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International trade linked with disease burden from airborne particulate pollution

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ABSTRACT

The importance of mitigating air pollution is well understood, while the role of trade on health burden induced by air pollution is not. A comparison between the geographic locations of PM emissions and those of airborne diseases shows large discrepancy. The incidence of PM emissions is dominated by countries outside of Asia, while half of the airborne disease burden occurs in China and India. Dealing with the air pollution issue from the endpoint (i.e. PM emissions-caused disease) is more relevant to health. Though there are many influential factors that cause high health burden of air pollution in developing countries, the high airborne disease burden caused by production in developing countries for fulfilling the demand for goods in developed countries cannot be ignored. We calculate the airborne disease footprints of 189 countries, and link the workers who are suffering from severe airborne disease with the consumers who are enjoying the goods without suffering the health risks of workers. China and India are the top two net exporters of both PM emissions and PM-caused airborne disease, but the net exports are much larger in terms of disease. The USA is the top net importer of airborne disease, followed by other developed nations such as Japan, Hong Kong, the UAE, and many wealthy European nations. These results can be helpful for international organizations and policy-makers to guide joint global efforts for combatting airborne diseases.

1. Introduction

Air pollution is a top environmental health hazard. In 2012 it accounted for seven million deaths worldwide (WHO, 2014a). Most of these air pollution-caused deaths occurred in developing countries (Madaniyazi et al., 2015; Apte et al., 2015). China and India are the two largest developing economies suffering severe air pollution. To sustain their rapid internal economic development, they have relied on fulfilling the consumption demands of developed countries through international trade, in the process producing large amounts of goods from energy- and pollution-intensive industries. For this they have paid a high environmental and social price creating high levels of airborne particulate matter (PM), which in turn has caused high levels of PM related disease (Oregon PSR, 2015). We recognise that a large portion of the PM-related deaths in China and India are due to domestic consumption (Zhang et al., 2017), but our study that focuses on PM-related health risks associated with final consumption outside of China and India aims to provide an additional perspective to deal with the airborne disease risks.

PM is one of the six common air pollutants, and the other five categories of common air pollutants are ground-level ozone, carbon monoxide, nitrogen dioxide, lead, sulfur dioxide. PM is a complex mixture of solid, liquid or solid and liquid particles suspended in the air. It consists of Polycyclic Aromatic Hydrocarbons (PAHs), soot, black carbon, absorbed water, aerosolized sulfuric acid droplets, other acids, nitrogen, sulfur, organic material, metals, and other toxic substances. Therefore, PM can include any or all of the other five categories of common air pollutants. It can be inhaled deep into the lungs and then brought into the bloodstream through the blood circulation (EPA, 2012). A study based on China shows that a per 100 μg/m3 annual increase of PM at all sizes reduces life expectancy by around 3 years (Crane and Mao, 2015). Previous studies have shown that multiple human diseases such as respiratory diseases, heart diseases, reduced lung function, stroke and cancers can be caused or exacerbated by PM pollution (Kim et al., 2015; WHO, 2014b; UNEP, 2014).

A recent report shows that 17% of all deaths in China are caused by air pollution (Rohde and Muller, 2015), which is 4400 deaths daily. The high cost of air pollution has consumed 6.5% of China's GDP each year since 2010 and has climbed with the increase in China's population and urbanization (Crane and Mao, 2015). Air pollution is also a leading cause of death in India. It was responsible for 620,000 deaths in 2010 (Swaniti Initiative, 2015). According to a World Bank report, India's

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annual expense on air pollution amounts to 3% of its GDP (Burney and Ramanathan, 2014).

Footprint studies of the adverse effects of global trade on developing nations are said to take a consumption-based perspective – implicating the consumer in the social and environmental effects of doing business. They are exemplified, for example, in footprints illustrating the extent, in products, of embodied greenhouse gas emissions (Peters and Hertwich, 2008), inequality (Alsamawi et al., 2014b), corruption (Xiao et al., 2017) or adverse working conditions (Simas et al. 2014a,b; Alsamawi et al., 2017). They show up the extent to which wealthy nations 'outsource' the adverse effects of their consumption to poorer, developing nations (Hoekstra et al., 2016; Malik and Lan, 2016).

Previous studies have also calculated footprints of air pollutant emissions, dealing with the source of the problem (the intervention point in life-cycle assessment (LCA) parlance), or dispersal as emissions affect air quality (known as the midpoint). Such studies include CO2 (Hertwich and Peters, 2009), SO2 (Kanemoto et al., 2014), N2O (Oita et al., 2016) and PM (Yang et al., 2016). Regarding the endpoint (health risk burden) of air pollutant emissions, there are few studies and conducted in limited PM sources or regions. For example, the studies conducted in China examined health effects of air pollution at the provincial level (Xia et al., 2016a,b; Jiang et al., 2015). The study based on US (Paulot and Jacob, 2013) investigated the health effects of PM pollution only from the source of ammonia emissions. A study based on the Asian area (Takahashi et al., 2014) investigated consumption-based health impacts of PM2.5 carbonaceous aerosols for 9 countries. There is a newly published paper (Zhang et al., 2017) that has studied the PM caused health risks that are associated with international trade at a global level, but which only shows the aggregated results in 13 world regions. To our knowledge, footprints in terms of disease burden caused by airborne particulate emissions (i.e. the endpoint), particularly at the national level with a wide coverage of 189 countries, have not yet been calculated. This is the focus of our work.

The LCA literature has for many years discussed the relative usefulness of intervention, midpoint and endpoint indicator studies, which trade for example the accuracy of emissions data at source for the social relevance of an LCA damage category such as "human health" (Heijungs et al., 2003; Lenzen, 2006). LCA studies comparing site-generic Life Cycle Inventory studies with studies that use population and geographic overlays to examine the endpoint have illustrated the importance of considering a wider range of factors in allocating responsibility for environmental and health effects of emissions (Potting et al., 1998; Sadamichi and Kato, 2006; Huijbregts et al., 2000; Bare et al., 2003; Nansai et al., 2005). In a similar vein the Brazilian Proposal to the Kyoto Protocol notes the shift in responsibility for climate change when the indicator annual emissions is exchanged for the endpoint indicator temperature increase (Federative Republic of Brazil, 1997; Meira and Miguez, 2000; Den et al., 1999; Rosa et al., 2004). Addressing the United Nations Framework Convention on Climate Change (UNFCCC)'s equity principle for the allocation of contribution to climate change, Geschke and colleagues show decisively that those countries responsible for the highest annual emissions, such as China and India, are not the same countries as those responsible for the highest contribution to temperature increase over time (Kanemoto et al., 2012). They demonstrate that choice of indicators and perceived locus of control need to be carefully conceived if we are to adhere to the UNFCCC's goal of equity in burden sharing (Friman and Linner, 2011).

With this equity principle in mind we suggest that the choice of endpoint indicator *PM-related disease* will better reveal the burden of poor *air quality* than the indicator *annual emissions*. This is because the area where there exists high air pollution due to emissions does not necessarily correlate with high rates of airborne disease. Policy-makers need to know the extent and location of the effects of air pollution on people at the *endpoint* in order to devise good policies and programs to mitigate the devastating consequences of those effects; and consumer nations need to know about the burden of PM-related disease embodied in the supply chain of goods and services in order to take some responsibility for contributing towards mitigation.

Our paper aims to show how international trade affects disease burden caused by emissions of airborne PM. Though there is a link between disease burden and PM-caused risks (Burnett et al., 2014; Zhang et al., 2017; Apte et al., 2015), this paper focuses on disease burden. The novelty in our work on previous work is the enhanced sectoral detail. The emissions that affect air quality can be controlled or ameliorated by sophisticated monitoring and public announcements. The results can be helpful for organizations such as WHO to combat airborne diseases through joint efforts of countries that import and export goods with high levels of embodied airborne disease. The PM-caused airborne disease footprint results can be used by decision-makers to develop relevant policies for encouraging partnership building between countries (Hesami, 2015). Our results, expressed in terms of disease burden that is dealing with the issue at a later stage, can provide a more accurate and targeted reference for international programs to ameliorate the effects of PM emissions on the health of developing nations. In addition, our footprint calculation shifting focus to the endpoint indicator, PM related disease, indicates where responsibility should lie for endeavours to ameliorate the devastating human consequences of that disease.

2. Methods and data

2.1. Input output analysis and footprint analysis

Input-output analysis (IOA) is an economic technique dealing with the complex interdependencies between production and consumption across all sectors of an economy (Leontief, 1936). IOA operates in monetary terms, but has been extended to capture physical impacts (Leontief and Ford, 1970). Non-monetary, physical extensions are arranged in so-called satellite accounts (UNSD, 2014). Extended IOA has been intensively applied to analyse global social and environmental issues (Dietzenbacher et al., 2013a; Tukker et al., 2016), using multi-region input-output (MRIO) models such as Eora (Lenzen et al., 2012a,b; Lenzen et al., 2013a,b), EXIOBASE (Tukker et al., 2013), GTAP (Peters et al., 2011; Andrew and Peters, 2013), IDE-JETRO (Meng et al., 2013) and WIOD (Dietzenbacher et al., 2013b). Social and environmental footprints show the domestic and imported social and environmental burden required to meet a particular final demand bundle (Hertwich and Peters, 2009; Feng et al., 2011; Steen-Olsen et al., 2012; Alsamawi et al., 2014a; Lan et al., 2016; Xiao et al., 2017). In this study, we use the Eora MRIO database (Lenzen et al., 2013a,b) to calculate global footprints in terms of disease burden from airborne particulate matter, or in short: airborne disease footprints.

The Eora MRIO database offers global MRIO tables for 189 countries at a detail of 25–500 sectors by country (Eora data can be downloaded from www.worldmiro.com). The Eora MRIO database includes three basic matrices: the $L \times N$ intermediate demand matrix $\mathbf{T}$, the $L \times N$ final demand matrix $\mathbf{y}$, and the $L \times N$ value added matrix $\mathbf{v}$. In input-output algebra, the sum of an economy's intermediate demand and final demand should equal total output

$$\mathrm{x} = \mathrm{T}\mathbf{1}^N + \mathrm{y}\mathbf{1}^M, \tag{1}$$

where $\mathbf{1}^N$ and $\mathbf{1}^M$ are suitable summation operators. Defining the input coefficients matrix $\mathrm{A} = \mathrm{T}\hat{\mathbf{x}}^{-1}$,where $\hat{\mathbf{x}}$ is a diagonalised vector $\mathbf{x}$, Eq. (1) can be transformed into

$$\mathrm{x} = (\mathbf{I} - \mathrm{A})^{-1}\mathbf{y}\mathbf{1}^M, \tag{2}$$

where the Leontief inverse matrix $\mathrm{L} = (\mathbf{I} - \mathrm{A})^{-1}$ contains direct and indirect links between an economy's total output $\mathbf{x}$ and its final demand $\mathbf{y}$ (Leontief, 1966).

In order to generalise the monetary IO calculus to operate in physical (here: disease burden) terms, we follow Leontief and Ford (1970) by coupling a satellite account of occupational airborne disease burden