International Trade, CO2 Emissions and Re-examination of “Pollution Haven Hypothesis” in China

Ran Wu

Harbin Institute of Technology

Tao Ma (✉ raynawu@163.com)

Harbin Institute of Technology <https://orcid.org/0000-0002-5260-9841>

Dongxu Chen

Harbin Institute of Technology

Wenxi Zhang

Ningxia University

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Title page

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Authors:

Ran Wu¹, Tao Ma^{1*}, Dongxu Chen¹, Wenxi Zhang²

1 School of Management, Harbin Institute of Technology, 150006 Harbin, China

2 School of Management, Ningxia University, 750021 Yinchuan, China

Corresponding author: Tao Ma, (+86)18804657010, raynawu@163.com

E-mail addresses:

422105999@qq.com (R. Wu)

raynawu@163.com (T.Ma)

18B910049@stu.hit.edu.cn (D. Chen)

zwx_chenxi@163.com (W. Zhang)

Abstract:

We use input–output analysis and Levinson’s structural decomposition method to measure China’s CO₂ emissions under the no-trade hypothesis, to calculate how international trade affects China’s emissions. We also analyze the driving factors of the difference between hypothetical no-trade CO₂ emissions and actual emissions and discuss the existence of “pollution haven hypothesis” (PHH) in China. The results show that (1) from 2000 to 2017, the hypothetical no-trade CO₂ emissions are 2.43%–14.67% lower than actual emissions. The scale effect is the main cause of this difference, while the composition effect fluctuates and has little impact. (2) Although exports make other economies’ CO₂ emissions transfer to China, imports also help avoid China’s emissions from some carbon-intensive sectors. (3) International trade has little impact on the cleanliness of China’s industry composition. The no-trade industry composition is slightly cleaner than the actual one before 2010, after which trade improves the cleanliness of industry composition to a small extent. PHH is invalid for China in recent years, and results for most developing countries do not support PHH. (4) The relationship between no-trade effects and income per capita for all the economies does not also support PHH. Most economies reduce emissions, and their industry compositions are cleaner because of trade, regardless of their development degree.

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1. Introduction

China’s CO₂ emissions account for almost 30% of global emissions and this is a great challenge for global environment. To date, China’s carbon emissions are the highest in the world, but statistical data shows that the growth of emissions has slowed since 2016. International trade is the main link of different countries’ economies and significantly affects countries’ emission patterns and global emission patterns. Because energy use is embodied more and more in trade products, CO₂ emissions embodied in trade are increasing, and most main economies’ carbon reliance on trade products has been higher in recent years (Andrew, Davis, and Peters 2013).

One quarter of global carbon emissions are related to export activities, and emissions embodied in products transfer among different countries (Davis and Caldeira 2010). One region’s emission reduction may lead to other regions’ emission increasing, defined as “carbon leakage” (Babiker 2005; Branger and Quirion 2014). This type of carbon transfer is also defined as “outsourcing of emissions”, while imports and exports correspond to outsourcing and insourcing, respectively. When a country’s outsourcing emissions are larger than insourcing emissions, it is a net outsourcer because it avoids emissions that should have been produced domestically through imports (Baumert et al. 2019). A similar term is “emission displacement”, indicating that keeping domestic and external demand unchanged and comparing with no-trade scenario, a country reduces its emissions through international trade but increases foreign emissions (Jiborn et al. 2018).

Methods of CO₂ emissions accounting are based mainly on input–output analysis, including production-based accounting and consumption-based accounting. Production-based accounting focuses on territorial emissions and pays less attention to the original source of emissions. Consumption-based accounting can improve the understanding of countries’ responsibility for global emissions but focuses little on the difference in technologies and emission efficiencies in different economies (Pan, Phillips, and Chen 2008; Peng, Wencheng, and Wei 2016; Peng, Zhang, and Sun 2015; Peters and Hertwich 2008). Taking technology differences in export sectors into consideration, Kander et al. propose a technology-adjusted consumption-based accounting method based on the world-average technology level, which can reflect how national policy changes affect total global emissions more accurately (Kander et al. 2015).

However, because of technology differences across countries, the effect of international trade on global emissions remains controversial. On the one hand, pollution haven hypothesis (PHH) indicates that production tends to be transferred to regions with relatively lax environmental regulations, and pollution is transferred as a result. Although some developed countries’ territorial

emissions decrease, their consumption-based emissions increase, and sectors that successfully lower domestic emissions usually increase their import of embodied emissions. This type of pollution displacement leads to an increase in global total air pollution, and the legislation and policies of major emitters on environmental improvement have not played positive roles in the global environment (Aichele and Felbermayr 2015; Jakob, Steckel, and Edenhofer 2014; Kanemoto et al. 2014; Peters et al. 2011). On the other hand, free trade seems to be good for the environment as a trade-induced technique, and scale effects imply a net reduction in pollution (Antweiler, Copeland, and Taylor 2001). International trade can also induce more advanced and clean technologies that lead to a cleaner domestic environment, and trade liberalization reduces emissions as a result (Gill, Viswanathan, and Karim 2018; Jebli, Youssef, and Ozturk 2016).

China has been highly integrated into the global production system after entering WTO, and its CO₂ emissions have been growing more strongly. Many studies have discussed the impact of international trade on China's carbon emissions in different periods. Net trade has little impact on China's CO₂ emissions from 1992 to 2002, as emissions increased by exports are almost the same as those reduced by imports (Peters et al. 2007). From 2002 to 2007, the surge of China's exports is an important reason for the increase in China's CO₂ emissions and global emissions. However, due to the improvement in export structure and production technology after the financial crisis, China's exported CO₂ emissions tend to stabilize, and the carbon intensity of exports declined (Pan et al. 2017; Yin 2019). Provincial research has demonstrated the following: international trade increases China's carbon emissions and negatively affects China's environment, the downward trend of China's carbon intensity from 1997 to 2008 is mainly attributed to the improvement in income level, trade opening increases CO₂ emissions and carbon intensity at the provincial level (Li and Qi 2011; Ma and Shi 2016; Sun, Li, and Wang 2015; Wang and Xu 2015), and carbon intensity of China's export during this period is much higher than that of developed countries (Jiang and Liu 2013).

Furthermore, disputes continue over “whether PHH is valid in China” from the perspective of CO₂ emissions. A large amount of China's production-based emissions come from the demand of developed countries, and there exists a serious problem of “consumption in developed countries and pollution in China”, especially after China's accession to WTO (Peng et al. 2015). China allowed itself to become a pollution haven from 1990 to 2010, for example, the United States transferred high-carbon industries such as the machinery and transportation manufacturing industry to China (Zhao, Wang, and Yan 2013). Rui and Zhao examine the cleanliness of import and export products and demonstrate that China's imports are cleaner than exports from 1995 to 2009 and that PHH is valid in China (Rui and Zhao 2016). International production division makes the pollution haven effect increasingly complex, although it effectively reduces total global emissions (Zhang, Zhu, and Hewings 2017). China's CO₂ emissions embodied in exports are growing rapidly, and China is a pollution haven for developed economies (Fei et al. 2020; Liu, Guo, and Xiao 2019; López et al. 2018).

The aforementioned studies have proved the negative effects of trade on China's emissions and pointed out that PHH is valid in China, but some researchers have continued to hold various perspectives. A study based on regression analysis shows that although international trade increases CO₂ emissions in high-carbon sectors, it benefits overall manufacturing industries' emissions from 1998 to 2006 (Fu and Zhang 2014). When developed countries transfer polluting industries to China, they also transfer clean industries. From 1998 to 2006, international trade reduced the total CO₂ emissions and carbon intensity of industrial sectors and did not make China become a pollution haven (Li and Lu 2010). In addition, foreign investment brought by international trade is one of the important ways to improve the environment; thus, PHH is not valid in China in the long run (Shao et al. 2019).

To further investigate the accurate degree of international trade's impact on China's carbon emissions, the technical level of China's imports should be considered. Compared with the assumption that all the imports are produced by China itself, whether a sector's actual import increases or decreases emissions is still uncertain (Ahmad and Wyckoff 2003). Because of technical differences and different environmental policy constraints, carbon intensity of the same sector on both sides of trade is not usually the same. Jiborn and Kander have taken technological differences between trading partners into account in the emissions accounting process (Kander et al. 2015). However, the accounting based on the global average technological level cannot accurately reflect the carbon efficiency and technological differences of specific sectors in specific

countries. The aforementioned definition of "emission displacement" also proposes to assess the trade effect on the environment by comparing actual emissions with no-trade emissions, but there is still a lack of research on emissions under this type of no-trade scenario.

To fill this gap in the literature, this paper suggests a no-trade hypothesis in which international trade is extracted, and all countries produce their imports domestically in terms of their technology and emission intensity to meet their own demands. Under this type of no-trade hypothesis, the difference between China's no-trade CO₂ emissions and actual emissions is discussed. Based on the aforementioned discussion, this paper uses input–output analysis and structural decomposition method to analyze the following research questions: (1) To what extent does international trade affect China's carbon emissions, and what explains the difference between no-trade emissions and actual emissions? (2) In the process of China's high involvement in international trade, which sectors' emissions are influenced most by international trade? (3) From the perspective of CO₂ emissions, how does international trade affect the cleanliness of China's industry composition and is PHH valid in China? (4) For other developing economies, is PHH valid?

The remaining sections are arranged as follows: the second section presents the research methods and data sources, the third section presents the results and analysis, the fourth section furtherly discusses PHH in other economies, and the final section presents conclusions and policy recommendations.

2. Method and Data

2.1 Measurement of value added and CO₂ emissions under the no-trade hypothesis

Based on an input–output database and input–output analysis, value added, value-added export, and value-added import are measured. Assuming that there are m countries and n sectors, the world input–output table can be expressed as equation (1). X denotes the $mn \times 1$ vector of gross output and A is the $mn \times mn$ technical coefficient matrix. Y denotes the $mn \times 1$ vector of final demand and $L = (I - A)^{-1}$ is the $mn \times mn$ Leontief inverse matrix, which directly reflects the relationship between final demands and gross output. Taking three countries r , s and t as an example, a specific expression can be expressed as equation (2). X^c and Y^c are both $n \times 1$ vectors, denoting gross output and final demand of different sectors in country c , respectively. F^c comprises Y^{cc} and Y^{cd} , denoting country c 's domestic final demand and country d 's final demand from country c , respectively.

$$X = AX + Y = (I - A)^{-1}Y = LY \quad (1)$$

$$\begin{bmatrix} X^r \\ X^s \\ X^t \end{bmatrix} = \begin{bmatrix} A^{rr} & A^{rs} & A^{rt} \\ A^{sr} & A^{ss} & A^{st} \\ A^{tr} & A^{ts} & A^{tt} \end{bmatrix} \begin{bmatrix} X^r \\ X^s \\ X^t \end{bmatrix} + \begin{bmatrix} Y^r \\ Y^s \\ Y^t \end{bmatrix} = \begin{bmatrix} L^{rr} & L^{rs} & L^{rt} \\ L^{sr} & L^{ss} & L^{st} \\ L^{tr} & L^{ts} & L^{tt} \end{bmatrix} \begin{bmatrix} Y^{rr} + Y^{rs} + Y^{rt} \\ Y^{sr} + Y^{ss} + Y^{st} \\ Y^{tr} + Y^{ts} + Y^{tt} \end{bmatrix} \quad (1)$$

With reference to previous research (Stehrer 2012), and by using one country as an example, country r 's value-added exports VAX^r and imports VAM^r can be expressed as equations (3) and (4). V^r is the $n \times 1$ vector, indicating value added caused by per unit of output at the sector level in country r . When calculating one country's value-added export, other countries' value-added rate row vectors are all set as zero. When calculating one country's value-added import, its own value-added rate row vector is set as zero. VA is a country's actual value added, and VA^* is value added under the no-trade hypothesis, as shown in equation (5).

$$VAX^r = \begin{bmatrix} V^r & 0 & 0 \end{bmatrix} \begin{bmatrix} L^{rr} & L^{rs} & L^{rt} \\ L^{sr} & L^{ss} & L^{st} \\ L^{tr} & L^{ts} & L^{tt} \end{bmatrix} \begin{bmatrix} 0 + Y^{rs} + Y^{rt} \\ 0 + Y^{ss} + Y^{st} \\ 0 + Y^{ts} + Y^{tt} \end{bmatrix} \quad (2)$$

$$VAM^r = \begin{bmatrix} 0 & V^s & V^t \end{bmatrix} \begin{bmatrix} L^{rr} & L^{rs} & L^{rt} \\ L^{sr} & L^{ss} & L^{st} \\ L^{tr} & L^{ts} & L^{tt} \end{bmatrix} \begin{bmatrix} Y^{rr} + 0 + 0 \\ Y^{sr} + 0 + 0 \\ Y^{tr} + 0 + 0 \end{bmatrix} \quad (4)$$

$$VA^* = VA - VAX + VAM \quad (5)$$

Then, CO₂ emissions under the no-trade scenario can be calculated by using sectoral emission intensity of value added. Here, we do not calculate hypothetical emissions by multiplying the emission intensity of value added with the hypothetical value added directly, because emission intensity is zero or not related to output directly in a few sectors. Instead, we multiply the net value-added import with emission intensity and add this number to actual emissions (denoted as E), obtaining CO₂ emissions under the no-trade scenario (denoted as E^*). In other words, when sectoral emissions or value added is zero, we set the emission intensity of this sector as zero and assume that no-trade emissions are the same as actual emissions. Based on the aforementioned discussion, no-trade CO₂ emissions at the country level can be expressed as follows, where f_i is the emission intensity of value added in sector i .

$$E^* = E + \sum_i (VAM_i - VAX_i) \cdot f_i \quad (6)$$

2.2 Assessment of the scale effect and composition effect

Based on the conventional decomposition method in Levinson's study, changes in total pollution can be divided into three sources: the economic scale, the composition of the economy, and technological progress (Levinson 2009). By referring to this theory, the change in CO₂ emissions can also be divided into three effects: scale effect, composition effect, and technique effect. However, actual emissions E and no-trade emissions E^* in this study occur in the same year, and emission intensity remains constant. Thus, the technique effect is zero, and we only focus on the previous two effects. CO₂ emissions at the country level can be expressed as equation (7), where S is total value added at the country level, e_i is sector i 's CO₂ emissions, and v_i is sector i 's value added. $f_i = e_i/v_i$ presents the emission factor of sector i , reflecting the sector's technological level. $c_i = v_i/S$ is the industry share of value added in the country's total.

$$E = \sum_i e_i = \sum_i v_i \cdot f_i = S \cdot \sum_i c_i \cdot f_i \quad (7)$$

Vector notation is shown as equation (8). S is the total GDP of each economy, and C and F are column vectors representing the market shares of each sector and their emission intensities, respectively. As mentioned earlier, F is constant in the same year and F^* is equal to F . The difference between E^* and E is shown as below. All the variables with "*" represent items under the hypothetical no-trade scenario.

$$\Delta E = E^* - E = S^* C'^* F^* - S C F' \quad (8)$$

To eliminate the residual in traditional decomposition methods, the polar decomposition method is applied in input-output analysis (Miller and Blair 2009). Different decomposition forms can be obtained in terms of different factors. One form is shown as equation (9). Taking the average of equation (9) and equation (10), assessments of the scale effect and composition effect are shown as equation (11), in which the first term represents the scale effect and the second term represents the composition effect. Two types of effects explain how the change in economic scale and industry composition affect CO₂ emissions.

$$\begin{aligned} E^* - E &= S^* C'^* (F^* - F) + S^* (C'^* - C') F + (S^* - S) C' F \\ &= S^* (C'^* - C') F + (S^* - S) C' F \end{aligned} \quad (9)$$

The other form is shown as equation (10).

$$\begin{aligned} E^* - E &= S^* C' (F^* - F) + S (C'^* - C') F^* + (S^* - S) C'^* F^* \\ &= S (C'^* - C') F^* + (S^* - S) C'^* F^* \end{aligned} \quad (10)$$

Taking the average of equation (9) and equation (10), assessments of the scale effect and composition effect are shown as equation (11), in which the first term represents the scale effect and the second term represents the composition effect. Two types of effects explain how the change in economic scale and industry composition affect CO₂ emissions.

$$\Delta E = \frac{1}{2} (S^* - S) (C' + C'^*) F + \frac{1}{2} (S + S^*) (C' - C'^*) F = E^s + E^c \quad (11)$$

ΔE represents the effect of no-trade on production-based emissions, and this can be regarded as the total effect, the sum of E^s and E^c . $\Delta E > 0$ indicates that moving to the no-trade scenario would increase emissions, and the observed trade flows reduce emissions. $\Delta E < 0$ indicates that moving to the no-trade scenario would reduce emissions, while the observed trade flows are increasing emissions. E^s is the scale effect, representing the impact of balanced trade on emissions. In trade-deficit countries' production, the associated emissions would have to increase to meet domestic demand; thus, $E^s > 0$. In trade-surplus countries' production, the associated emissions would have to decrease to adjust to domestic demand; thus, $E^s < 0$. E^c represents the impact of the no-trade composition on emissions. Similarly, $E^c > 0$ indicates that the no-trade industry composition would increase emissions, and the observed industry composition is cleaner.

2.3 Data

The World Input-output Database (WIOD) Release 2016 covers 56 sectors and 43 countries from 2000 to 2014 (in million dollars) (Timmer et al. 2015). WIOD Environmental Accounts (Corsatea et al. 2019) consistent with the World Input-Output Database Release 2016 from 2000 to 2016 are also published in 2019, in which sectoral CO₂ emissions (in million tons) corresponding to sectors in WIOTs are provided. China's Input-output Database of 2015 and 2017 are collected from China Statistical Yearbook, covering 42 sectors. China's emission data of 2015 and 2017 are collected from CEADS (Shan et al. 2017, 2020), covering 45 sectors. After corresponding sectors in national input-output database to sectors in CEADS database, 28 sectors are finally got. In this way, sectors in 2015 and 2017 have little difference with sectors in previous years. Household emissions are not considered in this study. Based on the three databases, our research period is from 2000 to 2017, and the research objects cover the whole world and 43 economies. Under the no-trade hypothesis, all the sectors would produce their domestic final demands on the basis of the domestic technological level. As an economic power, China has sufficient resources and products in all sectors. It can fulfill the requirement of the no-trade hypothesis. Data of income per capita are calculated by using population data and GDP data collected from PWT 9.1, and its unit is 1,000 dollars at the constant price of 2011.

3. Results

3.1 Results at the country level

Fig 1 compares China's actual CO₂ emissions E and emissions under the no-trade hypothesis E^* from 2000 to 2014, as well as the variation trend of their difference. China's no-trade emissions during the calculation period are much lower than the actual emissions. The bar chart below the horizontal axis in Fig 1 directly reflects the difference between E^* and E . In 2000, no-trade emissions are 109.59 million tons lower than the actual emissions, and the difference widens to a maximum of 1041.39 million tons in 2007, decreases to 216.52 million tons in 2017. This result suggests that China's CO₂ emissions would be significantly reduced under the no-trade hypothesis. In other words, international trade increases China's CO₂ emissions. Combined with China's economic development, by 2007, China's net exports are increasing annually, and exports have become the main pillar of China's economic development, and emissions caused by foreign demand are increasing as a result. Affected by the global financial crisis after 2007, the volume of international trade has decreased dramatically, slowing the increase in CO₂ emissions.

Fig 1. Actual CO₂ emissions and no-trade CO₂ emissions in China (in mt)

Fig 2. Total effect, scale effect and composition effect of China

More precisely, the difference between hypothetical CO₂ emissions and actual emissions E^*-E is analyzed. Fig 2 shows the ratio of no-trade emissions E^* , emissions with only composition effect E^c , and emissions with only scale effect E^s to actual emissions E . Comparing these numbers with 1, the direction and degree of different effects can be observed directly. A positive effect means increasing emissions, and a negative effect means reducing emissions. No-trade CO₂ emissions in 2000 are 3.25% lower than actual emissions, and this number reaches a maximum of 14.67% in 2007, and 2.43% in 2017. As can be seen from Fig 2, the overall trend of the scale effect, composition effect, and total effect are consistent. The scale effect mainly explains why no-trade emissions are lower, and the reduction of production scale under the no-trade scenario leads to emission reduction. More precisely, the scale effect helps reduce 3.55%, 10.65%, and 1.76% of CO₂ emissions in 2000, 2007, and 2017, respectively. The change in composition effect is not obvious, and the composition effect would reduce approximately 0.57% to 4.58% of CO₂

emissions from 2001 to 2009, during which the no-trade industry composition is slightly cleaner and exports tend to focus on sectors with high carbon intensity. From 2010 to 2017, we observe a turning point: the composition effect increases CO₂ emissions by a small amount and actual industry composition is cleaner, indicating that China's export becomes cleaner. Although the composition effect reduces emissions again in 2014 and 2017 (both less than 1%), the cleanliness of the no-trade industry composition is almost the same as the actual one.

3.2 Results at sector level

The previous section has shown that no-trade CO₂ emissions are lower than actual emissions in all the years. This section further analyzes the hypothetical emissions at the sector level. Figs 3 and 4 respectively present the sectors with the largest reduction or increase in CO₂ emissions under the no-trade hypothesis.

Fig 3. Sectors with the largest reduction of CO₂ emissions under the no-trade scenario (mt)

As shown in Fig 3, the total reduction of CO₂ emissions in 2000 is 109.59 million tons, and the sectors that make the biggest contribution include the manufacturing of other non-metallic mineral products and electricity, gas, steam, and air conditioning supply, accounting for 43.26% and 21.58% of total reduction, respectively. Transportation sectors including water transport and air transport also play important roles to reduce emissions. The structures of emission reduction under the no-trade scenario in 2007 and 2014 are similar, but there are some changes compared with 2000. Transportation sectors, evidently, no longer reduce emissions, and the reduction effects of the manufacture of chemicals and chemical products and the manufacture of rubber and plastic products become significant. Result of 2017 has little difference with that of previous years, as service sectors are divided in detail in previous years, and sectors in 2017 are more general. Wholesale, retail trade and catering services reduces most emissions, accounting for 31.69% of total reduction, and the trade scale of this sector is quite large. The other sectors are quite similar to previous years. From an overall perspective, sectors with the largest reduction of CO₂ emissions under the no-trade scenario remain focused on the following three sectors. In other words, international trade increases most emissions in these sectors: (1) For manufacture of other non-metallic mineral products, its emission reduction accounts for 12.51% and 26.66% of the total reduction in 2007 and 2017, respectively. Emission intensity of this sector is the second highest among all the sectors in China, and its export would greatly increase China's CO₂ emissions. (2) For manufacture of basic metals, in 2007 and 2014, emission reduction in this sector account for 17.51% and 24.75% of total emission reduction, respectively, and its emission intensity is also at a high level. Smelting and pressing of metals also belongs to manufacture of basic metals, and emission reduction in this sector accounts for 26.78% of total reduction in 2017. (3) For electricity, gas, steam, and air conditioning supply, emission intensity is the highest among all the industries and the reduction accounts for 12.51% and 28.47% of total reduction in 2007 and 2017 under the no-trade scenario.

Fig 4. Sectors with the largest increase in CO₂ emissions under the no-trade scenario (mt)

Although most sectors would reduce their CO₂ emissions to some extent under the no-trade hypothesis, some sectors would increase their emissions. However, the increase in emissions of these sectors is much lower than the emissions reduced by other sectors. As shown in Fig 4, manufacture of chemicals and chemical products under the no-trade hypothesis would increase CO₂ emissions by 11.46 million tons in 2000, accounting for -10.45% of the total reduction, followed by warehousing and support activities for transportation and mining and quarrying. Notably, mining and quarrying is the sector that increases emissions most under the no-trade scenario in most years, namely, 22.91 million tons in 2007 and 57.65 million tons in 2017, indicating that international trade helps reduce most emissions in this sector. As mining and quarrying is related to the exploitation of raw materials, for the mining of coal, oil, natural gas, and other energy and ancillary services activities, the emission intensity is relatively high; thus, its import and export would largely influence the sector's CO₂ emissions. China also avoids some of its own emissions through the net import of mining and quarrying. Additionally, emissions in sewerage; waste collection, treatment, and disposal activities; materials recovery; and remediation activities and other waste management services would also increase to a small extent under the no-trade scenario. Similar sectors include warehousing and support activities for transportation, scientific research and development, and administrative and support service activities, whose impacts are minimal.

3.3 Structure of CO₂ emissions embodied in trade

Figs 3 and 4 list the sectors influenced most by international trade. More precisely, this section respectively analyzes emissions embodied in value-added export and emissions avoided by value-added import.

Fig 5. CO₂ emissions embodied in value-added export and emissions avoided by value-added

import (mt)

Emissions embodied in value-added export are actual emissions embodied in value-added export, while emissions avoided by value-added import are calculated based on domestic emission intensity hypothetically. Fig 5 presents the main results in four years. The structures of CO₂ emissions embodied in trade are quite stable. Emissions embodied in either value-added export or avoided by value-added import mainly focus on five sectors, the emissions of which account for more than 80% in total emissions embodied in trade. These five sectors are electricity, gas, steam, and air conditioning supply; manufacture of other non-metallic mineral products; manufacture of basic metals; manufacture of chemicals and chemical products; and mining and quarrying. Emissions embodied in the trade of electricity, gas, steam, and air conditioning supply are highest in all the years, and its emissions embodied in exports account for more than 40% of total exported emissions. Correspondingly, if this sector's imports are produced domestically, this would induce the largest amount of emissions among all the sectors. In other words, the emissions avoided by imports in this sector are also the highest. Overall, structures of CO₂ emissions embodied in both export and import are consistent, but the export volume of major sectors remains much higher than that of import, which also explains the decline in domestic final demand under the no-trade hypothesis, thus reducing domestic CO₂ emissions.

4. Discussion of PHH

4.1 Discussion of PHH in developing economies

Our results have shown that China's CO₂ emissions would decrease if trade is excluded. No-trade emissions reduce more in the years with more net export. From the perspective of total CO₂ emissions, international trade transfers emissions of other countries to China. More precisely, this section also discusses the condition of other typical developing countries that are also large emitters including India, Russia, Mexico, Indonesia, and Brazil. Fig 3 shows the no-trade emissions of these countries and their scale effects and composition effects. Additionally, the result at the world level is provided for detailed analysis.

As shown in Fig 6, global CO₂ emissions would substantially increase under the no-trade hypothesis, that is, international trade promotes emission reduction at the world level. As production scale is not changed at the world level, this type of emission reduction occurs because international trade improves the overall cleanliness of global production composition. In the investigation of other developing countries, only the result of Russia is similar to that of China, namely, no-trade emissions would be reduced sharply. However, Russia's reduced emissions are mainly because of the composition effect, indicating that the no-trade industry composition is much cleaner. The result of Russia effectively supports the idea mentioned in PHH, that is, pollution-intensive industries are transferred to Russia, and its industry composition has been polluted by international trade. Notably, the main reason why China's no-trade emissions are lower than those of Russia is the change in production scale, and the cleanliness of industry composition in China is not influenced so much. In previous years before 2010, China's industry composition is slightly polluted, increasing emissions to a small extent, but is cleaned by international trade after 2009, and this result is a weak argument in support of PHH. As PHH mentions, if polluted industries are transferred to China, China's pollution intensity would increase.

Fig 6. Typical developing countries' scale effects and composition effects

In addition to Russia and China, other developing countries' no-trade emissions all increase substantially. This finding means that the environment of most developing countries benefits from international trade. In India, for example, its no-trade CO₂ emissions are 30% higher than its actual emissions since 2007. The influence degree of the scale effect is small; thus, its hypothetical production scale is similar to the actual scale. The difference between no-trade emissions and actual emissions is mainly because of the composition effect, indicating that international trade makes India's actual industry composition cleaner to a large extent. Indonesia and Mexico's results are similar to India, and their no-trade emissions are approximately 10% higher than actual emissions. Indonesia's scale effect is negative, and the composition effect is positive; thus, actual production composition is much cleaner than the no-trade composition. There are fluctuations in the results of Brazil. No-trade emissions are lower than actual emissions in most years before 2006, after which no-trade emissions are approximately 5% higher, and the composition effect dominates in this period, reflecting the improvement in the cleanliness of industry composition. The aforementioned discussion shows that international trade does not worsen the environment of developing countries in terms of CO₂ emissions; by contrast, it promotes the emission reduction of most developing countries and improves the cleanliness of their industry composition, contrary to the PHH.

4.2 Scale effect, composition effect, and income per capita

The prior subsection has discussed PHH in China and other developing countries, and this section further examines PHH from a wider scope. As income per capita can reflect the development degree of each economy, we investigate the relationship between different effects and income per capita and build simple regression models to test whether richer economies are polluting poorer economies. Fig 7 presents a scatter plot of different effects and income per capita in specific years.

Fig 7. No-trade effects and income per capita

Most economies' no-trade scenario would increase emissions in all the years, because most E^*/E are smaller than 1, indicating that most economies benefit from international trade in terms of reducing emissions. A slightly negative relationship is observed between E^*/E and income per capita, but the slope becomes smaller from 2000 to 2014. In 2000 and 2007, low-income economies' no-trade scenario would increase a larger percentage of emissions (or reduce a smaller percentage of emissions). In 2014, this relationship weakens, and it is difficult to observe a significant association between these two items. An obvious negative relationship between $(E+E^s)/E$ and income per capita can be obtained. We cannot get an obvious relationship between $(E+E^c)/E$ and income, and the composition effect may not be highly related to income per capita. However, most economies' composition effects are positive, indicating that the no-trade industry composition is dirtier.

To obtain the exact statistical relationship between no-trade effects and income per capita, we build simple OLS regression models by using the following steps. Outliers are excluded from the samples using the BACON algorithm (Billor, Hadi, and Velleman 2000; Weber 2010), setting p as 0.15 to obtain most a more accurate result. PHH suggests that developed economies transfer their emissions to developing economies through trade and pollute developing economies' industry composition. If PHH is valid, low-income economies would reduce emissions while rich economies would increase emissions under the no-trade scenario, and no-trade industry composition in low-income economies would be cleaner.

Table 1 shows that as income per capita increases, E^*/E decreases, and low-income economies' no-trade scenario would increase a larger percentage of emissions. This finding is opposite to PHH. For $(E+E^s)/E$, the scale effect would reduce a larger percentage of emissions in rich countries than in poor countries, and this model is more persuasive because R^2 is not as small as in the other two models. As rich economies such as those of oil producers tend to have large export surpluses, the no-trade scenario would significantly reduce their production scales, reducing emissions as a result. $(E+E^c)/E$ slightly increases with the increase in income per capita, indicating that richer

economies' no-trade industry composition would increase a larger percentage of emissions, but R^2 is too small to explain the model very well.

Table 1. Regression results

	(1) E*/E	(2) (E+E ^s)/E	(3) (E+E ^c)/E
Income per capita	-0.003*** (0.001)	-0.004*** (0.000)	0.001* (0.001)
Constant	1.172*** (0.020)	1.102*** (0.008)	1.074*** (0.017)
Observations	612	638	607
R-squared	0.026	0.259	0.006

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

When we combine the figures and regression results, PHH is not fully supported. Not only developed economies but most economies benefit from international trade in terms of reducing emissions. Richer countries' no-trade scale effects tend to be negative because of their larger export surpluses. Composition effects are not sensitive to income per capita, but most economies' composition effects are positive, indicating that the no-trade industry composition would induce more emissions.

5. Conclusion and Policy Implications

This paper calculates China's CO₂ emissions under the no-trade hypothesis from 2000 to 2017 by using input–output analysis. We also discuss the driving factors of the difference between hypothetical and actual emissions, based on Levinson's decomposition method. The paper further examines whether PHH is valid in China and other economies. Our main conclusions are as follows:

International trade increases China's CO₂ emissions. From 2000 to 2017, no-trade CO₂ emissions are approximately 2.43%–14.67% lower than the actual emissions. Trade induces the largest increase in CO₂ emissions in 2007, in which China's CO₂ emissions under the no-trade hypothesis would reduce 15% compared with that of the actual scenario. The difference between no-trade emissions and actual emissions widens before the global financial crisis and then narrows. The scale effect is the main reason for China's hypothetical CO₂ emissions' reduction, because China's production scale decreases after excluding imports and exports. The composition effect plays a minimal role, and China's no-trade industry composition is cleaner before 2010, after which there is no obvious difference between hypothetical composition and actual composition. From 2010 to 2017, the actual industry composition is a little cleaner than the hypothetical one, indicating that international trade has improved the cleanliness of China's industry composition in recent years.

International trade leads to the largest increase in CO₂ emissions in China in three sectors: manufacture of other non-metallic mineral products; manufacture of basic metals; and electricity, gas, steam, and air conditioning supply. Among these sectors, electricity, gas, steam, and air conditioning supply and manufacture of other non-metallic mineral products have the highest and second highest emission intensity among all industries in China, respectively; thus, net exports of these sectors will substantially increase China's carbon emissions. By contrast, mining and quarrying has the largest reduction in CO₂ emissions because of international trade, and China has also avoided part of its own emissions through mining and quarrying's net import. In addition, sectors such as sewerage; waste collection, treatment, and disposal activities; materials recovery; remediation activities, and other waste management services have also achieved smaller reductions of emissions because of international trade. Sectors with higher CO₂ emissions contained in exports and imports are similar, but the export volume is relatively higher than that of imports, explaining the decline in domestic carbon emissions.

International trade does not substantially affect the cleanliness of industry composition in China, and China's situation does not support PHH strongly in recent years. The increase in CO₂ emissions is mainly because of the expansion of the production scale. Production composition only increases emissions to a small extent before 2010 and helps to reduce emissions in recent

years. Results of other typical developing countries are also contrary to PHH. For India, Mexico, Indonesia, and Brazil, international trade significantly reduces carbon emissions and increases the cleanliness of production composition in these countries. By contrast, international trade has increased Russia's total CO₂ emissions and significantly polluted its industry composition, a result that is a powerful argument for making Russia a "pollution haven."

Furthermore, based on the relationship between no-trade effects and development degree for 43 economies, the support for PHH cannot be fully from an overall perspective. Most economies would reduce emissions when moving to the no-trade scenarios, and their no-trade industry compositions would be cleaner than actual ones. Both developed economies and developing economies benefit from international trade in terms of reducing CO₂ emissions. The no-trade production scale tends to decline because of larger export surpluses in rich economies. Trade also improves the cleanness of most economies' industry composition.

China's future reduction of reliance on exports will play a positive role in reducing domestic CO₂ emissions directly. Adjusting the export structure and improving export quality can also effectively promote emission reduction. What is of great significance is to improve carbon utilization efficiency through technological innovation, especially to reduce the carbon intensity of high-carbon sectors, so as to improve the cleanliness of local production composition and the trade structure. In addition, the utilization of clean energy can be strengthened to reduce the dependence of economic development on carbon-based energy.

Declarations

Ethics approval and consent to participate. We certify that the manuscript titled "International Trade, CO₂ Emissions and Re-examination of "Pollution Haven Hypothesis" in China" has been entirely our original work except otherwise indicated, and it does not infringe the copyright of any third party. The submission of the Paper to Environmental Science and Pollution Research implies that the paper has not been published previously. It is not under consideration for publication elsewhere, and its publication is approved by all authors and that. If accepted, it will not be published elsewhere in the same form, in English or any other language, without the written consent of the Publisher. Copyrights for articles published in Environmental Science and Pollution Research are retained by the author(s), with first publication rights granted to Environmental Science and Pollution Research. We affirm that all authors have participated in the research work and are fully aware of ethical responsibilities.

Consent for publication. We affirm that all authors have agreed for submission of the Paper to ESPR and are fully aware of ethical responsibilities.

Availability of data and materials. Research data can be obtained from the following websites, and the code can be obtained from the corresponding author through email.

<http://www.wiod.org/release16>;

<https://ec.europa.eu/jrc/en/research-topic/economic-environmental-and-social-effects-of-globalisation>

<http://www.stats.gov.cn/tjsj/ndsj/>

<https://www.ceads.net>

Competing interests. The authors declare that they have no conflict of interest.

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