IOP Publishing Environ. Res. Lett. 15 (2020) 094032 https://doi.org/10.1088/1748-9326/aba3d5

Environmental Research Letters

OPEN ACCESS

RECEIVED
12 March 2020

REVISED
9 June 2020

ACCEPTED FOR PUBLICATION
8 July 2020

PUBLISHED
21 August 2020

LETTER

Winners and losers of the Sino–US trade war from economic and environmental perspectives

Mingxi Du[1,11], Lulu Chen[1,11], Jintai Lin[1], Yu Liu[2,3], Kuishuang Feng[4,5], Qiuyu Liu[6], Yawen Liu[2,3], Jingxu Wang[1], Ruijing Ni[1], Yu Zhao[7], Wei Si[8], Ying Li[9], Hao Kong[1], Hongjian Weng[1], Mengyao Liu[10] and Jamiu Adetayo Adeniran[1]

1 Laboratory for Climate and Ocean-Atmosphere Studies, Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, Beijing 100871, People's Republic of China
2 Institutes of Science and Development, Chinese Academy of Sciences, Beijing 100190, People's Republic of China
3 School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
4 Institute of Blue and Green Development, Shandong University, Weihai 264209, People's Republic of China
5 Department of Geographical Sciences, University of Maryland, College Park, MD, 20742, United States of America
6 Department of Biological Sciences, University of Quebec at Montreal, Montreal H3C 3P8, Canada
7 School of the Environment, Nanjing University, 163 Xianlin Ave, Nanjing 210046, People's Republic of China
8 College of Economics and Management, China Agricultural University, Beijing 100083, People's Republic of China
9 China Animal Disease Control Center, Beijing 102600, People's Republic of China
10 Royal Netherlands Meteorological Institute, De Bilt, The Netherlands
11 These authors contributed equally to this work

E-mail: linjt@pku.edu.cn **and** liuyu@casipm.ac.cn

Keywords: air pollution, atmospheric transport, international trade

Supplementary material for this article is available online

Abstract

The ongoing trade war between the United States and China is having profound impacts on the global economy. As recent studies have found substantial amounts of carbon dioxide and air pollution embedded in the global supply chains, the Sino–US trade war may also affect emissions and health burdens worldwide, which remains poorly understood. Here, we estimate the potential changes in gross domestic product (GDP), anthropogenic emissions and particulate matter ($PM_{2.5}$) related premature deaths worldwide under two Sino–US trade war scenarios. We find that for the US and China, the trade war would reduce their GDP and, less significantly, emissions and mortality, suggesting that the trade war is not an effective means of environmental protection. The trade war would increase both GDP and mortality in many developing regions, because of their increased production of goods targeted in the Sino–US trade war. Surprisingly, Western Europe and Latin America and Caribbean would have higher GDP but lower emissions and mortality, an economic and environmental win-win outcome as a net result of the complex changes in the global supply chains. Neighbour regions of the US and China such as Canada, Japan and Korea would also have higher GDP but lower mortality, because of reduced atmospheric transboundary transport from the US and China overcompensating for increased local emissions of these neighbours. The complex consequences of the Sino–US trade war highlight the strong inter-regional and economic-environmental linkage in support of a global collaborative strategy to foster economic growth and environmental protection.

1. Introduction

The on-going trade war between China and the United States has attracted world attention with a series of escalating trade disputes and potential aggravation to the full-blown stage at which tariffs are imposed on all products imported from the other country. Such trade shocks not only affect economic output but also carbon dioxide (CO_2), pollution and health, because large quantities of emissions and pollution are embedded in traded products [1–6]. The impacts of trade war are worldwide, because other countries are tied to the two belligerents through the global supply chains [7, 8] and atmospheric transboundary transport [1, 9]. Many empirical studies have measured the economic impacts of the Sino–US trade war [10–12]. Our previous study has analysed the impact of trade restrictions on the global environment and health [13]. Yet little is known about what extent the trade war has positive or negative impacts on each region (especially on indirectly involved regions), and whether the environmental and economic effects are consistent or contrasting in sign.

Here we assess the impacts of Sino–US trade war on gross domestic product (GDP), emissions and particulate matter ($PM_{2.5}$) related premature mortality worldwide. Unlike our previous study [13], which focuses on the global environmental and health impacts as a whole, this study focuses on the direct and indirect regional economic-environmental consequences of the Sino–US trade war, with a particular focus on how the economy and environment of other regions may suffer/benefit from the Sino–US trade through the diversion effect of trade and the spillover effect of air pollution. We take an interdisciplinary approach that integrates the latest Global Trade Analysis Project (GTAP v10) Computable General Equilibrium model (CGE) [14–16] for global trade and economy, inventories of CO_2 and pollutant emissions [17–21], the GEOS-Chem atmospheric chemical transport model [22], a satellite-based dataset for near-surface $PM_{2.5}$ mass concentrations [23], and the Global Exposure Mortality Model (GEMM) [24] for pollution-health assessment. The detailed description and uncertainty analysis can be found in our previous study [13].

2. Method

We design two trade war scenarios with different magnitudes of tariff, in comparison with a BASE scenario with no trade war. Scenario TW1 represents the extent of the trade war by the end of 2018. Here, the US imposes additional tariffs on about $250 billion worth of products imported from China [25–27], while China imposes additional tariffs on about $110 billion worth of products from the US [28, 29]. Scenario TW2 represents a potential full-blown stage of the trade war at which the two countries impose an additional 25% tariff on every product imported from the other country. Until 2020, the Sino–US trade war has been escalating [30, 31]. Although the trade war tension has been partially alleviated by a Phase One agreement in early 2020 [32, 33], the TW1 related tariffs remain imposed and the exact future direction of trade war remains unclear.

Following our previous study, we consider trade and emissions of 31 regions and 20 sectors (see supplementary Data 3 in Lin *et al* [13]). For subsequent GEOS-Chem and GEMM models, the 31 regions are further aggregated to 13 to reduce the computational costs (see supplementary figure 1 (available online at stacks.iop.org/ERL/15/094032/mmedia)). The BASE scenario uses economic, trade, and emission data in 2014 (the latest year with all available necessary data) from the GTAP database and emission inventories. For TW1 and TW2, emissions in each sector are calculated as the product of sectoral output simulated by the GTAP CGE and emission intensities (*i.e.* emission per monetary output) calculated based on the emissions and sectoral output in BASE. Direct GEOS-Chem simulations are performed for BASE to obtain $PM_{2.5}$ concentrations. For $PM_{2.5}$ in TW1 and TW2, emissions are multiplied by chemical efficiencies (*i.e.* ambient concentration per unit emission; component specific) calculated from BASE. We further use a satellite-based $PM_{2.5}$ dataset together with the BASE modelled $PM_{2.5}$ concentrations to obtain scaling factors to adjust $PM_{2.5}$ in each trade scenario, such that the system bias of GEOS-Chem simulations is eliminated (see supplementary figure 10 in Lin *et al* [13]). We do not analyse emissions that are not directly related to economic output and thus are trade scenario-independent (*i.e.* from residential, international shipping and private vehicle), although they are included in GEOS-Chem simulations. $PM_{2.5}$ components analysed here include secondary inorganic aerosols (including sulphate, nitrate and ammonium), black carbon and primary organic aerosols.

3. Results and discussion

From BASE to TW1, the global GDP is reduced by 0.1% and mortality by 0.07%. The reductions are larger under TW2 (0.4% and 0.09% respectively). Hereafter, we focus on the regional impacts of the Sino–US trade war. We divide the 13 regions to four groups depending on their relative changes on their GDP and $PM_{2.5}$ related premature deaths under TW1 and TW2 comparing with BASE scenario (figure 1), including those with better health and better economy (BHBE), with better health but worse economy (BHWE), with worse health but better economy (WHBE), and with worse health and worse economy (WHWE). We do not discuss the case of WHWE, which only occurs in South Asia (mainly India) from BASE to TW1 with little changes in both GDP and mortality (below 0.05%). Quantitative changes in GDP and pollutant emissions in each region are detailed in supplementary table 1.

3.1. Regions with better health but worse economy (BHWE)

Compared with the BASE scenario, the Sino–US trade war leads to substantial reductions in GDP and pollution of China and the United States. China's GDP is decreased by 71.4 million US Dollar (0.6%) under Scenario TW1, and by 136.1 million (1.2%) if the trade war escalates to the full-blown stage (Scenario TW2). The number of premature mortality in

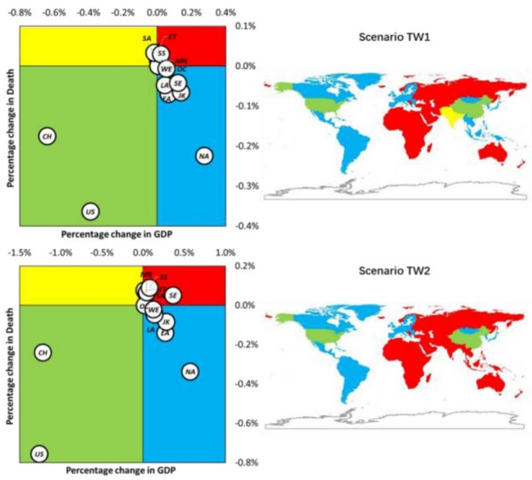

Figure 1. Diverse changes in GDP and mortality under the Sino–US trade war. All changes are relative to the BASE scenario. The 13 regions are divided into four groups: ‘BHBE’ (with better health and better economy, blue), ‘BHWE’ (with better health but worse economy, green), ‘WHBE’ (with worse health but better economy, red) and ‘WHWE’ (with worse health and worse economy, yellow). Regions here include China (CH), rest of East Asia (EA), economies in transition (ET), Japan and Korea (JK), Latin America and Caribbean (LA), Middle East and North Africa (MN), rest of North America (NA), Oceania (OC), South Asia (SA), South-East Asia and Pacific (SE), Sub-Saharan Africa (SS), the United States (US), and Western Europe (WE).

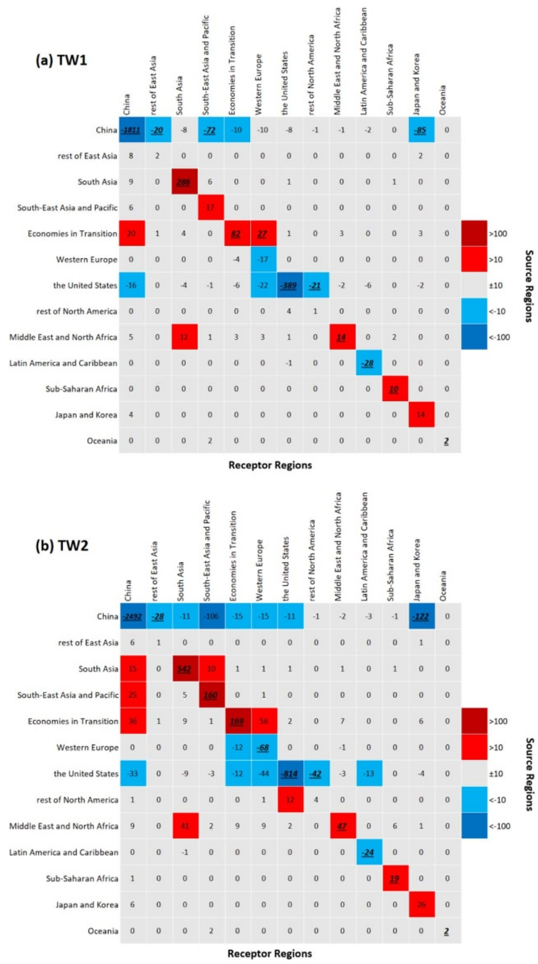

Figure 2. Changes in premature deaths worldwide in response to emission changes in each source region from BASE to (a) TW1 and (b) TW2. A bolded, underlined number for each column denotes the largest contribution to premature deaths of each receptor region.

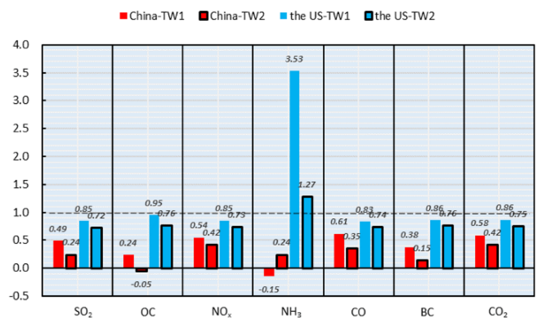

Figure 3. Elasticity of emissions to GDP change from BASE to TW1 and TW2.

China is decreased by 1774 (0.18%) under TW1 and 2425 (0.24%) under TW2. For the United States, the GDP and mortality reductions are also substantial: by 67.3 million (0.4%) and 392 (0.36%) in TW1 and by 218.5 million (1.3%) and 807 (0.76%) in TW2. Correspondingly, emissions of almost all pollutants are decreased in the United States (by up to 1.4% under TW1 and 1.6% under TW2) and China (by up to 0.4% and 0.5%, respectively). The BHWE result is because the trade war leads to reduced economic production and associated emissions of both countries. This effect is only partially compensated by the increase in atmospheric transboundary transport from other regions whose economic production and associated emissions are enhanced (figure 2).

Figure 3 shows the elasticity of emission to GDP change in response to the trade war, which represents the magnitude of relative change in emission associated with a 1% GDP change. For all pollutants except ammonia, the elasticity is smaller than 1 for both countries, that is, emissions are less sensitive to the trade war than GDP is. Furthermore, the elasticity decreases with the aggravation of the trade war from TW1 to TW2. This is because for these non-ammonia pollutants, economic sectors with a high emission intensity, such as Electricity and Road transport, usually do not directly produce goods for trade and are thus less sensitive to trade wars. By comparison, sectors with a low emission intensity, such as Transport Equipment and Leather products, often produce goods directly for trade and are more susceptible to trade restrictions. This effect is intensified with the increasing extent of trade war, leading to decreased elasticities from TW1 to TW2. Thus trade wars are not an effective means to protect the environment of the belligerents.

For all pollutants, the emission elasticities of China are smaller than those of the US. This is because the most affected sectors in China are mainly manufacturing sectors (such as Transport Equipment) with lower emission intensities than the most affected sectors in the US. The most notable example is ammonia emissions, for which the elasticity to GDP reduction is smaller than 1 for China and much greater than 1 for the US. This is because ammonia is emitted mainly from agricultural sectors, which are the main targets of China' counter actions against the US in the trade war. In contrast, the US imposes border taxes mainly on manufacturing sectors, with a weaker effect on ammonia emissions. More details of sectoral changes are shown in supplementary figure 2.

3.2. Regions with worse health but better economy (WHBE)

From the BASE scenario to TW1, four out of the 13 regions exhibit increased GDP and mortality, including South Asia (mainly India), Economies in Transition, Sub-Saharan Africa and Middle East and North Africa. Under the full-blown stage of trade war (TW2), South-East Asia and Pacific becomes an additional WHBE region. The increased GDP is because both the US and China increase imports from these WHBE regions to substitute the goods previously imported from each other, resulting in an import diversion effect. Among all WHBE regions, the GDP is increased by up to 0.33% in TW1 and 0.63% in TW2, which results in higher pollutant emissions by up to 0.41% and 1.07%, respectively. The increased emissions subsequently lead to more premature deaths, even though this effect is partially offset by the decreased transboundary transport from the US and China (figure 2). Besides, the health burden of these regions will also be affected by each other at certain degrees. For example, the increased emissions in the Middle East would lead to higher premature deaths in South Asia, due to the pollution atmospheric transport from Middle East and the relatively higher baseline mortality in the South Asia.

3.3. Regions with better health and better economy (BHBE)

Surprisingly, 6 out of the 13 regions achieve such an economic-environmental win-win outcome under TW1 compared to BASE, including Western Europe, the rest of North America (mainly Canada), Japan and Korea, South-East Asia and Pacific, Latin America and the Caribbean, and the rest of East Asia. Economically, these regions benefit from increased production of goods to be imported by the US and China through the aforementioned import diversion effect, which alone lead to higher mortality. Yet the reduction in their premature deaths is caused by other factors: the export diversion effect, indirect export restriction and the lessened atmospheric transboundary transport from the US and China.

For Western Europe (under TW2) and Latin America and the Caribbean (under TW1 and TW2), the mortality reduction is caused in part by an export diversion effect, that is, the US and China export to these BHBE regions more goods which would have been traded between the belligerents had the trade war not occurred. As a result, these BEBE regions do not produce as many goods and associated pollution themselves. For example, the European Union, the major region of Western Europe and one of the 31 regions simulated in GTAP, is the largest trade partner of China and the US. Due to the increased export of mineral products from both China (by 4.6% for TW1 and 11.1% for TW2) and the US (by 0.4% and 0.5%, respectively) to the European Union, the output of mineral goods in the European Union declines (by 0.1% and 0.2%, respectively), which further leads to reductions in associated emissions.

A second cause of the mortality reductions in Western Europe and Latin America and the Caribbean is an indirect export restriction associated with inter-sectoral and inter-regional connections. The tariffs imposed by the US and China indirectly reduce production of many sectors providing intermediate inputs for the trade war-targeted sectors, and such intermediate production often occurs in regions outside the two belligerents. Without the trade war, the US would import $36.3 billion worth of goods from the Mineral sector in Mexico (the major country of Latin America and the Caribbean), accounting for 72% of Mexico's total mineral export. The trade war reduces the production of mineral related sectors in the US, and subsequently its import of minerals from Mexico (by 3.0% for TW1 and 6.1% for TW2). As a result, production of the Mineral sector in Mexico is reduced by 1.7% for TW1 and 3.4% for TW2.

For other BHBE regions (North America, Japan and Korea, South-East Asia and Pacific, and the rest of East Asia), which are all geographic neighbours of the belligerents, the trade war-associated mortality reduction is mainly due to lessened atmospheric transboundary transport from the US and China. Because the US and especially China are major pollutant emitters, their emission reductions lead to substantial declines in the magnitude of transboundary pollution to the nearby BHBE regions. This effect more than offsets that of increased economic production and emissions in these BHBE regions. In particular, the decrease in mortality impact from China to Japan and Korea is higher than the increase due to Japanese and Korean emissions by a factor of 5.8 under TW1 and 4.5 under TW2. Similarly, the decreased contribution from the United States to the rest of North America (mainly Canada) exceeds the increased contribution from the rest of North American emissions by a factor of 10 and 8.2 under TW1 and TW2, respectively.

3.4. Discussion

When moving from the BASE scenario to TW2, the export volumes of China and the US to each other would decrease by 70% and 74%, respectively. This means that there are still trade activities between these two countries. If the trade war would escalate to the extent that a 100% additional tariff (rather than 25%) is imposed to each product traded between the two countries, the bilateral trade activities would be virtually banned – in other words, the export volumes would be decreased by 98% for both countries. As a result, China would experience reductions in GDP, CO_2 emission and mortality by 1.89%, 0.72% and 0.29%, respectively, compared to the BASE scenario. The US would experience larger reductions by 2.27%, 1.51% and 0.96%. We also examine the economic and environmental changes due to other levels of Sino–US trade war (*i.e.* 50% or 200% additional tariff). All scenarios together suggest monotonic responses of GDP, CO_2 emission and mortality to the increasing severity of trade war, so are the economic and environmental spillover effects on other regions (supplementary figures 3 and 4 and supplementary tables 2 and 3). As expected, the economic and environmental effects become saturated when the additional tariff exceeds 100%.

Detailed discussion of our methodological uncertainties is presented in Lin *et al* [13]. Briefly, the GTAP CGE does not simulate the dynamic evolution of the economies. However, our estimated economic effects for the United States, China and the world at different trade war stages are consistent with other studies that use different estimation approaches (see supplementary table 1 in Lin *et al* [13]). We assume constant sectoral emission intensities across all scenarios, although the overall emission intensity (combining all sectors) varies with the change in sectoral output structure. GEOS-Chem simulations are affected by errors in the representation of atmospheric chemical and physical mechanisms, although we use satellite-based $PM_{2.5}$ data to correct for systemic model biases. We do not consider anthropogenic secondary organic aerosols, which contribute less than 10% of $PM_{2.5}$ globally [34, 35]. We also exclude the effects of trade wars on other pollutants and their associated mortality, although there may be inter-connections between individual pollutants, such as a complicated anti-correlation between $PM_{2.5}$ and ozone [36, 37]. The use of chemical efficiencies for TW1 and TW2 introduces a slight additional error related to the weak chemical nonlinearity and the minor cross-scenario differences in emission spatial pattern. The GEMM pollution-health model does not account for the different toxicities of individual $PM_{2.5}$ components. Since we focus on the relative changes from one trade scenario to another, systematic errors from these aspects are not important. This is true particularly given the monotonic responses of GDP, CO_2 emission and mortality to the increasing severity of Sino–US trade war.

4. Conclusion

The economic globalization and atmospheric transport mean that regions' economies and environments are highly inter-connected. Perturbations to regional economies such as the ongoing Sino–US trade war would have important and often unforeseen consequences on the targeted economic sectors and their related sectors along the supply chains, on the targeted countries and their trade partners, and on the associated pollution worldwide. To better foster economic development and environmental protection, a broader view beyond unilateral and bilateral on economic-environmental issues may be taken. In addition to focusing on their own environmental management [38–42], countries like the US and China have the opportunity to demonstrate their economic and environmental leadership by improving their bilateral dialogs and collaborations and by incorporating other stakeholder regions. To this end, our study provides an example of the direct and indirect economic-environmental consequences of bilateral trade wars and disputes. In the long run, economic entities designing trade strategies under globalization should pay more attention to the linkage between economy and environment, the diversion effect of trade, and the transboundary spillover effect of air pollution.

Acknowledgments

This study is supported by the National Natural Science Foundation of China (41775115), the National Natural Science Foundation of China (71974186) and the National Key Research and Development Program of China (2016YFA0602500).

Author contributions

JL and MD conceived the research. JL, YL and MD designed the research. MD, LC and YL performed the research with inputs from QL, JW, RN, Yawen L, WS, Ying L., HK, HW, ML and YZ. MD and JL led the writing with inputs from K.F., KF, JAA and LC. All authors discussed the results and commented on the manuscript.

Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID iDs

Mingxi Du
https://orcid.org/0000-0002-6831-4255
Lulu Chen
https://orcid.org/0000-0002-8929-3414
Jintai Lin
https://orcid.org/0000-0002-2362-2940

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