Economies to die for: Impacts on human health embodied in production and trade

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Abstract

Using an extended input-output model of 41 regions, this study evaluates the responsibility of impacts on human health embodied in production and trade of countries in a similar manner as done in environmental studies related to ecological footprints. It analyzes occupational injuries, payments made to the health industry by economic activities in all regions, and deaths attributable to pollution that take place directly and indirectly when output is delivered to final demands home or abroad. Findings show that the most important sources of deaths embodied in trade are China, India, Russia, Germany, Indonesia, and Romania, while the most important destinations are Germany, France, Great Britain, Italy, the US. Conversely, counteracting health deterioration, industries with highest levels of payments to the health sector per direct and indirect unit of output intended for final demand are mostly located in the developed world, with the clear exception of China, whose heavy industries appear to be making big investments in human capital.

1 Introduction

This study presents an exploratory analysis of the distribution of impacts of economic activity on human health and the responsibility for those impacts around the world using input–output analysis. Although this methodology has been used extensively for the assessment of environmental impacts embedded in trade (see Wiedmann et al., 2007, for a review), its application to human health mostly has been undertaken in an indirect way. An adaptation of a multi-regional input–output model has been carried out here, in order to understand the more direct relationship between production, trade, and human health. The twofold question

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that adaptation tries to answer is: **"How does global trade relate to local health quality and payments to the health sector, and what is the distribution of responsibility for that dynamic among producers in different regions?"**

Section 2 presents a brief review of the literature of input–output studies related to trade and the environment, from which the intuition for the methodology used here is taken. Also, relevant literature that looks into the link between pollution and health is evaluated. An explanation of the pollution haven hypothesis and how it might play a role in this kind of studies is also provided, even if this study does not explicitly set out to prove or disprove its theoretical underpinnings. Section 3 presents a basic input–output model, which is then expanded to a multi–region model that takes the link between human health and production into account. It also explains the variables related to human health used in this study. Section 4 presents the results and a final section provides a conclusion.

2 Background

The notion of assessing the embodied content of health related variables in products and trade resembles that carried out in environmental studies of responsibility or "footprint" analyses—that is, evaluating to what degree a country extends its impacts on this earth across its borders. In this study an attempt is made to view human health under a similar light as the term *virtual water* (Allan, 2003) or the more broad "ecological footprint" (Rees, 1996; Wackernagel & Rees, 1996), which reflects the total land needed by a country, in order to absorb the impact of its residents on the planet.

In the particular case developed here, that means that imports allow an economy with less tolerance to human health deterioration (induced by industrial activity) to escape the stress of negatively affecting the health of its inhabitants by a factor given by the higher tolerance to health deterioration of its business partners. From this, it follows that it is possible to assess the global responsibility for direct and indirect impacts on health that are caused by a country's production by identifying the final destination, home and abroad, of that production.

As explained above, there is an established tradition of input-output literature that has undertaken these types of analysis for environmental variables (Wiedmann et al., 2007). Some focus not only on the accounting of environmental impacts embodied in trade, but also on the discussion of how to assign responsibility for them to consumers that buy products that come from abroad (Steenge, 1999; Munksgaard & Pedersen, 2001; Gallego & Lenzen, 2005; Rodrigues et al., 2006; Lenzen et al., 2007; Rodrigues & Domingos, 2008).

A preferred topic, due to the the special interest on climate change and the international agreements derived to address it, seems to be that of the emission content of imports and exports. Many of these studies focus on specific countries, such as India (Dietzenbacher & Mukhopadhyay, 2007), Italy (Mongelli et al., 2006), Denmark (Munksgaard & Pedersen, 2001), or Spain (Sánchez-Chóliz & Duarte, 2004; Serrano & Dietzenbacher, 2010), and a few take a bilateral approach (Rhee

& Chung, 2006, Ackerman et al., 2007, or Norman et al., 2007, for example). However, multi-regional studies can assess these global relationships of impacts of trade and responsibility allocation in a way that can provide better insights (Wiedmann et al., 2006; Turner et al., 2007).

The limitation behind conducting such multi–regional studies lays in the availability of input-output data for many regions. Nevertheless, important contributions have been made. For example, Peters & Hertwich (2008) analyzed CO_2 emissions embodied in international trade for 87 regions. Weber & Matthews (2007) also analyzed the trade environmental relationships between the US and seven of its trade partners, and Ahmad & Wyckoff (2003) estimated the emissions embodied in international trade of goods of over 20 regions/countries. For this study, use is made of the World Input-Output Datatabase (WIOD)[1], which provides input-output matrices for 27 European countries, 13 other relevant world economies, and the rest of the world.

Literature regarding the link between health and pollution is also extensive, although not commonly related to input-output studies. Cohen et al. (2004) and Ostro (2004) offer some of the most comprehensive evidence for the effect of pollution on human burden of disease as well as its assessment for international comparison and serve as empirical backing for the *deaths attributable to pollution* measure used in this study and explained in section 3.2.3. Notwithstanding, most of the literature concerning this link is done at the country level, due to the fact that impacts of different sources of pollution on health are a highly geographically localized issue. Zuidema & Nentjes (1997), for example, have investigated the link between work loss days for the labor population and average yearly concentrations of air pollution in 29 districts in the Netherlands, finding a significant relationship between pollutants and morbidity. Similarly, Khanna (2000) has developed an index of pollution based on the dose-response of each pollutant and certain types of welfare loss for the US. Cifuentes & Lave (1993), on the other hand, have estimated the marginal benefits of air-pollution abatement due to health effects also in the US, considering a damage function.

Mukhopadhyay & Forssell (2005) have claimed a more actual and concrete linear link between impacts on health and emissions from fuel combustion and have brought impacts on health into the realm of input-output studies. This has provided the structural analysis literature with an advance from so-called *impacts caused* (emissions) to *impacts borne* (health impacts). They essentially found out that, for the case of India, changes in air pollution and health impacts can be explained by changes in the same structural factors (pollution intensity, technology, and final demand). The present study aims to contribute to that line of work.

On the other hand, assessing the link between economic activity, pollution, and human health links this exercise to the pollution haven hypothesis, even if it is not the intention here to test it. This hypothesis posits that trade allows countries to move away from producing environmentally sensitive activities (in terms of natural resources, pollution, and, from the explanation above, health

[1] Available at http://www.wiod.org.

impacts), as explained in the opening sentences of this section.

This dynamic can be interpreted from the Heckscher-Ohlin model of trade, where an increase in trade will lead countries to specialize in industries where they enjoy a comparative advantage. The Heckscher-Ohlin model describes this advantage from the relative abundance of either labor or capital regarding another country. It predicts that the relatively labor abundant country will export the good that is produced relatively labor intensive and will import the relatively capital intensive good. Later efforts have extended the scope of analysis to include other factors, such as natural resources (see Leamer, 1980, 1985; or Bowen et al., 1987). For those extensions, in world with two countries and two goods, each country would specialize in the good for which the natural resource intensity relative to the other country's is the least.

A similar extension can be made regarding the measures for embedded health impacts used in this study, due to the link with environmental quality. The implication is that if the pollution haven hypothesis is true, developing countries will produce more "sick" commodities—those high in embedded health impacts—than their trade counterparts in developed countries, and at the same time they will meet their final demand of more "healthy" products (low on embedded injuries) via imports from developed nations. The opposite can be said from the latter.

This can happen because of different reasons. For example, it can be assumed that developed countries that have populations with higher incomes and better established institutions will demand better working conditions and health coverage systems, as well as better environmental controls. On the contrary, developing countries, with lower levels of income are thought to place a higher value on *any* jobs that can be generated, with less concern over the negative impacts that could accompany them. Accordingly, it can be assumed that in developing countries, controls for overall environmental quality and health will be lax.

In the context of the Heckscher-Ohlin model, these assumptions translate into developing countries being abundant in an intangible factor that can be thought of (in a somewhat draconian fashion) as the extent to which they are willing to deteriorate the health of their workforce. Developed countries, will be less abundant in this factor due to labor protection laws, collective agreements, and stronger controls. It follows that developing countries will specialize in "sick" commodities while the developed nations will do so in "healthy" commodities. As a consequence, trade will exacerbate existing health problems in those developing countries with relatively lax environmental and social security regulations.

Finally, *payments to the health sector*—another of the variables evaluated here—can be thought of a counteracting force against health deterioration. For example, Fang & Gavazza (2011) interpret such payments, when made by employers in a mixed public-private health care system, as a factor and take the viewpoint that health is a general form of human capital that affects workers' productivities on the job. Here it is thought that more developed countries will pay more for employees health per unit of output than less developed nations, making the latter specialize in commodities high on payments to health embedded in them.

3 Methodology

In this section the basic input-output model is presented and expanded to assess human health impacts in a multi-regional context. The number of injuries at the workplace—one of the measures—is used to explain the basic elements of the calculations and in later sections a generalization is made to other measures of health quality. Another of those measures is based on expenditures from all sectors in all countries to their respective health sector. A final approach assesses deaths attributable to pollution per unit of output at the global scale.

3.1 Model

3.1.1 Basic input-output model

Throughout this paper, economic relationships of interest are presented in the form of an input-output model of r regions. Each region is comprised of e economic sectors, which produce an output that may be used by themselves or other sectors as an input, or by final users (e.g. households, the government, etc.) as consumption, investment, or gross exports. Regions are thought to differ in the technology they use to produce. For that reason, different production "recipes" apply for a unit of a certain sector's output, depending on its origin.

Each region's interindustry inputs are given by the matrix $\mathbf{Z} = [z^r_{ij}]$, which identifies purchases of sector i's output by sector j in region r. A vector $\mathbf{f^r} = [f^r_j]$ defines the sales of sector j to final demand elements in region r and, consequently, a vector $\mathbf{x^r} = [x^r_j]$ gives total output of industry j in the same region. Put together for individual sectors, the relationship between these elements can be expressed as

$$x^r_j = z^r_{j1} + \cdots + z^r_{je} + f^r_j. \tag{1}$$

Stacking the equations for individual sectors, the same relationship can be expressed in matrix notation[2] as

$$\mathbf{x} = \mathbf{Zi} + \mathbf{f}, \tag{2}$$

where $\mathbf{i}$ is a summation vector of ones and length j. Consequently, direct input coefficients can be defined as $\mathbf{A^r} = [a^r_{ij} = z^r_{ij}/x^r_j]$, which in matrix form reads

$$\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{\mathbf{-1}}. \tag{3}$$

From (2) and (3), the entire system can be expressed more generally as

$$\mathbf{x} = \mathbf{Ax} + \mathbf{f}, \tag{4}$$

and rearranged results in

[2]Traditionally, in input-output studies bold, upright capital letters denote matrices, upright lower case letters, vectors, and italicized lower case letters, scalars. A diagonal matrix with a vector on its main diagonal and zeros elsewhere is denoted by an upright lower case letter with a circumflex (ˆ). See Miller & Blair (2009), *Appendix A* for an introduction.

$$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{f}. \tag{5}$$

Finally, if changes in demand are simulated, the new output can be estimated by solving (5) with standard matrix algebra

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{L}\mathbf{f}, \tag{6}$$

where $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{L} = [l_{ij}]$ is known as the *Leontief inverse* or the *total requirements matrix*. Its values represent the additional direct and indirect production in i that has to be realized in order to meet an additional unit of final demand of product j.

3.1.2 Extension of the basic model to a multi-regional model and assessment of the health sector

The approach described in this section expands the basic model to a multi-regional input-output model, in order to compute an international balance of injuries at the workplace between regions. The methodology is fashioned after a similar approach used to assess the responsibility of a country in regard to emissions, with some conceptual adjustments (See Serrano & Dietzenbacher, 2010, for a useful comparison of global responsibility evaluation methods). The coefficient of injuries per unit of output is used as an approximation of the on-the-job health deterioration embedded in goods and services that are traded locally and globally.

The extension of equation (6) to a multi-country approach is straightforward when interpreting the matrices explained in section 3.1.1 as a collection of regional matrices. In matrix notation, the arrangement of those regions in the input-output model, expanding on (4), is represented by the partitioned structure where $r, s = \{1, \ldots, n\}$ and

$$\begin{pmatrix} \mathbf{x^1} \\ \vdots \\ \mathbf{x^r} \end{pmatrix} = \begin{bmatrix} \mathbf{A^{11}} & \ldots & \mathbf{A^{1s}} \\ \vdots & \ddots & \\ \mathbf{A^{r1}} & & \mathbf{A^{rs}} \end{bmatrix} \begin{pmatrix} \mathbf{x^1} \\ \vdots \\ \mathbf{x^r} \end{pmatrix} + \begin{pmatrix} \mathbf{f^{11}} + \ldots + \mathbf{f^{1s}} \\ \vdots \\ \mathbf{f^{r1}} + \ldots + \mathbf{f^{rs}} \end{pmatrix}. \tag{7}$$

An important conceptual difference exists between the individual region and the multi-regional model. For the individual region model, all interregional[3] trade is given exogenously as part of the final demand ($\mathbf{f}$) in the form of exports, regardless of their use in the final destination. In the multi-region model, however, the interindustry inputs matrix ($\mathbf{Z}$) is composed of regional matrices ($\mathbf{Z} = \left[\begin{smallmatrix} \mathbf{Z^{11}} & \mathbf{Z^{1s}} \\ \mathbf{Z^{r1}} & \mathbf{Z^{rs}} \end{smallmatrix}\right]$), for which the off-diagonal elements represent the portion of interregional trade between sectors from different regions. Only the share of international trade destined for final demand remains in ($\mathbf{f}$) along with its other components.

A vector of coefficients $\mathbf{c^r}$, equivalent to $[c_j^r = h_j^r / x_j^r]$, is constructed to incorporate the health perspective, where c identifies the number of injuries h generated per unit of output x of sector j in region r. Total injuries (h) generated in all regions is defined by

[3]"Interregional" is to be interpreted as "intercountry".

$$\mathbf{h} = \mathbf{c}\mathbf{x} \tag{8}$$

Since it is known from (6) that $\mathbf{x} = \mathbf{L}\mathbf{f}$, then in patitioned form

$$\begin{pmatrix} \mathbf{h^1} \\ \vdots \\ \mathbf{h^r} \end{pmatrix} = \begin{bmatrix} \mathbf{c^1 L^{11}} & \dots & \mathbf{c^1 L^{1s}} \\ \vdots & \ddots & \\ \mathbf{c^r L^{r1}} & & \mathbf{c^r L^{rs}} \end{bmatrix} \begin{pmatrix} \mathbf{f^{11}} + \ldots + \mathbf{f^{1r}} \\ \vdots \\ \mathbf{f^{r1}} + \ldots + \mathbf{f^{rr}} \end{pmatrix}. \tag{9}$$

The multiplication of the coefficient vector ($\mathbf{c}$) with the Leontief inverse ($\mathbf{L}$) yields a vector of coefficients that translate final demands into direct and indirect totals of the health measure under evaluation. Further multiplication by the regional final demands added into one vector ($\mathbf{f}$) yields a single number of the system-wide total health measure (h). However, in order to assess the responsibilities of the different stakeholders (sectors, final demands, and regions) without having to resort to cumbersome partitioned notation, it is important to keep the individual elements disaggregated. That can be accomplished with resources from matrix multiplication rules and their notation conventions. In order to maintain disaggregation, the coefficient vector is turned into a diagonal matrix ($\hat{\mathbf{c}}$). It then premultiplies ($\mathbf{L}$), which yields a matrix $\mathbf{H} = [h_{ij}^{rs}]$. Its elements identify the extra direct and indirect injuries in sector i of region r that implicitly take place when an extra unit of goods or services from sector j is needed to satisfy final demands in region s. Thus,

$$\begin{pmatrix} \mathbf{h^1} \\ \vdots \\ \mathbf{h^r} \end{pmatrix} = \begin{bmatrix} \mathbf{H^{11}} & \dots & \mathbf{H^{1s}} \\ \vdots & \ddots & \\ \mathbf{H^{r1}} & & \mathbf{H^{rs}} \end{bmatrix} \begin{pmatrix} \mathbf{f^{11}} + \ldots + \mathbf{f^{1s}} \\ \vdots \\ \mathbf{f^{r1}} + \ldots + \mathbf{f^{rs}} \end{pmatrix}. \tag{10}$$

Matrix ($\mathbf{H} = \hat{\mathbf{c}}\mathbf{L}$) is interesting in itself, because it readily shows which sectors in which regions have the highest (or lowest) number of injuries per unit of final demand; or simply *health impact intensities*. However, since levels are important and responsibility is not only attributed to the producer, but also to those who trigger that production, a final procedure (equation 11 below) yields a mechanism to identify a net balance between stakeholders. First, if the individual regional final demand vectors from the last part of equation (10) are known, instead of summing into a single vector, a matrix ($\mathbf{F} = \left[\begin{smallmatrix} \mathbf{f^{11}} & \mathbf{f^{1s}} \\ \mathbf{f^{r1}} & \mathbf{f^{rs}} \end{smallmatrix}\right]$) can be constructed from them. Postmultiplication of ($\mathbf{H}$) with said matrix will yield a nonsquare final demand responsibility matrix ($\mathbf{G}$) of dimensions ($ne \times n$) as a collection of vectors ($\mathbf{g}$). The column sums correspond to the responsibilities of the final demand of each region in regard to the health measure at hand. The vector of its row sums of is equal to $\mathbf{h}$. In matrix notation, this is $\mathbf{G} = \hat{\mathbf{c}}\mathbf{L}\mathbf{F}$. Partitioned and continued from 10, it reads

$$\begin{bmatrix} \mathbf{g^{11}} & \dots & \mathbf{g^{1s}} \\ \vdots & \ddots & \\ \mathbf{g^{r1}} & & \mathbf{g^{rs}} \end{bmatrix} = \begin{bmatrix} \mathbf{H^{11}} & \dots & \mathbf{H^{1s}} \\ \vdots & \ddots & \\ \mathbf{H^{r1}} & & \mathbf{H^{rs}} \end{bmatrix} \begin{bmatrix} \mathbf{f^{11}} & \dots & \mathbf{f^{1s}} \\ \vdots & \ddots & \\ \mathbf{f^{r1}} & & \mathbf{f^{rs}} \end{bmatrix}. \tag{11}$$

The row sums of this matrix represent the producer responsibilities. The individual elements $\mathbf{g} = [g^{rs}]$ express the injuries in r responsibility of final demand in s or the trade of injuries. The balance between producer and final demand responsibility is finally given by substracting column sums from row sums aggregated to the country level:

$$\text{Net balance of injuries} = \sum g^{rs} - \sum g^{sr}. \tag{12}$$

Additionally, if the matrix is aggregated at the country level, then it becomes square and its off diagonal elements represent the trade of injuries between regions. The percentage structure of each column can be interpreted as the shares of origin of imported industries for every country. The percentage structure of each row, alternatively, denotes the shares of destination of injuries for every country.

3.2 Human health impact measures and coefficients

In order to better understand how economic regions interact with human health in the multiregional input-output model, the *coefficient of injuries per unit of output* $\mathbf{c^r} = [c_j^r = h_j^r / x_j^r]$ explained in section 3.1.2 is extended conceptually to reflect two more measures (to substitute for h_j^r). In practice, this translates into separate exercises being conducted for: 1) number of occupational injuries per unit of output, 2) payments to the health sector of a given region per unit of output; and 3) deaths attributable to outdoor air pollution per unit of output. These measures differ in the degree to which they can be considered good proxies for the relationship between human health and the economy and the kind of questions that they can answer.

3.2.1 Occupational injuries

The first set of coefficients is created using occupational injuries at the workplace in place of h_j^r explained above. Member countries of the International Labour Organization aim to collect data on occupational injuries by economic activity[4], with different degrees of success regarding detail and comprehensiveness. ILO has compiled this information within its Laborsta project for various years. The measure is constructed in a straightforward way by recording the cases of one worker incurring an occupational injury as a result of one occupational accident in a specific economic sector[5].

This measure provides a link between workforce health and economic sectors in the different regions.

Using this measure has the positive aspect that, for the most part, data on injuries is collected by national health statistics systems, which in turn use medical records and household surveys for their construction. This fact indicates that the sub-reporting that could be expected from employers is avoided.

[4]Following the *Resolution concerning statistics of occupational injuries* resulting from occupational accidents, available at:
http://laborsta.ilo.org/applv8/data/SSM8/E/ANNEX.html.

[5]See appendix A for details.

However, there are issues to consider. Even if this health metric is directly related to production, its unit of measurement refers to highly visible cases and does not account those that never make it to the hospital (or to treatment). Unhealthy working conditions may contribute to chronic illnesses (skin conditions, respiratory illnesses, cancer, and others) that presumably are not captured with this variable. Furthermore, the data that is available for this variable is difficult to compare internationally due to different definitions used by member nations and different levels of coverage. For example, while the US has disaggregated information for nine industrial sectors, China only offers a grand total for some state-owned enterprises. Without efforts of data reconciliation and harmonization, results cannot be conclusive. Time constraints allow this variable to be used as an exploratory reference resource only.

3.2.2 Payments to the health sector of a given region per unit of output

As implied in section 3.1.1, an individual column of the direct requirements matrix ($\mathbf{Z}$) represents the purchases that a given economic sector makes to itself and other industries home or abroad—the "recipe" to create its output. Of those entries, the purchases that industries make to the *Health and Social Work* industry[6] are considered a reasonable candidate to link industry output to direct and indirect human health costs of production in this study. The scope of said industry is given by the International Standard Industrial Classification of All Economic Activities (ISIC) and it is explained in detail in appendix A. The advantage of this indicator is that the information describing it is harmonized within the World Input-Output Database (WIOD) and it is comprehensive for the period covered by it (1995-2009).

Essentially, the health sector represents five clusters of activity. First, it quantifies the activities of general and specialized hospitals and other health institutions with accommodation facilities. These activities are directed to in-patients mainly and they are carried out under supervision of medical doctors. Second, it includes the consultation and treatment activities of general physicians and medical specialists including dentists, either at private practices or in clinics such as those attached to firms and other institutions. Third, it assesses those activities related to human health not performed by doctors or dentists, like optometry and occupational therapy, which may be conducted in the same private practices or clinics as the second category. Fourth, it describes the economic activities of orphanages, correctional facilities, homes for the elderly and such. Lastly, the health sector within the input-output system also takes into account activities of veterinary hospitals, veterinarians in the field, such as in farms, and other health services for animals provided by veterinary assistants.

Due to the above, purchases to the *Health and Social Work* sector represent actual health related services that can be linked to economic activity. Conversely, purchases to other related fields, like the *Defence and Compulsory Social Security* sector or the *Financial Intermediation*[7] sector, represent social security benefits

[6] Here, the "*Health and Social Work* sector", "the health sector", and "the health industry" are used interchangeably.

[7] In the case of private insurance.

or insurance services whose medical component may or may not be realized during the accounting period. Moreover, mandatory contributions to social security do not necessarily (have to) correlate with medical services rendered.

Nevertheless, a link with health can only be assumed when sectors purchase either of the first three components of the health sector explained previously (hospitals, clinics, and therapists) and not when the values refer to the last two (permanent institutions such as orphanages, or veterinary services). Since the actual shares spent on each category are not possible to disaggregate from the World Input-Output Model data, the study is conducted with the help of simplifying assumptions.

In the case of institutions like orphanages and correctional facilities, the assumption is made that governments, through the *Public Administration* activity, are most likely to be the ones purchasing these kinds of services. Thus, recorded payments to the health sector made by other industries refers only to health services. This study also assumes that no veterinary services are purchased by the industries considered, except for the health sector itself, and the agricultural sector[8], which presumably purchases a large share of veterinary services. To circumvent these issues, adjustment factors reduce the values of health purchases made by these three industries.

One of those factors reduces the agricultural sector's purchases of health to a lower level (15% of the original value), a second one reduces the health sector's purchases of own production to three quarters of the total value (75%), and a third one does the same for the *Public Administration* activity. It is recognized that this is done in an arbitrary manner in the face of data constrains. Further investigation can correct this situation by disaggregating National Accounts data for every country of the WIOD database.

In sum, it is assumed that firms that purchase from the health sector actually need medical services for their employees. In an exploratory manner, this variable is expected to provide insights regarding the global distribution of health costs.

3.2.3 Deaths attributable to outdoor air pollution

The third set of coefficients (in place of $\mathbf{c^r} = [c^r_j = h^r_j / x^r_j]$ above) uses the burden of disease resulting from exposure to urban outdoor air pollution in h. Specifically for this study, burden of disease refers to deaths that are brought about by a complex mixture of air pollutants emitted by industrial activities and households, of which fine particulate matter has the greatest effect on human health (Cohen et al., 2004).

Evidence from epidemiological studies have shown that exposure to urban air pollution is linked to three diseases in an important manner, among others (Ostro, 2004). These are respiratory infections in children under 5 years of age, as well as cardiopulmonary disease and lung cancer in adults over 30. The measure links the incidence of deaths from these diseases to air quality in urban centers worldwide.

A more detailed explanation of the indicator can be found in appendix A, but

[8] *Agriculture, Hunting, Forestry and Fishing.*

in essence, its calculation is done by combining information on the increased risk of a disease resulting from exposure to fine particulate matter with information of the spread of this exposure in cities. From this a fraction is derived that gives the total number of deaths from urban pollution when applied to the total incidence of the diseases mentioned above (WHO, 2012).

The information is collected and estimated by the Global Health Observatory of the World Health Organization and the unit of measurement is the number of deaths in a given year. For this study, this measure provides a direct link between the environment and the health of populations around the world. Since industrial production is a strong contributing factor to the quality of air in cities, an indirect link can be assumed to exist between the WIOD model and this variable. However, as stated above, quality of air is also influenced by households, so not all of the deaths attributable to pollution can be linked to economic industries. To correct for this situation, the number of deaths is reduced using the share of the production of total greenhouse gas emissions that corresponds only to economic industries for every region[9].

As with the measure of injuries described in section 3.2.1 if the pollution hypothesis holds true, then it can be expected that developing countries will be more abundant in a factor that reflects their implicit willingness to risk human lives for the creation of jobs. The opposite will be true of developed countries. Hence, developing countries will specialize in "fatal" commodities and will import "non-fatal" commodities to satisfy their final demand from developed countries. This will reflect a higher producer responsibility of deaths embedded in products versus the final demand responsibility leaving a positive balance for this class of nations.

[9]The input-output system presupposes linear relationships between its different matrices, vectors, and even the individual elements that form these. That is why it is possible to use the share of pollution of industries to correct the number of deaths directly, even if levels of pollution are not explicitly used within the model. This is mathematically equivalent to reducing the amount of pollutants to those generated by industries alone, and then multiplying them by a coefficient of deaths per ton of pollutant. Both reductions (of pollutants and deaths) would be in the same proportion. These assumptions of linearity constitute an important source of critique for this type of models; an issue that is revisited in the final comments.

4 Results

In the previous sections a basic input-output model was extended in order to obtain a multi-regional model with which to assess the global distribution of direct and indirect impacts on human health triggered by economic activity. In this section, results from these calculations are presented. First, focus is placed on payments to the health sector embedded in products. Afterwards, deaths attributable to pollution are assessed in a similar manner.

4.1 Occupational Injuries

The first measure assessed in the study identifies the distribution of injuries sustained at the workplace around the world. With the help of the adapted model from section 3, responsibility for direct and indirect injuries embedded in output was determined. Due to the fact that the data for various countries has not been harmonized, results included can only serve as test of the methodology and reference.

Table 1 shows the average intensity of occupational injuries—direct and indirect per $US billion of output destined for final demand home and abroad. In the top quintil, Portugal, Germany, Spain, Slovenia, Mexico, Malta, and France can be found as the places with most injuries per unit of output. On the other hand, the bottom quintil is dominated by Greece, Latvia, Japan, China, Romania, Ireland, and India.

In general, the results of this measure appear to follow no intuitive pattern, but this is thought to be an issue of data reconciliation and harmonization. The other two measures show international relationships that seem more intuitive in the realm of global distribution of health impacts and their responsibilities. Attention is directed at payments to the health sector and deaths due to pollution embedded in trade.

4.2 Payments to the Health and Social Work Industry

All sectors in every region may make purchases to their respective health sector. From the World Input–Output Database the direct payments can be read straightaway for each year of the period 1995–2009, showing the distribution of the employer-paid health care around globally. With help of the model explained in section 3, it has been possible to capture the indirect payments to the health industry that are made worldwide when final demands for all regions are met [10].

Matrix $\mathbf{H}$ from equation (10)—when calculated for this health measure—provided the intensities for each of the 1435 production industries considered in the WIOD[11], related to the delivery of one monetary unit of final demand to each of the 41 regions. For comparison, *average intensities* were estimated as row averages of that matrix. Table 2 shows the results for the 30 sectors with the highest

[10] The year 2008 is used for several items of this discussion, for presentation purposes, but information for more years was estimated and can be found in appendix B.

[11] 35 industries $\times$ 41 regions.

Table 1: Average Intensity of Occupational Injuries (*direct and indirect injuries per $US billion of output*) – Year 2008

Region	**Average Intensity**	**Region**	**Average Intensity**
Portugal	16,087	Hungary	3,022
Germany	15,301	Slovakia	2,551
Spain	14,879	Luxembourg	2,503
Slovenia	14,635	Great Britain	2,354
Mexico	11,167	Cyprus	1,972
Malta	8,867	Austria	1,900
France	8,557	Bulgaria	1,671
Italy	7,663	Netherlands	1,606
Czech Republic	6,984	Sweden	1,505
Australia	6,107	Russia	1,487
Brazil	5,644	Lithuania	1,417
Finland	5,417	Greece	1,104
Poland	4,916	Latvia	1,040
Canada	4,597	Japan	734
Belgium	4,481	China	659
Rest of the world	3,802	Romania	564
Denmark	3,463	Ireland	531
United States	3,231	India	100
Estonia	3,099		

average payments to the health sector that were made per monetary unit delivered to final demand in the year 2008[12].

The first element that draws attention is that this table is headed by the public administration and social security sector of Canada, which triggered the payment of $US107.1 in health services for every dollar of output that was delivered to final demand home or abroad in 2008. The reasons behind this disproportionate number in relation to the rest of the list deserves attention. This can be explained due to a high interconnectedness of this sector with industries that pay extensively to the health sector (home and abroad), as well as to the acclaimed universal public health coverage of Canada.

A second feature of interest of table 2 relates to the fact that it is dominated by Chinese heavy industry: Basic Metals and Fabricated Metal, $US27.5; Electrical and Optical Equipment, $US26.0; Machinery, $US25.7; Mining and Quarrying, $US24.9; Transport Equipment, $US16.0; Chemicals and Chemical Products, $14.7; Other Non-Metallic Mineral $US8.1; Pulp and Paper, $US7.7, per dollar of output intended for final demand. Here, this is presumed to be explained by the amount of the world's production that has been relocated to China over the past decades and its sheer size. Most of the Chinese industries in the list correspond to sectors that are traditionally capital intensive, but that can easily be argued that make heavy use of the abundant labor in that country, and hence are related to extensive payments to the health sector per unit of output there. It has to be emphasized that the intensity described here refers, not only to direct payments made by these sectors, but also to payments made by all sectors related to them directly and indirectly via inputs in the production process.

It is also noteworthy that the *Mining and Quarrying* industry of the Rest of the World is positioned as second highest in the list ($US43.8 per dollar of output intended for final demand). The World Input-Output Database has a strong emphasis on the European economy and other prominent countries in the world economy[13]. This means that very few of the lower end of the developing economies are featured explicitly in it and get lumped together in the Rest of the World region.

The role of less developed countries in the production of raw materials, especially minerals, has been a traditional topic of interest in international economics and other discussions about social and environmental global justice. The fact that it appears here as an important element can count as evidence that the negative health externalities associated with mining are being pushed to some extent onto the developing world as a whole, and employers need to make large payments to health per unit of output. The size of the health impact depends, however, on the actual level of final demand required from that sector. In that sense, the *Mining*

[12] 30 are shown for space considerations and explanatory purposes. They correspond to 2% of the cases for that year. The same calculations have been conducted for all years of the 1995–2009 period. More can be found in appendix B. The *Health and Social Work* industry of all regions has been removed from this ranking, due to its overwhelming intensity and size, which comes from extensive purchases to itself, presumably in the form of subcontracting. Table 3 shows an aggregate of that industry.

[13] 27 EU countries and 13 other economies in addition to the Rest of the World.

Table 2: 30 industries with highest average intensity and their regions (*$US of health expense per $US of output intended for final demand*) – Year 2008

Industry	**Region**	**Average Intensity**
Public Adm. and Defence; Social Security	Canada	107.1
Mining and Quarrying	Rest of the world	43.8
Basic Metals and Fabricated Metal	China	27.5
Electrical and Optical Equipment	China	26.0
Machinery	China	25.7
Mining and Quarrying	China	24.9
Financial Intermediation	Great Britain	20.2
Education	Canada	16.5
Transport Equipment	China	16.0
Renting of Machinery and Equipment	France	15.8
Renting of Machinery and Equipment	Spain	15.3
Chemicals and Chemical Products	China	14.7
Electricity, Gas and Water Supply	China	13.6
Renting of Machinery and Equipment	Sweden	10.3
Wholesale Trade and Commission Trade	Spain	10.0
Renting of Machinery and Equipment	Netherlands	9.5
Renting of Machinery and Equipment	Denmark	9.1
Renting of Machinery and Equipment	China	9.0
Renting of Machinery and Equipment	Rest of the world	8.8
Retail Trade	Taiwan	8.5
Renting of Machinery and Equipment	India	8.4
Other Services	Malta	8.3
Other Non-Metallic Mineral	China	8.1
Chemicals and Chemical Products	Great Britain	7.9
Pulp and Paper	China	7.7
Chemicals and Chemical Products	Austria	7.6
Other Services	France	7.2
Renting of Machinery and Equipment	Great Britain	7.2
Financial Intermediation	Greece	7.1
Post and Telecommunications	Spain	6.7

and Quarrying industry of the Rest of the World placed fifth, accounting for 1% of the total global direct and indirect payments to the health industry in 2008, as shown in table 3 derived from matrix (**G**) in equation 11.

Table 3 also confirms that, not only do the Chinese heavy industries have some of the highest average intensities in payments to the health sector, but their levels are also among the highest in the world. The value refers to direct and indirect payments made both home and abroad. However, despite of their high volume of foreign trade, most of the commercial relations of Chinese industries are local. If the assumptions made in this study regarding the link between payments to the health sector and human health hold true, it can be stated that China's heavy industry in general is one of the places where employers will pay more for the deteriorating health of their employees.

It can also be read from table 3 that, even if the intensity of the US public sector is not featured in table 2, its weight is still important in the global distribution of payments to the health sector (2.6% of the world total). This may be related to the size of its population. In this study, it can only be speculated that the war efforts of that country are deeply intertwined with any variables related with human health expenses as well.

It is evident that more than half of the world's payments to the health industry are made by that industry itself (54.2%). This is is explained by own production purchases that are presumably made due to subcontracting within the sector. In order to make the impact of other industries more evident, the *Health and Social Work* industry has been singled out in table 3 as an aggregate of all regions.

Other sectors also feature prominently in tables 2 and 3. In the case of *Renting of Machinery* for various countries, for example, the intuition for its explanation can resemble that of the industrial cases discussed above, even if it is a service, because it involves substantial capital goods that need human operators. However, for others, like the Canadian *Education* sector and the British *Financial Intermediation* industry, the interpretation of their presence high above in the lists is more difficult and remain confounding.

In terms of producer and final demand responsibility for the payments made to the health industry worldwide, table 4 shows this relationship for 2008 at the country level. A positive balance means that the production sector is a net causer of payments to the health sector, rendering the country a net producer of human health deterioration, whereas the opposite—a negative balance—would mean that the final demand of that country is a net consumer of deteriorated health home and abroad. From Serrano & Dietzenbacher (2010) it is known that, while the value of exports and imports of embedded payments to the health sector in products differs from producer and consumer responsibility for those payments, their balance is the same (due to the fact that own production purchased in the country is subtracted and added, respectively, to arrive at the first measures). From that perspective, a positive balance can also be interpreted as the country saving its business partners the trouble of having to make payments for health, while demanding less that the same be done on its behalf abroad.

The table shows that many countries are borderline in this sense, because they

Table 3: 30 industries with highest levels of direct and indirect payments to the health industry (*$US of direct and indirect payments*) – Year 2008

Industry	**Region**	**$US mill.**	**%**
Public Adm. and Defence; Social Security	Canada	22,083.6	8.3
Public Adm. and Defence; Social Security	United States	7,030.1	2.6
Machinery	China	4,082.2	1.5
Electrical and Optical Equipment	China	3,437.0	1.3
Basic Metals and Fabricated Metal	China	3,379.8	1.3
Mining and Quarrying	Rest of the world	2,554.9	1.0
Transport Equipment	China	2,289.1	0.9
Financial Intermediation	Great Britain	1,866.2	0.7
Education	Canada	1,784.0	0.7
Mining and Quarrying	China	1,713.8	0.6
Public Adm. and Defence; Social Security	China	1,665.2	0.6
Other Non-Metallic Mineral	China	1,501.1	0.6
Education	China	1,367.6	0.5
Chemicals and Chemical Products	China	1,305.9	0.5
Renting of Machinery and Equipment	France	1,304.6	0.5
Electricity, Gas and Water Supply	China	1,298.5	0.5
Public Adm. and Defence; Social Security	Rest of the world	1,162.6	0.4
Hotels and Restaurants	Japan	1,088.4	0.4
Other Services	France	939.6	0.4
Education	Rest of the world	927.8	0.3
Renting of Machinery and Equipment	Rest of the world	910.4	0.3
Renting of Machinery and Equipment	Japan	896.9	0.3
Other Services	United States	869.2	0.3
Construction	China	859.8	0.3
Wholesale Trade and Commission Trade	Japan	851.5	0.3
Food, Beverages and Tobacco	China	832.8	0.3
Other Services	Great Britain	776.5	0.3
Renting of Machinery and Equipment	China	760.9	0.3
Renting of Machinery and Equipment	Spain	759.5	0.3
Construction	Japan	642.9	0.2
Health and Social Work	All regions	144,192.6	54.2
Remaining industries	Remaining regions	51,048.0	19.2
Total		266,183.1	100.0

are positive or negative only by a small fraction of either producer or consumer responsibility. This means that they could easily go from net payers of health services to net consumers of products with health services embedded in them, after modest externally or internally induced changes in their trade balance. This is the case for countries like Belgium, Canada, Denmark, Great Britain, and South Korea, for example. Others, like China, the US, Russia and Mexico, for example have a more definite position. In this sense, it can be argued that China is a net payer of health services, while the US, Russia, and Mexico benefit from the payments to health that their business partners make on their behalf.

4.3 Deaths due to pollution embedded in output

Calculations have also been conducted for deaths due to pollution embedded in products. This measure provides a more intuitive link between the global distribution of production and human health. At the same time it can also be interpreted from the perspective of the pollution haven hypothesis. With the measure described in the previous section, more payments to the health sector, not necessarily could be interpreted as a more deteriorated health. However, deaths due to pollution are a clear indicator of the negative externalities that production has on the countries where it is located. In this section, results are presented for the year 2008. More can be found in appendix B.

Data for deaths attributable to pollution is only available at the national level so results cannot be disaggregated at the sector level, and furthermore, Taiwan had to be aggregated into China and Malta had to be aggregated into the rest of the world region. Table 5 provides average intensities for each of the regions analyzed, sorted from highest to lowest intensity. The top quintil of direct and indirect deaths due to pollution per billion dollars of output destined for final demand is occupied by China (336), India (284), the Rest of the World (217), Russia (157), Bulgaria (152), Indonesia (97), and Romania (70).

On the other end of the distribution, the bottom quintil is dominated by Belgium (5), Sweden (5), Finland (5), Canada (3), Austria (3), Ireland (1), and Luxembourg, with a (0.2), which in terms of deaths is the equivalent as having no deaths per billion dollars worth of direct and indirect output delivered to final demand.

The top quintil is interesting in the sense that it includes some of the countries that traditionally have been thought of having lax environmental regulations and have attracted polluting industries, such as China, India, and Russia. However, while the intensity of health impact (deaths due to pollution per $US billion of direct and indirect output needed to satisfy final demand) provides a clear point of comparison between countries, the country's impact on global human health can only be properly assessed when compared with the level of production, the origin of the deaths delivered to a country embedded in trade, and the destination of a country's embedded deaths.

Matrix ($\mathbf{G}$) from equation (11) provides such information when its rows are aggregated to the country level. As explained in section 3, its off diagonal elements correspond to trade of embedded deaths between regions. Table 6 shows deaths

Table 4: Producer and Final Demand Responsibility and Balance for Payments to the *Health and Social Work* Industry Worldwide – Year 2008

Region	Producer Responsibility	Final Demand Responsibility	Balance
Austria	1,609.0	1,894.6	(285.6)
Australia	953.9	1,056.7	(102.8)
Belgium	3,933.3	3,920.1	13.2
Bulgaria	11.4	59.8	(48.4)
Brazil	1,025.0	1,266.5	(241.6)
Canada	27,917.2	27,450.6	466.6
China	30,114.7	20,038.2	10,076.5
Cyprus	25.8	52.5	(26.7)
Czech Republic	389.2	421.0	(31.8)
Germany	7,649.0	9,174.1	(1,525.0)
Denmark	963.1	951.4	11.6
Spain	10,535.5	10,290.3	245.2
Estonia	62.0	65.7	(3.7)
Finland	1,632.7	1,666.5	(33.8)
France	11,244.4	10,854.2	390.3
Great Britain	74,308.3	72,913.3	1,394.9
Greece	349.7	546.2	(196.5)
Hungary	478.3	483.6	(5.3)
Indonesia	576.9	769.9	(193.0)
India	772.4	1,081.4	(309.0)
Ireland	4,935.1	4,666.1	269.0
Italy	10,878.5	11,589.9	(711.4)
Japan	15,124.9	14,800.7	324.2
South Korea	2,878.3	2,872.7	5.6
Lithuania	40.1	63.8	(23.6)
Luxembourg	50.4	81.4	(31.1)
Latvia	50.6	61.8	(11.1)
Mexico	71.9	455.3	(383.4)
Malta	22.4	26.2	(3.8)
Netherlands	4,599.1	3,979.1	620.1
Poland	2,447.3	2,507.6	(60.2)
Portugal	1,392.9	1,536.8	(143.9)
Romania	237.3	282.1	(44.7)
Russia	2,031.3	2,683.2	(651.9)
Slovakia	303.2	315.9	(12.7)
Slovenia	240.3	221.2	19.1
Sweden	2,450.4	2,108.0	342.4
Turkey	1,485.3	1,598.0	(112.7)
Taiwan	1,206.0	1,147.2	58.8
United States	28,144.1	33,640.3	(5,496.2)
Rest of the world	13,041.8	16,589.3	(3,547.5)
Total	266,183.1	266,183.1	0.0

Table 5: Average Intensity of Deaths Due to Pollution (*direct and indirect deaths per $US billion of output*) – Year 2008

Region	**Average Intensity**	**Region**	**Average Intensity**
China	336	United States	14
India	284	Czech Republic	13
Rest of the world	217	Germany	12
Russia	157	Japan	12
Bulgaria	152	Italy	12
Indonesia	97	Spain	10
Romania	70	Slovakia	9
Turkey	66	Netherlands	7
Latvia	58	Australia	7
Brazil	31	France	6
Poland	28	Denmark	6
South Korea	25	Slovenia	5
Mexico	25	Belgium	5
Lithuania	24	Sweden	5
Portugal	22	Finland	5
Hungary	22	Canada	3
Greece	21	Austria	3
Estonia	17	Ireland	1
Cyprus	16	Luxembourg	0
Great Britain	15		

embodied in exports, imports and a balance for the year 2008. It shows that for that year, Bulgaria, China, Indonesia, India, Latvia, Romania, Russia, and the Rest of the world are net “killers”. It can be said that these regions can be considered pollution havens for the rest, if the assumption that those deaths can be attributed to the pollution brought about by their industries.

That those eight economic regions can be considered pollution havens comes from the fact that the deaths embedded in their exports are more numerous than the deaths embedded in their imports. However, that does not imply that the rest of regions do not export deaths. Matrix (**G**) from equation (11) allows us to identify the origin (rows) and destination (columns) of the embodied deaths in trade. Figure 1 shows a stylized version of this[14]. In part 1(a), the percentage structure was calculated for the columns, and then the diagonal (corresponding to local transactions) was removed. This structure corresponds to the shares of origins of deaths embodied in trade for every region. A gray scale identifies the larger origins with darker tones. Part 1(b) was done in a similar fashion. However, in this case the percentage structure was calculated for the rows, identifying the destinations of deaths embodied in trade for every region. Higher percentages in the destinations are marked with darker tones, as well.

Visual examination of these two figures shows some trends in the form of darker horizontal or vertical lines. The darker horizontals in 1(a) identify countries that are important origins of the direct and indirect deaths embodied in trade. This is the case of China, India, Russia, and the Rest of the World, followed by a faint Germany, Indonesia, and Romania.

The darker verticals in 1(b) identify countries that are important destinations for the direct and indirect deaths embodied in trade intended for final demand. In this case, Germany, France, Great Britain, Italy, the United States, and the Rest of the world are clear destinations, followed by China and Spain.

5 Conclusion

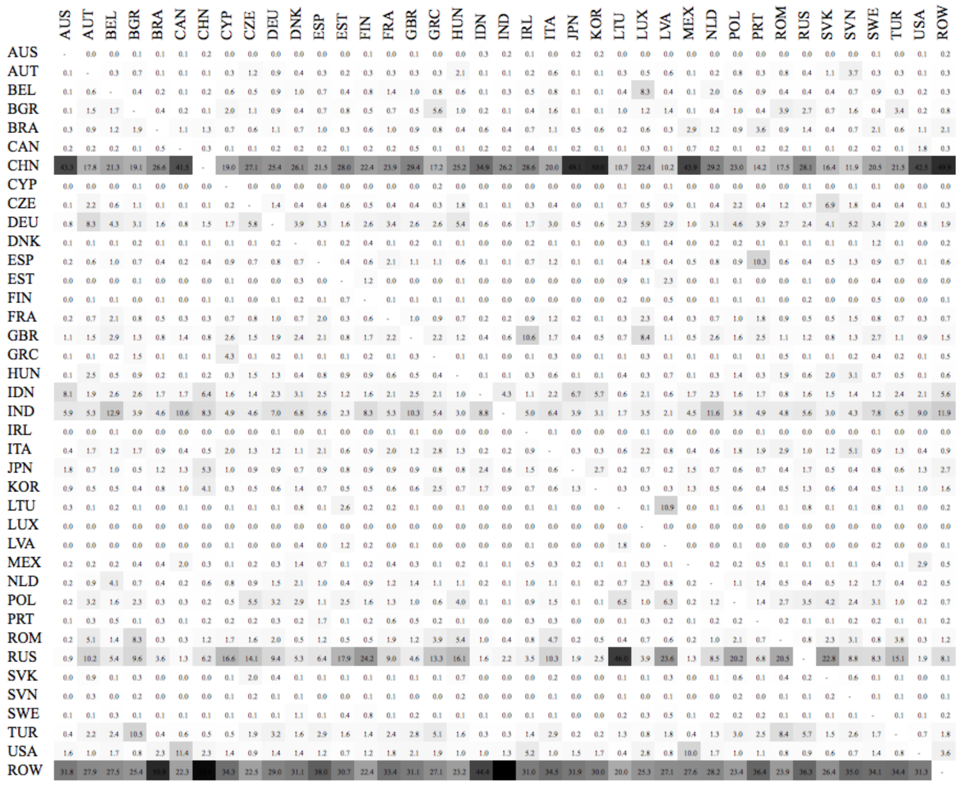
The present study acknowledges that although much has been written about the effects of industry on pollution and, hence, on the quality of the environment, input–output methodology has seldom made the link to the resulting quality of human health. This in spite that the literature linking health and pollution is also extensive.

Here, a 41 region input–output model has been extended to account, in an exploratory manner, for the embodied content of occupational injuries, deaths due to pollution, and payments to the health sector in trade. The model borrows heavily

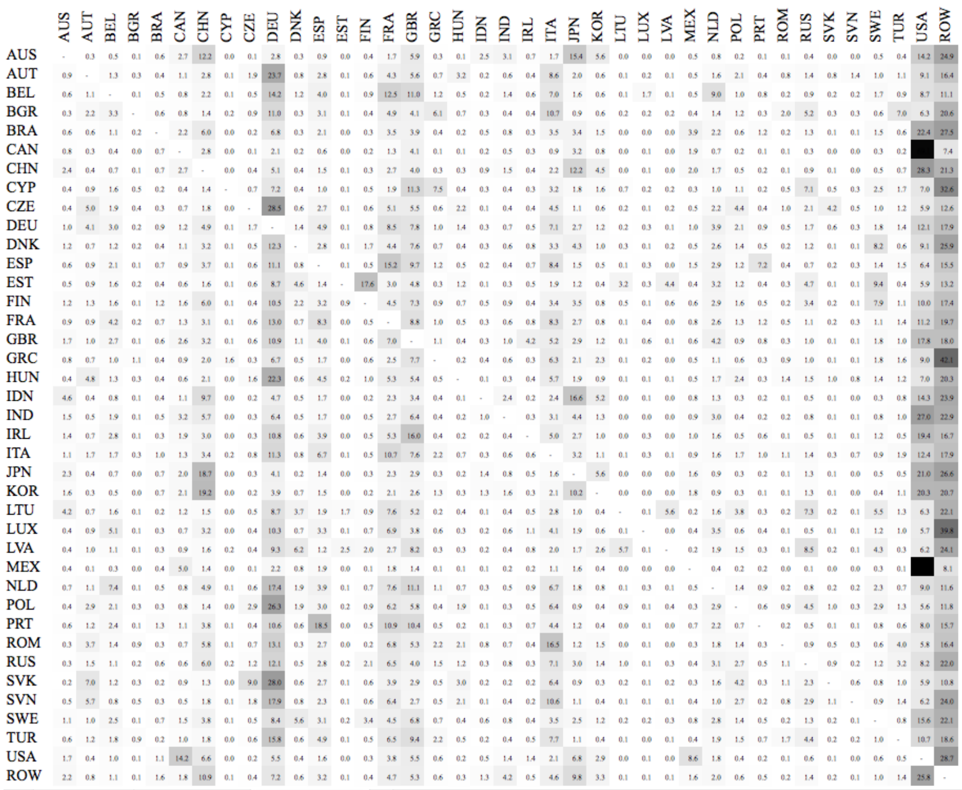
[14]Abbreviations: AUS (Austria), AUT (Australia), BEL (Belgium), BGR (Bulgaria), BRA (Brazil), CAN (Canada), CHN (China), CYP (Cyprus), CZE (Czech Republic), DEU (Germany), DNK (Denmark), ESP (Spain), EST (Estonia), FIN (Finland), FRA (France), GBR (Great Britain), GRC (Greece), HUN (Hungary, IDN (Indonesia), IND (India), IRL (Ireland), ITA (Italy), JPN (Japan), KOR (South Korea), LTU (Lithuania), LUX (Luxembourg), LVA (Latvia), MEX (Mexico), NLD (Netherlands), POL (Poland), PRT (Portugal), ROM (Romania), RUS (Russia), SVK (Slovakia), SVN (Slovenia), SWE (Sweden), TUR (Turkey), USA (United States), ROW (Rest of the World).

Table 6: Deaths embodied in exports, imports, and balance – Year 2008

Region	**Deaths in Exports**	**Deaths in Imports**	**Balance**
Austria	236	6,222	(5,986)
Australia	469	2,221	(1,752)
Belgium	586	3,420	(2,834)
Bulgaria	1,634	589	1,045
Brazil	2,497	5,214	(2,717)
Canada	598	7,857	(7,259)
China	159,071	20,348	138,723
Cyprus	26	223	(197)
Czech Republic	686	1,729	(1,043)
Germany	3,462	20,716	(17,254)
Denmark	349	1,864	(1,515)
Spain	1,175	8,767	(7,592)
Estonia	77	206	(129)
Finland	193	1,737	(1,544)
France	1,130	12,330	(11,200)
Great Britain	2,480	13,040	(10,560)
Greece	457	2,151	(1,694)
Hungary	882	1,250	(368)
Indonesia	5,150	3,610	1,540
India	26,218	8,327	17,891
Ireland	64	1,591	(1,527)
Italy	1,942	11,210	(9,268)
Japan	3,177	24,713	(21,536)
South Korea	4,105	10,743	(6,638)
Lithuania	208	504	(296)
Luxembourg	4	255	(251)
Latvia	267	224	43
Mexico	2,630	4,941	(2,311)
Netherlands	1,034	6,155	(5,121)
Poland	1,860	3,352	(1,492)
Portugal	590	1,196	(606)
Romania	1,546	1,357	189
Russia	15,618	7,092	8,526
Slovakia	235	899	(664)
Slovenia	63	422	(359)
Sweden	373	2,521	(2,148)
Turkey	3,421	4,471	(1,050)
United States	4,823	65,483	(60,660)
Rest of the world	89,785	70,171	19,614
Total	339,121	339,121	0



(a) Origin of deaths embodied in trade (shares)



(b) Destination of deaths embodied in trade (shares)

Figure 1: Origin and Destination of deaths embodied in trade – Year 2008

from methodologies traditionally used to assign responsibilities for environmental degradation to producers and consumers in different countries.

Seeing that for several reasons some countries might have a higher or lower tolerance for health deterioration, the idea has been developed that this might be a source of comparative advantage. Under a Hecksher-Ohlin perspective of the so–called *pollution haven hypothesis*, that means that countries with a lower tolerance to health deterioration of their workforce can benefit from trade, buying products from countries with a higher tolerance for such deterioration. In that manner, countries can be said to have an impact, not only on local health, but also on the overall health of its trade partners in a similar fashion as the idea of *virtual water* embodied in products or that of the *ecological footprint*. This study also posits that payments to the health sector might be viewed under the light of investment in human capital, counteracting the negative effects of health deterioration.

Regarding *payments to the health sector*, it has been argued in this paper that this variable might serve as a counteracting force in the direction of health restoration. One of the most interesting findings is that, both when evaluating intensity (payments to the health sector per unit of output intended for final demand), as well as the gross amount of those payments, nine Chinese heavy industries feature high in the list of 1435 industries evaluated here. These intensities range from $US7.6 per $US of output intended for final demand in the case of the *Pulp and paper* industry to $27.5 per $US of output in the case of *Basic Metals and Fabricated Metal*. This means that, even if that country ranks high in the deaths attributable to pollution variable, as explained in the following paragraphs, the Chinese also have some of the highest levels of investment in human capital.

Within that topic, it is also interesting that the *Mining and Quarrying* industry of the Rest of the World ranks high in payments to the health sector ($43.8 per $US of output intended for final demand) because the extraction of minerals in less developed countries has been a controversial topic, regarding global responsibility for social rights. Since the model used here lumps most of the less developed countries under this region, it is relevant that in general high investments in human capital (as defined here) are being undertaken in this industry as a counteracting force to deteriorating health.

Deaths attributable to pollution embodied in output and trade also yielded interesting results. For example, the economies with highest direct and indirect deaths due to pollution per billion dollars of output destined for final demand are China (336), India (284), the Rest of the World (217), Russia (157), Bulgaria (152), Indonesia (97), and Romania (70). This is important, because China, India, Russia, and to some extent the Rest of the World are traditionally considered "pollution havens", even if evidence for that affirmation remains scarce in the economic literature.

When estimating a balance between deaths embodied in imports and death embodied in exports, it has been found that Bulgaria, China, Indonesia, Latvia, Romania, Russia, and the Rest of the Wolrd are net killers of individuals, rendering them pollution havens for the rest of the regions examined in this study. That means that deaths embodied in their exports are higher than in their imports, but it does not mean that other countries do not have fatalities. In fact, estimating for each region the shares of origins of deaths and shares of destinations of deaths it has been revealed that the most important sources of deaths embodied in trade are China, India, Russia, the Rest of the World, Germany, Indonesia, and Romania. Conversely, the most important destinations for deaths embodied in trade are Germany, France, Great Britain, Italy, the United States, and the Rest of the World.

The latter findings more or less confirm the intuition of pollution havens as centers that absorb the negative effects to the environment and to human health of the production needed by other countries. For the case of China, India, Russia, Indonesia, and the Rest of the World this might seem as not much of a surprise. For economies like Romania and Germany, the idea is less intuitive, but it is in line with the fact that industry remains important for those economies, while other countries in the developed world have moved toward having more service-oriented economic structures.

The model used here makes strong assumptions about the linear relationships between the variables analysed (health and production). In reality, health impacts are more related to exponential functions. Low levels of pollution might play no role whatsoever on the incidence of some illnesses until they reach a certain level, after which they might have a sudden strong importance. For that reason, it cannot be said that the intensities described here will be the same when increasing output in an important manner, for example. Thus, the descriptive power of the model is interesting, but care must be taken when using it for predictive purposes like policy evaluation, for example.

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A Data, classifications and explanatory notes

Information about the WIOD database, ISIC health industry descriptions, and deaths attributable to pollution metadata.

B Results

See the file appendix.xlsx