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Article

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Abstract

The 2030 Agenda for Sustainable Development pursues 17 sustainable development goals (SDGs), the achievement of which may be influenced by a country's role in global supply chains and position in international trade patterns. Global trade changes constantly with an increasing share of flows between developing countries. However, little is known about the impacts of change in trade on multi-dimensions of sustainable development at both global and country levels. Here we assess how structural change in trade during three time periods, between 2004 and 2014, impact 13 SDG indicators in 141 countries or regions. We find that socio-economic indicators (e.g., high- and medium-skilled labor, GDP) are less sensitive to change in trade, compared with resource and environmental indicators (e.g., water consumption, GHG emissions). Moreover, change in trade aggravated inequality among countries. The number of indicators that significantly worsened by change in trade decreased from eight indicators (2004-2007) to one (2011-2014) for high-income and upper-middle-income countries, but increased from five to fourteen for lower-middle-income and low-income countries. Furthermore, change in trade led to a coupling of value added with most resource and environmental indicators for low-income countries, while strengthening decoupling or reducing coupling for other countries.

Keywords: SDGs, Global Trade, Structural Change, Decoupling, Inequality, Input-output, Decomposition

Introduction

In 2015, 193 nations committed to the 2030 Agenda for Sustainable Development, announcing 17 sustainable development goals (SDGs) with 169 associated targets. The goals and targets will guide future human activities in three interconnected and indivisible sustainable dimensions, related to economic, social, and environmental aspects of development (UN, 2015). The achievement of the SDGs may be affected by international trade patterns given that international trade leads to massive geospatial transfer of not only economic benefits, but also social and environmental burdens, with 10% to 70% of economic, social, and environmental impacts being embodied in trade (Wiedmann and Lenzen, 2018). These trade patterns are subject to change driven by changes in technology, demand, prices, and other global forces (Lund et al., 2019). For example, most recently, we could observe the relocation of the early production stages in the global value chains being relocated from China and India to lower income economies, especially after the global financial crisis in 2008 (Meng et al., 2018). The increasing share of flows between developing countries has led to worldwide changes in employment and environmental burden because developing countries tend to have relatively low labor productivity, production efficiency, and lower levels of environmental regulation, monitoring and enforcement (Wiedmann and Lenzen, 2018). In addition, this reorganization of global trade has posed noticeable impacts on each component of sustainable development, for instance, contributed to an uneven distribution of material extraction (Schaffartzik et al., 2019), land use (Prell et al., 2017), and income (Bensidoun et al., 2011), between and within countries (Mi et al., 2017).

A large number of previous studies evaluated environmental pollution or resource extraction embodied in international trade, but the scope is usually limited to a specific aspect of sustainable development, such as, greenhouse gas (GHG) emissions (Chen et al., 2018), land (Yu et al., 2013), human appropriation of net primary productivity (Dorninger et al., 2021), particulate matter (PM) emissions (Tessum et al., 2019), water pollution (Oita et al., 2016), and associated health implications (Lin et al., 2019). A few studies incorporated multiple indicators, but with less focus on lower income countries (Tukker et al., 2016) or were limited to a specific region (Yang et al., 2020). For example, Xu et al. (2020) evaluated the impacts of international trade on achieving nine environmental SDGs for 40 countries, but lower income countries were highly aggregated and socio-economic SDGs were not considered. Analysis on the impacts of structural change in global trade on lower income countries and on a wider range of sustainability indicators is still missing.

Moreover, the impacts of international trade on the SDGs can significantly differ between countries. Because of differences in terms of labor productivity, technology, efficiency, governance and environmental regulation, trade not only enables countries to benefit economically from participating in global supply chains, but also shifts both location and magnitude of social and environmental impacts (Mongelli et al., 2006; Acquaye et al., 2017). There is a substantial body of literature that argues that the benefits and costs triggered by international trade are imbalanced between countries (Chen et al., 2021; Wang et al., 2020a; Xiong and Wu, 2021) and that international trade helps rich countries avoid environmental losses at the cost of increasing environmental burdens in poor countries (Xu et al., 2020). For example, for simple extractive sectors, the global share of sulfur dioxide driven by US consumption for core countries is only 16% whereas its global share of value added is 77%, while the global share of sulfur dioxide and value added for periphery countries are 17% versus 4%, respectively (Prell et al., 2014). Core countries tend to be higher income and industrialized countries whereas countries at the periphery tend to be low-income countries (Wallerstein, 2011; Prell et al., 2014). Thus, assessing the impacts of international trade and its structural change on sustainable development for different types of countries provides a better understanding of the roles of countries at different income levels in global value chains and the potential implications for different SDGs.

Here, we focus on structural changes in international trade and evaluate their impacts on sustainable development for 141 countries or regions. In addition, we compare between countries at different levels of income and explore whether impacts differ between high- and low-income countries. The detailed regional classification provides a comprehensive evaluation that includes low-income countries which happen to be the ones facing the greatest challenges and deserving special attention towards achieving SDGs. This study answers the following questions: first, what are the global impacts of structural change in global trade on different SDG indicators and how do these impacts change over time? Second, how do these impacts differ between countries? Third, are structural changes in global trade beneficial to decoupling of each SDG indicator from value added in different countries?

To answer these questions, we selected 13 indicators that are closely related to international trade and can be clearly quantified as proxy for twelve SDGs, covering all three dimensions of sustainability. The 13 SDG indicators include economic indicators, i.e. GDP, compensation of employees, and taxes on production; environmental indicators, i.e. water pollution, blue water consumption, blue water withdrawal, total fossil fuel consumption, mineral resource use, CO_2 emissions, PM emissions, GHG emissions, and forest area loss; and social indicators, i.e. high- and medium-skilled labor. The list of the indicators and the corresponding goals are shown in Table S1 (see more details in Methodology and Supplementary Information). Using multi-regional input-output (MRIO) analysis and structural decomposition analysis we quantify the entire impacts embodied in trade related to 13 SDG indicators and distinguish the impacts induced by structural change in trade for three time periods, which are 2004-2007, 2007-2011, and 2011-2014 (see more details in Methodology).

Results

Impacts on SDG indicators at global level

Resource and environmental SDG indicators were significantly affected by structural change in global trade, while socio-economic SDG indicators were less affected. From 2004 to 2014, changes in the trade structure have hardly affected global economic development, with all three economic indicators in each time period changing less than 1% (Figure 1a). In comparison, other dimensions of sustainable development associated with resource and environment, were profoundly affected by structural change (Figure 1a). In the period 2004-2007, structural change in global trade increased pollution discharge and resource utilization globally, especially water pollution (increased by 12%) and water consumption (increased by 10%). In the period 2007-2011, fossil fuel consumption (Ind 5), GHG emissions (Ind 11), and forest area loss (Ind 12) decreased by 4%, 1%, and 4% respectively, which were accompanied by a decline in employment (decreased by 2%) and an increase in water consumption (increased by 17%). In the period 2011-2014, most SDG indicators changed only slightly, less than 3%, except for the substantially increased fossil fuel consumption (increased by 13%) and decreased water consumption (decreased by 5%). Generally, number of SDG indicators with higher percentage changes (> 3%) declined from eight (in the period 2004-2007) to four (in the period 2007-2011) to three (in the period 2011-2014), whereas number of SDG indicators with lower percentage changes (≤ 3%) increased (Figure 1b), indicating the impacts of structural change in global trade on sustainable development decreased from 2004 to 2014.

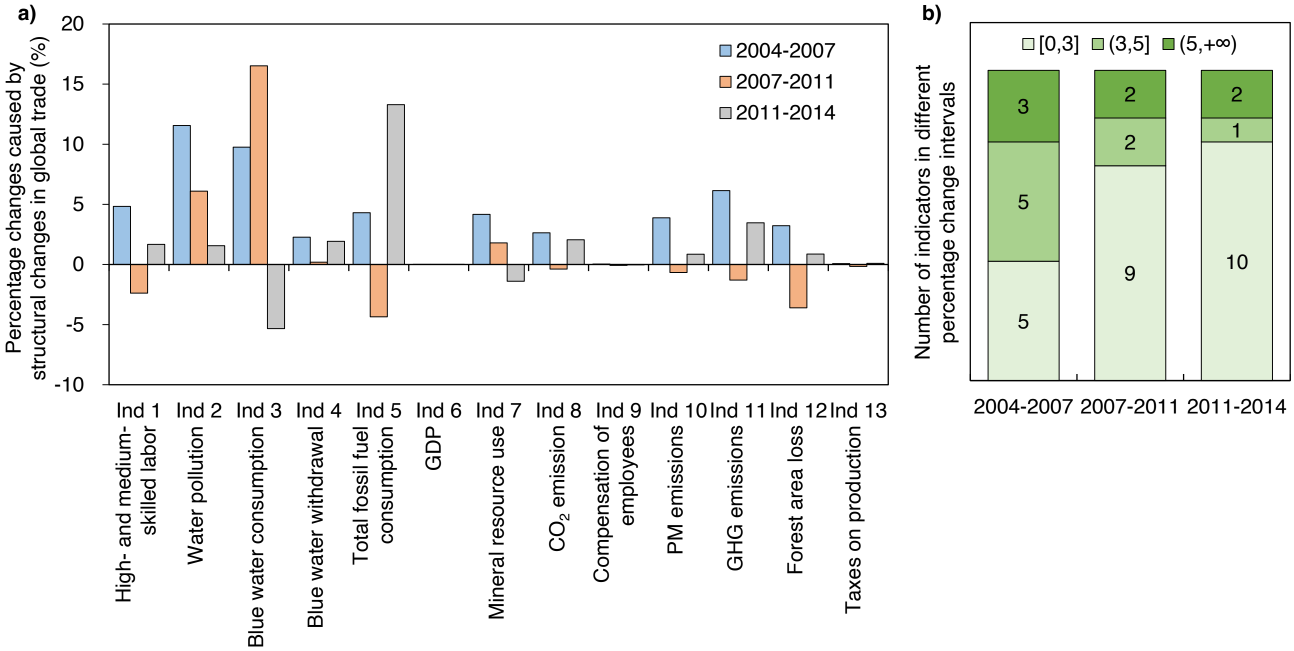

Figure 1 Global changes of SDG indicators in three time periods caused by structural change in global trade. a) Percentage changes of 13 SDG indicators. b) Number of SDG indicators in different percentage change intervals.

Impacts on SDG indicators among different income groups

Structural change in global trade aggravated inequality among income groups. For the detrimental impacts triggered by structural change in global trade, the relatively large bubbles (Figure 2), representing the magnitude of impact, were concentrated in high-, upper-middle- and lower-middle-income countries in the period 2004-2007 (Figure 2a), then changed to low-income countries with some negative impacts (e.g., water pollution and blue water consumption) still remaining in upper-middle- and lower-middle-income countries in the period 2007-2011 (Figure 2b) and concentrated in lower-middle- and low-income countries in the period 2011-2014 (Figure 2c). If we further investigate the number changes of SDG indicators that were negatively affected by structural change in global trade with percentage change higher than 5% (Figure 2d), the number of indicators for high- and upper-middle-income countries decreased from eight to three to one during the three time periods. Whereas the number of indicators for lower-middle- and low-income countries increased from five to nine to fourteen. For high-income countries, out of the total 39 data points of the percentage changes, indicating 13 SDG indicators over the three time periods, most (31 data points) were within ±3%, with just five exceptions of which the percentage changes larger than ±5% (Figure 2a, b, c). Thus, sustainable development of high-income countries was not sensitive to the structural change in global trade. Moreover, for the four income-level countries, percentage changes of all three economic indicators (Ind 6, Ind 9, Ind 13) over the three time periods were basically within ±3%, which are very small compared to percentage changes of other indicators and confirm the aforementioned finding that the impacts of structural change on the global economy were small.

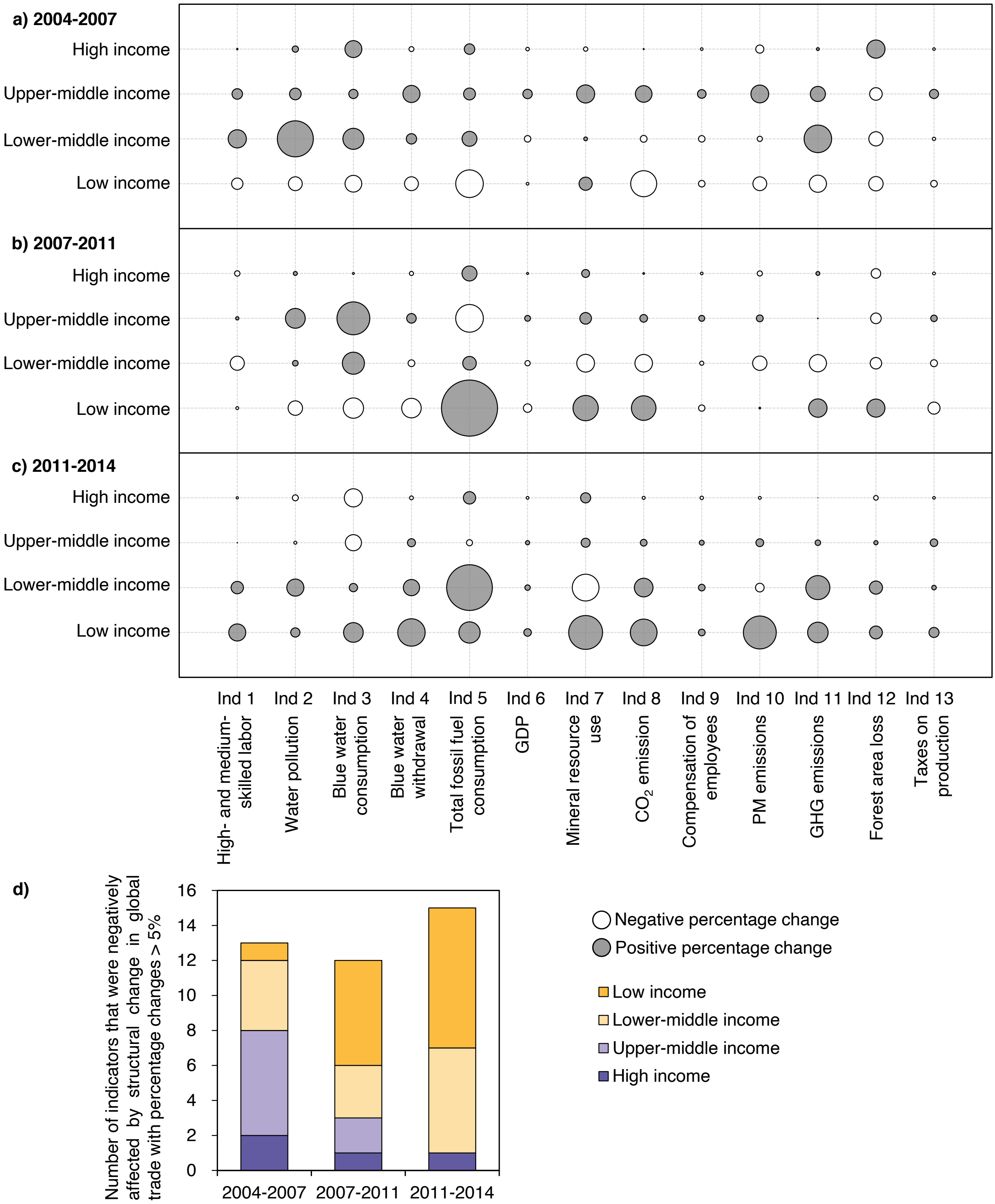

Figure 2 Impacts of structural change in global trade on income groups. The size of the bubbles indicates percentage change. White bubbles and grey bubbles stand for negative and positive percentage change, respectively. a) Impacts of structural change in global trade from 2004 to 2007. b) Impacts of structural change in global trade from 2007 to 2011. c) Impacts of structural change in global trade from 2011 to 2014. d) Number of indicators that were negatively affected by structural

change in global trade with percentage changes higher than 5%.

Impacts on decoupling of environment and economy among different income groups

Sustained global economic growth relies on excessive resource consumption and has generated numerous environmental problems such as accelerated climate heating (Schandl et al., 2016). Decoupling economic growth from environmental pressure has been widely accepted as a necessity to achieve long-term sustainability (Schandl et al., 2016) and has been proposed in SDG 8.4. Relative decoupling refers to resource and environmental impacts growing slower relative to growth of value added (① in Figure S1 in Supplementary Information) or reducing faster relative to decline of value added (③). While absolute decoupling refers to a decline of resource and environmental impacts as value-added grows (②). In contrast, rising resource and environmental impacts relative to value added indicates relative coupling, regardless of whether value added is rising (⑥) or falling (④). While rising resource and environmental impacts relative to declining value added indicates absolute coupling (⑤).

From a dynamic perspective, a path of an income group that starts at the upper-left parts (④, ⑤, ⑥) and ends at the bottom-right parts (①, ②, ③) shows a group that moves from coupling to decoupling of economic growth and sustainability. Furthermore, a path that starts at ⑤ and ends at ④ or ⑥ shows a group that moves from absolute coupling to relative coupling, and alternatively, a path that starts at ① or ③ and ends at ② shows a group that moves from relative decoupling to absolute decoupling. The above three paths refer to a trade structure that reduces coupling or strengthens decoupling.

As shown in Figure 3, for high-income countries, structural change in global trade led countries moving from coupling to decoupling of value added from water consumption (Ind 3) and forest area loss (Ind 12). For upper-middle-income countries, structural change in global trade strengthened decoupling of value added from water consumption (Ind 3), and reduced coupling to some extend for CO_2 emissions (Ind 8) and PM emissions (Ind 10), and GHG emissions (Ind 11), as well as led countries moving from coupling to decoupling of value added from water pollution (Ind 2), fossil fuel consumption (Ind 5), but reduced decoupling of value added from forest area loss (Ind 12). For lower-middle-income countries, structural change in global trade reduced coupling of value added with water pollution (Ind 2), water consumption (Ind 3), water withdrawal (Ind 4), fossil fuel consumption (Ind 5), GHG emissions (Ind 11), and led countries moving from coupling to decoupling of value added from mineral resource use (Ind 7) and PM emissions (Ind 10), but led countries moving from decoupling to coupling for CO_2 emissions (Ind 8) and forest area loss (Ind 12). For low-income countries, structural change in global trade reduced coupling of value added with mineral resource use (Ind 7), but led countries moving from decoupling to coupling of value added with water pollution (Ind 2), water consumption (Ind 3), water withdrawal (Ind 4), fossil fuel consumption (Ind 5), CO_2 emissions (Ind 8), PM emissions (Ind 10), GHG emissions (Ind 11), and forest area loss (Ind 12). Thus, structural change in global trade promoted decoupling of value added from most SDG indicators for higher income countries, but resulted in coupling of value added with most SDG indicators for low-income countries.

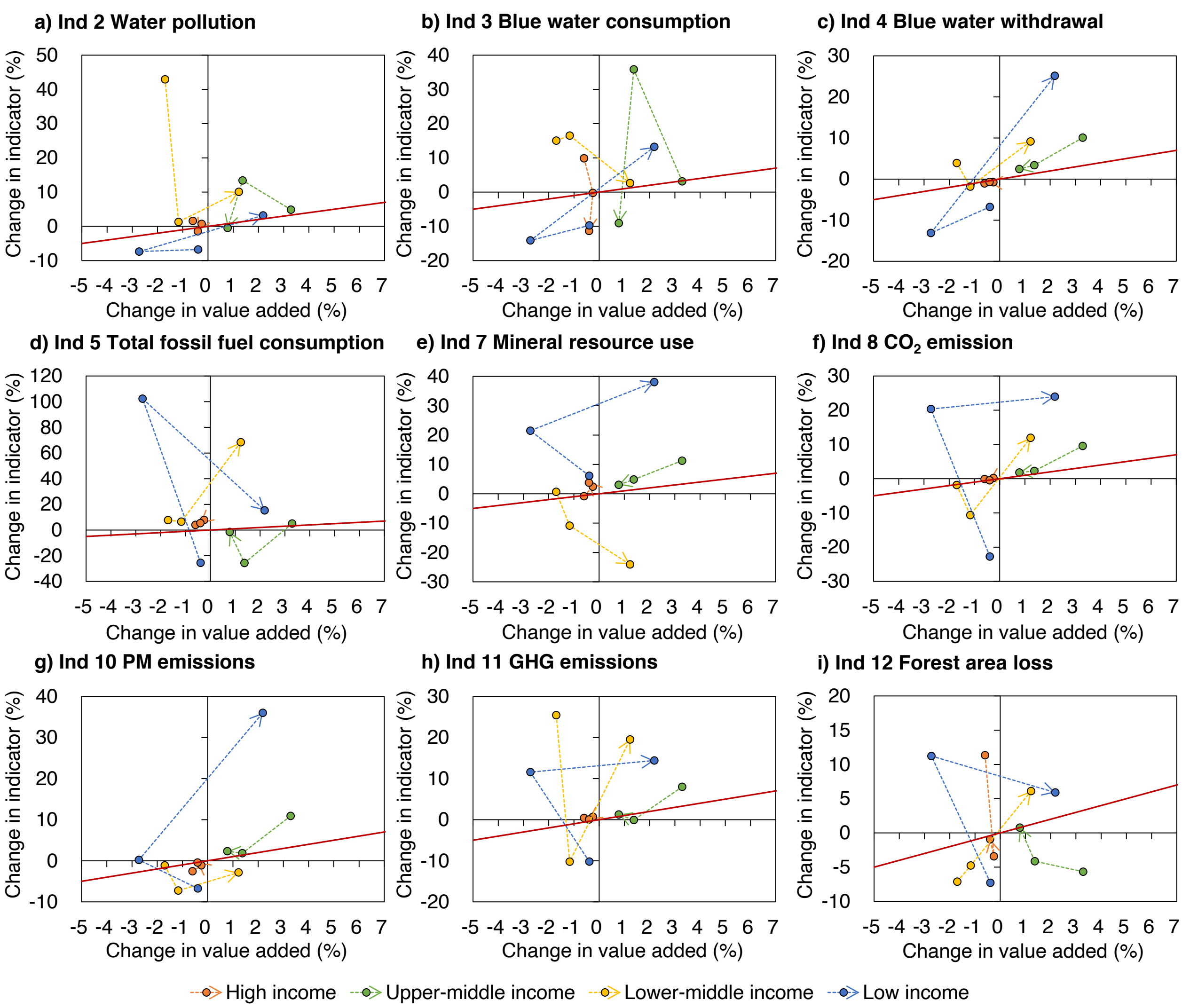

Figure 3 Coupling versus decoupling effects of global trade on each resource and environmental

SDG indicators for income groups. The horizontal axis represents percentage change in value added and the y-axis represents percentage change in indicator in a single time period for a specific income group. Arrow points from the period 2004-2007 to 2007-2011 to 2011-2014. The red line indicates that the percentage change in value added equals the percentage change in an SDG indicator and represents the boundary between coupling and decoupling. Given that social and economic SDG indicators were not sensitive to structural change in global trade based on the previous analysis, only nine environment and resource related SDG indicators are included in this figure.

Impacts on decoupling of environment and economy for specific countries

We further explore the decoupling and coupling effects triggered by structural change in trade on individual countries. Taking the period 2011-2014 and seven economies as an example (see Figure 4), for high-income countries, structural change in global trade led to a decoupling of blue water withdrawal (Ind 4) from value added in the EU27, the US, and Russia, and led to a decoupling of forest area loss (Ind 12) in the US and Russia. For upper-middle-income countries, structural change in global trade from 2011 to 2014 led to a coupling of CO_2 emission (Ind 8) with value added in China, Brazil, and South Africa, while led to a decoupling of blue water consumption (Ind 3), PM emissions (Ind 10), and GHG emissions (Ind 11) from value added in Brazil and China. For India, a lower-middle-income country, structural change in global trade led to a decoupling of mineral resource use (Ind 7) and PM emissions (Ind 10) from value added, but to a coupling of blue water consumption (Ind 3), blue water withdrawal (Ind 4), total fossil fuel consumption (Ind 5), CO_2 emission (Ind 8), and GHG emissions (Ind 11) with value added. This logic can likewise be used to analyze the decoupling impacts of structural change in global trade on any SDG indicator, country, and time period (see impacts on more individual countries at different income levels in Figure S3—Figure S6 of Supplementary Information). Additionally, Figure S2 (see Supplementary Information) shows number of countries at different levels of income affected by decoupling and coupling related to all resource and environmental indicators in the three time periods.

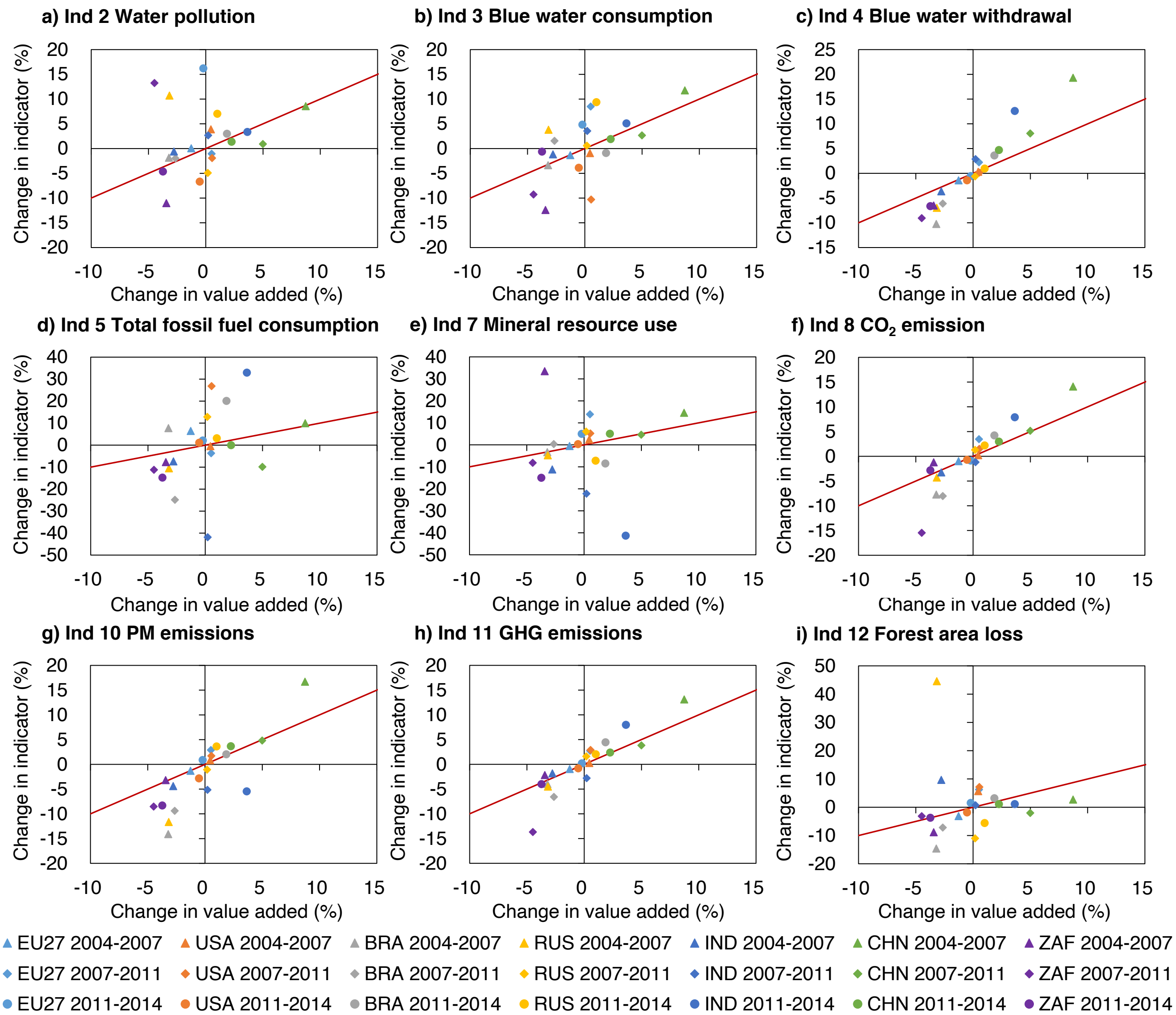

Figure 4 Coupling versus decoupling effects of structural change in global trade for each resource and environmental SDG indicators and seven economies. The horizontal axis represents percentage change in value added and the y-axis represents percentage change in indicator. Triangles, rhombus, and circles refer to effects driven by structural change in trade during 2004-2007, 2007-2011, and 2011-2014, respectively. The red line indicates percentage change in value added equals the percentage change in an SDG indicator and represents the boundary between coupling and decoupling. Considering social and economic SDG indicators were not sensitive to structural change in global trade based on the previous analysis, only nine environment and resource related SDG indicators are included in this figure. EU27: 27 countries of the European Union, USA: United States of America, BRA: Brazil, RUS: Russian Federation, IND: India, CHN: China, ZAF: South Africa.

Discussion and conclusion

In this study, we proposed a framework quantifying the impacts of structural change in global trade on SDG indicators at the global and country level for three time periods. This framework contributes to the existing research in following aspects: 1) existing research lacks a comprehensive analysis that covers all sustainable elements and their integration (Nerini et al., 2018). Our study considers multiple indicators referring to the three sustainable dimensions, corresponding to 12 goals and 14 targets, which is the most exhaustive in terms of research on impacts of structural change in trade on globally sustainable development so far. 2) Current research on SDGs lacks information for developing countries and the least developed countries. Our study has a global coverage including 141 countries or regions. 3) Existing research on evaluating impacts of structural change in global trade on sustainable development tends to calculate the share of contribution of each driving factor and lacks in-depth analysis on the mechanism of these impacts. Our approach is able to quantify the contribution of structural change in trade on multiple SDG indicators and the degree of decoupling between value added and those indicators.

Our analysis shows that, a) resource and environment related SDG indicators were susceptive to structural change in global trade, while socio-economic SDG indicators and high-income countries were not sensitive to these changes during the investigated time period. b) Although global percentage changes of most of the SDG indicators driven by structural change in global trade decreased between 2004 and 2014, the impacts of structural change in trade still showed significant differences for countries at different income levels. c) Change of trade structure unequally distributes the gains of trade as the number of SDG indicators which are significantly and negatively affected by changes in trade decreased in high- and upper-middle-income countries but increased in lower-middle- and low-income countries. d) The trends of structural change in global trade might further increase global inequality. Structural change in global trade enhanced decoupling of value added from most SDG indicators for higher income countries, but led to coupling for low-income countries. Our study suggests the necessity to provide long-term monitoring of multi-dimensional indicators associated with SDGs. Although we have included as many indicators as possible, it still cannot cover all 17 goals. Improving the availability of comparable and unified-standard data of a wider range of indictors for various countries and industries provides a foundation for SDG-related scientific research. This study focused on assessing the differential impacts of structural change in global trade between countries, future studies can specifically elucidate the changes of each country's role in global supply chains and its impact on sustainable development.

Methodology

SDG Indicators. The "Global Indicator Framework for the Sustainable Development Goals and Targets of the 2030 Agenda for Sustainable Development Report" (UNSD, 2020) concretized the conceptual goals by proposing series of quantizable "sub-targets", and thus provided us the reference to select indicators. Given that both production characteristic and share of trade volume vary by sectors even in a specific country, the indicators we choose must be supported by sub-sectoral data, which is exactly the advantage of the satellite data of MRIO table. Thus, we matched the satellite of EXIOBASE MRIO table and the sub-targets proposed by UNSD, and finally selected 13 indicators corresponding to 12 goals (see Table S1 in Supplementary Information). We understand that these indicators cannot fully represent the corresponding goals, but the indicators we chose are highly correlated with the goals and can be clearly quantified. By reconciling EXIOBASE satellite with GTAP MRIO table, our study managed to cover all three dimensions of economy, society, and environment that SDGs emphasized.

MRIO analysis. Input-output analysis is widely used to measure the total socio-economic or environmental flows along supply chains from sector's perspective (Wang et al., 2020b). Moreover, global MRIO analysis and its databases are propitious to monitor sustainable development progress under a global scope (Wiedmann and Lenzen, 2018). Thus, we applied global MRIO analysis to calculate the entire employment, resource consumption, environmental pollution, and economic benefit associated with production activities along the global supply chains for 141 countries or regions and their sectors.

Assuming there are *m* countries and *n* sectors for each country, the direct input coefficient *A* can be derived from equation (1):

$$A_{ij}^{OD} = \frac{x_{ij}^{OD}}{x_j^{D}} \qquad (1)$$

where A_{ij}^{OD} represents the inputs from sector *i* in country *O* (origin country) driven by one unit of the demands of sector *j* in country *D* (destination country). X_{ij}^{OD} denotes the intermediate monetary flows from sector *i* in country *O* to sector *j* in country *D*, while X_j^D denotes the total output in sector *j* of country *D*. In this study, parameter *X* is from the GTAP MRIO tables, while *i*, *j*=1, 2, …, *n* (*n*=65) and *O*, *D*=1, 2, …, *m* (*m*=141), respectively.

To measure the sustainable impacts embodied in trade, we need to calculate the direct intensity coefficient *CA* for each indicator:

$$CA_i^O = \frac{S_i^O}{X_i^O} \qquad (2)$$

where S_i^O is the physical amount of each indicator (e.g., total economic benefit, resource consumption, or pollutant discharge) of sector *i* in country *O*. Thus, direct intensity coefficient CA_i^O represents the amount of economic benefit, resource consumption, or pollutant discharge to increase a unit of output of sector *i* in country *O*. In this study, *S* is from the EXIOBASE satellite.

Finally, using the Leontief inverse matrix $(I\text{-}A)^{-1}$, the entire virtual transfer *VT* of each SDG indicator along the global supply chains can be calculated as follows:

$$VT^O = \sum_{D=1}^{n} \sum_{i=1}^{m} \widehat{CA_i^O} \cdot \left(I - A_{ij}^{OD}\right)^{-1} \cdot Y_i^{OD} \qquad (3)$$

where $\widehat{CA_i^O}$ is the diagonalizable *CA*. *I* is the identity matrix. *Y* is the final demand matrix, of which the element means inputs from sector *i* in country *O* driven by the final demand in country *D*. Using the equation $\widehat{CA} \cdot (I - A)^{-1} \cdot Y$, the virtual transfer from sector *i* in country *O* to country *D* can be clearly traced. Furthermore, the total amount of all sectors and all destinations in a specific country can be calculated by adding up the above virtual transfer matrix by sectors and by destinations.

Inflation procedure. To ensure the GTAP MRIO tables comparable over time, we need to eliminate the impacts of price changes caused by inflation. Referring to the approach used by the EXIOBASE technical documents (Wood et al., 2014), we calculated the annual price indices using the current-year-price and the previous-year-price WIOD database:

$$PI\ (t, t-1) = \frac{X(t,t)}{X(t,t-1)} \qquad (4)$$

where *X* (*t*, *t*) and *X* (*t*, *t*-1) denote the total output in year *t* measured in current-year price and in previous-year price in WIOD database, respectively. *PI* (*t*, *t*-1) is the annual price index showing the price change between the year *t* and the previous year *t*-1. For the 43 countries or regions that are included in WIOD, the corresponding price indices can be calculated respectively. For other countries or regions, the price indices were approximately represented by the price indices of the "rest of the world". Then, we changed the annual price indices to chained price indices:

$$PI\ (t, t-n) = PI\ (t, t-1) \times PI\ (t-1, t-2) \times \cdots \times PI\ (t-n+1, t-n) \qquad (5)$$

which shows the price changes in year *t* compared to year *t-n*. Moreover, because WIOD is expressed in USD but GTAP is expressed in EUR, the unit was translated from USD into EUR:

$$PI_{EUR}\ (t, t-n) = \frac{ER\ (t)}{ER\ (t-n)} \times PI_{USD}\ (t, t-n) \qquad (6)$$

where *ER* (*t*) and *ER* (*t-n*) denote exchange rates between EUR and USD in year *t* and *t-n*, respectively. PI_{EUR} and PI_{USD} stand for chained price indices measured in EUR and USD, respectively. For detailed derivation process of the currency conversion, please see Supplementary Information. In this study, the base year was 2014 and the three previous GTAP MRIO tables were inflated to the price level of 2014 using double deflation method (Wood et al., 2014).

Decomposition analysis. The most widely used method to identify the effect of structure change in trade is to decompose the whole embodied transfer (e.g., pollutant discharge) into contributions of various driving factors, one of which is trade structure usually denoted by export or import structure (e.g., Arto and Dietzenbacher, 2014, Meng et al., 2018, Perrier et al., 2019). Consequently, the impacts of structural change in trade can only be depicted as to what extent the changing structure increases or decreases the pollutant discharge without the detailed exploration for the mechanism about why this changing structure would have such impacts on sustainable development. Xu and Dietzenbacher (2014) looked into the impacts of structural change by decomposing the emissions embodied in trade to changes in trade structure, production technology, total final demands, emission intensities and distinguishing the changes at home and abroad, but the range is only for CO_2 emissions. To capture the impacts of structure change in trade on multiple aspects of sustainable development, we followed the framework used in Jiang et al. (2018) and conducted a simulation assuming that the structure of exporting country in year *t*1 is replaced by the structure in year *t*2, with production technology, and intensity coefficient of each indicator unchanged.

First, we decomposed the direct input coefficient *A* matrix into technical coefficients A^* and exporting pattern of intermediate use *C*. A^* indicates the share of the intermediate inputs from each sector irrespective of the exporting country, while *C* indicates the intermediate inputs from each region irrespective of the exporting sector. Meanwhile, the trade pattern changes affect not only input structures in intermediate products, but also in final products. Similarly, the final demand *F* can be decomposed into the stacked final demand Y^* and the exporting pattern of final demand *F*. Thus, equation (3) can be writing as:

$$VT = \widehat{CA} \cdot (I - C \times A^*)^{-1} \cdot (F \times Y^*) \qquad (7)$$

To simplify the expression and make the decomposition process more clearly, the superscripts and subscripts indicating region and sector were not displayed in equation (7).

Then, through equation (8), we can calculate the virtual transfer of each indicator in year *t*1 under the baseline scenario that the trade structure, production scale, production technique, and intensity coefficient all in year *t*1:

$$VT_{t1}^{t1} = \widehat{CA_{t1}} \cdot (I - C_{t1} \times A_{t1}^*)^{-1} \cdot (F_{t1} \times Y_{t1}^*) \qquad (8)$$

where VT_{t1}^{t1} represents virtual transfer in *t*1 with *t*1's trade structure.

Meanwhile, through equation (9), we can also calculate the virtual transfer of each indicator in year *t*1 under the simulation scenario that the trade structure is replaced by the structure in year *t*2 with production scale, production technique, and intensity coefficient remain unchanged:

$$VT_{t1}^{t2} = \widehat{CA_{t1}} \cdot (I - C_{t2} \times A_{t1}^*)^{-1} \cdot (F_{t2} \times Y_{t1}^*) \qquad (9)$$

where VT_{t1}^{t2} represents virtual transfer in *t*1 with *t*2's trade structure.

Thus, the changing rate of an indicator caused by structural change in global trade between the time period *t*1 and *t*2 can be expressed as:

$$CR_{t1\sim t2} = \frac{(VT_{t1}^{t2} + VT_{t2}^{t2})/2 - (VT_{t1}^{t1} + VT_{t2}^{t1})/2}{(VT_{t1}^{t1} + VT_{t2}^{t1})/2} \qquad (10)$$

where $(VT_{t1}^{t2} + VT_{t2}^{t2})/2$ denotes the virtual transfer under the *t*2's trade structure and the average level of other factors from *t*1 to *t*2, while $(VT_{t1}^{t1} + VT_{t2}^{t1})/2$ denotes the virtual transfer under the *t*1's trade structure and the average level of other factors from *t*1 to *t*2. Thus, $CR_{t1\sim t2}$ indicates the changing rate of an indicator triggered by the replacement of the trade structure from *t*1 to *t*2, based on the average economy development level (production scale, production technique, and intensity coefficient) of the period *t*1 to *t*2. In this study, we calculated $CR_{2004\sim2007}$, $CR_{2007\sim2011}$, and $CR_{2011\sim2014}$, respectively. We measured the effects of structure change in the three time periods instead of a whole ten-year (2004-2014) period because: first, the global financial crisis in 2008 had a huge impact on global trade pattern, and the global trade pattern has changed markedly different before, during, and after the global financial crisis; second, the production technology has been improved a lot during this decade, assuming the economic development level in the very latest year (2014) replaced by that in the very earliest year (2004) would lead to biased estimate.

Data. The MRIO tables were acquired from GTAP (Aguiar et al., 2019). We chose the GTAP MRIO tables in 2004, 2007, 2011, and 2014 not only because these are the latest available data, but more importantly, the three time periods composed by these four years represent the financial-crisis era and the two periods before and after it. The most popular global MRIO tables include: WIOD, EORA, EXIOBASE, and GTAP (Tukker and Dietzenbacher, 2013). Given that the GTAP database has detailed country category (140 countries or regions and one "rest of the World") with the sectoral classification consistent for different countries, we selected GTAP database instead of other global MRIO tables. The 141 economies were further divided into high-income group (56 economies), upper-middle-income group (31 economies), lower-middle-income group (37 economies), and low-income group (17 economies). However, the satellite data of GTAP is limited, only including data about air pollutions, land use, energy volumes, and migration, while satellite data of EXIOBASE covers many fields that the UN SDGs focus on, we thus obtained satellite data from the EXIOBASE database (Stadler et al., 2018). The country and sector classifications are diverse in different data source, we adjusted them in accordance with the classifications of GTAP MRIO tables. To ensure monetary value comparable between different years, the price indices were calculated based on the current-year-price WIOD database and the previous-year-price WIOD database (Timmer et al., 2015). Income groups are classified according to the World Bank Analytical Classifications in 2014 (WB, 2020). For detailed information about the harmonization of country category and sector category among different global MRIO databases and the country list in each income group, please see Supplementary Data.

Data Availability

All source data described in Data section were retrieved from GTAP database (https://www.gtap.agecon.purdue.edu/), Exiobase database (https://www.exiobase.eu/), WIOD database (http://www.wiod.org/home), and the World Bank (https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.

html). Data of figures are provided in Supplementary Information files.

Code Availability

Code developed for conducting the analyze is available from the corresponding author upon reasonable request.

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