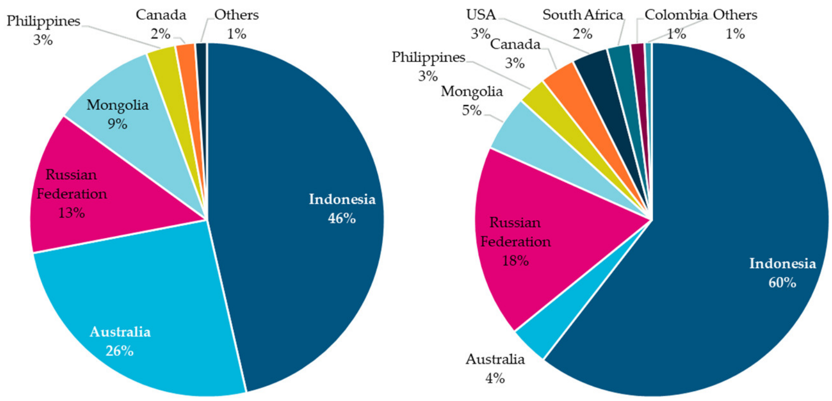

Figure 6. Major trading partners for China's imports of coal in 2020 (**left**) and 2021 (**right**). Source: General Administration of Customs, P.R.China.

We took the example of Indonesian coal imports for our analysis. The freight rate, trading price, and carbon charge for imported coal from Indonesia to China are shown in Figure 7, assuming carbon charges of 100, 200, and 300 USD per ton, respectively. The cost of carbon per unit of bulk shipping from China to South and Southeast Asia, according to our estimate in Section 3.2, is 1.15, 2.30, and 3.46 USD per ton, respectively. These amounts represent 6%, 12%, and 17% of the freight rate, and nearly 1%, 1%, and 2% of the trading price for coal.

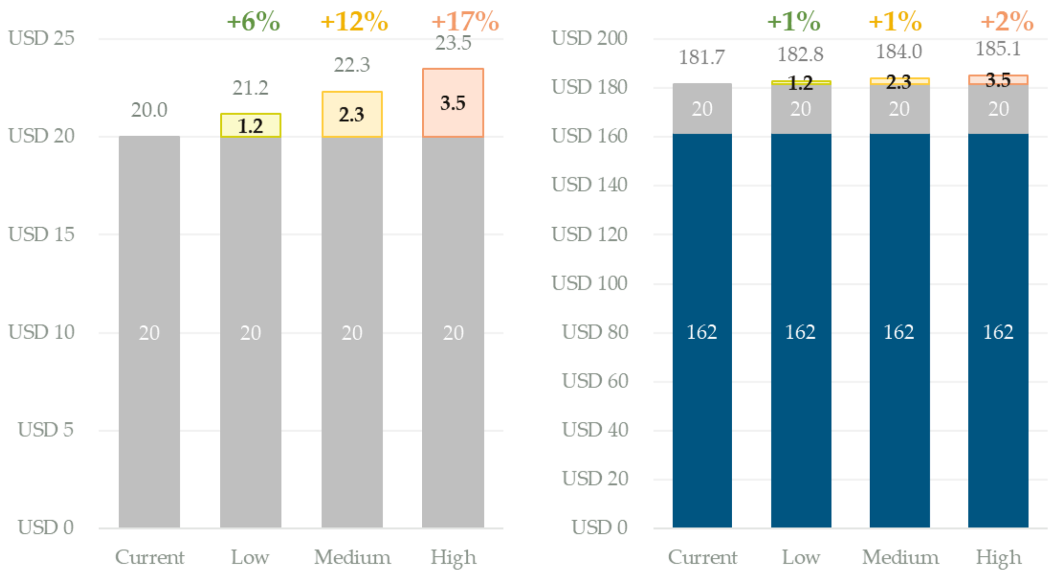

Figure 7. The impact of the carbon tax under various charging levels on freight rate (**left**) and trading price (**right**) for coal (assuming trades from Port Taboneo, Indonesia to Guangzhou, China). Notes: Indonesia's Ministry of Energy and Mineral Resources (ESDM) set the reference coal price (HBA) at 161.63 USD/ton for Oct 2021. The average freight rate for coal from Indonesia to China was roughly 20.02 USD/ton. Source: Shanghai Shipping Exchange.

By way of contrast, we discovered that the introduction of the carbon tax would have a considerable impact on freight rates and trading prices for dry bulk cargoes, which would also depend on the trade regions and the carbon charges. According to preliminary estimates, the carbon tax may result in a 10–30% increase in freight rates and a 1–4% increase in import costs for China's main dry bulk trades (coal and iron ore). The increase in logistic costs would prompt shipping companies to adopt operational measures such as slow sailing, as well as the optimization of sailing routes and speed, to reduce carbon emissions in the short term. It would also prompt shipping companies and sectors to develop new shipping carbon reduction technologies and low- or zero-carbon fuels. However, the impact of the carbon tax on carbon emissions reduction would vary greatly depending on the carbon charges. Assuming a carbon charge of 100 USD per ton, freight prices would increase by no more than 10%, and transaction costs would increase by no more than 1%; hence, a higher carbon tax would be needed to drive the decarbonization of the shipping and to achieve long-term carbon reduction targets.

4.2. Impact of the Carbon Tax on Shipping Trade Pattern

4.2.1. Iron Ore

The impact of the carbon tax on different trading regions may vary significantly due to differences in route distance, trade volume, and vessel size, which may lead to changes in trade patterns. As seen in Figure 3, Australia is China's largest supplier of iron ore. Together, the exports from Brazil, South Africa, and India to China are less than half those from Australia, but the carbon tax could soon change that.

Figure 8 depicts our analysis of the cost of China's iron ore imports following the adoption of the carbon tax in major iron ore exporters. In comparison, Australia would be the least affected, followed by India with a cost increase of 2–6%. The cost increase for iron ore imports from Brazil and South Africa ranges from 3% to 8%. Therefore, the implementation of the carbon tax would somewhat reduce the competitiveness of iron ore from Brazil and South Africa. China is likely to become more dependent on imports of iron ore from Australia and India.

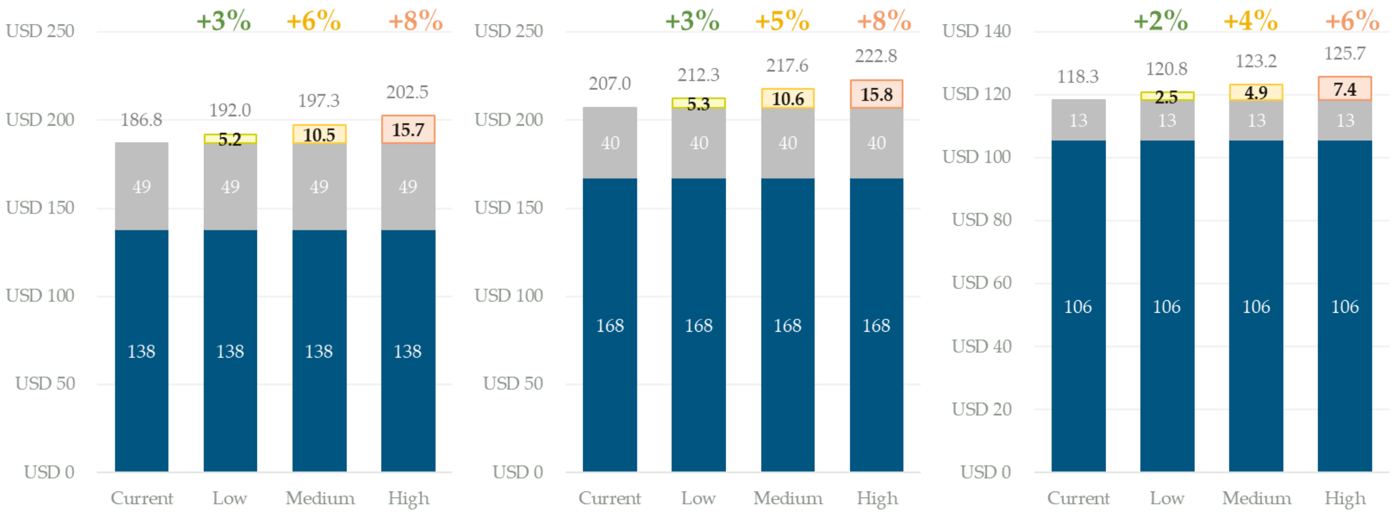

Figure 8. The impact of the carbon tax under various charging levels on trading prices for iron ore (**Left**: Brazil, **Middle**: South Africa; **Right**: India). Notes: In October 2021, the highest freight rates for iron ore imports from Brazil and South Africa to China were 48.55 USD/ton (Tubarao–Qingdao) and 39.5 USD/ton (Saldanha–Qingdao), while the shipping cost from India was estimated at 12.5 USD/ton (Goa–Qingdao, Jan 2021). The average trading prices of iron ore were estimated at 138.25 USD/ton, 167.5 USD/ton, and $105.78 USD/ton, respectively. Source: Shanghai Shipping Exchange.

Of course, China has recently been trying to diversify its sources of iron ore. For instance, compared to 2019, the volume of iron ore exported from India to China increased by over 90% in 2020. At the same time, there has been an increase in ton-mile trade by bulk carriers on the Africa–China route, which may be a result of more iron ore being shipped from South Africa [50]. In addition, Guinea could also reportedly become a new supplier of iron ore to China, as it has largely untapped reserves of high-quality iron ore and is scheduled to begin shipping iron ore in 2026 [51,52]. However, the introduction of a carbon tax could hinder this transition process due to the additional shipping costs.

4.2.2. Coal

It should be noted that China is now gradually reducing its coal imports from Australia, focusing more on regions such as India and South Africa in terms of shipping (coal from Russia and Mongolia is mainly transported by land). However, there is no denying that the high quality of Australian coal and the shorter sailing distances make importing coal from Australia a very significant natural advantage.

Figure 9 compares the freight rates, trading prices, and carbon charges associated with importing coal from Australia and South Africa in the context of the carbon tax. We discovered that the carbon tax would have less of an effect on the cost of importing coal from Australia (an increase of 1–3%), but a significant influence on the cost of importing coal from South Africa (an increase of 3–8%). This suggests that the adoption of the carbon tax would strengthen China's reliance on Australian coal and that China's coal import costs could rise dramatically in the future if the relationship between China and Australia does not improve.

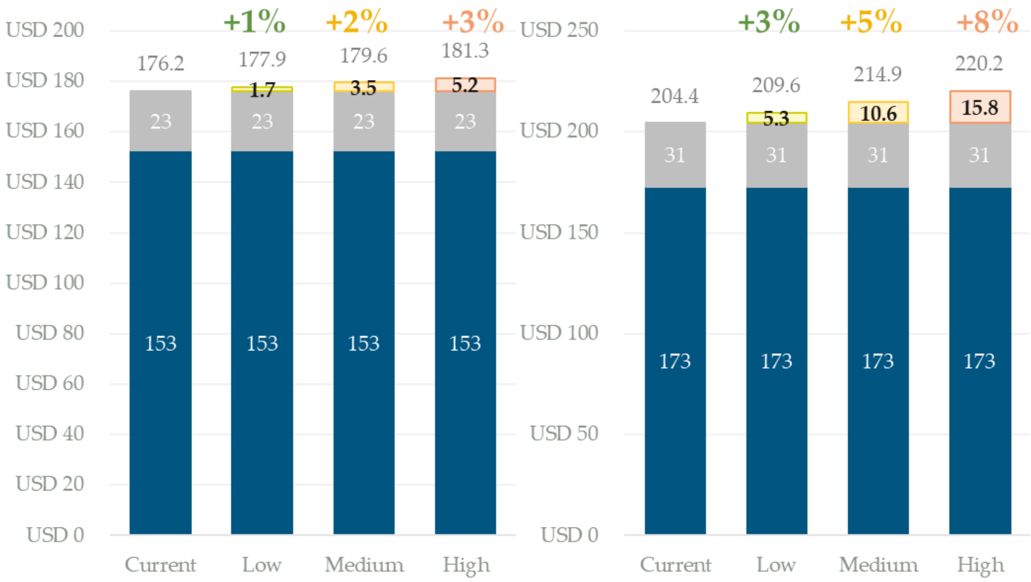

Figure 9. The impact of the carbon tax under various charging levels on trading prices for coal (**Left**: Australia, **Right**: South Africa). Notes: In October 2021, the average freight rates for coal imports from Australia and South Africa to China were 23.37 USD/ton (Newcastle–Zhoushan) and 31.37 USD/ton (Richards–Qingdao). The average trading prices of coal were traded at an estimated 152.78 USD/ton and 172.99 USD/ton. Source: Shanghai Shipping Exchange.

On the basis of the above analysis, we found that the implementation of carbon tax would hinder long-distance ocean transportation. China is likely to become more dependent on imports of iron ore, coal, and other goods from nearby regions such as Australia, India, and Indonesia. For shipping companies and sectors, they may need to redeploy fleets and plan routes to devote more ships to the dry bulk shipping trade between China and Australia or South Asia. In addition, investments in ship research and development should be increased to develop larger and more carbon-efficient bulk carriers to meet the growing demand for cargo volumes.

5. Conclusions

A medium-term market-based carbon reduction measure, global shipping carbon tax, is being considered by the IMO, while zero-carbon fuels will continue to be developed as a long-term carbon reduction measure. Through the literature review, we found that existing carbon tax studies mainly focused on the assessment of carbon reduction effects and the optimization of shipping company operations. Theoretically, few studies have addressed the economic analysis of the carbon tax on global shipping trade, and our work attempts to fill this gap. Specifically, a trade-volume-based shipping carbon model was developed to estimate the carbon emissions and the carbon costs for China's dry bulk shipping trade. On the basis of these results, we provided an in-depth analysis and discussion of the impact of the carbon tax on shipping costs and maritime trade patterns.

It was found that China's share of global carbon emissions from international dry bulk sea freight is 7%. Assuming a carbon price of 100 to 300 USD, the cost associated with the carbon charge for dry bulk shipping in China was estimated at 7.7 to 23.1 billion USD. The carbon tax would have a significant impact on freight rates and trading prices for bulk cargoes. Freight costs for imports from Australia (a major source country for iron ore) and Indonesia (a major source country for coal) would increase by 10–30%, while trading prices for iron ore and coal would increase by 1–4%. The increase in logistic costs would prompt shipping companies to adopt operational measures such as slow steaming or route planning to reduce emissions in the short term. However, in the long run, the actual carbon reduction effect would depend on the carbon charges. Unless the carbon tax is very high, small changes in logistic costs would reduce the incentive for shipping companies to develop new decarbonization technologies. Therefore, the shipping sectors should consider setting a higher carbon tax initially to accelerate the decarbonization of shipping.

Furthermore, the carbon tax may have a significant impact on trade patterns. Taking iron ore as an example, Australia and India would become more competitive than Brazil and South Africa due to the sailing distance leading to fewer emissions per trading tonnage. For the trading of coal, although China has significantly cut back on Australian coal imports due to recent political tensions, the shipping carbon tax may favor Australian coal compared to the main trade competitors including Indonesia and South Africa due to its short trading distance with China. To address this situation, on the one hand, shipping companies and sectors can redeploy fleets to devote more ships in China's dry bulk shipping trade with Australia, South, and Southeast Asia; on the other hand, they can develop larger and more efficient ships to meet the growing volume of dry bulk demand.

Lastly, the impact of the carbon charge on shipping companies is likely to be twofold, including the cost of carbon in the short term and the cost of investment by companies to develop new energy-efficient technologies and green fuels in the long term. How these increased costs will be passed on to end consumers and affect the industry's demand for raw materials is worth further study. In addition, the impact of the carbon charge is likely to be all-encompassing, and data can continue to be collected in the future to analyze the impact of the carbon tax on container and tanker shipping using the methodology discussed in this paper.

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