Environmental Science & Technology LETTERS

pubs.acs.org/journal/estlcu

Letter

Examining the Sensitivity of Global CO_2 Emissions to Trade Restrictions over Multiple Years

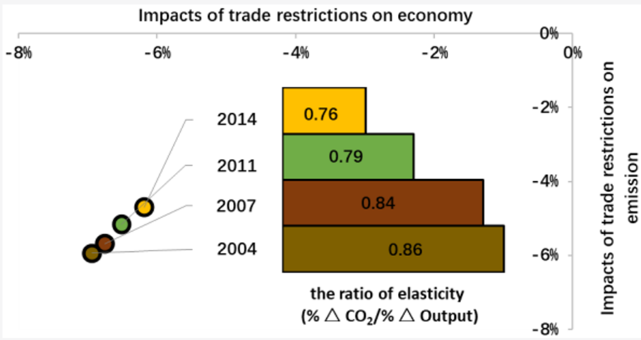
Mingxi Du,*[,β] Qiuyu Liu,[β] Graham K. MacDonald, Yawen Liu, Jintai Lin, Qi Cui, Kuishuang Feng, Bin Chen, Jamiu Adetayo Adeniran, Lingyu Yang, Xinbei Li, Kaiyu Lyu, and Yu Liu*

Cite This: https://doi.org/10.1021/acs.estlett.2c00127

Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Shocks to international trade conditions, such as imposing tariffs, not only affects the global economy but also has substantial implications for carbon emissions. However, it is unclear whether the impact of changes in trade on carbon emissions will be consistent or change over time, as both trade patterns and emission intensity are dynamic in nature. Here, we simulated the economy and carbon dioxide (CO_2) emissions in four representative years from 2004 to 2014 under a free trade scenario and a trade restriction scenario. Our simulations show that trade restrictions would have decreased global emissions by 6.0%, 5.7%, 5.2%, and 4.7% in 2004, 2007, 2011 and 2014; however, restrictions also drove a relative increase in emission intensity for all years. Although more pressure to emit was placed on developing regions with trade development over the study period, the impacts of trade restrictions on CO_2 emissions weakened due to an absolute decrease in emission intensity across regions over time, especially for developing regions. Enabling continued improvements in emission intensity in developing regions by enhancing financial assistance, knowledge sharing, and technology exchange with trade is therefore critical to ensure win-win situations for both economic development and global carbon mitigation.



KEYWORDS: *Carbon dioxide emissions, Trade restrictions, International trade, Emission intensity, Globalization*

■ INTRODUCTION

Trade refers to the production of goods in one region that are consumed in other regions, which has a significant impact on global greenhouse gases and air pollution.[1−5] Recent studies based on empirical trade data show that there are large amounts of carbon dioxide (CO_2), pollution, and premature death associated with trade.[6−12] Additionally, with trade conditions becoming more liberalized or restricted, CO_2 emissions and health impacts are also significantly affected at both the global and regional levels.[13,14] Our previous study[14] based on the trade and emission structures in 2014 indicated that trade restrictions led to a decrease in global CO_2 emissions, if the emission intensity (emissions per monetary output) in each country and each sector is held constant. As trade patterns changed over the years with the emergence of complex global value chains,[15] emission transfers between developed and developing regions increased substantially.[3]

Meanwhile, regional technologies, policies, investments, and even ambitions to reduce emissions have continuously changed.[16−20] This has led to a variety of changes in each country's emission intensity,[21,22] adding yet another complication to the relationship between trade and emissions in the temporal dimension. Therefore, whether the impact of trade restrictions on emissions will be different or consistent over time considering the changes in both the trade pattern and emission intensity is an important question. To answer this question, we simulated the economic changes under a free trade scenario and a trade restriction scenario through the standard Global Trade Analysis Project (GTAP) model and latest database.[23] To further distinguish the relative contributions of both trade pattern and emission intensity, we constructed a series of scenarios with either the trade pattern or emission intensity fixed, alongside the effects of trade restrictions. In this study, we uniquely conducted these simulations across multiple years: 2004, 2007, 2011, and 2014.

■ MATERIALS AND METHODS

For each base year, the economic, trade, and CO_2 emissions data were obtained from the GTAP v 10a database.[23] All economic values are expressed in constant 2014 United States (US) dollar ($) values. The impacts of trade restrictions are

Received: February 21, 2022
Revised: March 29, 2022
Accepted: March 29, 2022

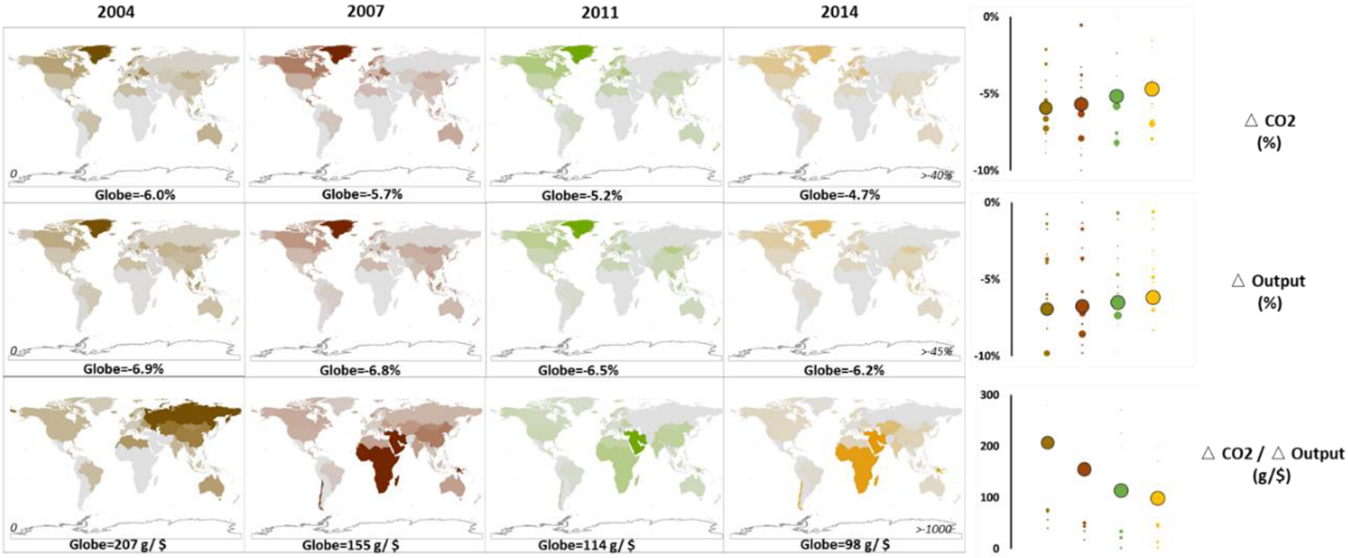


Figure 1. Impact of trade restrictions on CO_2 emissions, economic output, and elasticity over multiple years. The four maps show the relative value changes for each country in each of the four study years; the large dots in the figures on the right show the average global effect for each year across all regions (the smaller dots for each country). The numbers below each row provide the respective highest and lowest values in the maps for that variable (e.g., for △ CO_2, among the four maps, the darkest color corresponds to −40% and the lightest color to 0%).

considered as the gap between the "global free trade" (GFT) scenario and the "global trade barrier" (GTB) scenario, which was set based on our previous study.[13,14] The "actual" scenario represents the real world situation according to the tariff and other economic data in the GTAP v10a database for each corresponding year. Compared with the actual scenario, the GFT scenario represents the whole world with a zero tariff for each commodity and each region, while under the GTB scenario each region imposes an extra 25% tariff on all products imported from all other regions. The imposed tariff value (25%) is derived from the policy of economic sanctions by the United States and China under the Sino-US trade war. The impacts of trade restrictions on the global economy were simulated by the standard GTAP model. The model is a comparative static analysis model that assumes that the market is completely competitive and that the returns to scale of production remain unchanged.[24]

Here, we used all 65 original production sectors and 31 aggregated regions based on the 141 original regions from the latest GTAP database (v10a).[23] The regional aggregation was based on their trade volume, economic volume, and proximity following our previous studies.[13,14] The CO_2 emissions of each sector and each region under the GFT and GTB scenarios were calculated by the GTAP model as the products of simulated changes in economic output and emission intensities based on the emissions and sectoral output of the corresponding base year. As this study focuses on trade impacts, the CO_2 emissions considered here are related to economic production, which means that emissions from noneconomic activities such as residential and private transport are not included. See Table 1 of the Supporting Information for detailed descriptions of the sectors and regions, Table 2 of the Supporting Information for all estimated data, and Figure 1 and the text of the Supporting Information for a discussion of uncertainty and limitations.

■ RESULTS AND DISCUSSION

Impacts of Trade Restrictions across Multiple Years. On the basis of our results (Figure 1 and Table 3 of the Supporting Information), the impacts of simulated trade restrictions (difference between GTB and GFT) decreased global economic output by 6.94% ($4.8 trillion), 6.75% ($6.8 trillion), 6.51% ($9.0 trillion), and 6.19% ($9.7 trillion) in 2004, 2007, 2011, and 2014, respectively, while trade restriction impacts on global CO_2 emissions decreased by 6.0% (996.7 Tg), 5.7% (1060.4 Tg), 5.2% (1018.2 Tg), and 4.7% (953.9 Tg), respectively. Comparing the changes in each year, we can infer that the magnitude of trade effects on both global GDP and CO_2 emissions increased over time, which is associated with the rapid increase in the scale of trade; the value of global trade increased from $9.9 trillion to $20.5 trillion over the study period. However, based on the relative percentage changes over the period, the impacts decreased due to the more rapid growth in global economic output; the share of the trade value in economic output decreased from 14.4% to 13.2%.

The elasticity of emissions to changes in economic output in response to trade restrictions can be used to evaluate the relative impacts on the economy and emissions.[9] On the basis of our results (Figure 1 and Table 3 of the Supporting Information), the ratio of elasticity ($\%\triangle CO_2/\%\triangle$Output) was 0.86, 0.84, 0.79, and 0.76 in 2004, 2007, 2011, and 2014, respectively, and the value of elasticity ($g\triangle CO_2/\$\triangle$Output) was 207 to 155, 114, and 98 g/$, respectively. This observation was substantial for most regions in each year, not only at the global scale. For developing regions like western Asia and sub-Sahara Africa, they tend to have relatively higher elasticities, and for developed regions like European Union and Japan, they tend to have relatively lower elasticities. These characteristics among regions were mainly caused by the following two reasons: different effects of emission intensity gaps between regions on global emissions under trade shocks and different changes in economic output under trade restrictions due to trade patterns arising within complex global supply chains.

https://doi.org/10.1021/acs.estlett.2c00127
Environ. Sci. Technol. Lett. XXXX, XXX, XXX−XXX

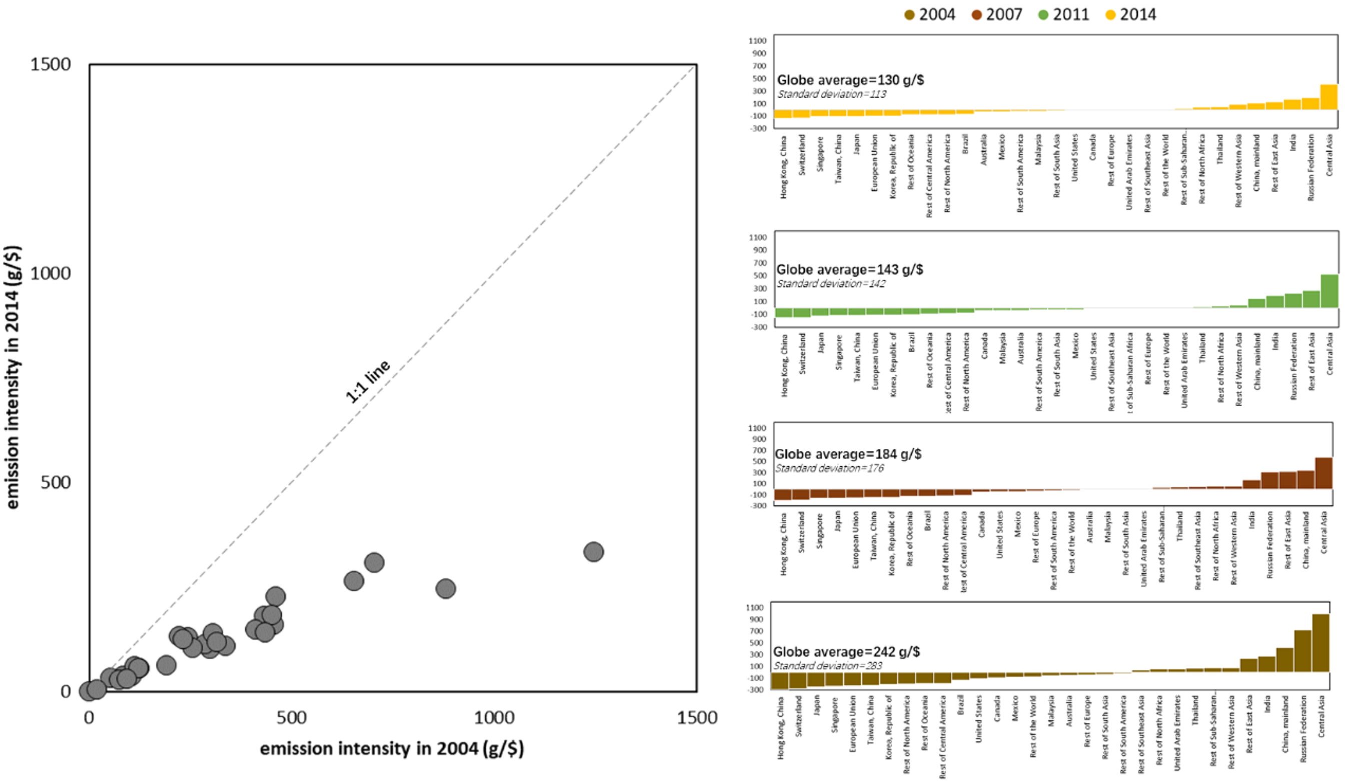


Figure 2. Emission intensity differences between 2004 and 2014, as well as regional changes over multiple years. The left scatterplot shows the absolute emission intensity for each region in 2004 compared to 2014 on a 1:1 scale. Values below the 1:1 line indicate that emission intensity decreased between the two periods. The panels on the right show the global average (weighted) emission intensity for each of the four years, including the deviation in emission intensity ($EI_r - \overline{EI}$) across all regions, highlighting the effects of emission intensity changes of each region over multiple years.

At the global scale, the common characteristic of the ratio of elasticity in each year is that the values are all less than 1.0, which indicates that emissions are less sensitive than the economy to trade restrictions. In line with our previous findings,[13,14] elasticity with a value less than 1.0 is due to the disproportionate impacts on less emission-intensive sectors, such as machinery and equipment products, which are usually more affected by trade fluctuations; on the other hand, there are relatively low impacts on emission-intensive sectors, such as electricity and road transport that are more indirectly involved in trade. Similar to our finding but based on different methods and data, Zhang et al.[21] found that global value chains incorporating international trade reduce global emission intensity by 1.7%. Wood et al.[17] also indicated that trade restrictions and declines in trade volumes do not improve global carbon mitigation even though they reduce the total emissions transfer. Therefore, from the perspective of efficiency, the lower elasticity means that the mitigation benefit from trade restrictions became lower and lower globally.

The weaker impacts of trade restrictions on CO_2 emissions essentially reflect the reduced redistribution effect of trade on emissions among regions. The redistribution effect of trade results in continually changing production among regions with different emission intensities.[13] However, we found that the regional emission intensity showed constant large gaps between regions with different development levels across all years (Table 3 of the Supporting Information). The substantial disparity between developing and developed regions has been reported previously[18,21] and has also been captured here by our results. For example, the CO_2 emission intensities of developed regions, such as Japan (32 g/$) and the EU (36 g/$), are lower than the world average (130 g/$). Meanwhile, developing regions, such as India (308 g/$), and Central Asia (546 g/$), usually have much higher CO_2 emission intensities.

The higher emission intensities of developing regions can be explained by several factors. First, most developed regions have gradually shifted from coal to natural gas and renewable energy, while developing regions are still heavily dependent on coal.[25] Meanwhile, the energy use efficiency of developing regions is much lower than that of developed regions.[26,27] Second, developed regions have transferred domestic production of relatively emission-intensive products to developing regions.[28] Also, considerable technological gap between developing and developed regions also persists for specific sectors.[27,29] Third, a high proportion of infrastructure development in the economy acts as resistance for some developing regions to reduce their higher emission intensity, like building manufacturing infrastructure and transport infrastructure.[18,22,30] Finally, emission regulations in developed regions are generally more stringent and enforced than those in developing regions.[31,32]

Scenarios with Emission Intensity Changed but Trade Pattern Fixed. In a relative sense globally, we found that the gap in emission intensity between regions decreased in the decade between 2004 and 2014 (Figure 2). The global average emission intensity decreased from 242 g/$ in 2004 to 184 g/$ in 2007, then from 143 g/$ in 2011 to 130 g/$ in 2014. The standard deviation of emission intensity across regions also decreased by 60% from 2004 to 2014. Emission

https://doi.org/10.1021/acs.estlett.2c00127
Environ. Sci. Technol. Lett. XXXX, XXX, XXX−XXX

intensity decreased across all regions, with reductions ranging from 39% (lowest) to 73% (highest) by 2014. The rate of decrease for developing regions with higher absolute emission intensities, such as China (72% decrease), was almost 2 times that of developed regions with lower emission intensities, such as Japan (39% decrease). Slowly decreasing carbon intensity in developed regions and rapidly decreasing carbon intensity in developing regions is also reported by Wood et al.[17] based on the EXIOBASE data set. The effort of developing regions by improving their efficiency further helps reduce material demand and its associated emissions.[16]

We quantified the impacts of changes in emission intensity for each region in each year by designing hypothetical scenarios with only the emission intensity changed but the trade pattern fixed for each country to 2004 (Figure 3) compared with the real-world scenario (actual scenario) and further simulated with the additional assumptions of GFT and GTB. Considering that the main effect of trade on global emissions is from the redistribution effect of trade on production, a smaller gap in emission intensity will reduce the impact of trade on emissions worldwide. By comparing the results under GFT and GTB for each year, we deduce the impact of trade restrictions on emissions with only emission intensity changed effects reduced by 997 to 477 Tg from 2004 to 2014, respectively. In a similar vein, under the GTB scenario, the value of elasticity associated with trade restrictions was decreased from 207 to 99 g/$, which is even smaller than that under the actual scenario. In short, the improvement in regional emission intensity under this scenario decreased the influence of trade restrictions on global CO_2 emissions. Wood et al.[17] support our findings that the improved emission intensity in developing regions leads to the stabilization of embodied emissions even with the growth in trade values.

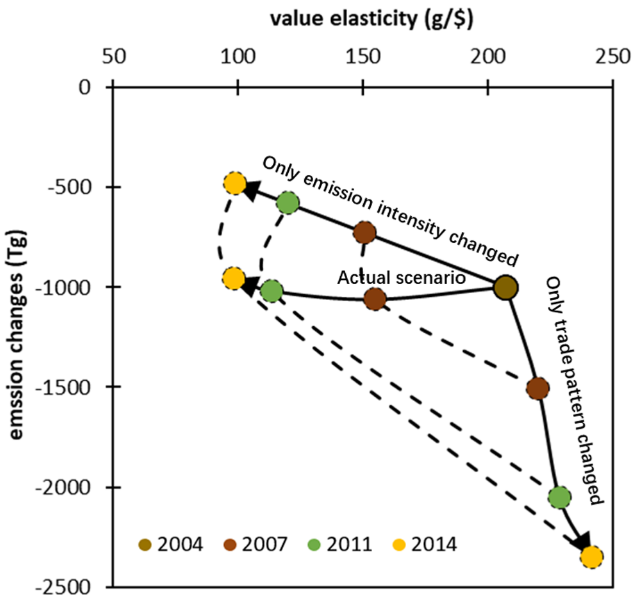


Figure 3. Impacts of trade restrictions on CO_2 emissions in multiple years under different scenarios. The value elasticity of emissions to changes in GDP is calculated by evaluating the relative impacts on the economy and emissions (g$\triangle CO_2$/$\triangle$Output). Scenarios named "only trade pattern changed" represent the trade restrictions with the emission intensity fixed to the value of 2004 for each year. Scenarios named "only emission intensity changed" represent the trade restrictions with the trade pattern fixed to the value of 2004 for each year.

Scenarios with Trade Pattern Changed but Emission Intensity Fixed. While regional emission intensities changed over time, regional trade patterns were also being reconfigured. Several studies have examined the role of consumption and trade in the regional formation attributes to CO_2 emissions.[3,8,21,33] A common finding of these studies is that with the transfer of economic production, especially energy intensive industries, there is an obvious "carbon leakage" embedded in international trade where emissions are displaced.[1] In recent years, the net impact of CO_2 emissions displaced through trade has kept rising,[18] and such patterns result in emission disparities between developing and developed regions.[3,14] While the North−South trade between developing and developed regions remained dominate in recent years,[17] South−South trade between developing regions in the Global South has shown strong growth in this period.[3] Carbon leakage has fostered discussions around producer vs consumer responsibility for regions that emit CO_2 due to the production of goods compared to those that consume the final goods from trade.[34,35]

To quantify the impacts of the trade pattern, for each year, we designed a series of scenarios with only the trade pattern changed but the emission intensity fixed for each country to 2004 (Figure 3), which are similar to hypothetical scenarios mentioned in the Scenarios with Emission Intensity Changed but Trade Pattern Fixed section. Our results showed that from 2004 to 2014, the share of trade value from emission-intensive regions and sectors increased (Figure 2 of the Supporting Information), which could intensify carbon leakage effects. Emission-intensive regions (regions with emission intensities higher than the global average) together contributed 28% of global exports in 2004, with this number gradually increasing to 38% in 2014. Under this scenario, comparing the GFT and GTB for each year, the impact of trade restrictions on emissions with only trade pattern changed effects was changed from 997 to 2347 Tg from 2004 to 2014, respectively, and the value of elasticity was 207 and 242 g/$, respectively. Thus, there was a net increase in emissions globally when trade patterns were allowed to change but emission intensity was fixed. Our results therefore indicated that global trade patterns over the decade of the study developed in such a way that it intensified global emissions, with more carbon leakages occurring compared to the actual scenario. Results from Zhang et al.[21] based on the WIOD and Eora databases also indicated that outsourcing production to developing regions is the main barrier to the decarbonization of global value chains.

In summary, our findings suggest that restrictions on trade and the global economy may be inefficient ways to achieve mitigation targets. Such restrictions may be becoming increasingly ineffective mechanisms to reduce carbon emissions considering the lower and lower efficiency and elasticity of emission mitigation to economic losses. Rather than trying to reduce emissions by trade restriction, enhancing the carbon efficiency of domestic production and consumption is much more effective.[36] If all regions can continue to decrease emission intensity, concerns over increasing emissions due to trade development can be alleviated. Such a double win for the economy and mitigation will require enormous domestic efforts for environmental sustainability as well as strong international support by enhancing financial assistance, knowledge sharing, and technology exchange.[37] Therefore, not only

https://doi.org/10.1021/acs.estlett.2c00127
Environ. Sci. Technol. Lett. XXXX, XXX, XXX−XXX

should trade liberalization be a free trade in commodities between trade partners, but it should also facilitate communication and cooperation among trade partners toward these goals, especially for developing regions receiving support from developed regions.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.estlett.2c00127.

Uncertainty and limitations (text), relative changes in GDP of individual regions from actual to each scenario under trade restriction series test (Figure 1), and share of regions with emission intensity above the global average as a percentage (%) of total global trade in this study (Figure 2)(PDF)

Table 1: detailed descriptions of the sectors and regions (XLSX)

Table 2: all estimated data (XLSX)

Table 3: all summarized data (XLSX)

■ AUTHOR INFORMATION

Corresponding Authors

Mingxi Du − *School of Public Policy and Administration, Xi'an Jiaotong University, Xi'an 710049, China; Department of Geography, McGill University, Montreal H3A 0B9, Canada;* orcid.org/0000-0002-6831-4255; Email: dumingxi28@xjtu.edu.cn

Yu Liu − *Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China; School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China*; Email: liuyu@casipm.ac.cn

Authors

Qiuyu Liu − *Department of Biological Sciences, University of Quebec at Montreal, Montreal H3C 3P8, Canada*

Graham K. MacDonald − *Department of Geography, McGill University, Montreal H3A 0B9, Canada*

Yawen Liu − *Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China; School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China*

Jintai Lin − *Laboratory for Climate and Ocean-Atmosphere Studies, Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, Beijing 100871, China;* orcid.org/0000-0002-2362-2940

Qi Cui − *School of Economics and Resource Management, Beijing Normal University, Beijing 100875, China*

Kuishuang Feng − *Department of Geographical Sciences, University of Maryland, College Park, Maryland 20742, United States;* orcid.org/0000-0001-5139-444X

Bin Chen − *Fudan Tyndall Center, Department of Environmental Science & Engineering, Fudan University, Shanghai 200438, China*

Jamiu Adetayo Adeniran − *Environmental Engineering Research Laboratory, Department of Chemical Engineering, University of Ilorin, Ilorin 240003, Nigeria*

Lingyu Yang − *Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China; School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China*

Xinbei Li − *Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, China; School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China*

Kaiyu Lyu − *Institute of Agricultural Economics and Development, Chinese Academy of Agricultural Sciences, Beijing 100081, China*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.estlett.2c00127

Author Contributions

[β]M. Du and Q. Liu contributed equally to this work.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was supported by the Youth Talent Fund (11302291010701) from Xi'an Jiaotong University, the National Natural Science Foundation of China (72125010 and 71974186), the National Natural Science Foundation of China (NSFC)-CGIAR Cooperation Program (71761147004), and the Trottier Institute for Science and Public Policy (TISPP) at McGill University. G.K.M. acknowledges support from the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants program (RGPIN-2016-04920).

■ REFERENCES

(1) Peters, G. P.; Hertwich, E. G. CO2 Embodied in International Trade with Implications for Global Climate Policy. *Environ. Sci. Technol.* **2008**, *42* (5), 1401−1407.

(2) Hertwich, E. G.; Peters, G. P. Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environ. Sci. Technol.* **2009**, *43* (16), 6414−6420.

(3) Meng, J.; Mi, Z.; Guan, D.; Li, J.; Tao, S.; Li, Y.; Feng, K.; Liu, J.; Liu, Z.; Wang, X.; Zhang, Q.; Davis, S. J. The rise of South−South trade and its effect on global CO 2 emissions. *Nat. Commun.* **2018**, *9* (1), 1−7.

(4) Caldeira, K.; Davis, S. J. Accounting for carbon dioxide emissions: A matter of time. *Proc. Natl. Acad. Sci. U. S. A.* **2011**, *108* (21), 8533−8534.

(5) Simas, M.; Wood, R.; Hertwich, E. Labor embodied in trade: The role of labor and energy productivity and implications for greenhouse gas emissions. *Journal of Industrial Ecology* **2015**, *19* (3), 343−356.

(6) Lin, J.; Pan, D.; Davis, S. J.; Zhang, Q.; He, K.; Wang, C.; Streets, D. G.; Wuebbles, D. J.; Guan, D. China's international trade and air pollution in the United States. *Proc. Natl. Acad. Sci. U. S. A.* **2014**, *111* (5), 1736−1741.

(7) Zhang, Q.; Jiang, X.; Tong, D.; Davis, S. J.; Zhao, H.; Geng, G.; Feng, T.; Zheng, B.; Lu, Z.; Streets, D. G.; Ni, R.; Brauer, M.; van Donkelaar, A.; Martin, R. V.; Huo, H.; Liu, Z.; Pan, D.; Kan, H.; Yan, Y.; Lin, J.; He, K.; Guan, D. Transboundary health impacts of transported global air pollution and international trade. *Nature* **2017**, *543* (7647), 705.

(8) Davis, S. J.; Caldeira, K. Consumption-based accounting of CO2 emissions. *Proc. Natl. Acad. Sci. U.S.A.* **2010**, *107* (12), 5687−5692.

(9) Oita, A.; Malik, A.; Kanemoto, K.; Geschke, A.; Nishijima, S.; Lenzen, M. Substantial nitrogen pollution embedded in international trade. *Nature Geoscience* **2016**, *9*, 111.

(10) Lin, J.; Tong, D.; Davis, S.; Ni, R.; Tan, X.; Pan, D.; Zhao, H.; Lu, Z.; Streets, D.; Feng, T.; Zhang, Q.; Yan, Y.; Hu, Y.; Li, J.; Liu, Z.; Jiang, X.; Geng, G.; He, K.; Huang, Y.; Guan, D. Global climate forcing of aerosols embodied in international trade. *Nature Geoscience* **2016**, *9* (10), 790.

(11) Wang, X.-T.; Liu, H.; Lv, Z.-F.; Deng, F.-Y.; Xu, H.-L.; Qi, L.-J.; Shi, M.-S.; Zhao, J.-C.; Zheng, S.-X.; Man, H.-Y.; He, K.-B. Trade-linked shipping CO2 emissions. *Nature Climate Change* **2021**, *11* (11), 945−951.
(12) Liu, H.; Meng, Z.-H.; Lv, Z.-F.; Wang, X.-T.; Deng, F.-Y.; Liu, Y.; Zhang, Y.-N.; Shi, M.-S.; Zhang, Q.; He, K.-B. Emissions and health impacts from global shipping embodied in US−China bilateral trade. *Nature Sustainability* **2019**, *2* (11), 1027−1033.
(13) Du, M.; Chen, L.; Lin, J.; Liu, Y.; Feng, K.; Liu, Q.; Liu, Y.; Wang, J.; Ni, R.; Zhao, Y.; Si, W.; Li, Y.; Kong, H.; Weng, H.; Liu, M.; Adeniran, J. A. Winners and losers of the Sino−US trade war from economic and environmental perspectives. *Environmental Research Letters* **2020**, *15* (9), 094032.
(14) Lin, J.; Du, M.; Chen, L.; Feng, K.; Liu, Y.; Martin, R. V.; Wang, J.; Ni, R.; Zhao, Y.; Kong, H.; Weng, H.; Liu, M.; van Donkelaar, A.; Liu, Q.; Hubacek, K. Carbon and health implications of trade restrictions. *Nat. Commun.* **2019**, *10* (1), 4947.
(15) Hertwich, E. G. Carbon fueling complex global value chains tripled in the period 1995−2012. *Energy Economics* **2020**, *86*, 104651.
(16) Hertwich, E. G. Increased carbon footprint of materials production driven by rise in investments. *Nature Geoscience* **2021**, *14* (3), 151−155.
(17) Wood, R.; Grubb, M.; Anger-Kraavi, A.; Pollitt, H.; Rizzo, B.; Alexandri, E.; Stadler, K.; Moran, D.; Hertwich, E.; Tukker, A. Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers. *Climate Policy* **2020**, *20* (sup1), S14−S27.
(18) Wood, R.; Stadler, K.; Simas, M.; Bulavskaya, T.; Giljum, S.; Lutter, S.; Tukker, A. Growth in Environmental Footprints and Environmental Impacts Embodied in Trade: Resource Efficiency Indicators from EXIOBASE3. *Journal of Industrial Ecology* **2018**, *22* (3), 553−564.
(19) Tollefson, J. Can Joe Biden make good on his revolutionary climate agenda? *Nature* **2020**, *588*, 545.
(20) Normile, D. Can China, the world's biggest coal consumer, become carbon neutral by 2060? *Science* **2020**, DOI: 10.1126/science.abf0377.
(21) Zhang, D.; Wang, H.; Löschel, A.; Zhou, P. The changing role of global value chains in CO2 emission intensity in 2000−2014. *Energy Economics* **2021**, *93*, 105053.
(22) Lamb, W. F.; Wiedmann, T.; Pongratz, J.; Andrew, R.; Crippa, M.; Olivier, J. G. J.; Wiedenhofer, D.; Mattioli, G.; Khourdajie, A. A.; House, J.; Pachauri, S.; Figueroa, M.; Saheb, Y.; Slade, R.; Hubacek, K.; Sun, L.; Ribeiro, S. K.; Khennas, S.; de la Rue du Can, S.; Chapungu, L.; Davis, S. J.; Bashmakov, I.; Dai, H.; Dhakal, S.; Tan, X.; Geng, Y.; Gu, B.; Minx, J. A review of trends and drivers of greenhouse gas emissions by sector from 1990 to 2018. *Environmental Research Letters* **2021**, *16* (7), 073005.
(23) Aguiar, A.; Chepeliev, M.; Corong, E. L.; McDougall, R.; van der Mensbrugghe, D. The GTAP Data Base: Version 10. *Journal of Global Economic Analysis* **2019**, *4* (1), 1.
(24) Hertel, T. W. *Global Trade Analysis: Modeling and Applications*; Cambridge University Press: Cambridge, England, 1997.
(25) Quadrelli, R.; Peterson, S. The energy−climate challenge: Recent trends in CO2 emissions from fuel combustion. *Energy Policy* **2007**, *35* (11), 5938−5952.
(26) Farquharson, D.; Jaramillo, P.; Samaras, C. Sustainability implications of electricity outages in sub-Saharan Africa. *Nature Sustainability* **2018**, *1* (10), 589−597.
(27) Wu, Y.; Zhang, L. Can the development of electric vehicles reduce the emission of air pollutants and greenhouse gases in developing countries? *Transportation Research Part D Transport & Environment* **2017**, *51*, 129−145.
(28) Jakob, M.; Marschinski, R. Interpreting trade-related CO2 emission transfers. *Nature Climate Change* **2013**, *3*, 19.
(29) Du, Y.; Ge, Y.; Ren, Y.; Fan, X.; Pan, K.; Lin, L.; Wu, X.; Min, Y.; Meyerson, L. A.; Heino, M.; Chang, S. X.; Liu, X.; Mao, F.; Yang, G.; Peng, C.; Qu, Z.; Chang, J.; Didham, R. K. A global strategy to mitigate the environmental impact of China's ruminant consumption boom. *Nat. Commun.* **2018**, *9* (1), 4133.
(30) Guan, D.; Klasen, S.; Hubacek, K.; Feng, K.; Liu, Z.; He, K.; Geng, Y.; Zhang, Q. Determinants of stagnating carbon intensity in China. *Nature Climate Change* **2014**, *4* (11), 1017−1023.
(31) Geng, Y.; Wei, Y. M.; Fischedick, M.; Chiu, A.; Chen, B.; Yan, J. Recent trend of industrial emissions in developing countries. *Applied Energy* **2016**, *166*, 187−190.
(32) Oliva, P. Environmental regulations and corruption: automobile emissions in Mexico city. *Journal of Political Economy* **2015**, *123* (3), 686−724.
(33) Peters, G. P.; Minx, J. C.; Weber, C. L.; Edenhofer, O. *Growth in emission transfers via international trade from 1990 to 2008* **2011**, *108* (21), 8903−8908.
(34) Shue, H. J. I. a. Global environment and international inequality. *International Affairs* **1999**, *75* (3), 531−545.
(35) Guan, D.; Lin, J.; Davis, S. J.; Pan, D.; He, K.; Wang, C.; Wuebbles, D. J.; Streets, D. G.; Zhang, Q. Reply to Lopez et al.: Consumption-based accounting helps mitigate global air pollution. *Proc. Natl. Acad. Sci. U.S.A.* **2014**, *111* (26), E2631−E2631.
(36) Wood, R.; Neuhoff, K.; Moran, D.; Simas, M.; Grubb, M.; Stadler, K. The structure, drivers and policy implications of the European carbon footprint. *Climate Policy* **2020**, *20* (sup1), S39−S57.
(37) Akimoto, K.; Sano, F.; Homma, T.; Oda, J.; Nagashima, M.; Kii, M. Estimates of GHG emission reduction potential by country, sector, and cost. *Energy Policy* **2010**, *38* (7), 3384−3393.