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Abstract
The contribution of this paper is twofold. First, it provides a concise review of the approaches and literature on structural decomposition analysis (SDA), focusing on such issues as policy relevance of SDA, methodological approaches to SDA (i.e. additive vs. multiplicative and chaining vs. non-chaining SDAs), methods of correcting for price changes to obtain input-output data of different years in volume terms for SDA purposes, types of SDAs (i.e. single-region, multi-region and global SDAs, further classified as temporal, between-country and between-database SDA), and structural path decomposition (SPD) as an extension of SDA. Second, we apply the SPD method in a global setting, where the drivers of growth in world greenhouse gas emissions along the individual supply chains (or paths) are quantified.

Keywords: structural decomposition analysis, structural path decomposition, drivers of world emissions along the supply chains/paths

JEL classification codes: C67, D57, F64, O44

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1. Introduction

Decomposition analysis is a popular and well-established method for analysing the decoupling (or lack there-of) across a range of environmental and socio-economic indicators. Structural Decomposition Analysis (SDA) is a form of decomposition analysis that uses input-output (IO) relationships (Leontief, 1941, 1936) to describe the changing technological relationships between systems of production and the final demand of populations. The approach is gaining popularity, and stems from a rich tradition of other forms of decomposition analysis such as index decomposition analysis, which share some common features but are distinct from each other in terms of their underlying theories, data requirements, study scope, and obtained results (see e.g., Hoekstra and van den Bergh, 2003).

Despite the rich literature on SDA, we see a need for an updated review on the crucial details as well as the strengths and limitations of SDA topics and recent literature, particularly given the increase in availability of multi-regional and temporal environmentally-extended IO databases. Hence, the purpose of this paper is twofold. First, we provide a concise and up-to date review of the SDA approaches and literature with a particular focus on the following issues:

- policy relevance of SDA;
- methodological approaches to SDA: additive vs. multiplicative and chaining vs. non-chaining SDA approaches;
- methods for obtaining IO tables (IOTs) of different years in volume terms that make them comparable for SDA purposes (i.e., price changes are taken into account that makes SDA meaningful) both when data are available only for two time periods and when there exists time-series of IOTs;
- types of SDA in terms of regional coverage: Single-Region SDA (SR-SDA), Inter/Multi-Region SDA (MR-SDA) and Global Multi-Region SDA (GMR-SDA). A finer classifications of SR-SDA into temporal vs. between-country SR-SDA, and of (G)MR-SDA into temporal vs. between-database (G)MR-SDA are also discussed;
- Structural Path Decomposition (SPD) as an extension of SDA.

Second, we focus on one application area of the above review - applying the SPD method in a global setting, where the drivers of growth in world greenhouse gas emissions along (the most important) individual supply chains (or paths) are quantified. To our knowledge this is the first global multi-region (GMR) SPD application, as so far all the SPD applications focus solely on national economies (see e.g. our review in the next section) neglecting the role of interregional (inter-country) supply linkages. For this purpose, we use the EXIOBASE database which is a global multi-regional environmentally extended supply-use and input-output database, covering 43 countries (accounting for 95% of the global economy) and the rest of the world region.[1]

The rest of this paper is organized as follows. In Section 2 a comprehensive review of the above-mentioned issues relevant for any SDA or SPD study is presented. The mathematical description of the SPD method and its global multi-region application are discussed in Section 3. Section 4 ends with concluding remarks.

2. Review of selected issues and the relevant literature of input-output decomposition analysis

Rose and Casler (1996) is the first comprehensive survey paper of structural decomposition analysis (SDA) literature that also extensively discusses the history of SDA, related methods, namely, shift-share analysis, growth accounting, and index decomposition analysis (IDA), SDA link to the neoclassical production functions, and its usefulness for projections, forecasts and policy analysis. Subsequently, this literature was reviewed by Rose (1999), Hoekstra and van den Bergh (2002), and Su and Ang (2012a). An excellent discussion of (additive) SDA is given in Miller and Blair (2009, chapter 13.1), who besides giving ample relevant references, also present the aggregate results of 8 economic (mainly focusing on gross output changes[2]) and 5 environmental SDA studies at national level, and 3 economic studies at regional, inter- or multi-

[1] For further details about the EXIOBASE database, see http://www.exiobase.eu/.

[2] These include the very first applications of SDA that mainly focused on gross output changes. The very first SDA studies, also mentioned in Miller and Blair (2009) as such, are Chenery, Shishido and Watanabe (1962) on Japanese economy and Vaccara and Simon (1968) on the US economy. The first application of SDA to an environmental issue seems to be Leontief and Ford (1972).

regional levels. In what follows we contribute to these SDA survey studies by discussing details of the selected relevant and, in our view, important topics, particularly focusing on recent contributions. We also mention a few relevant issues from the IDA literature[3].

Policy relevance of SDA. Climate change and energy sustainability issues are currently at the forefront of governments' policy agendas worldwide.[4] In this respect it has been long argued that consumption-based emissions provide valuable information next to the production-based emission accounting, and thus may help to differentiate commitments between countries in an international dialogue of climate mitigation. IO and SDA help facilitate this policy agenda by explicitly analysing the connection between consumption-based and production-based emissions. For example, it may be claimed that a large net importer of greenhouse gas (GHG) emissions may face a greater emission commitment than the large net exporter of GHG emissions (Peters, 2008). For effective climate mitigation policies, however, it is of utmost importance to target factors that are largely responsible for growth in emissions. This explains why applications of SDA for better understanding the fundamental sources of growth in emissions and energy use have been steadily increasing over time (see the recent survey papers mentioned above). Such need for SDA is justifiable, because emissions generation is a result of complex interactions of various factors and economic sectors that is adequately captured by the underlying IO framework. Usually, SDA studies distinguish population, affluence (GDP per capita), consumption (product) mix, trade structure, and technology as important driving forces. SDA, in effect, can be considered as an extension of the well-known Kaya identity and IPAT (Impact = Population x Affluence x Technology) equation by explicitly taking into account complex (direct and indirect) interactions between economic sectors and final users at the economy level using the Leontief (1936, 1941) IO framework. Thus, in comparison to other decomposition techniques, SDA can distinguish between a range of technological and *final demand* effects.

From a policy perspective, SDA studies can contribute to, at least, the following issues.

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[3] For details on IDA techniques, the reader is referred to, e.g. Ang and Zhang (2000) and Ang (2004). The first paper surveys 117 energy and environmental studies in total, out of which 15 are SDA articles.

[4] For example, Europe 2020 strategy for smart, sustainable and inclusive growth calls for 20% reduction of greenhouse gas emissions, 20% increase in the share of energy from renewables, and 20% increase in energy efficiency by 2020, which are one set of five Europe 2020 headline targets (European Commission, 2010).

1. SDA assists in assessing the outcomes of existing policies and/or in developing future environmental and climate policies. For example, the obtained product mix effects from SDA studies indicate how a shift of final demand to a more environmentally favourable consumption package(s) so far has affected (or in the future is expected to affect) total emissions. As an example of such SDA work, recently Baiocchi and Minx (2010) found evidence for *displacement effects* of structural (production and demand) factors in their study of UK CO_2 emissions changes. That is, emission reductions achieved in the UK are not only due to greening of domestic supply change, but also reflect structural shifts in the international division of labour in the global production of goods and services.
2. SDA helps us to better understand the connection between economic growth and environmental pressures. All SDA analyses consistently show that final demand level (GDP) effect is generally the most important determinant of growth in environmental pressures. In particular, this effect is largely dominating in developing countries (Guan et al., 2008; Huang and Wu, 2013; Peters et al., 2007). On the other hand, changes in technology (i.e., changes in IO coefficients and emission intensities) are often the most important source of downward pressure on pollution emission, energy and material use (Hoekstra and van de Bergh, 2002).
3. SDA makes explicit the role of different economic sectors and final demand categories in emissions growth. These results may be very useful in determining specific targets of environmental policies. For example, Guan et al. (2009) find that growth in manufactured exports was an important driver for CO_2 emissions growth in China between 2002 and 2005. Similarly, Yamakawa and Peters (2011) conclude that production of exports was responsible for about 70% of the growth in energy consumption and GHG emissions in Norway from 1990 to 2002, where these exports were dominated by oil and gas production.
4. SDA could be very useful in forecasting and backcasting of existing trends, which are a critical part of scenario analyses of diverse policies (see e.g., Mattila et al., 2013). Conceptual framework for identifying potential sources of growth and impacts of alternative development strategies within the SDA setting are discussed in Siegel et al. (2005). Hoekstra (2005, chapter 9) convincingly shows the usefulness of SDA scenario analysis in his study of material use of the Dutch basic plastics and iron and steel sectors

by projecting 1990-1997 observed SDA effects up to 2030 considering four forecasting scenarios (business-as-usual (BAU), isolated-effects, adjusted BAU and BAU with limits) and one backcasting scenario. The last method that calculates the possible paths of SDA effects leading to dematerialization (in general, any other) target is proposed by the author, which he refers to as 'target analysis'. In particular, if applied in conjunction with multiple year decomposition, target analysis reveals whether the changes in SDA effects are consistent with (or converging to) a policy target objective or not.

Methodological approaches to SDA. Given that any change can be analysed either additively or multiplicatively, it is no surprise that there are *additive SDA* and *multiplicative SDA* approaches. Often the first is applied to an *absolute indicator* change, such as changes in pollution emissions, employment, or energy use, while the second approach is used to identify determinants of an *intensity* (or *ratio*) *indicator* growth, such as growth of energy intensity or labor productivity. The overwhelming majority of SDA analyses so far have adopted additive SDA, and so far only a few studies use its multiplicative counterpart (which include e.g., Han and Lakshmanan, 1994; Dietzenbacher et al., 2000, 2004; Yang and Lahr, 2010; Zhang and Lahr, 2014).[5] However, the choice of additive or multiplicative SDA is a matter of taste and, possibly, presentation, in which case some would state that "[n]on-experts interpret additive decompositions relatively easily" (Hoekstra and van den Bergh, 2003, p. 43).

Whenever more than two IOTs are available, there is also a choice between *non-chaining SDA* vs. *chaining SDA* (Su and Ang, 2012b). In non-chaining SDA an analyst uses only the data of the starting and terminating years of the covered period, while in chaining SDA all the data of the intervening years are used and then the results are summed up to give the outcome for the entire period. The crucial advantage of chaining SDA is that it provides valuable information about the paths of different effects (i.e., size of the determinants) over time. Therefore, in our

[5] The widely used additive IDA counterpart of the additive SDA (Dietzenbacher and Los, 1998) is the Montgomery decomposition that makes use of the logarithmic mean Divisia index, LMDI (Choi and Ang, 2012, 2003; De Boer, 2008). Similarly, the multiplicative IDA counterpart of the multiplicative SDA (Dietzenbacher et al., 2004) is the Sato-Vartia decomposition that uses LMDI (Choi and Ang, 2012, 2003; De Boer, 2008). It should be noted that Dietzenbacher and Los (1998) method is equivalent to Sun (1998) method, showed by Lenzen (2006), while Ang et al. (2003) proved that Sun's method is exactly equivalent to Shapley (1953) value that has been brought into IDA literature by Albrecht et al. (2002). Therefore, this decomposition method in the literature is also referred to as S/S method (Su and Ang, 2012a) or DSA method (Lenzen, 2006).

view, chaining SDA is a more policy-relevant approach (hence should be a preferred approach whenever data is available) as the dynamics of changes of various SDA factors over the period under study are discovered that potentially could be related to policies implemented and other relevant events happening during the covered period.

Methods for obtaining IOTs in volume terms. It is obvious that comparison of economic and/or environmental accounts over time is meaningful only if changes in prices are corrected for so that SDA is implemented on volume changes only. Hence, usually SDA researchers use IOTs expressed in one chosen year prices, i.e., expressed in *constant prices*.[6] However, not always officially published IOTs in constant prices are available, thus analysts use various methods to estimate such tables themselves. Quite frequently SDA studies use the so-called *double deflation* method advocated by United Nations (1999) in order to construct the required constant-price IOTs. For this purpose one needs sector- (or product-) specific deflators, which are then multiplied by all intermediate and final transactions of the IOT row-wise corresponding to the appropriate sector selling the intermediate and final products. In order to balance the resulting IOT, value added is then computed as a residual.

In other studies intermediate deliveries are instead deflated using the so-called RAS procedure (for details on RAS balancing, see e.g. Lahr and De Mesnard, 2004; Temurshoev et al., 2013). This method has been suggested by Dietzenbacher and Hoen (1998) with the motivation that, while with double deflation method sectoral values added in constant prices are computed as residuals, often the relevant published information could be readily available. Hence, it makes (more) sense to use this published data on sectoral value added in constant prices, which could be also preferred since then the final results will be consistent with the official estimates of GDP in constant prices.[7]

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[6] See Dietzenbacher and Temurshoev (2012) for a rather detailed examination of the results of input-output analysis based on frameworks in current and constant prices.

[7] In their empirical analysis, Dietzenbacher and Hoen (1998) found that RAS deflation performs better than double deflation, in particular for the columns of the matrix of intermediate deliveries, because "… double deflation suffers severely from aggregation problems" (p. 121). See also Dietzenbacher and Hoen (1999).

Whenever there is a time series of IOTs both in current and previous year prices, two options exist to have SDA in volume changes. First, the year-to-year changes on the base of these data are computed and simply added in order to have the results for a longer period of interest. For example, volume changes from 1995 to 1996 are based on 1995 IOTs in current prices and 1996 IOTs in previous year prices of 1995. Similarly, volume changes from 1996 to 1997 are based on 1996 IOTs in current prices and 1997 IOTs in previous year prices. The total volume change from 1995 to 1997 is then simply equal to the sum of 1995-1996 and 1996-1997 volume changes. This is also true for any factor effect within the SDA setting. Such approach is used in Arto and Dietzenbacher (2014).

The second approach is using the *chained* constant price IOTs. The rational for using chained index is that the accuracy of any fix base index (e.g. Laspeyres, Paasche or Fisher index) generally decreases the farther one moves away from a specific base year, because the price configurations are changing over long period of time due to changes in the structure of the economy. Further, in general, when chained indices replace fix base indices, the index number spread between Laspeyres and Paasche is greatly reduced, thus the choice of index number formula becomes less relevant.[8] To construct chained constant prices data - the value data from an arbitrary year *t* in the prices of a given base year *0*, the data are sequentially linked (chained) by multiplying the (volume) indices for all adjacent periods together (European Communities, 2001). However, as the base year is constantly changing in a chained index, the problem of 'chaining discrepancy' arises: the sum of two chained quantities is not equal the chained sum. In terms of chained IOTs, for example, the chained gross output does not equal the sum of chained intermediate and final transactions. In their SDA study that uses this approach, Yamakawa and Peters (2011) chose the sum of the chained transactions as output in dealing with the problem of chaining discrepancy.

Regional dimension of SDA. According to the regional dimension coverage, three types of SDA can be distinguished: Single-Region SDA (SR-SDA), Inter- or Multi-Region SDA (MR-SDA) and Global Multi-Region SDA (GMR-SDA). In the following, we discuss these types of SDA studies in somewhat more detail.

[8] For further details, see EC, IMF, OECD, UN and WB (2009, Chapter 15).

SR-SDA uses the single region Leontief IO framework with a focus on one country or one region, hence requires national IOTs or IOTs of the region of interest. The vast majority of existing SDA papers are SR-SDA studies, which could be explained by the fact that this type of analysis requires less data than (G)MR-SDA and such data were the first IOTs compiled and made available. The SR-SDA, in turn, could be classified into two types:

- *Temporal SR-SDA* where determining the drivers of an indicator change *over time* is the key study focus. Temporal SR-SDA makes the majority of existing SR-SDA studies.
- *Between-country SR-SDA* where the focus lies solely on *inter-country differences* of the determinants of an indicator of interest (e.g., energy consumption) for any two selected countries (see e.g., Chung, 1998; Proops and Faber, 1993). Using between-country SR-SDA approach in analysing per capital energy use in 8 OECD countries (Australia, Canada, France, Germany, Japan, UK and USA), de Nooij et al. (2003) find that in 1990 the US energy intensity and final demand level effects (resp. intermediate and final demand structure effects) were higher (resp. lower) in the majority of the other OECD countries. Hence, they conclude that "the US environmental policy should focus on stimulating the adoption of energy-saving technology, whereas the other 7 OECD countries should focus especially on how to reduce the energy intensity of their intermediate and final demand structure" (p. 370). Note that in comparison to temporal SDA, between-country SR-SDA does *not* require the availability of constant price data.[9]

MR-SDA studies are based on inter- or multi-regional IO framework and analyse an indicator change/growth underlying factors for, at least, two regions and/or countries, thus providing additional useful insights from interregional setting that are ignored in SR-SDA studies. For example, Dietzenbacher at al. (2000) applies MR-SDA to labor productivity growth in six Western European countries and find that productivity effects of input structure changes and of trade structure effects are small compared to those of labor productivity levels in individual sectors. Using a series of nine-region IOTs of Japan (1980-1985-1990), Hitomi et al. (2000)

[9] The study on inter-country *cost* level and structure comparison by Fujikawa et al. (1995) falls also into the between-country SR-SDA category with the only difference that it uses instead the Leontief *price* IO model (see e.g. Miller and Blair, 2009, Chapter 2.6), which is a dual (and independent) of the Leontief quantity IO model that is used when the focus of SDA is volume and/or physical changes.

discover that interregional trade has played an important role in determining regional output, while the technology effect had a tendency to decrease over time. Similarly, one of the several interesting findings of Kagawa and Inamura (2004) MR-SDA study based on China-Japan inter-country IOTs for 1985 and 1990, was that the contribution of the Japanese final demand shifts on the total change in Chinese primary energy requirements was 40 times larger than that of the Chinese final demand shifts on the primary energy demand of Japan. Hence, the authors call for Japanese policy makers concentrating on the energy impacts of domestic final demand shifts rather than on the changes in Chinese final demand shifts.

While in MR-SDA some countries/regions of the world are exogenous, in the GMR-SDA studies the intermediate and final linkages between all regions are explicitly taken into account. Obviously, this type of analyses are most complete because they capture the actual complex production and demand interrelationships among countries, and as such fully take into account all kinds of intra- and inter-regional feedback and spillover effects (see e.g. Miller 1966, 1967; Temursho, 2014). But it should be also mentioned that usually the more detailed an IOT is, the less reliable its certain individual data points become as at current stage there is no way of avoiding the use of some sort of non-survey, estimation techniques for producing such high-level disaggregated data (this issue also holds for SR IOTs, especially when the corresponding time series are estimated). Also the more detailed an IOT is, the more important conceptual changes/accounting changes/classification changes are in analysing trends over time. For these reasons some recent IO studies using (G)MR IOTs do uncertainty analysis (see e.g. Lenzen et al., 2010). The related issues, which we do not discuss here, are sectoral, spatial and/or temporal (dis)aggregation.[10]

The GMR-SDA literature is very recent because global IOTs were not available earlier, but constructed and made available (and continuously being improved) only recently (for an overview of these databases, see Tukker and Dietzenbacher, 2013). A rather important gap that still needs to be filled in in this respect is producing constant (e.g. previous-year) price global IOTs, which is not a straightforward task as it might seem at the first glance. For example, application of double deflation method is now problematic because the obtained residual value-

[10] See e.g. Su et al. (2010), Su and Ang (2012b, 2010) and Lenzen (2011).

added of the separate countries distinguished in a global IOT may (largely) differ from the corresponding statistics of GDP available from national accounts data.

To the best of our knowledge, so far there are only three SDA studies that have used GMR IO framework. The first study is done by Baiocchi and Minx (2010) who use aggregated four-region (i.e., UK, OECD Europe, OECD non-Europe and non-OECD) MR IO framework in a Supply and Use formulation, and analyse the (4 and 6) constituent factors of changes in the UK's CO2 emissions. One of their main conclusions on displacement effects has been already mentioned above in the part of policy relevance of SDA approach. The second study is Lenzen et al. (2013a) that develops and applies an iterative causal model on the linkages between land use, biodiversity and agricultural productivity. Using this predictive model they dissect an increase in global biotic production (i.e., crops, grains, milk, meat, fibre, timber, etc., from all land types) of 2.5 gigatonne between 2005 and 2050. In the parts of the model where IO model is used, the MR IO model assumes 1-sector economies and does not distinguishes more sectoral detail (using MR *multi-sector* IO framework is considered by the authors as one of the possible improvements of the model applications). Using Paasche-type additive decomposition, they distinguish six factors: per-capita GDP growth, population growth, land yield increase (technology), land yield decrease (land degradation), positive fertilization effect of increased atmospheric CO_2 concentration, and biodiversity decline in productivity. The authors find that the first three mentioned factors are the major positive drivers of the increase in biotic production, while the other factors have minor contributions and essentially cancel each other out.

Arto and Dietzenbacher (2014) is the first most extensive GMR-SDA study, which focuses on the change of global GHG emissions over the period 1995-2008 and is based on IOTs from the World Input-Output Database (www.wiod.org). Their main findings in terms of underlying sources of global GHG increase of 8.9 gigatonnes CO_2 equivalent (Gt) in this period are as follows. Changes in the levels of consumption per capita has, unsurprisingly, the largest contribution to global emissions (+14.0 Gt), followed by population growth (+4.2 Gt) and changes in the trade structure (+0.6 Gt). These positive effects were partially offset by the changes in technology (-8.4 Gt) and product mix effect (-1.5 Gt). From geographical perspective, the authors find that changes in the emerging economies (Brazil, Russia, India, Indonesia and

China; BRIIC) have caused 44% of emission growth, whereas the increase in their national emissions accounted for no less than 59% of emission growth. This implies that 15% (1.4 Gt) of all extra GHG emissions between 1995 and 2008 emitted in BRIIC countries were caused by changes in other countries.

So far we have discussed *temporal* GMR-SDA studies. However, there is another type of (G)MR-SDA which could be considered a counterpart of the between-country SR-SDA analysis, where the focus of comparative study are not different countries/regions, but different (G)MR IOTs for the same time period and same countries. Thus, we term this type of SDA as *between-database (G)MR-SDA*, which is a useful tool in better understanding the main sources of divergences between two or more (G)MR IOTs constructed by different institutes. This is entirely a new line of research, given that the choice of using two or more GMR IOTs became possible only recently. A special issue of *Economic Systems Research* (Volume 26, Issue 3, 2014) includes papers that use between-database (G)MR-SDA in comparative evaluation of (G)MR IO databases. For example, Owen et al. (2014) focuses on the changes in emissions using three databases of Eora, GTAP and WIOD, and finds that the main differences between Eora and GTAP are attributed to differences in the Leontief inverse and emissions' data, whereas the variation between Eora and WIOD is due to differences in final demand and the Leontief inverse. This study also find that GTAP and WIOD produce similar results for the majority of regions. On the other hand, Arto et al. (2014) identify the most important sources of differences in the global carbon footprints of nations calculated using GTAP and WIOD databases. They find that the differences in the datasets of four countries (the US, China, Russia and India) explain almost 50% of the differences in the computed carbon footprints, and that at sectoral level, 50% of the differences are explained by divergences in electricity, refining and inland transport.

Extensions and other SDA-related issues. Structural Path Decomposition (SPD) is a method proposed by Wood and Lenzen (2009) that combines SDA and Structural Path Analysis (SPA), the later approach being proposed by Defourny and Thorbecke (1984). SDA aggregate results usually hide many competing trends as indicators improvements in some sectors are often offset by relevant deteriorations in other sectors. SPA, on the other hand, allows tracing the most important paths in the economy using the Taylor series expansion of the Leontief inverse. This allows one to observe how the main impacts are caused: directly by final consumption, or its combination with the first- and/or higher-order effects that reflect the direct and indirect production linkages between industries. Hence, SPD being a combination of SDA and SPA is a powerful tool in examining temporal changes of *specific* production chain paths, which otherwise could be neglected due to their negligible net impact in the SDA outcomes because of the competing nature of these specific paths. Using the SPD approach, Oshita (2012), for example, discovers critical supply chain paths deriving changes in Japanese CO_2 emissions. Mattila (2012) implements the same empirical exercise for Finnish ecological footprint.

There are other SDA-related issues that we shall not discuss here, most of which are discussed in the survey papers mentioned above and/or other related (recent) studies. These include, among other issues, studies related to one-tier SDA vs. two-tier KLEM (capital, labor, energy and materials) SDA (Rose and Chen, 1991), SDA based on open vs. closed IO model, hybrid units-based vs. direct impact coefficients-based SDA (Miller and Blair, 2009, chap. 9), SDA based on hybrid IOTs (Dietzenbacher and Stage, 2006), price IO model use in SDA (e.g., Fujikawa et al., 1995, see fn. 7), SDA based on Ghosh (1958) model (Zhang, 2010), SDA with dependent determinants (Dietzenbacher et al., 2000) and SDA of vertical specialization measures (Pei et al., 2011).

All in all, we conclude from this overview that SDA approach can help understand the factors affecting decoupling of environmental impacts from growth in final demand, is a well-established decomposition method and has really wide scope of existing and forthcoming applications. We see the need for more work at the global level to really capture the trade dimension of our global economy, in particular with respect to the impact of off-shoring production facilities. In this light, we propose such an analysis to investigate changes in global supply chains in the next section.

3. Global multi-region structural path decomposition

As discussed in the previous section, in Wood and Lenzen (2009) a suggestion was made to apply a Structural Path Analysis to the decomposition results in order to understand the supply chains that drive the major changes in impacts over time. As such, the method known as Structural Path Decomposition (SPD) allows insights into what nodes in the global production system have actually driven the greatest increase or decrease in emissions (or any other policy-relevant indicator).

The methodology of SPD. Before reporting the results of our empirical application, we first briefly present the mathematics of SPD in a single-region setting. The starting point is the basic generalized IO model of the form

$$\mathbf{f} = \hat{\mathbf{c}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \,, \tag{1}$$

where $\mathbf{f}$ is the column vector of total greenhouse gas (GHG) emissions by industry, $\hat{\mathbf{c}}$ is a diagonal matrix with sectoral GHG intensities (i.e. GHG emission per unit of gross output) along its diagonal, $\mathbf{I}$ is the identity matrix of appropriate dimension, $\mathbf{A}$ is the input matrix, and $\mathbf{y}$ denotes the vector of final demand. The typical *ij*-th element of the well-known Leontief inverse matrix $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ quantifies total (i.e. direct and indirect) impact of a unit increase of final demand of sector *j* on the output of sector *i*. Its further multiplication by the GHG intensity of sector *i* translates the obtained output effect into the relevant GHG impact.

IO model then allows one to quantify the contributions of different factors underlying the changes of GHG emissions over time. Using the simplest for SDA purposes IO model (1) that distinguishes between three factors (however, one could extend (1) to include as many relevant factors as desired), the typical three-factor additive SDA formula takes the following form:

$$\Delta\mathbf{f} = \Delta\hat{\mathbf{c}}\mathbf{L}\mathbf{y} + \hat{\mathbf{c}}\Delta\mathbf{L}\mathbf{y} + \hat{\mathbf{c}}\mathbf{L}\Delta\mathbf{y} \,, \tag{2}$$

where Δ refers to change in the variable following the delta (change) sign. Hence, (2) decomposes the change (growth) in sectoral GHG emissions $\Delta\mathbf{f}$ into GHG emissions intensity effect $\Delta\hat{\mathbf{c}}\mathbf{L}\mathbf{y}$, technical coefficient (technology or industrial structure) effect $\hat{\mathbf{c}}\Delta\mathbf{L}\mathbf{y}$, and final demand level effect $\hat{\mathbf{c}}\mathbf{L}\Delta\mathbf{y}$. The estimation of period-wise change in a variable necessitates the knowledge of the integral path, and with only end-point information available, assumptions must be made on the shape of the path. We use the logarithmic mean divisia index, where a change in the dependent variable y is calculated based on the values of independent variables x_i's using the following formula:

$$\Delta y = \sum_{i=1}^{m} \Delta y_i = \sum_{i=1}^{m} \frac{y_{i,1} - y_{i,0}}{\ln y_{i,1} - \ln y_{i,0}} \ln \frac{x_{i,1}}{x_{i,0}}, \tag{3}$$

where subscripts 0 and 1 refer to period 0 and 1, respectively. A potentially significant problem of using logarithmic based indices in detailed datasets is the handling of zeros and negative numbers. As a result, a number of implementation rules based on numerical limits should be used (Wood and Lenzen, 2004; Ang and Su, 2006).

In moving from SDA to SPD one has to simply use the well-known Taylor series expansion of the Leontief inverse matrix (see e.g. Miller and Blair, 2009, chapter 2.4). That is, using the fact that

$$\mathbf{L} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \mathbf{A}^4 + \cdots \ , \tag{4}$$

and substituting (4) into (2), we obtain the following typical three-factor SPD formula:

$$\begin{aligned} \Delta\mathbf{f} = {} & \Delta\hat{\mathbf{c}}(\mathbf{I} + \mathbf{A} + \mathbf{AA} + \mathbf{AAA} + \cdots \ )\mathbf{y} \\ & + \hat{\mathbf{c}}(\Delta\mathbf{A} + \Delta\mathbf{A}\mathbf{A} + \mathbf{A}\Delta\mathbf{A} + \Delta\mathbf{A}\mathbf{A}\mathbf{A} + \mathbf{A}\Delta\mathbf{A}\mathbf{A} + \mathbf{A}\mathbf{A}\Delta\mathbf{A} \cdots)\mathbf{y} \\ & + \hat{\mathbf{c}}(\mathbf{I} + \mathbf{A} + \mathbf{AA} + \mathbf{AAA} + \cdots \ )\Delta\mathbf{y} \ . \end{aligned} \tag{5}$$

The nice feature of the SPD formula (5) compared to the SDA equation (2) is that the Taylor series expansion of the Leontief inverse allows one to disentangle the effects of any considered factor along all possible individual paths of the supply chain. These include the shortest paths of initial (or first-order) impact on emission generation and longer paths of direct and indirect due to the presence of interindustry linkages (or second-, third- and higher-order) impacts. Some examples of such single-path tiered results are:

1st order impacts: $\Delta c_i y_i$, or $c_i \Delta y_i$; (6)

2nd order impacts: $\Delta c_i A_{ik} y_k$, or $c_i \Delta A_{ik} y_k$; (7)

3rd order impacts: $\Delta c_i A_{in} A_{nk} y_k$, or $c_i A_{in} \Delta A_{nk} y_k$; (8)

The first example $\Delta c_i y_i$ is the change in GHG emissions brought about by the change in GHG intensity of production of sector *i* for satisfaction of final demand *i*, whereas the second 1st order impact example is the GHG change in the same production chain caused by the change in final demand *i*. The 2nd-order impact example $c_i \Delta A_{ik} y_k$ indicates the change in GHG emissions of sector *i* due to the change in the direct (first-order) input coefficient of industry *k*. This supply chain has to do with the emissions produced by sector *i* that are embodied in the inputs to industry *k* and destined for final demand of sector *k*. Similarly, the 3rd order impact example $c_i A_{in} \Delta A_{nk} y_k$ quantifies the change in GHG emissions along the supply chain {sector *i*} → {sector *n*} → {sector *k*} → {final consumer of good *k*} that are produced in sector *i* due to the change in the indirect second-order input coefficient A_{nk}. These are emissions generated by sector *i* that are embodied in the inputs to industry *n*, which are further embodied in a subsequent use of industry *n*'s output as inputs to sector *k* that are ultimately destined for final demand *k*.

Since we apply the SPD approach to the global multi-region (GMR) IO tables that include all countries/regions of the world, we will have additional regional dimension. However, the basic principles and interpretations used in the single-region SPD (SR-SPD) framework presented above remain valid for our (or any) GMR-SPD study as well. Take for example the last 3rd order impact case discussed above, which in the GMR-SPD setting could be instead $c_i^R A_{in}^{RS} \Delta A_{nk}^{SG} y_k^G$, where the superscripts denote countries (or regions). This would show the change in GHG emissions along the supply chain {sector *i* in region *R*} → {sector *n* in region *S*} → {sector *k* in region *G*} → {final user of good *k* in region *G*} that are produced in sector *i* in region *R* due to the change in the indirect (second-order) input coefficient ΔA_{nk}^{SG}.

Empirical application of the GMR-SPD approach. We use the 59 sector model of EXIOBASE 1.0 and EXIOBASE 2.2 in order to undertake a GMR-SPD analysis of the changes in global GHG emissions over the period of 2000 to 2007. While in 2000 the world GHG emissions amounted to 27,405 Megatonnes (Mt) CO_2 equivalent (CO_2-eq), they have further increased by roughly 22% totalling to 33,344 Mt CO_2-eq in 2007. Given this significant growth in the global GHG emissions, it is important to better understand the sources of GHG changes with both positive and negative contributions from the more detailed supply-chain perspective. We first provide the macro-overview of our GMR-SPD results in Table 1.[11]

Table 1: Macro overview of the GMR-SPD results

	Δc	**ΔA**	**Δy**	**Total**	**Δc**	**ΔA**	**Δy**	**Total**	**Δc**	**ΔA**	**Δy**	**Total**
	Number (#) of paths				# of paths: %% of row total				# of paths: %% of column total			
1st order impact	486	0	396	882	55	0	45	100	33	0	38	22
2nd order impact	711	928	519	2158	33	43	24	100	48	66	49	55
3rd order impact	285	480	138	903	32	53	15	100	19	34	13	23
Intra-country paths	1208	810	975	2993	40	27	33	100	82	58	93	76
Inter-country paths	274	598	78	950	29	63	8	100	18	42	7	24
Total	1482	1408	1053	3943	38	36	27	100	100	100	100	100
	GHG emission value (Mt CO2-eq)				GHG value: %% of row total				GHG value: %% of column total			
1st order impact	-1093	0	1516	423	-259	0	359	100	41	0	38	31
2nd order impact	-1271	-95	1920	554	-230	-17	347	100	47	-106	48	41
3rd order impact	-333	184	533	384	-87	48	139	100	12	206	13	28
Intra-country paths	-2812	50	3952	1190	-236	4	332	100	104	55	100	87
Inter-country paths	115	40	16	171	67	23	9	100	-4	45	0	13
Total	-2697	89	3968	1360	-198	7	292	100	100	100	100	100

Source: Own elaborations using EXIOBASE data.

We have found top 3,943 paths (all paths over 1Mt CO2-eq) that overall amount to 1,360 Mt CO_2-eq of GHG emissions, which make 23% of the total change of 5,939 Mt CO_2-eq. Some of the main findings observed from Table 1 are as follows:

1. Overall in the entire globe for the period considered 2nd order impacts dominate both in terms of the number of top paths and the size of contributions to the world GHG emissions change. That is, Table 1 shows that more than half, namely 55%, of the 3,943 top paths make 2nd order impacts, while the rest are roughly equally divided between the 1st and 3rd order impacts that include, respectively, 22% and 23% of the remaining paths. Similarly, in terms of value contributions to the change in GHG emissions, nearly the same ordering is observed: 2nd order impacts account for 41% of the change in global GHG emissions, 1st order impacts – 31%, and 3rd order impacts – 28%.

[11] We have used double deflation method to make the 2000 and 2007 EXIOBASE input-output tables price-comparable.

2. Although the majority of paths are intra-country paths, the role of *inter*-country effects is not negligible at all. Within the top 3,943 paths, 24% include inter-country paths, which overall contribute 13% to the global GHG emissions growth.
3. For the global system, we find roughly identical number of top paths (i.e., 38%, 36% and 27%) driven, respectively, by changes in direct emission intensity (**Δc**), in industrial structure (**ΔA**) and in final demand (**Δy**). However, it terms of contributions to world GHG growth within the considered top paths, changes in the level of final demand increased GHG emissions by 292%, which were partially compensated by the direct emission intensity effects amounted to -198%. The remaining 7% is attributed to the paths driven by changes in direct and indirect input coefficients.
4. At the world level, all the considered three factors contribute *positively* to the global GHG emissions change along all the 950 *inter*-country paths. In comparison to intra-country paths with (usual) dominating final demand effect, the inter-country paths show dominating impact of the emission intensity and industrial structure changes. Out of 171 Mt CO_2-eq GHG emissions generation related to the inter-country structural paths, 67% and 23% are driven by emission intensity and industrial structure effects, and only the remaining 9% is attributed to the changes in consumption level.

The last finding is particularly interesting because it essentially implies that over the 2000-2007 period structural changes related to paths crossing national borders were damaging from an environmental perspective at the global level. However, of course, there are individual inter-country paths that had beneficial environmental impact, but these were largely offset by the counteracting impact of the other inter-country paths. These details can be seen from **Appendix 1**, which provides the list of selected paths in four table partitions: the top 31 paths are presented first which consists of only intra-country paths (ranks 1 – 31), then the top inter-country paths with individual contribution in absolute value of at least 1 Mt CO_2-eq follow (non-inclusive ranks 282 – 1547), next remaining inter-country paths of 3rd order impacts each with a contribution in absolute value of at least 200 kilotonnes (kt) CO_2-eq are reported (non-inclusive ranks 282 – 1547), and finally the remaining 3rd order impact inter-country paths which pass across two different national borders are presented.

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Appendix 1: Selected GMR-SPD results

Rank	Value (kt CO2-eq)	Factor	Emission producer (1st order impact)	Emission producer (2nd order impact)	Emission producer (3rd order impact)
1	680590.9	dc	ROW_Electrical energy, gas, steam & hot water		
2	392170.5	dA	CHN_Construction work	CHN_Other non-metallic mineral products	
3	336412.8	dy	CHN_Construction work	CHN_Other non-metallic mineral products	
4	-333282.8	dc	CHN_Construction work	CHN_Other non-metallic mineral products	
5	-285637.3	dc	ROW_Agriculture, hunting		
6	-228097.5	dc	IND_Agriculture, hunting		
7	-195600.2	dc	CHN_Agriculture, hunting		
8	189888.9	dy	CHN_Electrical energy, gas, steam & hot water		
9	186167.0	dy	ROW_Electrical energy, gas, steam & hot water		
10	-180444.6	dc	ROW_Construction work		
11	-166402.2	dc	ROW_Food products, beverages	ROW_Agriculture, hunting	
12	161269.4	dy	CHN_Construction work	CHN_Basic metals	
13	-147750.5	dc	CHN_Electrical energy, gas, steam & hot water		
14	-119440.8	dc	USA_Food products, beverages	USA_Agriculture, hunting	
15	106477.9	dy	CHN_Machinery and equipment	CHN_Basic metals	
16	104235.5	dc	USA_Electrical energy, gas, steam & hot water		
17	92184.3	dc	ROW_Construction work	ROW_Other non-metallic mineral products	
18	-85435.6	dy	USA_Electrical energy, gas, steam & hot water		
19	83736.9	dc	ROW_Chemicals, chemical products, fibres		
20	79864.1	dy	ROW_Rubber and plastic products		
21	-77414.1	dc	RUS_Agriculture, hunting		
22	-73785.9	dy	ROW_Water transport services		
23	72872.2	dy	ROW_Wholesale trade		
24	70429.2	dy	CHN_Electrical machinery and apparatus	CHN_Basic metals	
25	-70385.2	dc	USA_Agriculture, hunting		
26	69626.5	dA	CHN_Electrical energy, gas, steam & hot water	CHN_Electrical energy, gas, steam & hot water	
27	-69572.7	dc	BRA_Food products, beverages	BRA_Agriculture, hunting	
28	-69313.7	dc	ROW_Sewage and sanitation		
29	66548.8	dy	RUS_Electrical energy, gas, steam & hot water		
30	-64090.0	dc	BRA_Agriculture, hunting		
31	-62722.2	dc	CHN_Food products, beverages	CHN_Agriculture, hunting	
282	12096.1	dc	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
352	9708.4	dc	ITA_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
362	9514.4	dc	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
391	8984.5	dc	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
393	-8953.6	dA	IND_Construction work	CHN_Basic metals	
433	7969.5	dc	USA_Coke, refined petroleum, nuclear fuels	MEX_Crude petroleum, natural gas	

437	7932.1	dc	ROW_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
529	6487.0	dc	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
597	5742.7	dA	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
626	5501.8	dc	ITA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
631	5456.3	dA	USA_Coke, refined petroleum, nuclear fuels	CAN_Crude petroleum, natural gas	
665	5188.6	dA	USA_Public administration and defence	GRC_Water transport services	
667	5180.2	dc	KOR_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
709	4850.5	dA	POL_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
750	4560.0	dA	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
811	4050.2	dc	JPN_Land transport, transport via pipeline	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
883	3565.8	dc	FRA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
888	3533.0	dc	FRA_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
920	-3221.0	dA	JPN_Electrical energy, gas, steam & hot water	AUS_Coal and lignite, peat	
931	3153.5	dA	JPN_Construction work	CHN_Other non-metallic mineral products	
932	-3144.6	dy	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
939	-3093.5	dA	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
941	3085.0	dc	FIN_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
961	-2946.0	dc	JPN_Electrical energy, gas, steam & hot water	AUS_Coal and lignite, peat	
971	2876.1	dc	ESP_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
986	2824.4	dc	LTU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
992	-2812.0	dc	JPN_Food products, beverages	USA_Agriculture, hunting	
994	-2792.2	dA	USA_Construction work	IND_Other non-metallic mineral products	
1000	2783.9	dc	USA_Coke, refined petroleum, nuclear fuels	CAN_Crude petroleum, natural gas	
1041	2515.6	dc	ESP_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1067	-2394.8	dA	USA_Machinery and equipment	CHN_Basic metals	
1084	2301.7	dy	FRA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1087	-2290.4	dc	JPN_Construction work	CHN_Other non-metallic mineral products	
1107	2236.5	dc	GRC_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1111	-2217.4	dc	JPN_Coke, refined petroleum, nuclear fuels	AUS_Coal and lignite, peat	
1124	2154.4	dc	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1127	2145.8	dc	USA_Public administration and defence	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
1128	2143.3	dc	USA_Construction work	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
1150	-2053.4	dc	USA_Food products, beverages	CAN_Agriculture, hunting	
1163	2010.3	dc	ITA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1169	1987.4	dA	USA_Construction work	CHN_Other non-metallic mineral products	
1178	-1964.1	dA	JPN_Land transport, transport via pipeline	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
1191	1922.8	dA	JPN_Land transport, transport via pipeline	JPN_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
1193	-1920.3	dA	USA_Motor vehicles, trailers & semi-trailers	CHN_Basic metals	
1215	-1863.4	dA	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1216	-1861.6	dc	USA_Food products, beverages	ROW_Agriculture, hunting	
1218	-1857.3	dA	POL_Coke, refined petroleum, nuclear fuels	BEL_Metal ores	

1243	-1773.8	dA	JPN_Water transport services	ROW_Water transport services	
1247	1757.7	dc	ESP_Coke, refined petroleum, nuclear fuels	MEX_Crude petroleum, natural gas	
1248	1756.2	dy	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1253	1725.1	dc	USA_Public administration and defence	USA_Coke, refined petroleum, nuclear fuels	MEX_Crude petroleum, natural gas
1255	1724.7	dc	USA_Construction work	USA_Coke, refined petroleum, nuclear fuels	MEX_Crude petroleum, natural gas
1264	1701.9	dA	ITA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1272	1669.5	dA	JPN_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1279	1634.4	dA	FRA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1287	1601.9	dA	USA_Construction work	CHN_Fabricated metal products, exc. mach&eq.	CHN_Basic metals
1291	-1585.0	dA	USA_Public administration and defence	JPN_Water transport services	
1304	1555.5	dc	ROU_Electrical energy, gas, steam & hot water	RUS_Crude petroleum, natural gas	
1305	-1554.3	dc	JPN_Food products, beverages	ROW_Agriculture, hunting	
1316	1492.2	dc	GRC_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1333	1437.4	dc	DEU_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1334	1436.7	dc	CZE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1336	1430.8	dc	USA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1347	-1403.6	dA	DEU_Motor vehicles, trailers & semi-trailers	GRC_Water transport services	
1353	1396.3	dA	USA_Construction work	CHN_Electrical machinery and apparatus	CHN_Basic metals
1357	1386.1	dc	FRA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1377	-1334.0	dc	USA_Construction work	CHN_Other non-metallic mineral products	
1391	1303.4	dy	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1396	1297.3	dy	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1397	1293.7	dA	USA_Electrical energy, gas, steam & hot water	ROW_Crude petroleum, natural gas	
1406	1262.2	dy	LTU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1415	-1248.6	dA	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Electrical energy, gas, steam & hot water
1421	1238.8	dc	BGR_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1429	1222.2	dy	ESP_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1436	1205.4	dy	FRA_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1438	1204.0	dA	USA_Construction work	USA_Coke, refined petroleum, nuclear fuels	CAN_Crude petroleum, natural gas
1443	1184.3	dc	SWE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1450	1177.4	dc	USA_Electrical energy, gas, steam & hot water	CAN_Crude petroleum, natural gas	
1459	-1163.1	dc	USA_Food products, beverages	ROW_Food products, beverages	ROW_Agriculture, hunting
1463	1155.7	dA	POL_Land transport, transport via pipeline	POL_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
1483	1121.8	dc	NLD_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1515	1065.9	dc	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Crude petroleum, natural gas
1518	1059.0	dc	ROU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1530	-1036.0	dA	USA_Food products, beverages	ROW_Agriculture, hunting	
1542	-1011.7	dA	LTU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	
1547	1004.5	dA	BEL_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	
1662	-798.8	dA	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	RUS_Electrical energy, gas, steam & hot water
1682	778.4	dc	ITA_Land transport, transport via pipeline	ITA_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas

1687	774.9	dA	GBR_Air transport services	ROW_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
1755	699.2	dA	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	RUS_Electrical energy, gas, steam & hot water
1757	-696.2	dA	ITA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Electrical energy, gas, steam & hot water
1772	682.7	dc	DEU_Construction work	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
1778	676.9	dA	POL_Construction work	POL_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
1815	625.0	dc	ITA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Crude petroleum, natural gas
1862	574.0	dc	NLD_Coke, refined petroleum, nuclear fuels	RUS_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
1890	549.4	dA	ITA_Machinery and equipment	ITA_Fabricated metal products, exc. mach&eq.	CHN_Basic metals
1936	496.5	dc	BGR_Land transport, transport via pipeline	BGR_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
1966	467.8	dA	DEU_Construction work	CHN_Electrical machinery and apparatus	CHN_Basic metals
1998	438.9	dA	ESP_Construction work	ESP_Fabricated metal products, exc. mach&eq.	CHN_Basic metals
2019	420.0	dc	FRA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Crude petroleum, natural gas
2029	-408.4	dA	FRA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Electrical energy, gas, steam & hot water
2033	403.4	dA	DEU_Machinery and equipment	CHN_Machinery and equipment	CHN_Basic metals
2051	384.4	dc	DEU_Coke, refined petroleum, nuclear fuels	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2052	384.1	dc	DEU_Air transport services	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2060	-380.1	dc	DEU_Food products, beverages	ROW_Food products, beverages	ROW_Agriculture, hunting
2067	375.9	dA	DEU_Health & social work services	CHN_Chemicals, chemical products, fibres	CHN_Electrical energy, gas, steam & hot water
2105	-347.5	dA	ESP_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Electrical energy, gas, steam & hot water
2123	338.8	dA	FRA_Chemicals, chemical products, fibres	CHN_Chemicals, chemical products, fibres	CHN_Electrical energy, gas, steam & hot water
2125	336.5	dy	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	RUS_Electrical energy, gas, steam & hot water
2131	332.4	dc	ESP_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas	ROW_Crude petroleum, natural gas
2137	327.1	dc	FIN_Coke, refined petroleum, nuclear fuels	FIN_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2162	-312.9	dc	FRA_Food products, beverages	BRA_Food products, beverages	BRA_Agriculture, hunting
2170	307.7	dA	DEU_Motor vehicles, trailers & semi-trailers	CHN_Electrical machinery and apparatus	CHN_Basic metals
2179	303.0	dc	DEU_Land transport, transport via pipeline	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2196	-294.5	dc	ESP_Food products, beverages	ROW_Food products, beverages	ROW_Agriculture, hunting
2198	-293.6	dA	DEU_Motor vehicles, trailers & semi-trailers	DEU_Motor vehicles, trailers & semi-trailers	GRC_Water transport services
2200	-293.2	dA	BGR_Land transport, transport via pipeline	BGR_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2240	274.2	dA	DEU_Construction work	CHN_Fabricated metal products, exc. mach&eq.	CHN_Basic metals
2242	273.6	dA	DEU_Machinery and equipment	DEU_Fabricated metal products, exc. mach&eq.	RUS_Basic metals
2246	-272.2	dA	DNK_Water transport services	ROW_Supporting & auxiliary transport services	ROW_Electrical energy, gas, steam & hot water
2250	270.0	dA	DEU_Air transport services	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2257	-266.0	dc	DEU_Hotel and restaurant services	ROW_Food products, beverages	ROW_Agriculture, hunting
2260	264.1	dc	ESP_Coke, refined petroleum, nuclear fuels	ESP_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
2262	262.5	dc	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas	RUS_Crude petroleum, natural gas
2267	-260.5	dA	DEU_Motor vehicles, trailers & semi-trailers	ZAF_Metal ores	ZAF_Electrical energy, gas, steam & hot water
2269	260.2	dA	DEU_Motor vehicles, trailers & semi-trailers	DEU_Fabricated metal products, exc. mach&eq.	RUS_Basic metals
2270	259.8	dA	DEU_Health & social work services	USA_Chemicals, chemical products, fibres	USA_Electrical energy, gas, steam & hot water
2278	257.4	dA	DEU_Construction work	DEU_Fabricated metal products, exc. mach&eq.	RUS_Basic metals
2284	254.5	dA	DEU_Chemicals, chemical products, fibres	CHN_Chemicals, chemical products, fibres	CHN_Electrical energy, gas, steam & hot water

2301	243.2	dc	ESP_Coke, refined petroleum, nuclear fuels	ESP_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2320	237.8	dA	DEU_Air transport services	ROW_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
2324	-235.1	dA	DEU_Construction work	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2327	233.4	dc	DEU_Wholesale trade	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2330	-232.2	dA	DEU_Machinery and equipment	ZAF_Metal ores	ZAF_Electrical energy, gas, steam & hot water
2353	222.6	dc	CZE_Construction work	CZE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2368	216.8	dA	AUT_Electrical energy, gas, steam & hot water	AUT_Electrical energy, gas, steam & hot water	DEU_Electrical energy, gas, steam & hot water
2376	213.7	dc	DEU_Air transport services	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2378	212.9	dc	DEU_Public administration and defence	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2382	212.1	dc	DEU_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2391	209.4	dc	DEU_Education services	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2394	208.3	dA	DEU_Motor vehicles, trailers & semi-trailers	CHN_Fabricated metal products, exc. mach&eq.	CHN_Basic metals
2410	201.5	dA	DEU_Machinery and equipment	CHN_Electrical machinery and apparatus	CHN_Basic metals
2437	192.67	dc	BEL_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2467	180.59	dc	DEU_Construction work	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2576	149.10	dA	DEU_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2632	135.44	dA	BEL_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2696	119.82	dc	AUT_Construction work	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
2875	83.97	dc	AUT_Land transport, transport via pipeline	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3037	-61.85	dA	AUT_Construction work	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3095	56.30	dc	BEL_Chemicals, chemical products, fibres	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3144	51.47	dc	AUT_Construction work	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3164	49.09	dc	BEL_Coke, refined petroleum, nuclear fuels	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3193	-46.04	dA	BEL_Coke, refined petroleum, nuclear fuels	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3195	-45.03	dA	AUT_Construction work	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3257	39.58	dA	BEL_Chemicals, chemical products, fibres	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3261	39.21	dc	AUT_Land transport, transport via pipeline	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3267	38.74	dA	BEL_Coke, refined petroleum, nuclear fuels	FIN_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3314	35.30	dc	BEL_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
3316	34.94	dy	BEL_Coke, refined petroleum, nuclear fuels	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3339	33.74	dc	BEL_Wholesale trade	NLD_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3382	-31.55	dA	AUT_Land transport, transport via pipeline	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3410	29.79	dc	BEL_Coke, refined petroleum, nuclear fuels	SWE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3415	29.56	dc	AUT_Health & social work services	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3440	28.36	dc	BEL_Coke, refined petroleum, nuclear fuels	FIN_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3486	26.15	dc	AUT_Education services	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3522	24.32	dA	BEL_Coke, refined petroleum, nuclear fuels	SWE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3535	-23.62	dA	BEL_Coke, refined petroleum, nuclear fuels	FRA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas
3538	23.51	dc	AUT_Public administration and defence	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3556	22.76	dc	AUT_Hotel and restaurant services	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3557	-22.68	dA	BEL_Coke, refined petroleum, nuclear fuels	USA_Coke, refined petroleum, nuclear fuels	ROW_Crude petroleum, natural gas

3602	20.46	dA	AUT_Land transport, transport via pipeline	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3613	20.11	dc	AUT_Health & social work services	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3670	-17.72	dA	AUT_Construction work	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3724	-15.76	dA	AUT_Construction work	CZE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3730	15.63	dc	AUT_Agriculture, hunting	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3749	14.85	dA	AUT_Fabricated metal products, exc. mach&eq.	POL_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3780	14.06	dc	AUT_Hotel and restaurant services	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3788	13.76	dc	AUT_Construction work	CZE_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3802	-13.50	dA	AUT_Land transport, transport via pipeline	DEU_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3895	-10.92	dA	AUT_Motor vehicles, trailers & semi-trailers	DEU_Motor vehicles, trailers & semi-trailers	GRC_Water transport services
3898	10.85	dc	AUT_Retail trade services	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas
3930	10.29	dc	AUT_Wholesale trade	SVK_Coke, refined petroleum, nuclear fuels	RUS_Crude petroleum, natural gas

Note: The country abbreviations are as follows: AUS – Australia, AUT – Austria, BEL – Belgium, BGR – Bulgaria, BRA – Brazil, CAN – Canada, CHE – Switzerland, 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 – Korea, LTU – Lithuania, LUX – Luxembourg, LVA – Latvia, MEX – Mexico, MLT – Malta, NLD – Netherlands, NOR – Norway, POL – Poland, PRT – Portugal, ROU – Romania, RUS – Russia, SVK – Slovak Republic, SVN – Slovenia, SWE – Sweden, TUR – Turkey, TWN – Taiwan, USA – United States of America, ZAF – South Africa and ROW – rest of the world.

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