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Impacts on quality-induced water scarcity: drivers of nitrogen-related water pollution transfer under globalization from 1995 to 2009

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Abstract

Globalization enables the transfer of impacts on water availability. We argue that the threat should be evaluated not only by decrease of quantity, but more importantly by the degradation of water quality in exporting countries. Grouping the world into fourteen regions, this paper establishes a multi-region input-output framework to calculate the nitrogen-related grey water footprint and a water quality-induced scarcity index caused by pollution, for the period of 1995 to 2009. It is discovered that grey water embodied in international trade has been growing faster than total grey water footprint. China, the USA and India were the three top grey water exporters which accounted for more than half the total traded grey water. Dilemma rose when China and India were facing highest grey water scarcity. The EU and the USA were biggest grey water importers that alleviated their water stress by outsourcing water pollution. A structural decomposition analysis is conducted to study the drivers to the evolution of virtual flows of grey water under globalization during the period of 1995 to 2009. The results show that despite the technical progress that offset the growth of traded grey water, structural effects under globalization including both evolution in the globalized economic system and consumption structure, together with consumption volume made a positive contribution. It is found that the structural effect intensified the pollution-induced water scarcity of exporters as it generally increased all nations' imported grey water while resulting in increases in only a few nations' exported grey water, such as Brazil, China and Indonesia. At last, drawing from the 'cap-and-trade' and 'border-tax-adjustment' schemes, we propose policy recommendations that ensure water security and achieve environmentally sustainable trade from both the sides of production and consumption.

1. Introduction

Not only a decrease of quantity, but also degradation of quality will result in water scarcity. The anthropogenic activities related to these two forms of scarcity can be defined as consumptive use and degenerative water use. International trade enables the consumptive water use to be transferred across national boundaries, known as virtual water trade (Hoekstra 2010, Dalin *et al* 2012, Suweis *et al* 2013). Although the spatial transfers of water never happen as the water consumption remains in the country of origin, the consumption

is regarded as passed on to producing countries in a virtual way. The water quantity-induced scarcity by consumptive water use of producers has been widely recognized and assessed through various methodologies (Brown and Matlock 2011), while water quality-induced water scarcity receives less attention. Not only demand of water resources, the water pollution driven by far-end consumption is transferred to exporting nations through trade, threatening the water availability of exporting nations. What's more, adverse environmental impacts have been witnessed to shift from developed countries to developing countries through

globalization such as ‘carbon leakage’ of CO₂ emissions (Peters *et al* 2011). As more than one in every six people in the world affected by water stress are living in developing countries (United Nations Development Programme 2006), there is an urgent need to study how globalized economy intensifies the water quality-induced scarcity in developing countries in the context of ‘pollution leakage’.

To focus on the quality-induced scarcity under globalization, we incorporate grey water footprint to indicate degenerative water use. The grey water footprint is the volume of fresh water required to assimilate the load of pollutants based on the existing ambient water quality standard (Hoekstra and Mekonnen 2012). It serves as an intuitive representation of the first-round occupation of water resources by water pollution in terms of dilution. The dilution does not necessarily happen in reality. However, the core purpose of assessing pollution via a fresh water ‘equivalent’ rather than concentrations of specific contaminants is to bring a comparable measure on water pollution and consumptive use. A lower grey water amount means less water is needed for dilution, allowing the available water for other competitive purposes. Therefore the water quality-induced scarcity based on grey water can indicate the physical water stress in obtaining fresh water for dilution during a period of time. Understanding the severe consequences of eutrophication resulted from nitrogen-related water pollution, analysis of nitrogen-related grey water footprints on global scale have been conducted in previous studies (Hoekstra and Mekonnen 2012, Mekonnen and Hoekstra 2015).

However, the previous grey water studies have drawn a picture of global embodied pollution transfer and the quality-induced scarcity faced by exporters, while the process of how the picture was formed is absent. In the interest of developing strategies from the aspect of globalization to alleviate quality-induced scarcity, an investigation into the drivers in global grey water transfer is needed. This is conducted by introducing the multi-region input-output (MRIO) based structural decomposition analysis (SDA) in our study. The MRIO analysis is a top-down method, which quantifies the far upstream pressures through circulatory input among sectors across economies (Wiedmann 2009). It has been successfully employed in water footprint accounting on cities, watersheds, national and global scales (Feng *et al* 2010, Yu *et al* 2010, Zhang *et al* 2011, Chen and Chen 2012, Feng *et al* 2012, Steen-Olsen *et al* 2012). The SDA is an approach quantifying the relative contribution of factors by a set of comparative static variations in key parameters in the input-output (IO) model, and has been widely used in assessing the drivers of water consumption, carbon emission and energy use (Guan *et al* 2008, Liu *et al* 2010, Xu *et al* 2011, Zhang *et al* 2012, Su *et al* 2013). It can help identify the determinants which contribute to the changes of a variable

over a period to understand the drivers that change global embodied pollution transfer. Lastly, we proposed an initial design of policies on global pollution transfer control based on our accounting. These policies are aimed at achieving environmentally sustainable production under globalization.

This paper is organized as follows. In section 2, methods and material used in the study are described. In section 3, we use the MRIO model to quantify the grey water embodied in production and trade, and calculate national scarcity caused by the demand of dilution during the period of 1995 to 2009. An SDA is then conducted to identify the determinants to the changes in pollution transfer over time. In section 4, policy implications are proposed from the sides of both production and consumption.

2. Method and materials

2.1. Method

2.1.1. Multi-region input-output (MRIO) model based structural decomposition analysis (SDA)

The present study adopts a standard environmental extended MRIO model consisting of fourteen regions where each region includes thirty-five sectors. The description of MRIO framework is presented in the appendix.

In the present study, the changes in global grey water transfer over 1995–2009 are decomposed into four factors under structural decomposition analysis (SDA) including: 1—technical effect, 2—economic system effect, 3—consumption structural effect, 4—scale effect. The technical effect is the change in direct grey water coefficient—grey water generated per unit total production—which indicates the development of technology of the producer or exporter. The economic system effect is reflected by changes in the Leontief inverse matrix of the MRIO model. It indicates the changes of the interdependence among sectors of different nations, which describes the evolution of the structure of globalized production. The consumption structural effect elucidates the contribution of changes in the sectoral distribution of final demand. It implies the changes in consumption preference of residents over the period. Scale effect stands for the changes in total amount of national final consumption, which is associated with economic status or population growth. The last two factors depict the contribution from the aspect of consumer or importer. Consequently, changes in global traded grey water can be presented by the contribution of exporter and importer, linked by the evolution of global supply chain. In expressing the changes between two target years, the average values of the decomposition results of the base year and the end year values are adopted (Zhang *et al* 2012). The decomposition the changes in traded grey water from region *r* to region *s* is demonstrated as follows.

The technical effect can be expressed as:

$$T^{rs} = \frac{1}{2}(\Delta W^r \times B_1 \times P_1^s \times Y_1^s + \Delta W^r \times B_0 \times P_0^s \times Y_0^s) \quad (1)$$

The economic system effect can be expressed as:

$$ES^{rs} = \frac{1}{2}(W_0^r \times \Delta B \times P_1^s \times Y_1^s + W_1^r \times \Delta B \times P_0^s \times Y_0^s) \quad (2)$$

The consumption structural effect can be expressed as:

$$CS^{rs} = \frac{1}{2}(W_0^r \times B_0 \times \Delta P^s \times Y_1^s + W_1^r \times B_1 \times \Delta P^s \times Y_0^s) \quad (3)$$

The scale effect can be expressed as:

$$S^{rs} = \frac{1}{2}(W_0^r \times B_0 \times P_0^s \times \Delta Y^s + W_1^r \times \Delta B_1 \times P_1^s \times \Delta Y^s) \quad (4)$$

W^r is a row vector of direct grey water coefficient where only the entries describing region r (exporter) are non-zero. ΔW^r is the change of W^r . B is the Leontief inverse matrix of global supply chain and ΔB is the change of B . P^s is the consumption structure of region s (importer), which is a column vector whose entries are shares of the final consumption of one sector to the total final consumption of region s . Y^s is the summation of final consumption of region s . The subscripts '1' and '0' denote end year and base year, respectively.

2.1.2. Grey water scarcity

The grey water scarcity (GWS) here is defined as the ratio of grey water footprint to fresh water resource in a region. It is an index for quantifying the water scarcity induced by pollution. A threshold of 1 is adopted as if GWS exceeds 1 the fresh water availability is not enough for the dilution of polluted water (Zeng *et al* 2013). The GWS is expressed as follows:

$$GWS = \frac{WF_{\text{grey-production}}}{WA} \quad (5)$$

Since water footprint can be differentiated into consumption-based and production-based accounts according to the distribution of export and import (Peters 2008), here we adopt the production-based grey water footprint ($Gt\ y^{-1}$) which includes grey water embodied in export while excludes import since the pollution impacts remain in producer and threat its water availability. The WA is the fresh water availability of the producer ($Gt\ y^{-1}$) during the questioned period.

2.2. Data

2.2.1. IO tables

Both input-output tables and water accounts in this study are acquired from the World Input-Output

Database (WIOD) ranging from 1995 to 2009 (Dietzenbacher *et al* 2013). The database covers 27 EU countries and 13 other major countries with a resolution of 35 industries for each nation.

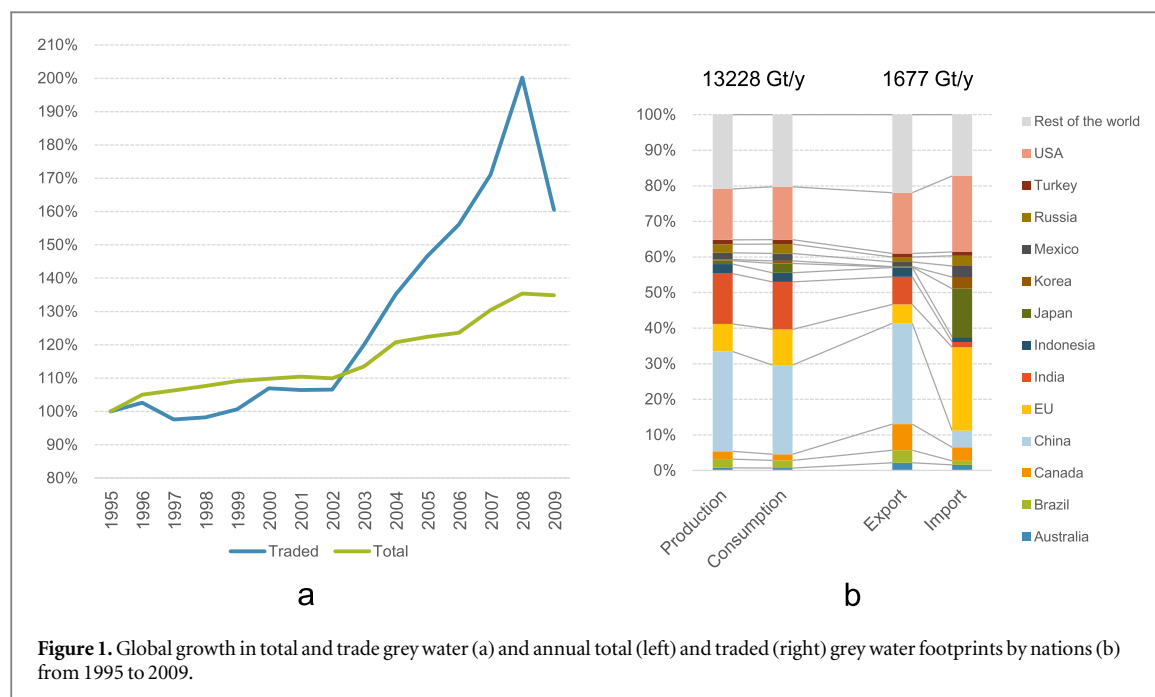
2.2.2. Grey water inventory and fresh water availability

The data of the nitrogen-related grey water covering all economic sectors in WIOD was based on a series of studies on water footprints and virtual water trade, which was done by Mekonnen and Hoekstra (2010a, 2010b, 2011). Thus the nitrogen-related grey water data in WIOD is the diluting water needed to treat nitrogen discharge of either diffuse sources or point sources. And the result of a recent study from Mekonnen and Hoekstra is incorporated to modify the original grey water account in WIOD (Mekonnen and Hoekstra 2015). In the case of agricultural production (diffuse), nitrogen discharge was resulted from the leaching and runoff of nitrogen from soil to ground or surface water, based on the balance of nitrogen in the soil. This was achieved by calculating both the sources and removal of nitrogen to the soil. For point sources, the domestic grey water was based on the N intake by dietary per capita protein consumption per country. Industrial grey water was set as a function of the urban domestic load due to data availability (Mekonnen and Hoekstra 2015). At last, dilution water demand (grey water) was derived by combining the nitrogen discharge and ambient water quality standard. Detailed description of grey water accounts is presented in the appendix. The fresh water availability is obtained from the total renewable surface water in AQUASTAT of FAO (FAO 2016). Finally, in order to emphasize the economic distinctiveness with pollution transfers, the 41 regions are further grouped into 14 regions. The detailed aggregation is presented in table A1.

3. Results

3.1. Global grey water footprints from 1995 to 2009

Water footprint can be categorized into consumption-based footprint and production-based footprint according to the allocation of grey water embodied in import and export. The consumption-based grey water footprint includes grey water embodied in domestic production and foreign production which is imported for domestic consumption. The production-based grey water footprint however excludes imported grey water for domestic consumption while including grey water embodied in exported goods and services from domestic production. It is recognized that the importing nations can transfer the pollution to exporting countries as a way of outsourcing. However, we still state the goods exporter to be the pollution exporter where the direction of embodied pollution transfer is consistent with trade flow. Such expression is widely seen in IO studies on virtual flow



(Peters and Hertwich 2008, Davis and Caldeira 2010, Steen-Olsen *et al* 2012, Jakob and Marschinski 2013). As a result, the ‘pollution exporter’ is in fact where the pollution remains.

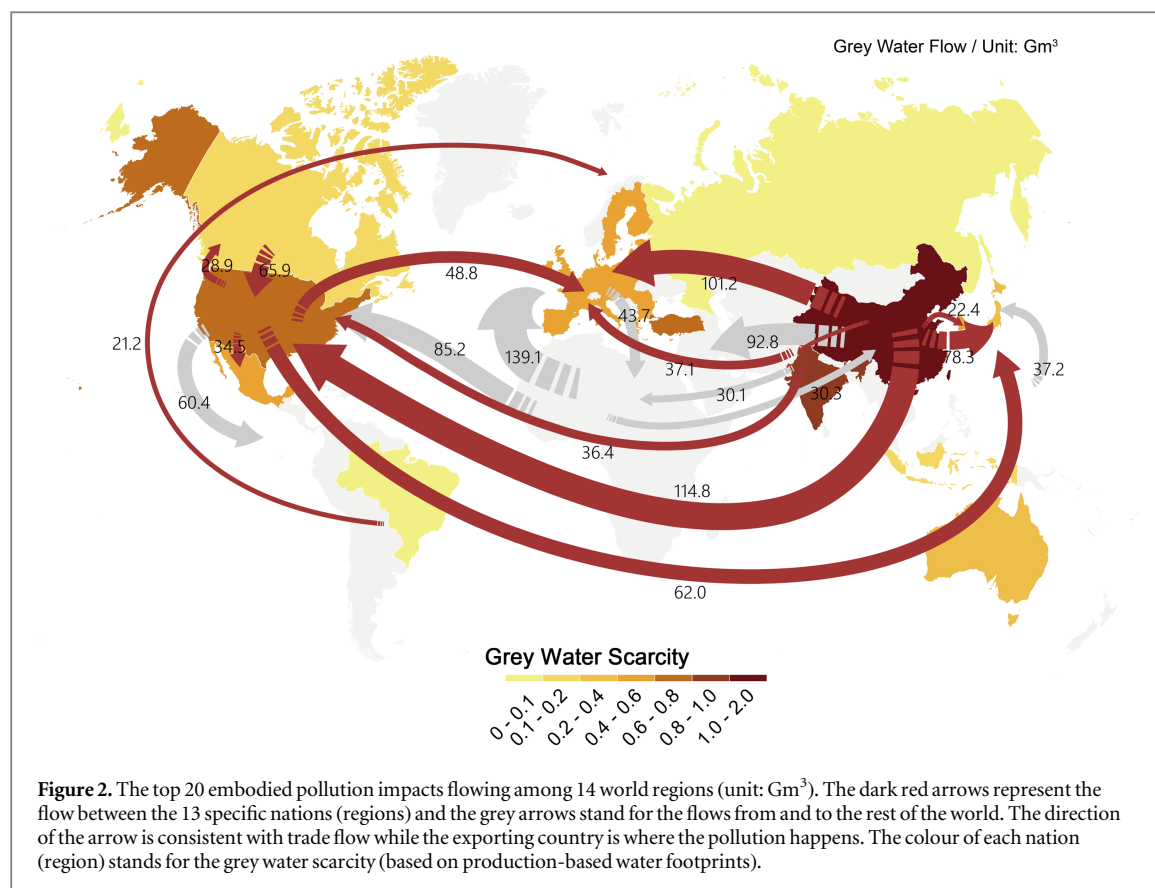
The global nitrogen-related grey water footprint from 1995 to 2009 was 13228 Gt y^{-1} in average while with an annual growth rate of 2.2% (figure 1(a)). Illustrated in figure 1(b), China was ranked first for consumption-based (3313.0 Gt y^{-1} , 25% of world total) and production-based (3709.7 Gt y^{-1} , 28% of world total) grey water footprint, followed by the USA with a grey water footprint of 1965.5 Gt y^{-1} (14.9% of world) in terms of consumption and 1893.5 Gt y^{-1} (14.3% of world) in terms of production. India and the EU was ranked the third and fourth, respectively in both consumption-based and production-based footprint accounts. The national distribution was a little different from the result of Mekonnen and Hoekstra (2015). The reason is that MRIO method presented a reallocation of grey water since it traced the looping interdependencies among sectors and regions compared with the previous bottom-up method. The grey water embodied in trade was 1676.7 Gt y^{-1} , accounting for 13% of global total grey water footprint. By exporting 475.4 Gt grey water annually, China was ranked first among world exporters, accounting for 28% of total traded grey water. Following were the USA (285.5 Gt y^{-1}) and India (130.0 Gt y^{-1}). More than half of the total traded grey water were from the three top exporters. On the other hand, the EU stood out as the biggest importer with an annual imported grey water of 393.1 Gt , 23.4% of world total. Being a substantial exporter as mentioned, the USA was also a significant importer (357.6 Gt). In addition, Japan showed up among top importers with 228.7 Gt imported grey water. This implies that pollution that could have been

caused in their own territories were shifted to other nations under globalization. For Japan, its imported grey water took up 65% of its total consumption-based grey water footprint, resulting in a highest external water dependency, followed by Korea (58%) and the EU (30%). On the contrary, India had the highest self-sufficiency of grey water, as its imported grey water only made up 1% of its total grey water footprint, followed by China (2%), Indonesia (7%) and Brazil (7%).

From figure 1(a), it can be observed that before 2002 grey water embodied in trade maintained constant and were boosted afterwards during the period from 2002 to 2008 with an annual growth rate of 11.1%. This endowed traded grey water a bigger annual growth rate (3.4%) than total grey water footprint during the whole period, consequently. Therefore, more and more nitrogen-related grey water was incorporated in international trade and transferred outwards under globalization despite the relatively stable total grey water footprint.

3.2. Global transfer of water pollution over grey water scarcity

The top 20 grey water flows from exporters to importers together with regional grey water scarcity (GWS) are demonstrated in figure 2. As mentioned above, a threshold of 1 is the indicator of the severity of pollution-induced water scarcity. On national level, China had the largest GWS (1.31) and the only exceeding 1 among the 14 regions, indicating that China’s water pollution had been going beyond its capacity for dilution. India obtained a GWS of 0.98 which was on the edge of sever scarcity. Higher GWS can also be found Turkey (0.77), the USA (0.62), Korea (0.60) and Mexico (0.54). In figure 2, the arrows



denote the top 20 pollution impacts which flow from exporters to importers, which added up to 1170.2 Gm^3 , or 70% of total grey water transfers. The most dominant flows among nations are found from China to the USA (114.8 Gm^3), the EU (101.2 Gm^3) and Japan (78.3 Gm^3). The 20 top flows were dominated by mutual transfers among China, India, the USA, the EU and Japan. China also dominated in net exported (difference between exported and imported grey water) (396.7 Gm^3) grey water while the EU dominated with the largest net import (303.6 Gm^3).

In figure 2, a paradox can be found as grey water was exported from nation with higher GWS to nation with lower one. It is obvious that China was exporting large amount of grey water to the USA and the EU despite its highest GWS and the USA was also exporting to the EU and Japan where the latter had lower GWS. As a result, risks are lurking as the outsourcing of water pollution could deteriorate water scarcity of exporters along with the expansion of globalization.

3.3. Determinates for changes in international displacements of water pollution

Using SDA, the percentage contribution of each four factors to the changes in international trade grey water is demonstrated in figure 3 including technical effect, economic system effect, consumption structure effect and scale effect. The lines above the x -axis imply positive effects to incremental traded grey water while the ones below indicate negative effects which offset

the increments. First, it can be observed that the contribution of the four factors was relatively small along with the relatively constant traded grey water during 1995–2002. The scale effect dominated in increasing traded grey water with a positive contribution of 44.1% during 1995–2002 and 42.3% during 2002–2009 (figure A1), respectively. The amount of grey water will inevitably grow with the growth of total final demand as total traded grey water could double (a growth of 92.5%, figure 3) in 2009 when considering scale effect alone. Secondly, consumption structural effect was also helping push the transfer of pollution, which accounted for 21.4% during 1995–2002 and 7.3% during 2002–2009. As for technical effect, it played a negligible role in decreasing total traded grey water (-1.6%) while its contribution in balancing the increasing grey water flows became significant during 2002–2007 (36.3%). At last, the economic system effect performed conversely between the two periods while consequently resulting in a cumulative contribution of 10.2% among all determinants in increasing traded grey water during 1995–2009 (figure A2).

4. Discussions

4.1. Structural effects intensify international displacement of pollution

Percentage contributions of four factors in national level from import and export aspects are illustrated in table 1. Intuitively, the scale effect, which was the total

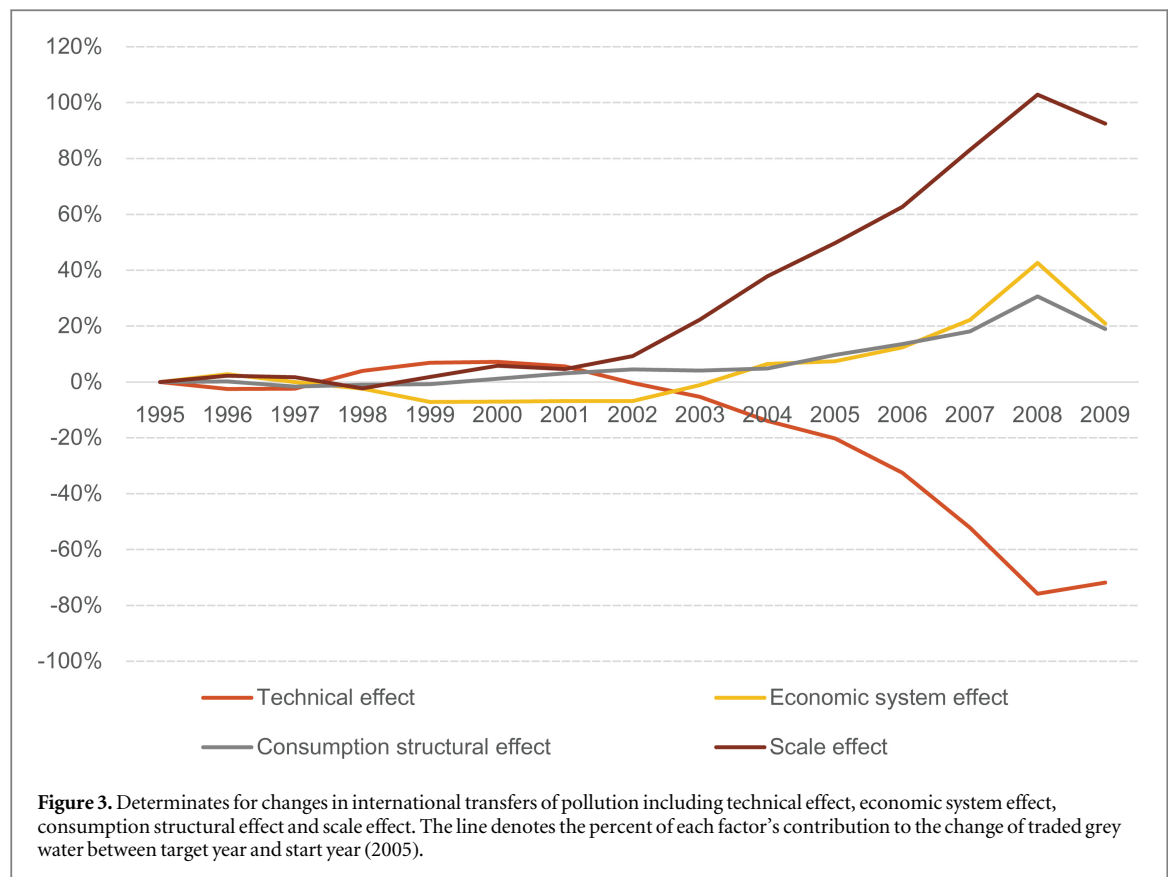


Table 1. Percentage contributions of four factors in national level from import and export aspects.

	SDA-import				SDA-export			
	1	2	3	4	1	2	3	4
Australia	−31%	12%	9%	48%	−18%	−23%	−15%	45%
Brazil	−29%	7%	−9%	56%	−30%	24%	3%	43%
Canada	−29%	4%	12%	55%	−13%	−24%	0%	62%
China	−15%	3%	−10%	73%	−39%	20%	18%	23%
EU	−38%	10%	12%	40%	−6%	−17%	−8%	69%
India	−25%	16%	10%	50%	−43%	−1%	3%	53%
Indonesia	−32%	12%	3%	52%	−28%	18%	−8%	46%
Japan	−61%	10%	16%	−13%	−8%	−17%	−14%	60%
Korea	−47%	24%	1%	28%	12%	−18%	−12%	58%
Mexico	−18%	14%	8%	60%	−40%	−3%	9%	47%
Russia	−25%	7%	20%	47%	−40%	5%	2%	53%
Turkey	−16%	23%	33%	27%	−33%	5%	−8%	53%
USA	−39%	9%	11%	41%	−2%	−16%	−16%	66%
Rest of the world	−31%	11%	6%	52%	−32%	9%	9%	51%

*1—technical effect, 2—economic system effect, 3—consumption structural effect, 4—scale effect.

final consumption of importers, was generally the dominant factor in increasing global water pollution transfers from section. And technical effect—direct grey water coefficient—have offset the growth, except for Korea. Moreover, it is clear that structural effects from both production (economic system effect) and consumption (consumption structural effect) sides under globalization have drastically contributed to the global growth of pollution transfer. However, differences existed when studying national disparities from import and export sides through SDA. Either

economic system effect or consumption structural effect has increased nations' imported grey water presented in column 2, 3 under 'SDA-Import in table 1, except for the negative contributions of consumption structural effects for Brazil (−9%) and China (−10%). Therefore, structural evolution in both production and consumption sides could intensify nations' external dependencies, in terms of water pollution. It is not surprising that most nations had higher growth rates of grey water import than export from 1995–2009 (figure A2). In summary, structural

effects have enhanced nations to outsource water pollution through globalization. On the other hand, the outsourced pollution was not distributed equally. Despite the generally positive structural effects spotted in increasing national imported grey water, the structural effects on national export showed up differently (column 2, 3 under 'SDA-export' in table 1).

In terms of production, being the largest grey water exporter, economic system effect had made a significant contribution (20%). This was reflected in China's participation in the production for global demand, known as the 'world factory'. Along with China's massive penetration into global supply chain, water pollution happened domestically in China, becoming more and more intensive and responding to the variations in global consumption. Similarly, structural effects in the production side also contributed to 24% of Brazil's growing grey water export, endowing Brazil a highest growing rate of export among nations. Being the second largest exporter, the USA's growing export was largely attributed to scale effect (66%). The adjustment of its role in global production has reduced its exported grey water with a contribution of -16%, which could alleviate the stress from its GWS (0.62). In terms of the effects of consumption, the evolution of global final demand structure (column 3 under 'SDA-export' in table 1) has generally made positive contributions to China's, India's and Brazil's exported grey water. The changes in the structure of final consumption of foreign consumers have intensified their domestic burdens from water pollution. Considering the highest GWS in China and India, their increasing exported grey water caused by structural effects from either production or consumption side could lead to further conflicts in fresh water demand. As a result, determined by distinctive roles in global supply chain, structural changes in global production and consumption under globalization could contribute to the international transfer of water quality-induced water scarcity.

4.2. Management of structural transformation and discharge regulation from the production side

4.2.1. Adjustments of roles in global supply chains

It has been discovered in table 1 that globalized production has intensified grey water export for several nations such as Brazil, China and Indonesia through changes in global production structure. To reduce the pollution impacts, adjustments on both roles in global supply chains—the industrial restructuring—and domestic pollution discharge are needed. As for China, since globalized production is becoming more and more dependent on its participation, large amount of effluent remains domestically. Therefore, it calls for industrial restructuring in China to either improve its domestic economic system efficiency or alter its position in global value chains thus reducing

the adverse effects from globalization. Moreover, since the offset from technical effects contributed to a decrease in exported grey water, regulation of pollution discharge on production sites should also be considered necessary and urgent.

4.2.2. Regulation in domestic pollution discharge

First, to ensure the effectiveness of discharge reduction, an effective monitoring is fundamental. According to the current study which is based on nitrogen-related grey water, monitoring of both diffuse (agricultural) and point (industrial and household) sources is indispensable. The former calls for a better monitoring of fertilizer usage, which is a substantial anthropogenic source of nitrogen intake. The latter depends on an effective control of sewage treatment and discharge. This is a primary element in quantifying the grey water volume from production. The effective monitoring of grey water generated on production side is also important for enterprises to be aware of the urgency of technical renovation in reducing the grey water during production. For example, the only positive contribution of the technical effect was found in Korea (table 1), indicating that Korea's unit effluent discharge on production site was increased. It was even reported in 2013 by the Ministry of Environment in Korea that over one hundred Korean leading enterprises including Samsung, Hyundai, SK and LG had been discharging wastewater illegally, worsening the situation (Xinhuanet 2013). Considering Korea's relatively high GWS (0.60), a stringent monitoring is especially crucial when managing its production and export.

Secondly, the perspective of supervision and control should be considered. The administrative regulatory measures—'command-and-control'—could push for official regulation and pollution control. However, a 'cap-and-trade' tool (which is a market-based scheme) could offer vital flexibility over administrative schemes, since the administration alone offers no incentive for polluters to go beyond the standard (Zhang and Baranzini 2004). The cap-and-trade method originated in the SO₂ control program of the US in the 1990s and has been further developed as an Emission Trading Scheme (ETS) in the greenhouse gas strategy by the EU (Christiansen and Wettstad 2003, Ellerman and Buchner 2007, Napolitano *et al* 2007). There was also a successful implementation of the cap-and-trade strategy of water rights dealing with regional water scarcity in Australian watersheds, and the method was also considered for implementation in the Colorado River Basin in the US (Wildman and Forde 2012). If this mechanism is introduced into the pollution control sector, the 'cap' should be designed as the limit of the total volume of grey water generated, or the limit of nitrogen into water body for agricultural production. Under caps, allowances of grey water discharge for regions are allocated or traded over boundaries. To achieve the trade, the impacts of grey water

must be internalized into the cost of waste water discharge. Thus, the differentiated impacts of polluted water can be reflected by the prices of discharge adopted in different regions. The differentiated costs could encourage production entities within a region of higher water scarcity to buy allowances from entities facing lower levels of scarcity. The total tradable allowances should also be strictly limited to ensure their value (this is a lesson learned from the EU's ETS). The allocation of allowances should be achieved by auctioning rather than by free allocation. In addition, the free allocation of allowance should be made according to the grey water generated per unit GDP of best performing installations to ensure that only the environmentally well-performing entities are stimulated by free quotas. Due to 'curtailed allocations with spurred trading', nations with high GWS might seek technical or structural innovations to reduce the volume of discharged grey water or buy allowances to cover the total discharges. Otherwise, they will be under stringent obligations to pay for discharging grey water which is beyond the cap. This is meaningful particularly for countries with high GWS such as China and India as biggest producers. However, the biggest challenge still arises in the monitoring of pollution discharge as wastewater of non-point sources, which is much more difficult to measure compared to air pollution. Thus the feasibility of such a scheme depends on the future development of methods for monitoring pollution discharge. Moreover, trading allowances should be implemented in a careful way under effective monitoring and supervision with law enforcement agencies in order to 1) prevent the cap-and-trade becoming a form of blue-washing that the industry uses to disguise itself as environmental stewards and 2) avoid pollution leakage.

4.3. Regulation on commodity trade and water supply from the consumption side

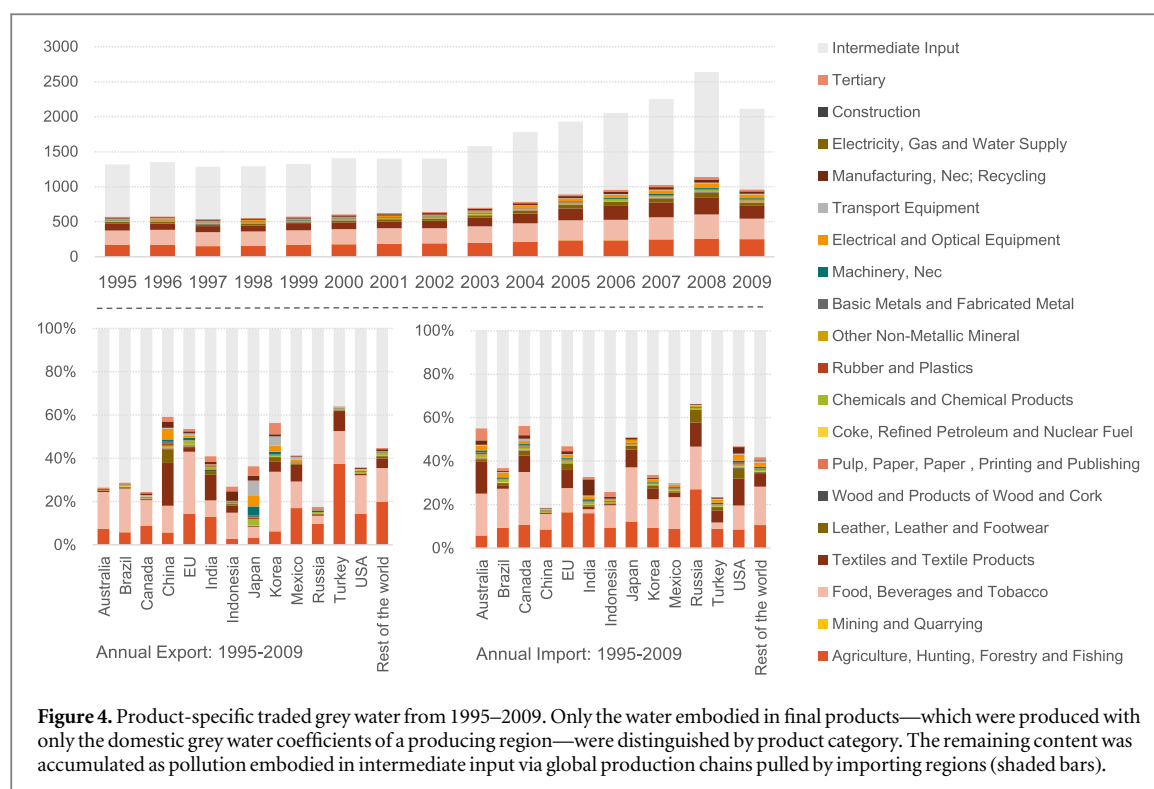
4.3.1. Labelling of product consumption

From the aspect of consumption, the first step is labelling. At the commodity level, the labelling of grey water footprints attached to products or categories can demonstrate production pressures. Apart from agricultural products, textiles and textile products, food, beverages and tobacco, electrical and optical equipment and chemicals and chemical products made up the biggest grey water flows (figure 4, upper), and disparities exist among different nations from the aspects of exporter and importer (figure 4, lower). Thus, labels informing the grey water content of products under such categories would be meaningful.

4.3.2. Trade adjustment scheme

Another strategy from consumption side is the adjustment of trade. First imagine a basic scenario under international trade where there are no environmental taxes for either the producer (exporter) or the

consumer (importer). The price of products will leave the exporting nation and enter the importing country at a constant price with no incentives for either side. However, the tax system can bring benefits to both sides. For exporters, taxes for producers are first levied to internalize the environmental prices of water pollution. If such a policy exists in the exporting country, the exported goods may get rebated taxes to regain competitiveness in the untaxed global market by lowering the prices. For importers, when the traded goods enter the markets of importing countries, the products with untaxed prices in the global market will be taxed again. Products with higher pollution shall face higher import tax rates compared with domestic products with lower, where the latter enjoys lower costs from pollution control. In short, imported 'dirty' products will be more expensive than domestic products. Thus the market attractiveness and competitiveness of the imported goods may be reduced, which could possibly lead to an import transformation of consumers, and the potential 'pollution leakage' caused by production reallocation to nations with dirtier production could also be confined. As a result, by attaching the pollution impacts embodied in trade with international competitiveness, reducing the amount of grey water content will become a priority issue for exporters. Simultaneously, the extra costs from the taxes levied on imported goods will affect import activities, especially for countries with higher import. On the other hand, if production is reallocated to regions where there are lower environmental costs, the border tax shall be reduced for trade promotion. In summary, exports causing high pollution impacts will be restricted and exports causing fewer pollution impacts will be promoted. As a result, the production may be optimally allocated to regions with lower environmental costs rather than lower economic costs. The success of such schemes depends greatly on environmental costs in production, which calls for strict monitoring and supervision, as previously discussed. On the other hand, although the GATT allows the taxes to be imposed on imported goods equivalent to domestic charges for the conservation of exhaustible natural resources (WTO 1994), exporters may still face new barriers brought on by the taxes, which could be perceived as a kind of sanction with the potential to create controversy. Moreover, the tax scheme designed in the present study may not necessarily be politically feasible or be put into effect in the short term. Here we are actually more focused on providing a *rethinking* of international trade, to further consider and internalize the environmental externalities of economic growth. In the long run, if the tax rates can be set in a progressive way after being fully considered and regulations properly developed, they can accelerate the transition towards an environmentally sustainable economic mode for exporters. Exporters should seek to be positive and take measures to primarily administrate their production to reduce the



impact of external tariffs. After all, the purpose of the tariff scheme is to raise the urgency of technical transformation and industrial upgrade for exporters, to minimize their impact on water resources through industrial adjustment and optimization.

5. Conclusions

Unprecedented growth can be witnessed in traded grey water especially during the recent decade. China was the largest grey water exporter while the EU the largest importer from 1995–2009. Water scarcity caused by the degradation of water quality was severer in China despite its largest grey water export remaining tremendous domestic pollution impacts induced by foreign demands. Structural changes along with the evolution of globalized production and consumption even intensified the pollution impacts of several important exporters. Nevertheless, there are several limitations in this study. First, as the actual water pollutants are far more complex and complicated than the indicator ‘grey water’, it calls for multiple measurements if specific contaminants need to be traced. For example, the microbial activity removes most of the pollutants, and physical pollutants such as turbidity and suspended solids as well as deposits due to gravity should all be accounted for. Future work shall bring specific investigation and detailed analysis of these issues. Secondly, as water scarcity is highly spatially specific, the accounting based on national level in the MRIO framework left out the details on micro levels such as

watershed or river basin which results in uncertainties. However, this method can still identify the hot spots of pollution impacts in the supply chains.

Despite the limitations, this paper has provided information about the contributors to global pollution transfer for further regulatory adjustments. The combination of policy suggestions with the derived indicators also raises new ideas on effluent management, such as reforming local water regulations or changing external trade. More efforts are still a sine qua non as we believe that both the cap-and-trade and BTA schemes are only an induction mechanism to relieve the current tension between economic globalization and water resources. The key point is a substantial transition to cleaner production with innovation in both technologies, structures and administration to keep the pollution out of water.

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