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Trade Openness and Carbon Leakage: Empirical Evidence from China's Industrial Sector

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Abstract: China is a large import and export economy in global terms, and the carbon dioxide emissions and carbon leakage arising from trade have great significance for China's foreign trade and its economy. On the basis of trade data for China's 20 industrial sectors, we first built a panel data model to test the effect of trade on carbon dioxide emissions and the presence of carbon leakage for all industrial sectors. Second, we derived a single-region input–output model for open economies based on the industrial sectors' diversity and carbon dioxide emissions, and performed an empirical test. We estimated the net carbon intensity embodied in export, which is 0.237tCO_2/ten thousand RMB, to divide all sectors (ACSs) into high-carbon sectors (HCSs) and low-carbon sectors (LCSs). The results show that higher trade openness leads to a reduction in the intensity of CO_2 emissions and gross emissions and that there are obvious structural differences in different sectors with different carbon emission intensity. The coefficient of trade openness for LCSs is -0.073 and is statistically significant at the 1% level, so higher trade openness for LCSs leads to a reduction in the CO_2 emissions intensity. However, the coefficient for HCSs is 0.117 and is statistically significant at the 10% level, indicating that higher trade openness increases the CO_2 emissions' intensity for HCSs. The difference is that higher trade openness in LCSs can help reduce the CO_2 emissions' intensity without the problem of carbon leakage and with the existence of the environmental Kuznets curve (EKC), whereas there is no EKC for HCSs and carbon leakage may happen. We introduced dummy variables and found that a "pollution haven" effect exists in HCSs. The test results in HCSs and LCSs are exactly the opposite of each other, which shows that the carbon leakage of ACSs cannot be determined. The message that can be drawn for policy makers is that China does not need to worry about the adverse impact on the environment of trade opening up and should, in fact, increase the opening up of trade, while becoming acclimatized to environmental regulation of a new trade mode and new standards. This will help amplify the favorable impact of trade opening up on the environment and improve China's international reputation. The policies related to trade should encourage structural adjustment between the sectors via the formulation of differential policies and impose a restraint on sectors that have high levels of CO_2 emissions embodied in export.

Keywords: CO_2 emissions embodied in trade; trade openness; carbon leakage; EKC; industrial sector

1. Introduction

The Paris conference on climate change in December 2015 set up the global climate governance mechanism from 2020 to 2030, and China restated that it would peak carbon dioxide emissions around 2030. The China–US Joint Announcement on Climate Change was released in November 2014. It is expected that total CO_2 emissions in China will peak around 2030, and the Chinese government has announced that it will make efforts to reach this peak sooner. Before the Joint Announcement, China's target for reducing CO_2 emissions was a 40–45% decline of CO_2 emissions per unit of GDP by 2020 as compared to 2005. This was a relative goal with no upper limit imposed. However, in this Announcement, China promised that the peak of CO_2 emissions will be reached before 2030, which sets a ceiling on CO_2 emissions associated with China's industrialization and urbanization. China is the world's largest trading nation, and trade openness is closely related to a transition to a low-carbon economy, energy saving, and emissions reduction. Opening up of foreign trade is very likely to cause the transfer of polluting sectors and carbon leakage (Figure 1). This fact has considerable bearing on policy-making related to trade openness and achieving the CO_2 emissions reduction commitment under the context of the new Chinese economic normality, and it even affects the responsibility definition of CO_2 emissions and climate negotiation results.

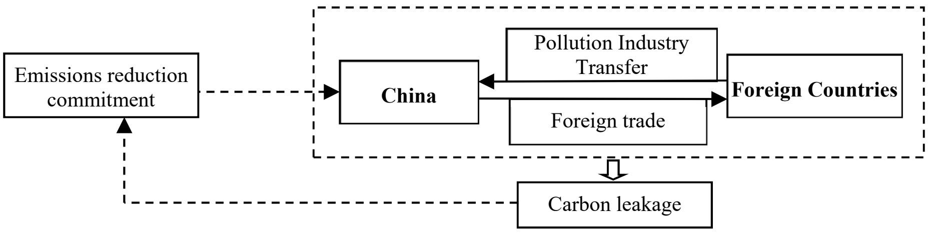

Figure 1. Carbon leakage affects emission reduction commitments.

2. Literature Review

The relationship between trade and environment is an important academic research topic. Since the 1990s, the positive and negative effects of trade opening on the environment have aroused heated discussion, which has brought forth several theories, including the environmental Kuznets curve (EKC), the pollution haven hypothesis, and the race-to-the-bottom corollary. Despite theoretical advancement, the empirical studies tend to come to inconsistent conclusions. Some propose that the pollution haven hypothesis and the factor endowment effect exist side-by-side but play opposite roles [1–3]. The pollution haven hypothesis posits that low-income developing countries have poor environmental regulation intensity and enjoy comparative advantages in pollution-intensive sectors seeking low external costs. The factor endowment effect posits that developed countries enjoy comparative advantages in capital-intensive polluting sectors. Unfortunately, the fact is that a country may feature either high income and capital abundance or low income and low capital, so the two traits always go hand in hand. Thus, the structural effect induced by trade cannot be used for theoretical prediction but serves as a question to be tested empirically [4].

As China is experiencing drastic growth of foreign trade, the connection between trade and CO_2 emissions has become a hot topic. Most of the existing literature deals with either of two topics. One is the CO_2 emissions embodied in China's foreign trade. Shui and Harriss (2006) examined the influence of US–China trade on national and global emissions of carbon dioxide during 1997–2003 and found about 7–14% of China's current CO_2 emissions were a result of producing exports for US consumers [5]. Weber et al. (2008) found that around one-third of Chinese emissions (1700 Mt CO_2) were due to production of exports in 2005, and this proportion rose from 12% (230 Mt) in 1987 and only 21% (760 Mt) as recently as 2002 [6]. Su and Ang (2013) finished empirical studies using five Chinese input–output (IO) tables, 1997, 2000, 2002, 2005, and 2007 and showed that the transitions of China's emissions embodied in imports to those in the exports account for around 4.6–13.3% of total emissions if the competitive imports assumption is used [7]. Wu et al. (2018) used input–output analysis to measure CO_2 emissions (CEs) embodied in Chinese provinces' exports and imports and explore the interprovincial spillover of CEs induced by exports through the domestic supply chains [8]. Besides this, Ahmad and Wyckoff (2003), Yan and Yang (2010), Lin and Sun (2010), Du et al. (2011), Chen et al. (2011), Chen and Yu (2012), and Lin et al. (2014) have done similar research and estimation from a unilateral, bilateral, or multilateral perspective [9–15]. Most studies agree that the CO_2 emissions embodied in China's export are huge. It is thus inferred that China has become a pollution haven for the transfer of CO_2 emissions from developed countries and that carbon leakage does exist due to trading between China and the developed countries.

The second topic is testing for the existence of EKC. Tao et al. (2008) found that there was a long-run cointegrating relationship between the per capita emission of three pollutants and the per capita GDP, and all three pollutants are inverse U-shaped [16]. Song et al. (2013) tested the existence of EKC for thirty provinces and cities in Mainland China through Copeland model, and empirical analysis indicates that EKC does not exist for Liaoning, Anhui, Fujian, Hainan, and Qinghai, while EKC of Shanghai, Guizhou, Tibet, Jilin, and Beijing have reached inflection point [17]. Liu et al. (2018) introduced two subdivisions of trade diversification–export product diversification and export market diversification as proxy variables for economic development in rectification of the EKC, and found the evidence that GDP per capita and export diversification had a robust relationship with ecological footprint and, therefore, the EKC hypothesis holds in Korea, Japan, and China in the long run [18]. Empirical study conclusions diverge greatly. Some researchers have even derived the curves of a non-inverted U-shape. Shen (2006) used Chinese provincial data from 1993 to 2002 to examine the existence of EKC and found an EKC relationship was found in COD (Chemical Oxygen Demand), Arsenic, and Cadmium emissions in China, but SO_2 showed a U-shaped curve and Dust Fall indicates no relationship with income level [19]. Other researchers, such as Jalil and Mahmud (2009), Diao et al. (2009), He and Wang (2012), Liu (2012), Ho et al. (2013), and Yin et al. (2015), have also done relevant empirical research [20–25]. The absolute CO_2 emissions embodied in export depend on the volume of exported goods, and the effect of export volume may play a decisive role in the growth of CO_2 emissions embodied in export. Moreover, the test for EKC is affected by indicator variables and data availability, especially the choice of time periods under investigation.

According to the pollution haven hypothesis and the race-to-the-bottom corollary, there will be a transfer of high-pollution and high-emission industries from developed countries to developing countries; this gives rise to the problem of carbon leakage. If a developed country raises its environmental standards, its production activities will inevitably decrease, while the output of a developing country with lower environmental standards will increase. The net result is an overall increase in global CO_2 emissions. Some representative studies on carbon leakage have come to diverse conclusions. Barker et al. (2007) investigated potential carbon leakage from six EU Member States (MSs) that implemented Environmental Tax Reform (ETRs) unilaterally over the period of 1995–2005 and constructed a counterfactual Reference case, assuming that the six countries did not introduce ETRs, and then alternative scenarios were developed to assess the effects of the ETRs, including effects on CO_2 emissions for the EU25 economies [26]. Most MSs recorded a reduction in CO_2 emissions when comparing the Baseline case to the Reference case, and the results show that carbon leakage is very small and in some cases negative, due to technological spillover effects. Kuik and Hofkes (2010) explored some implications of border adjustment measures in the EU ETS, for sectors that might be subject to carbon leakage and found that border adjustment might reduce the sectoral rate of leakage of the iron and steel industry rather forcefully, but that the reduction would be less for the mineral products sector, including cement, and the reduction of the overall or macro rate of leakage would be modest [27]. Elliott et al. (2014) used a full CGE model with many countries and many goods to measure effects and varied elasticity of substitution and confirmed the analytical model's prediction that negative leakage depends on the ability of consumers to substitute into the untaxed good and the ability of firms to substitute from carbon emissions into labor or capital [28].

BöHringer et al. (2017) showed that the combination of output-based rebating and a consumption tax for emission-intensive and trade exposed goods can be equivalent with border carbon adjustment, and supplementing output-based rebating with consumption tax constituted robust policies to mitigate carbon leakage [29]. Felder and Rutherford (1993), Smith (1998), Paltsev (2001), Aukland et al. (2003), Gerlagh and Kuik (2007), Rosendahl and Strand (2009), Eichner and Pethig (2011), Baylis et al. (2013), and Carbone (2013) have also done relevant research [30–38]. Surprisingly, some researchers argue that carbon leakage can be negative by model or analysis based on assumptions. One country, typically a developed country, will reduce production activities to meet higher environmental standards, whereas a developing country with lower environmental standards will increase its output; in this process, the intensity of CO_2 emissions in developing countries is lessened through the flow of technological innovation and production factors, ultimately leading to a reduction of global CO_2 emissions. Fullerton et al. (2011) used a general equilibrium model to solve for effects of a small increase in carbon tax on leakage, and reported that the taxed sector substitutes away from carbon into capital so it may absorb capital, which shrinks the other sector, causing negative leakage [39]. Winchester and Rausch (2013) investigated leakage in computable general equilibrium models under alternative fossil fuel supply elasticity values and factor mobility assumptions, and found that fossil fuel supply elasticity must be either equal or close to infinity to generate net negative leakage [40].

In summary, existing research has carried out a creative theoretical design and obtained different conclusions, which means that the structural effect induced by trade cannot be used for theoretical prediction but serves as a question to be tested empirically. There have been many results in empirical research. Although the amount of CO_2 emissions embodied in China's trade is huge, it does not indicate that there must be carbon leakage, especially as the results of the EKC test are inconsistent. We believe that, considering these dynamics, CO_2 emissions embodied in trade, EKC, and carbon leakage can be integrated into one framework so that the logistic connections between them can be analyzed. Carbon leakage is the result of transferring high-carbon sectors (HCSs) from developed countries to developing countries and the developed countries needing to import large volumes of goods from the developing countries—the huge level of CO_2 emissions embodied in the export directly lead to carbon leakage. However, this is only a necessary condition, not a sufficient condition. If the developing countries are indeed a pollution haven, there will be no inverted U-shaped EKC; if there is an inverted U-shaped EKC, persistent carbon leakage will not occur. CO_2 emissions embodied in trade and EKC are mostly studied empirically, whereas carbon leakage is estimated using theoretical models. We built our panel data model based on the trade data of China's industrial sectors. Through empirical analysis, the existence of carbon leakage due to China's opening up of trade was proven. Then, the existence of EKC was examined by introducing the linear term and the quadratic term of per capita GDP of the sector. The reliability of the regression was enhanced by adding a control variable, such as the number of employees in the sector. The innovations of this study are summarized as follows: (1) The effect of foreign investments in China on CO_2 emissions shows large variation across the sectors (Lin and Yang, 2013) [41]. Therefore, this article takes China's industrial sector sub-sector as the research object, which is different from most previous studies, and a single-region input–output model (SRIO model) is derived for open economies. The low-carbon sectors (LCSs) and HCSs are divided based on the intensity of CO_2 emissions embodied in net export for each sector. This method fully considers the distinct features of foreign trade, as compared with the classification by CO_2 emissions' intensity for each sector. The research design is also more in line with the characteristics of developing countries and can more effectively test the trade and economic development of developing countries. (2) The cross term of trade openness and the sector's development level are added into the regression equation to test carbon leakage. Moreover, the dummy variable is designed to capture the pollution haven hypothesis. (3) In terms of policy recommendations, we analyzed the policies with 2030 emission reduction commitments latest proposed by the Chinese government, which is also the significance of the research.

3. Empirical Model and SRIO Model Derivation

3.1. Empirical Modeling

Grossman and Krueger (1991) laid the foundation for the analytical framework of the relationship between trade and environment [42]. Antweiler et al. (2001) also proceeded from this framework. We built our panel data model using the sector-based data of China's industrial sectors from 2000 to 2014 [1]. Usually, trade openness of a country can be measured in two ways: One is by measuring the trade barrier directly—the lower the nominal trade barrier, the higher the trade openness; the other is by measuring the trade flow, from which the trade openness is estimated indirectly. The closer the trade flow to the estimate corresponding to completely free trade, the higher the trade openness (Li and Huang, 2006) [43]. Referring to the existing literature, such as Zhao and Ding (2012) and Ma and Li et al. (2012) [44,45], we measured trade openness by the ratio of the sum of imports and exports to the output for the sector. Bao et al. (2003) estimated China's trade openness using five indicators: degree of dependence on foreign trade, effective tariff rate, cost of black market transaction, Dollars' index, and corrected degree of dependence on foreign trade [46]. It is now recognized that only the degree of dependence on foreign trade (namely the ratio of the sum of imports and exports to GDP) is a better reflection of the connections between China's trade openness and economic growth.

Many empirical analyses have been done concerning EKC hypothesis. De Bruyn et al. (1998) were the first to study the dynamics of one country's EKC using time series [47]. In recent years, Dinda and Coondoo (2006) and Soytas and Saria et al. (2009) have argued that analysis based on the cause-and-effect relationship was more fruitful [48,49]. The most common approach is analysis based on panel data (Dinda, 2004) [50], and most studies use per capita GDP as an indicator of economic growth when it comes to the question of how economic growth is related to environmental pollution. The effect of trade openness on CO_2 emissions of different sectors and the existence of EKC were tested by regression analysis. However, this direct effect cannot explain the structural effect of trade openness. That is, the effect of trade openness on China's industrial structure cannot be determined under the constraint of comparative advantage. We introduce the cross term about trade openness proposed by Richard and Piergiuseppe et al. (2012) [51] and test the existence of carbon leakage via trade with China at the industry level. The cross term is the product of trade openness and the sector's development level. The analysis model is constructed as follows:

$$\ln CEM_{i,t} = \alpha_0 + \alpha_1 \ln Y_{i,t} + \alpha_2 (\ln Y_{i,t})^2 + \alpha_3 \ln IDL_{i,t} + \alpha_4 TOI_{i,t} \cdot IDL_{i,t} + \beta X_{i,t} + \varepsilon_{i,t}$$

where subscript i denotes the sector; subscript t denotes time (unit: year); $CEM_{i,t}$ is the CO_2 emissions' intensity in sector i in the t-th year (or total CO_2 emissions); $Y_{i,t}$ is the per capita GDP in sector i in the t-th year; $TOI_{i,t}$ is trade openness in sector i in the t-th year; $TOI_{i,t} \cdot IDL_{i,t}$ is the cross term of trade openness and the sector's development level $IDL_{i,t}$; $X_{i,t}$ is other control variable, e.g., number of employees in the sector $POP_{i,t}$, intensity of research and development $TOR_{i,t}$, and intensity of economic activities $ACT_{i,t}$. $\varepsilon_{i,t}$ is a random error term. To eliminate the influence of heteroscedasticity, the indicator data are expressed in the form of natural logarithm.

3.2. Variable Explanation and Data Source

The data used came from the China Statistical Yearbook, the China Industry Economy Statistical Yearbook, the China Population & Employment Statistics Yearbook, the China Statistical Yearbook on Environment, and the China Energy Statistical Yearbook. Part of the data has been downloaded from the OECD database, DRCnet, and the CEInet Statistics Database [52–56]. The variables are explained as follows:

(1) CO_2 emissions' intensity (or total CO_2 emissions): $CEM_{i,t}$. Two indicators are used to measure China's CO_2 emissions, namely, total CO_2 emissions and CO_2 emissions' intensity. Total CO_2 emissions are a scale indicator that depends on the output scale, output structure, and production conditions of

the sector. It is obtained by calculating the product of energy consumption and the carbon emission coefficient. CO_2 emissions' intensity is a relative indicator that highlights the effect of output structure and production conditions. It is calculated as the CO_2 emissions per unit output of the sector.

(2) Per capita GDP: $Y_{i,t}$. According to the EKC hypothesis, income level is an important control variable that affects pollutant emissions. As mentioned above, per capita GDP reflects how increases of output and income affect scale effect and technology effect of CO_2 emissions. Here we use actual per capita GDP as the variable related to economic growth to test the EKC hypothesis in China's industrial sectors. If the coefficient α_1 of the linear term of per capita GDP is positive and the coefficient α_2 of the quadratic term of per capita GDP is negative, then the relationship between environmental pollution and the income level can be described by an inverted U-shaped curve. Thus, EKC exists.

(3) Trade openness: $TOI_{i,t}$. As in most studies, the ratio of the sum of imports and exports to the output of a sector is calculated as the indicator of trade openness. Trade openness is associated with the structural effect caused by import and export. The trade data of the sectors come from the OECD database. All data from International Standard Industrial Classification (ISIC) are classified into 20 sectors' data compared with the industry classification of input–output (IO) and are then expressed in Renminbi (RMB) using the annual average exchange rate. If the estimated coefficient α_3 of trade openness is positive, it means that higher trade openness aggravates environmental pollution; if α_3 is negative, it means that higher trade openness alleviates environmental pollution and contributes to emission reduction.

(4) Cross term: $TOI_{i,t} \cdot IDL_{i,t}$. The cross term is constructed between trade openness and a sector's development level to examine carbon leakage. If the coefficient α_4 of the cross term is negative, it can be confirmed that there is not a transfer of high-emission sectors from developed countries to developing countries and carbon leakage does not exist. The sector's development level is measured by the added value of the industrial sector $IVA_{i,t}$ and the per capita output $GPC_{i,t}$ of the sector. The data came from the China Statistical Yearbook and the China Industry Economy Statistical Yearbook. Adjustments were made if necessary.

(5) Control variable: $X_{i,t}$. The control variables used are the number of employees in the sector $POP_{i,t}$, the intensity of research and development $TOR_{i,t}$ and the intensity of economic activities $ACT_{i,t}$. To some extent $POP_{i,t}$ influences per capita CO_2 emissions of the sector and is also an important factor influencing per capita income and per capita GDP. This indicator is usually considered when evaluating the damage done by CO_2 emissions and making policies on emission reduction. $TOR_{i,t}$ has an impact on the technology effect of emission reduction. This indicator is expressed as the ratio of research and development expenditures to the output. The data on research and development expenditures come from the China Statistical Yearbook on Science and Technology. A higher $ACT_{i,t}$ usually indicates greater CO_2 emissions of the sector. The intensity of economic activities is expressed in terms of electric power consumption, according to Peng et al. (2013) [57].

3.3. Derivation of SRIO Model for Embodied Emissions Measurement

Based on the overall test of all industries in China's industrial sector, we attempt to conduct a classification test in order to obtain the results of different industries. It is common to divide HCSs and LCSs by the CO_2 emissions' intensity of sectors. Fu and Zhang (2014) directly estimated the CO_2 emissions' intensity as a criterion to divide HCSs and LCSs [58]. Although the cross-sector differences in CO_2 emissions can be directly determined, this method provides no differentiation between CO_2 emissions due to domestic or foreign production activities in the context of international trade effect. Different from their studies, we tried to calculate the CO_2 emissions embodied in imports and exports and net embodied emissions, respectively, to divide the sectors into HCSs and LCSs. Pertinently, this method contains the effect of trade openness on CO_2 emissions.

The most common method for estimating CO_2 emissions embodied in trade is the IO. This model was first proposed by US economist Leontief for national economic accounting. Through constant extension and integration with other economic accounting techniques and optimal control theory, the IO model has found wide application. Based on research by Ahmad and Wyckoff (2003) and Lin and Sun (2010) [9,11], we derived the SRIO model based on open economic operation logic. According to classical IO theory, the total output was calculated:

$$X = AX + Y, \text{ i.e., } X = (I - A)^{-1} \cdot Y$$

where X is the column vector of total output; A is the direct consumption coefficient matrix; Y is final consumption, namely final demand; and $(I - A)^{-1}$ is the Leontief inverse matrix, or the complete demand coefficient matrix.

The above formula represents the operation of a completely closed economy. In contrast, for open economies, parts of the imported goods (including services) are consumed by final users, and the remains become intermediate input, which enters domestic production link. The direct consumption coefficient matrix A for an open economy is $A = A^d + A^{im}$. For the part of the imported goods used as intermediate input, the direct consumption coefficient matrix is $A^{im} = MA$, where M is the diagonal matrix of the proportion of imported goods in the direct consumption coefficient; for the domestic products used as intermediate input, the direct consumption coefficient matrix is $A^d = (I - M)A$. In the diagonal matrix M, element m_{ii} is calculated by $m_{ii} = x_i^{im}/(x_i + x_i^{im} - y_i^{ex})$, where x_i^{im} is imported goods, x_i is total output, and y_i^{ex} is exported goods. Total import X^{im} is divided into two parts based on the flow of production and the consumption link, including the imported goods as intermediate input, $A^{im}X$, and the imported goods consumed domestically, Y^{im}. The intermediate input is transformed into final product, $A^{im}(I - A)^{-1}Y$, after domestic production, and, therefore, the total import is expressed as $X^{im} = A^{im}(I - A)^{-1}Y + Y^{im}$.

The intermediate input for an open economy is from the products of domestic or foreign industrial sectors. However, CO_2 emissions are generated throughout the production chain, ranging from production to transportation, to consumption; these emissions are referred to as the embodied CO_2 emissions. The CO_2 emission coefficient for sector j is divided into the direct emission coefficient e_j^d and the embodied emission coefficient E_j^d; and the embodied emission coefficient $E^d = e^d(I - A)^{-1}$. The goods produced and consumed by an open economy are divided as either imported or exported goods. Based on where the goods are produced and consumed, the embodied CO_2 emissions are divided into four categories (Lin and Sun, 2010; Yan and Zhao, 2012) [11,59]. Y^{ex} indicates the goods that are domestically produced and intended for export. The four categories of embodied CO_2 emissions are represented by I, II, III, and IV, respectively, as shown in Table 1.

Table 1. Four categories of embodied CO_2 emissions.

Classification	Domestically Consumed	Consumed in Foreign Countries
Domestically produced	I	II
Produced in foreign countries	III	IV

Category I is the CO_2 emissions embodied in goods that are domestically produced and consumed: $E^d(Y - Y^{ex})$;

Category II is the CO_2 emissions embodied in goods that are domestically produced and consumed in foreign countries: E^dY^{ex};

Category III is the CO_2 emissions embodied both in imported goods that are domestically consumed and in the domestically consumed goods transformed from the imported goods as intermediate input in domestic production: $E^dY^{im} + E^dA^{im}(I - A)^{-1}(Y - Y^{ex})$;

Category IV is the CO_2 emissions embodied in the exported goods that are produced domestically using the imported goods as intermediate input: $E^dA^{im}(I - A)^{-1}Y^{ex}$.

The sum of category II and IV is the CO_2 emissions embodied in the exported goods, and the sum of category III and IV is the CO_2 emissions embodied in the imported goods. The net CO_2 emissions embodied in export Q^{net} are calculated by deducting the CO_2 emissions embodied in the imported goods from the CO_2 emissions embodied in the exported goods:

$$Q^{net} = E^d Y^{ex} - E^d Y^{im} - E^d A^{im} (I - A)^{-1} (Y - Y^{ex})$$

4. Test Based on Industrial Sector Classification

4.1. Empirical Test of China's Industrial Sector as a Whole

We conducted our empirical analysis using Eviews 6.0 and Matlab. EViews is the abbreviation of Econometrics Views, which is developed by economists and mainly used in the field of economics, and MATLAB is a commercial mathematics software produced by MathWorks Company in the United States. Firstly, we performed a data stationary test. An LLC test and a Fisher-ADF test indicated that the data of each indicator were non-stationary panel data under the 1% significance level. The first-order differential data were stationary. Then, the variable combinations were subjected to a co-integration test. Here, we used the Hausman test to determine whether the fixed effects model or the random effects model fit under the 5% significance level. The data of the cross term were subjected to centering to reduce the errors in regression caused by collinearity [60].

The results of empirical analysis using panel data of China's 20 sectors are shown in Table 2. The first four columns (1)–(4) are the results of regression of the intensity of CO_2 emissions in each sector; the last four columns (5)–(8) are the results of regression on total CO_2 emissions. The regression of the control variables in (1) and (5) indicates that the coefficient is statistically significant at the 1% level. After introducing $TOI_{i,t}$ into (2) and (6), the regression fitting degree was improved, indicating the significance of trade openness in influencing CO_2 emissions. Moreover, high trade openness leads to a reduction in both CO_2 emissions' intensity and total CO_2 emissions. As to the effect of the control variable on CO_2 emissions in each sector, the coefficient for intensity, $ACT_{i,t}$, is always positive, hence, the more active the economic activities, the higher the CO_2 emissions' intensity and total CO_2 emissions. The coefficient for the number of employees in the sector $POP_{i,t}$ is positive in the regression of carbon emission intensity and negative in the regression of total CO_2 emissions, which indicates that higher $POP_{i,t}$ will reduce the CO_2 emissions' intensity in the sector but increase total CO_2 emissions. Higher intensity of research and development will reduce the CO_2 emissions of the sector, but, when considering other influencing factors, the coefficient becomes positive and insignificant.

Carbon leakage via international trade was tested. If the regression coefficient of the sector's development level is positive and the regression coefficient of the cross term of trade openness is negative, this means there is no carbon leakage, and China is not a pollution haven for HCSs. According to the regression, the coefficient of the added value of the industrial sector is positive, as might have been expected. Thus, higher added value of the industrial sector increases CO_2 emissions. The coefficient of the cross term between trade openness and the added value of the industrial sector is negative but insignificant, which means that, when either the CO_2 emissions intensity or the total CO_2 emissions is used, carbon leakage result cannot be proven. Testing of the EKC hypothesis by regression indicates that the coefficient of the linear term is negative and that of the quadratic term is positive. This is inconsistent with the EKC hypothesis, and the regression coefficient is not statistically significant. From this we can infer that the variations of CO_2 emissions in China's 20 sectors are characterized by uncertainty. China has greatly diverse sectors, with huge cross-sector differences. Lin (2013) found that the influence of foreign investment on China's CO_2 emissions varies greatly and has very different characteristics in different sectors [61]. So, to further analyze the effect of trade openness on CO_2 emissions in different sectors, we carried out our empirical analysis by dividing the sectors into HCSs and LCSs.

Table 2. Results of regression for all sectors.

Variable	Carbon Emission Intensity in the Sector				Total CO_2 Emissions in the Sector			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Constant	4.614 *** (16.767)	4.704 *** (17.456)	5.075 *** (20.664)	4.944 *** (2.679)	4.614 *** (16.768)	4.703 *** (17.457)	5.075 *** (20.665)	4.942 ** (2.678)
ln*POP*	−0.375 *** (−5.916)	−0.399 *** (−6.422)	−0.666 *** (−9.777)	−0.482 *** (−8.593)	0.624 *** (9.858)	0.600 *** (9.650)	0.333 *** (4.885)	0.517 *** (9.218)
ln*TOR*	−0.080 *** (−3.697)	−0.045 ** (−1.902)	0.002 (0.130)	0.002 (0.094)	−0.080 *** (−3.697)	−0.045 ** (−1.903)	0.002 (0.129)	0.002 (0.093)
ln*ACT*	0.267 *** (7.124)	0.228 *** (−3.106)	0.158 *** (4.412)	0.158 *** (4.527)	0.267 *** (7.127)	0.228 *** (5.931)	0.158 *** (4.414)	0.158 *** (4.529)
ln*TOI*		−0.115 *** (−3.106)	−0.027 (−0.788)			−0.115 *** (−3.106)	0.158 (4.414)	
ln*IVA*			0.180 *** (6.570)				0.180 *** (6.570)	
ln*TOI·IVA*			−0.001 (−1.069)				−0.001 (−1.069)	
ln*Y*				−0.105 (−0.362)				−0.104 (−0.361)
$(\ln Y)^2$				0.011 (1.029)				0.011 (1.028)
Adjusted R-squared	0.9969	0.9971	0.9977	0.9977	0.9970	0.9972	0.9978	0.9978
Mode Type	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect	Fixed Effect

Note: (1) The symbol in parentheses is the t value; (2) *, **, and *** indicate either that the data are statistically significant or that the null hypothesis is rejected at the 10%, 5%, and 1% significance levels, respectively.

4.2. Embodied Emissions Estimation and Industrial Sector Classification

China's 2010 Input–Output Table and the China Energy Statistical Yearbook 2011 were used as the data sources. Combining the output and export data of 20 sectors from the DRCnet database, the diagonal matrix of export coefficient $\overline{M}$ was calculated. To reduce the errors in CO_2 emissions' calculation that appeared during the conversion into either standard coal or solid–liquid–gas energy, we estimated CO_2 emissions using 18 physical quantities of energy consumption and the corresponding emission coefficients in the China Energy Statistical Yearbook 2011. IPCC (2006) provided the formula of CO_2 emission coefficient of energy unit identification: $\theta_i = NCV_i \times CC_i \times COF_i \times (44/12)$, where NCV_i is the average low heating value; CC_i is the CO_2 emission factor; and COF_i is the carbon oxidation factor. The default value is 1 according to IPCC, and 44 and 12 are the molecular weights of carbon dioxide and carbon, respectively. The CO_2 emissions of 20 sectors were estimated to calculate the intensity of direct CO_2 emissions, and then the CO_2 emissions embodied in the exported goods and the imported goods were calculated for each sector to finally obtain the intensity of CO_2 emissions embodied in net export.

The average intensity of CO_2 emissions is usually used to divide HCSs and LCSs. The average intensity of net CO_2 emissions embodied in export is 0.237tCO_2/ten thousand RMB. Using this criterion, seven sectors were classified as HCSs, namely, production and supply of electric power and thermal power, coal mining and dressing, non-metallic mineral products, metal smelting and calendaring, petroleum processing, coking and nuclear fuel processing, the chemical industry, paper making, printing and stationery, and sporting goods. The remaining 13 sectors are LCSs. Fu and Zhang (2015) used the intensity of direct CO_2 emissions as the criterion [58], and, as the average intensity in China's sectors is 0.3718 tCO_2/ten thousand RMB, classified six sectors as sectors with high intensity of direct CO_2 emissions; these are coal mining and dressing, non-metallic mineral products, metal smelting and calendaring, petroleum processing, coking and nuclear fuel processing, the chemical industry, paper making, printing and stationery, and sporting goods.

Although both the gas production and supply industry and the oil and gas exploration industry are also sectors with high intensity of direct CO_2 emissions, they are not classified as HCSs. This is probably because the direct CO_2 emissions in these two sectors are not caused by trade. We calculated the net CO_2 emissions embodied in export, aiming to reveal the relationship between trade openness and CO_2 emissions. The scatter plot showing the relationship between trade openness and CO_2 emissions' intensity was drawn for HCSs and LCSs (Figure 2). It is obvious that the trade openness is positively correlated with the CO_2 emissions' intensity for HCSs, with a mild linear increasing trend; however, for LCSs, the trade openness is negatively correlated with the CO_2 emissions' intensity. Thus, the relationship between trade openness and intensity of carbon emissions varies for different sectors, which shows that the empirical results of industrial industry as a whole are inadequate and need to be classified and tested. Meanwhile, it is proven from another perspective that the effect of trade openness on CO_2 emissions is uncertain for China's industrial sectors on the whole.

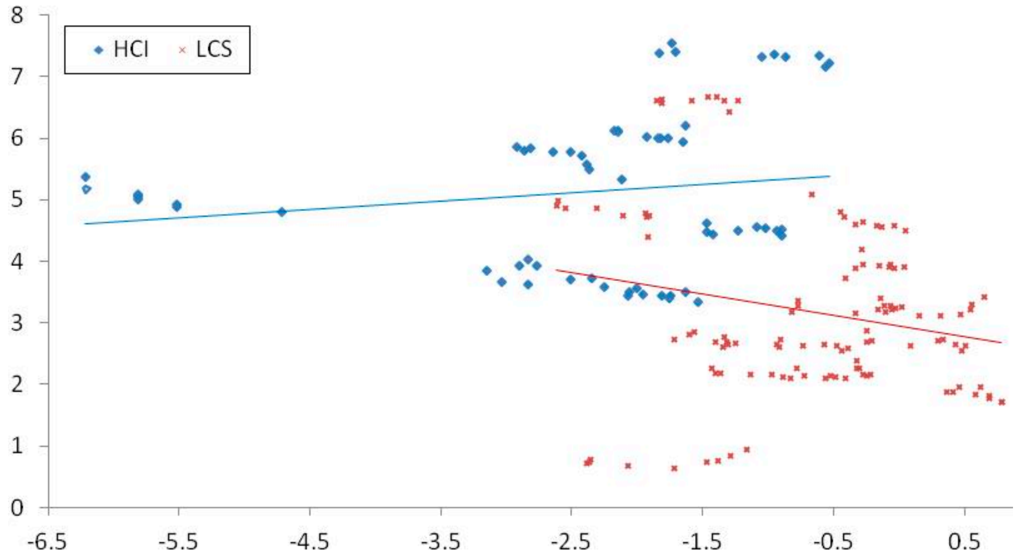

Figure 2. Scatter plot of trade openness vs. CO_2 emissions' intensity for high-carbon sectors (HCSs) and low-carbon sectors (LCSs).

4.3. Empirical Analysis for HCSs and LCSs

In Table 3, columns (1)–(4) and (5)–(8) are the regression results of CO_2 emissions' intensity for 7 HCSs and 13 LCSs. After introducing $TOI_{i,t}$ into the two equations, the fitting degree was improved, indicating the significance of trade openness to CO_2 emissions, which is consistent with the regression result of all sectors (ACSs). For LCSs, higher trade openness leads to a reduction in the CO_2 emissions intensity; however, for HCSs, the coefficient is positive and statistically significant at the 10% level for $TOI_{i,t}$, indicating that higher trade openness increases the CO_2 emissions' intensity for HCSs. The regression results of control variables are basically consistent with the regression for ACSs. The economic activities' intensity varies in the same direction as the CO_2 emissions' intensity for the sector. However, the situation is the opposite for the number of employees in the sector, and the intensity of research and development has no significant impact on the CO_2 emissions' intensity.

Table 3. Regression analysis of CO_2 emissions' intensity in HCSs and LCSs.

Variable	HCSs				LCSs			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	4.155 *** (6.113)	4.411 *** (6.541)	6.374 *** (10.784)	7.646 *** (3.753)	4.009 *** (12.627)	4.110 *** (12.767)	4.245 *** (13.603)	0.213 (0.054)
ln*POP*	−0.331 ** (−2.055)	−0.383 ** (−2.405)	−0.870 *** (−6.206)	−0.686 *** (−5.853)	−0.356 *** (−5.360)	−0.372 *** (−5.570)	−0.548 *** (−6.498)	−0.424 *** (−6.405)
ln*TOR*	−0.061 * (−1.980)	−0.027 (−0.787)	0.006 (0.228)	0.018 (0.758)	−0.046 (−1.512)	−0.029 (−0.907)	0.010 (0.321)	−0.009 (−0.303)
ln*ACT*	0.428 *** (5.010)	0.373 *** (4.261)	0.203 *** (2.851)	0.158 *** (4.527)	0.236 *** (5.897)	0.213 *** (5.023)	0.147 *** (3.388)	0.183 *** (4.347)
ln*TOI*		0.117 * (1.975)	0.043 (0.814)	0.161 ** (2.301)		−0.073 *** (−1.55)	−0.028 (−0.624)	
ln*IVA*			0.265 *** (6.497)				0.134 *** (3.530)	
ln*TOI·IVA*			0.001 (0.095)				−0.031 ** (−2.250)	
ln*Y*				−0.284 (−1.004)				0.565 * (1.908)
(ln*Y*)^2				0.021 * (1.909)				−0.017 ** (−3.702)
Adjusted R-squared	0.9922	0.9955	0.9975	0.7605	0.9903	0.9963	0.9967	0.3207
Mode Type	Fixed Effect	Fixed Effect	Fixed Effect	Random Effect	Fixed Effect	Fixed Effect	Fixed Effect	Random Effect

Note: (1) The symbol in parentheses is the *t* value; (2) *, **, and *** indicate either that the data are statistically significant or that the null hypothesis is rejected at the 10%, 5%, and 1% significance levels, respectively.

As to the testing of carbon leakage, the regression coefficient is positive for the added value of both types of sectors, which is consistent with ACSs. This means that the higher added value of the industrial sectors causes the increase in the CO_2 emissions' intensity. The coefficient of the cross term between trade openness and added value of LCSs is negative and statistically significant at the 5% level, indicating the absence of carbon leakage. However, the coefficient of the cross term is positive and statistically insignificant for HCSs, indicating the possible existence of carbon leakage (albeit uncertain). The results again demonstrate the above uncertainty of carbon leakage. The coefficient is positive for the linear term of per capita income and negative for the quadratic term in the regression for LCSs—significant at the 10% level—so the EKC hypothesis is confirmed for LCSs. However, for HCSs, the coefficient of the linear term is negative, and that of the quadratic term is positive, which does not agree with the EKC hypothesis. Moreover, the coefficient of the linear term is statistically insignificant. The testing of EKC hypothesis for the two types of sectors also proves the uncertainty of the existence of the EKC. In other words, higher trade openness leads to a reduction in CO_2 emissions' intensity for both LCSs and HCSs, but the existence of carbon leakage and EKC is uncertain for both LCSs and HCSs, which provides valuable information for making decisions on trade openness and industrial policies with the purpose of energy saving and emission reduction.

5. Robustness Test

5.1. Cross Term Between Trade Openness and Per Capita Output

A robustness test was performed subsequently. The sector's development level was measured by per capita output $GPC_{i,t}$ of the sector, and then we tested the existence of carbon leakage for ACSs, HCSs, and LCSs using the cross term $TOI_{i,t} \cdot GPC_{i,t}$ between trade openness and per capita output.

The regression results are shown in Table 4. Due to limited space, the coefficients of constant term and control variables are not reported. We can see that the regression coefficient is positive and statistically significant for per capita output of the sector. Hence, higher per capita output increases the CO_2 emissions' intensity. The coefficient of the cross term between trade openness and per capita output is negative and statistically insignificant for ACSs, demonstrating the uncertainty of carbon leakage. The coefficient of the cross term between trade openness and per capita output is positive and statistically insignificant for HCSs, indicating the possible existence of carbon leakage in HCSs (albeit uncertain). The coefficient of the cross term is negative and statistically significant for LCSs, indicating non-existence of carbon leakage for LCSs. These regression results are the same as that of the cross term between trade openness and added value, which proves good robustness.

Table 4. Regression analysis of cross term between trade openness and per capita output.

Variable	ACSs	HCSs	LCSs
ln*TOI*	−0.008 ** (−0.237)	0.094 ** (1.963)	−0.023 (−0.503)
ln*GPC*	0.187 *** (6.685)	0.278 *** (7.362)	0.141 *** (3.478)
ln*TOI*·*GPC*	−0.001 (−1.379)	0.029 (0.170)	−0.038 * (−1.812)
Adjusted R-squared	0.9977	0.9980	0.9967
Mode Type	Fixed Effect	Fixed Effect	Fixed Effect

Note: (1) The symbol in parentheses is the *t* value; (2) *, **, and *** indicate either that the data are statistically significant or that the null hypothesis is rejected at the 10%, 5%, and 1% significance levels, respectively.

5.2. Testing of the Pollution Haven Hypothesis

There is no carbon leakage in LCSs, but there is probably carbon leakage in HCSs. For ACSs, carbon leakage is more likely to be absent. To further test this conclusion, we tried to use the method by Halkos (2003) and Peng et al. (2013) by introducing the dummy variables [57,62]. As a result of higher trade openness, the countries (regions) or sectors implementing lower environmental regulations tend to be pollution havens for HCSs. Therefore, the CO_2 emissions' intensity can reflect the intensity of implementation of the environmental regulations. Pollution havens will be those countries with lower intensity of implementation of environmental regulations.

$$\ln CEM_{i,t} = \lambda Z_{i,t} + \phi_1 \ln TOI_{i,t} + \phi_2 \ln TOI_{i,t} \cdot CEM_{i,t} DUM_{i,t} + \mu_{i,t}$$

where $CEM_{i,t}$ is total CO_2 emissions (or emission intensity) of the sector; $Z_{i,t}$ are the variables, except for $\ln TOI_{i,t}$; the cross term is the product of the dummy variable $CEM_{i,t}DUM_{i,t}$ of the CO_2 emission intensity and trade openness. For HCSs, the value of the dummy variable is 1; otherwise, it is 0. Thus, for LCSs and HCSs, the effect of trade openness on CO_2 emissions is ϕ_1 and $\phi_1 + \phi_2$, respectively. If $\phi_1 \prec 0$, $\phi_1 + \phi_2 \succ 0$, then higher trade openness leads to environmental improvement for sectors implementing higher environmental regulations and having lower CO_2 emissions' intensity, but it is not conducive to environmental improvement for sectors implementing lower environmental regulations and having higher CO_2 emissions' intensity. According to our results, $\phi_1 = -0.155$, $\phi_1 + \phi_2 = 0.030$. Thus, higher trade openness leads to reduction in CO_2 emissions' intensity for LCSs, but increases CO_2 emissions' intensity for HCSs. The pollution haven hypothesis is confirmed for China's HCSs, which are the destination for the transfer of higher-carbon sectors from the developed countries.

6. Conclusions and Policy Suggestions

We carried out an empirical analysis of the effect of trade openness on CO_2 emissions and tested the existence of carbon leakage for all and classified industrial sectors in China, by building a panel data model and deriving a single-region input–output model for the classification of high-carbon sectors (HCSs) and low-carbon sectors (LCSs). Firstly, the empirical test results of the industry as a whole and the classification industry in China's industrial sectors have confirmed that higher trade openness leads to reduction of both CO_2 emissions' intensity and gross CO_2 emissions in the industrial sectors. So, China's policy makers do not need to worry too much about the adverse impact of trade openness on the environment. Instead, the environmental standards should be raised to further benefit the process of environmental improvement in an open economy. Some countries have discussed new standards and a new trade mode with greater emphasis on environmental cooperation, which represents both a challenge and an opportunity. As China is faced with an urgent need for energy saving and environmental protection, raising the environmental standards is not only a pathway to achieving economic transition, but also a means of strengthening the long-term competitiveness of China's exports. This will also reduce the pressure on China, as the world's largest CO_2 emitter, in climate negotiation.

Secondly, analysis based on industrial sector classification indicates dramatic cross-sector difference in CO_2 emissions' intensity. Higher trade openness can help reduce the CO_2 emissions' intensity. For China's industrial sectors on the whole, no carbon leakage exists, whereas EKC does. For HCSs, there is no EKC, but carbon leakage probably occurs. The pollution haven hypothesis was confirmed by introducing the dummy variable. However, the divergent conclusions reached for LCSs and HCSs point to the uncertainty of carbon leakage. China should encourage structural adjustment through relevant policies during green low-carbon development, as well as the transition and upgrading of exports. Since net CO_2 emissions embodied in export tend to vary from one sector to another, differential policies with structural features should be adopted to perform structural adjustment, and government can place tighter restraint on HCSs to appropriate to achieve low carbon development of industrial structure. This is in accord with the economic transition taking place under the new normality of the Chinese economy.

Thirdly, the regression analysis of the control variables also provides some clues. The Chinese government has announced that China's CO_2 emissions will peak around 2030 and efforts will be made to reach this peak sooner. Reducing the CO_2 emissions embodied in export is favorable to acquire the CO_2 emission space for Chinese economic development. From the empirical results, China's industrial sector has an optimized space for improving the structure of human capital, as the reduction effect of China's human resources is not obvious and higher population density will enhance the response of environmental policies to the income level [63]. As a country with a large population, China needs to further optimize its human resource structure and play its role in reducing emissions. In addition, the impact of R&D investment in China's industrial sector on reducing carbon intensity has not yet emerged clearly. Therefore, enhancing the emission reduction techniques is an important pathway to optimizing not only energy efficiency and the carbon production rate, which are a qualitative index, but also optimizing the number of high- and low-carbon industries, which is a quantitative index.

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