# Output Upstreamness and Input Downstreamness of Industries/Countries in World Production

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# Output upstreamness and input downstreamness of industries/countries in world production*

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**Abstract**

Using the world input-output tables available from the WIOD project, we quantify production line positions of 35 industries for 40 countries and the rest of the world region over 1995-2011. In contrast to the previous related literature we do not focus only on the output supply chain, but also consider sectors' input demand chains. This distinction is important because both these chains jointly constitute the entire production process, and the output sales structure of each sector is generally different from the structure of its inputs purchases. We use the output upstreamness (OU) measure of Antràs et al. (2012) and our proposed input downstreamness (ID) measure to quantify industry relative position, respectively, along the global output supply chain and the global input demand chain. Focusing on time variation, we find that potential input-output data uncertainties do not affect the observed patterns of the average OU and ID changes for the vast majority of countries and sectors. Further, for most countries the increase of OUs/IDs over time is found to be driven by a rise in cross-border intermediates sales/purchases.

**Keywords:** output upstreamness, input downstreamness, output supply chain, input demand chain, industry production position, structural decomposition analysis

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## 1 Introduction

Trade in intermediates has become an important issue in recent decades as nations across the world are becoming more open over time. This raises new questions, but also provides an opportunity to explain certain economic facts. For example, Jones (2011) shows that including linkages between firms through intermediate goods into the standard neoclassical growth models significantly improves our understanding of the observed large income differences across countries.[1] The literature focusing on trade in intermediates is by now quite large and is rapidly growing (see e.g., Jones and Kierzkowski, 1990; Hummels et al., 2001; Antràs et al., 2006; Baldwin, 2006; Koopman et al., 2011; Johnson and Noguera, 2012; Timmer et al., 2013, 2014).

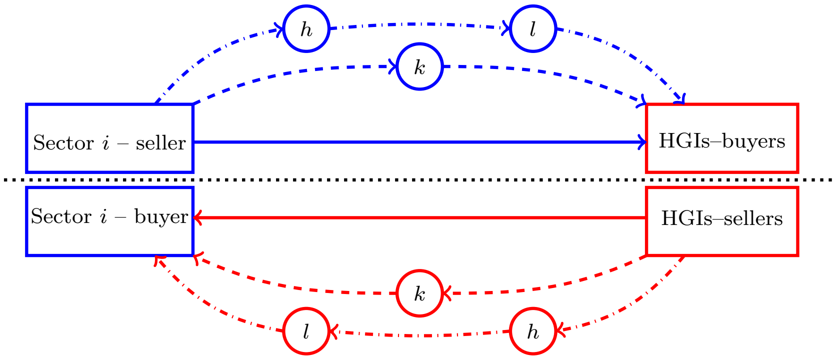
This paper is about an industry's position in the world production chain. There are already several important issues where this concept has been shown to be crucial theoretically and/or empirically. For example, Alfaro and Charlton (2009) find that multinational firms choose to own proximate stages of production. Antràs and Chor (2013) develop a property-rights model, where a firm decides whether to outsource inputs or produce them internally within its boundaries (and empirically confirm their theory), and find that a firm's position in the production line turns out to be one of the crucial relevant factors. This concept is similarly important in the business cycle literature on transmission of shocks through production chains (see e.g., Burstein et al., 2008; di Giovanni and Levchenko, 2010; Zavacka, 2012; Carvalho, 2014). All this literature in quantifying production line position of sectors takes a perspective in which industries are selling their outputs to other sectors and final consumers. In this paper we, however, also recognize that it is not only the output supply chain, but also the input demand chain of firms that make up the complete picture of the entire production process. This distinction is important because at the sectoral level these two chains are not equivalent; for the same producer (industry) the structure of output sales is generally different from that of

[1] See e.g., Krugman and Venables (1995) for an earlier account of the impact of globalization on divergence and/or convergence of real incomes of the developed (core) vs. developing (periphery) nations in the spirit of New Economic Geography literature. In their model, for example, the interaction of transport costs and trade in intermediates creates externalities via linkages between firms (through input-output structure), which may lead to agglomeration of industrial activities.

inputs purchases. There is a huge literature on industry clusters (see e.g., Porter, 1990; Ellison and Glaeser, 1997) stating that related industries tend to agglomerate and on "agglomeration economies" focusing on the analysis of mechanisms driving firms and employees to co-locate geographically, one of which is the so-called *input sharing* mechanism (see e.g., Holmes, 1999; Li and Lu, 2009; Ellison et al., 2010; Jofre-Monseny et al., 2011). However, this literature, to the best of our knowledge, considers only direct intermediate input and output links among sectors, while in this paper the entire production chain perspective is examined, including indirect input demand links and the role of households, governments and investors (HGIs).

A sector's production line position is regarded ultimately with respect to HGIs. These play two different roles in this relation. First, HGIs buy final output (goods and services) from producers. In this output supply chain some firms are located closer to HGIs in the sense of selling a large amount of their outputs directly to final consumers, while other firms are positioned more distant from HGIs in the sense that significant parts of their outputs are heavily used as intermediate inputs by other producers. For this positioning the strength and complexity (i.e., existence of direct and indirect links) of the output supply linkages play an important role. The upper part of Figure 1 illustrates three examples of output supply chains. The solid blue arrow shows a direct link along which sector $i$ sells its final output directly to HGIs. The two other chains are indirect. The dashed blue arrow shows a supply chain from $i$ that goes through sector $k$ and only then ends up in HGIs. Along this chain the output of sector $i$ is used as intermediate input in sector $k$ whose final output is bought by HGIs. Thus, here sector $i$ acts as *indirect seller of output* to HGIs. Similarly, the longer blue dash-dotted arrow shows an indirect supply link from industry $i$ that goes through two intermediate sectors $h$ and $l$ before ultimately reaching HGIs. The number of paths and thus of intermediate sectors could be infinity (in theory), and sector $i$ can itself become an intermediate (which is usually the case) in its own supply chains. Antràs et al. (2012) proposed an indicator that quantifies this relative positioning which they referred to as an "upstreamness measure" of industries. It is an upstreamness measure because firms are positioned upstream in the output supply chain with respect to HGIs. In this paper we refer to

Figure 1: Output supply chains vs. input demand chains




*Note*: Circles with letters denote sectors. The upper part (above the dotted horizontal line) gives examples of output supply chains, while the lower part illustrates examples of input demand chains.

the Antràs et al. (2012) upstreamness indicator as an "output upstreamness" (OU) measure of industries, where "output" is added to signify that one is talking about industry production line position along the *output supply* chain.

Second, HGIs provide (sell) primary inputs (i.e., labour, administration services and capital) to firms. In this input demand chain some firms are positioned close to HGIs in the sense that primary inputs directly supplied by HGIs make up a considerable part of their total inputs, while other firms are located further from HGIs in the sense that they buy a large amount of intermediate inputs from other firms. For this positioning the strength and complexity (i.e., existence of direct and indirect links) of the input demand chains play a crucial role. The bottom part of Figure 1 illustrates three examples of input demand chains. The solid red arrow shows a direct link along which HGIs sell their primary inputs directly to sector $i$. The two other chains are indirect. The dashed red arrow shows a demand chain (from $i$'s perspective) originating from HGIs that goes through sector $k$ and only then ends up in sector $i$. Along this chain primary inputs of HGIs are used as primary inputs in sector $k$ whose output is finally bought by $i$ as intermediate input. Thus, here HGIs act as *indirect providers of inputs* to sector $i$. Similarly, the longer red dash-dotted arrow shows an indirect demand link from HGIs that goes through two intermediate sectors $h$ and $l$ before ultimately reaching $i$. The number of chains and thus of intermediate sectors could be infinity (in theory), and sector $i$ can itself become an intermediate (which is usually the case) in its own demand chains. We propose an "input downstreamness" (ID) measure of industries that quantifies this relative positioning, similar to the Antràs et al. (2012) OU measure. We call it an "input downstreamness" measure because in this case the focus is on the *input demand* chain, in which firms are located downstream with respect to HGIs.

The ID measure presented here is mathematically exactly equivalent to Fally's (2012) measure of "average number of production stages embodied in each product" or "weighted-average number of plants involved sequentially in the production of a certain good". It should be mentioned that the foundation provided by Fally (2012) for both the OU and ID measures is quite distinct from the distance formulation/interpretation of the OU indicator as given by Antràs et al. (2012) and of the ID measure as proposed in this paper. In particular, Fally uses recursive formulations that yield the same measures.[2] Nevertheless, the interpretations are different. In particular, we interpret the ID measure as the average distance between HGIs as suppliers of primary inputs and sectors as inputs purchasers along the input demand chain. In addition, this paper explicitly spells out the notion of "input demand chain" and emphasizes the distinction at the firm/industry level between the (global) input demand chain and the (global) output supply chain. Finally, in our empirical application we focus on the OUs and IDs differences across countries, industries and over time, using the 1995-2011 time series of the world input-output tables available from the EU-funded World Input-Output Database project (see Timmer, 2012; Dietzenbacher et al., 2013). One is able to understand the role of trade in intermediates globally in determining relative positions of industries along global output supply and input demand chains *only* by taking explicitly inter-country production linkages into account. Thus, compared to Antràs et al. (2012) and Fally (2012) which both use the US national input-output tables in their empirical analyses, we are able to account for both direct and indirect links among 35 industries and 40 countries plus the rest of the world in computing the OUs and IDs. We also run Monte Carlo simulations to understand the role of input-output data uncertainty issues on the estimates of the changes in OUs and IDs (see Appendix C). Importantly, we also quantify the drivers of changes in OUs and IDs

[2] We should note that the work of this paper was developed contemporaneously with and independently from Fally (2012).

using a structural decomposition approach (see Appendix D), and in particular, find that the main drivers of the observed increase in the overwhelming majority of the country-level OUs and IDs between 1995 and 2011 were, respectively, positive changes in *inter-country* intermediate output supply and input demand coefficients.

Similar to the OU measure, the proposed ID indicator could be very useful in empirical studies of issues raised in the theory of multinational firm, trade and business cycle literature, where the relative production line position of industries along the input demand chain matters (most).[3] Since the ID (OU) measure quantifies worker-firm (consumer-firm) linkages, potentially both could shed new light in further understanding of co-agglomeration phenomena. Another application of the OUs and IDs is related to the quantification of shared producer and consumer/worker responsibilities for generating pollution (Temurshoev and Miller, 2013).

The rest of this paper is organized as follows. In Section 2 we provide the mathematics and explanation of the OU and ID measures and their connection to linkage analysis in input-output economics. The results of our empirical analysis are discussed in Section 3. Section 4 contains concluding remarks.

## 2 Industries' output upstreamness and input downstreamness measures

The output-side accounting identity states that for each industry $i = 1, \ldots, n$, the value of gross output $x_i$ is equal to its final use $f_i$ plus its intermediate output sales to all industries $\sum_j z_{ij}$. If we denote the euro amount of sector $i$'s output needed per euro's worth of industry $j$'s output by $a_{ij} \equiv z_{ij}/x_j$ (referred to as an input coefficient), the mentioned output identity can be written as $x_i = f_i + \sum_j a_{ij} x_j$. By consecutively using the last identity for $x_j$ in its right hand-side, total output $x_i$ can be alternatively written as

$$x_i = f_i + \sum_j a_{ij} f_j + \sum_{j,k} a_{ik} a_{kj} f_j + \sum_{j,k,l} a_{il} a_{lk} a_{kj} f_j + \cdots . \tag{1}$$

[3] When an exogenous shock originates at HGIs as purchasers of final goods (resp. HGIs as suppliers of primary inputs), the OU (resp. ID) is a more appropriate indicator of an industry relative production line position (see also Figure 1). For example, ID is a relevant distance measure for analyses of supply shocks such as (unexpected) workers' strike.

While the first term on the right-hand side of Eq. (1) indicates the value of industry $i$'s *final sales*, the second term represents sector $i$'s *direct intermediate sales* to all industries $j = 1, \dots, n$ used as intermediate inputs by the latter in their first-round production processes. The remaining terms indicate sector $i$'s *indirect intermediate sales* to all industries (including industry $i$) that are used as inputs in their second and higher rounds production processes (for details, see Miller and Blair, 2009).

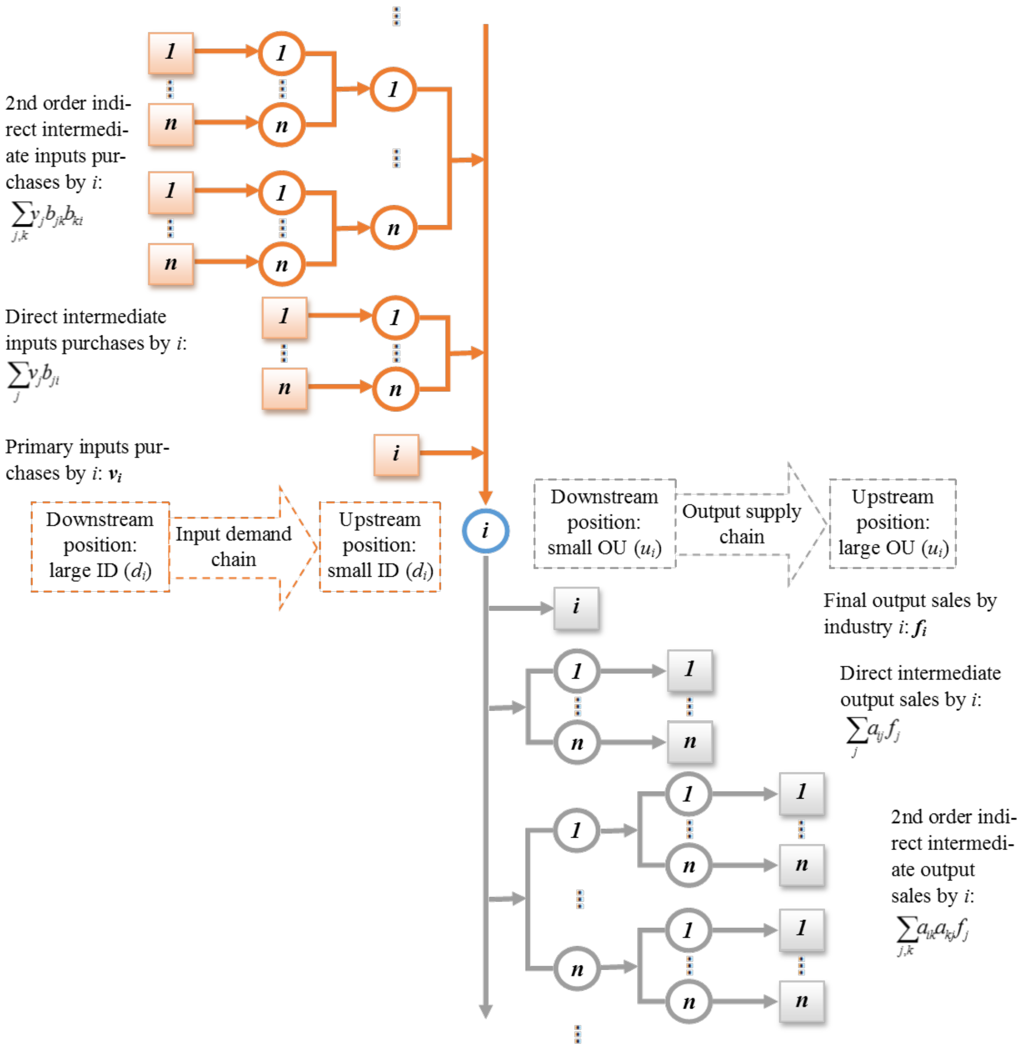
Alternatively, the input-side accounting identity states that industry $i$'s total input (which should be equal to total output) $x_i$ is equal to the value of its primary inputs (value added) $v_i$ plus its intermediate input purchases from all industries $\sum_j z_{ji}$. If we denote the share of industry $j$'s output that is used in industry $i$'s production by $b_{ji} \equiv z_{ji}/x_j$ (referred to as an output coefficient), the mentioned input identity can be written as $x_i = v_i + \sum_j x_j b_{ji}$. By consecutively using the last identity for $x_j$ in its right hand-side, total input $x_i$ can also be written as

$$x_i = v_i + \sum_j v_j b_{ji} + \sum_{j,k} v_j b_{jk} b_{ki} + \sum_{j,k,l} v_j b_{jk} b_{kl} b_{li} + \cdots . \tag{2}$$

Whereas the first term on the right-hand side of Eq. (2) indicates the value of industry $i$'s *primary inputs purchases*, the second term represents sector $i$'s *direct intermediate purchases* from all industries $j = 1, \dots, n$ required for the first-round production process of industry $i$. The remaining terms indicate sector $i$'s *indirect intermediate purchases* from all industries (including industry $i$) used as inputs by industry $i$ in its second and higher rounds production processes.

Note that the mentioned standard input-output (IO) economics explanations of the round-by-round production processes in Eqs. (1) and (2) can be also interpreted, respectively, as industries being one, two and higher *stages of production* away from the *direct*: (i) final use of their outputs by households, government(s) and investors (HGIs), and (ii) supply of primary inputs by HGIs to industries. In the first case HGIs play the role of buyers of final goods, in the second case they act as sellers of primary inputs to firms providing the latter with, respectively, labour, administration services and capital. Hence, the relative position of industries with respect to HGIs can be examined from the *output supply chain* perspective which corresponds to point (i) using the output-side accounting identity in Eq. (1), or from the *input demand chain* perspective which corresponds to point (ii) using the input-side accounting identity in Eq. (2).

Figure 2: Input demand and output supply chains for industry $i$ and its ID/OU value indication along these chains




Note: Squares and circles denote, respectively, HGIs and industries (firms).

For easier exposition of the follow-up material, Figure 2 presents a visual illustration of the input demand and output supply chains for an industry along with the respective up/down-streamness indication. As follows from Eq. (2) (resp. Eq. (1)), for the input demand (resp. output supply) chain, the sum of all contributions along its individual production stages, also illustrated in Figure 2, equals total input (resp. total output) of sector $i$. *Production stage* or simply *stage* is defined as the *number of* *steps* it takes HGIs to reach industries and vice versa (or distance between the two) along the input demand and output supply chains, respectively. For example, when sector $i$ directly buys primary inputs from HGIs we say that $i$ is one stage away from HGIs as providers of primary inputs along this particular input demand link. However, given that any sector, in general, can be also an *indirect purchaser/supplier* of intermediates from/to other industries, the distance between HGIs and any sector can be larger than one. Thus, sector $i$ is two stages away from HGIs as primary inputs suppliers when the number of steps in an input demand link is two, i.e. first HGIs provide primary inputs to all industries $j = 1, \ldots, n$, and these in turn sell intermediate inputs to sector $i$ (in Figure 2 this is called direct intermediate inputs purchases). Two and higher stages along the input demand chain are also referred to as, respectively, 2nd and higher order indirect intermediate purchases. Similar reasonings hold true for the output supply chain, with the difference that now the links originate at sectors and end with HGIs as users of final products.[4]

Taking the output supply chain perspective, Antràs et al. (2012) proposed the following measure of industry $i$'s upstreamness:[5]

$$u_i = 1 \cdot \frac{f_i}{x_i} + 2 \cdot \frac{\sum_j a_{ij} f_j}{x_i} + 3 \cdot \frac{\sum_{j,k} a_{ik} a_{kj} f_j}{x_i} + 4 \cdot \frac{\sum_{j,k,l} a_{il} a_{lk} a_{kj} f_j}{x_i} + \cdots . \tag{3}$$

That is, since in the output supply chain in Eq. (1) sector $i$ is positioned upstream with respect to HGIs as final users (see also Figure 2), $u_i$ in Eq. (3) quantifies $i$'s average upstream position from HGIs. For this reason, Antràs et al. (2012) refer to $u_i$ as industry $i$'s "average distance from final use" or "average production line position". It should be noted that in defining such average distance, in Eq. (3) an explicit assumption of imposing "an *ad hoc cardinality* in the sense that the distance between any two stages of production is set to one" (Antràs et al., 2012, p. 413,

[4]Note that since industry $i$ along its input demand chain is a purchaser of intermediates, the links from all sectors $j$'s to $i$ are represented by the output sales coefficients $b_{ji}$'s. In the same vein, along the output supply chain industry $i$ is selling its output to all sectors $j$'s used as their intermediate input, hence these links are represented by the input coefficients $a_{ij}$'s.

[5]Dietzenbacher et al. (2005) and Dietzenbacher and Romero (2007) are antecedents of somewhat similar line of research. They developed the concept of *average propagation length* that is defined as the average number of steps it takes a (demand-pull or cost-push) stimulus in one industry to propagate and affect another industry.

emphasis added) is made. If $u_i$ is large, then $i$ is interpreted to be an upstream industry in the sense that its output goes through many production stages before reaching final use. On the other hand, low values of $u_i$ (close to unity which is its lower bound by construction if $f_i \geq 0$ for all $i$) indicate that $i$ is a "downstream" industry with a large share of its output going directly to the end-user.

In this paper, we additionally consider the input demand perspective in quantifying industries' relative positions with respect to HGIs as their providers of primary inputs (see e.g. Figure 1). That is, reasoning as for Eq. (3) but on the base of the round-by-round intermediate input decomposition in Eq. (2), we define the average distance of industry $i$ from its providers of primary inputs as follows:

$$d_i = 1 \cdot \frac{v_i}{x_i} + 2 \cdot \frac{\sum_j v_j b_{ji}}{x_i} + 3 \cdot \frac{\sum_{j,k} v_j b_{jk} b_{ki}}{x_i} + 4 \cdot \frac{\sum_{j,k,l} v_j b_{jk} b_{kl} b_{li}}{x_i} + \cdots . \quad (4)$$

From Eq. (2) it follows that the shares in Eq. (4) sum up to one, as required. Since along the input demand chain in Eq. (2) sector $i$ is positioned downstream with respect to HGIs as its providers of primary inputs (see also Figure 2), $d_i$ can be alternatively viewed as a measure of industry $i$'s downstreamness. Note that a large value of $d_i$ indicates that sector $i$ is positioned rather downstream from its providers of primary inputs along the input demand chain with the majority of its inputs coming directly and indirectly from other production sectors. Since all these sectors also use primary inputs from their HGIs, one can alternatively state that primary inputs of all HGIs go through many production stages before reaching, in the form of intermediate inputs, an input-downstream sector $i$ with large $d_i$. On the other hand, a sector with a low value of $d_i$ (close to unity which is its lower bound by definition assuming that $v_i \geq 0$ for all $i$) is an "upstream" industry along the input demand chain with a large share of its input coming directly from HGIs. In order not to confuse the up/down-streamness in connection with the output supply and the input demand chains, we refer to $u_i$ in Eq. (3) and $d_i$ in Eq. (4), respectively, as "output upstreamness" (OU) and "input downstreamness" (ID) measures of industry $i$.[6]

[6]Hence, a sector with low $u_i$ (resp. low $d_i$) is an "output downstream" (resp. "input upstream") industry (see also Figure 2), where the term "output" (resp. "input") signifies industry position with respect to HGIs along the output supply (resp. input demand) chain.

In Table 1 we provide the primary reasons why a sector has large or small values of OU/ID measures. For example, a sector with large OU should have (a) a large share of intermediate output in its gross output *and* (b) highly interconnected and strong intermediate output supply links with *industries that have the same two characteristics*. The second reason explains why one simply cannot use the direct share of intermediate output in gross output, $\sum_j z_{ij}/x_i$, to quantify industry $i$'s OU (because e.g., a large intermediate output supplier $i$ may provide inputs to only few industries producing mainly final products, making $i$ an output downstream sector); instead Eq. (3) fully captures the complexity and size of sector $i$'s entire output supply network as well.

Table 1: Interpretation of the OU and ID measures

| | Output upstreamness (OU) measure, $u_i$ | Input downstreamness (ID) measure, $d_i$ |
|---|---|---|
| Large | (a) Large (small) share of intermediate output (final demand) in gross output, and (b) Complex [direct, indirect] and strong intermediate output supply links with similar sectors. | (a) Large (small) share of intermediate input (value added) in gross input, and (b) Complex [direct, indirect] and strong intermediate input demand links with similar sectors. |
| Small | (a) Small (large) share of intermediate output (final demand) in gross output, and (b) Simple and weak intermediate output supply links with similar sectors. | (a) Small (large) share of intermediate input (value added) in gross input, and (b) Simple and weak intermediate input demand links with similar sectors. |

It is clear that obtaining the exact values of $u_i$ from Eq. (3) and $d_i$ from Eq. (4) is impractical since the corresponding definitions require computing an infinite number of terms. However, using the well-known relations in IO economics allows one to derive alternative expressions for $u_i$ and $d_i$, which, in fact, will prove them to be exactly equivalent to widely-used linkage (or key-sector) indicators in this field.[7] Let $\mathbf{A}$ denote the input matrix with a typical element $a_{ij}$, $\mathbf{I}$ be the identity matrix, and $\mathbf{x}$ and $\mathbf{f}$ denote the vectors of gross outputs and final demand, respectively. Then Eq. (1) in matrix form can be written as

$$\mathbf{x} = \mathbf{Lf}, \tag{5}$$

where $\mathbf{L} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \cdots = (\mathbf{I} - \mathbf{A})^{-1}$ is the well-known Leontief-inverse matrix (Leontief, 1936, 1941). Further, let $\mathbf{B}$ denote the output (or allocation) matrix with

[7] For a recent overview and comparison of the IO linkages, see Temurshoev and Oosterhaven (2014).

a typical entry $b_{ji}$ and $\mathbf{v}$ be the vector of primary inputs. Then Eq. (2) in compact matrix form can be written as

$$\mathbf{x}' = \mathbf{v}'\mathbf{G}, \tag{6}$$

where transposition is indicated by a prime and $\mathbf{G} = \mathbf{I} + \mathbf{B} + \mathbf{B}^2 + \cdots = (\mathbf{I} - \mathbf{B})^{-1}$ is the equally well-known Ghosh-inverse matrix (Ghosh, 1958).

Given that $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$ and $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{Z}$, where $\mathbf{Z}$ is the inter-industry transaction matrix with typical element $z_{ij}$ and $\hat{\mathbf{x}}$ is the diagonal matrix with elements of $\mathbf{x}$ along its diagonal and zeros otherwise, it is easy to derive the explicit link between the Leontief-inverse and Ghosh-inverse matrices as follows:

$$\hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}} = \hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{Z}\hat{\mathbf{x}}^{-1})^{-1}\hat{\mathbf{x}} = \left[\hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{Z}\hat{\mathbf{x}}^{-1})\hat{\mathbf{x}}\right]^{-1} = (\mathbf{I} - \hat{\mathbf{x}}^{-1}\mathbf{Z})^{-1} = \mathbf{G}. \tag{7}$$

Now using the fact that $\mathbf{I}+2\mathbf{A}+3\mathbf{A}^2+\cdots = (\mathbf{I}+\mathbf{A}+\mathbf{A}^2+\cdots)(\mathbf{I}+\mathbf{A}+\mathbf{A}^2+\cdots) = \mathbf{LL}$ and the identities in Eqs. (5) and (7), the OU measures in Eq. (3) turn out to be simply the row sums of the Ghosh-inverse as follows from

$$\mathbf{u} = \hat{\mathbf{x}}^{-1}(\mathbf{I} + 2\mathbf{A} + 3\mathbf{A}^2 + \cdots)\mathbf{f} = \hat{\mathbf{x}}^{-1}\mathbf{LLf} = \hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}}\boldsymbol{\imath} = \mathbf{G}\boldsymbol{\imath}, \tag{8}$$

where $\boldsymbol{\imath}$ is the summation vector of ones. As mentioned by Antràs et al. (2012) and follows from Eq. (8), the OU measures are exactly industries' *total forward linkages* (TFLs) in terms of gross output – widely used indicators in IO analysis (see e.g., Miller and Blair, 2009, Section 12.2). This equivalence is not surprising. A large TFL sector supplies a significant part of its output as intermediate inputs to other industries, and that is precisely what places a sector in an upstream position in the output supply chain with respect to many industries buying inputs from that sector. In IO analysis TFL measures are used as indicators of sector's importance or "keyness". That is, other things being equal, a high TFL sector is interpreted as being a more appropriate target for economic stimulation purposes because it will bring more benefit to the entire economy (by making available more of its resources to other sectors) per stimulus euro, e.g., tax credits, than a sector with lower TFL.[8]

[8]The Ghosh IO model (6) when used in its *ex ante* causal interpretation is controversial in the IO literature. However, in linkage analysis its use is free from such a controversy as it is employed

Similarly, using the fact that $\mathbf{I} + 2\mathbf{B} + 3\mathbf{B}^2 + \cdots = \mathbf{GG}$ and the identities in Eqs. (6) and (7), the ID measures in Eq. (4) boil down to column sums of the Leontief-inverse as follows from

$$\mathbf{d}' = \mathbf{v}'(\mathbf{I} + 2\mathbf{B} + 3\mathbf{B}^2 + \cdots)\hat{\mathbf{x}}^{-1} = \mathbf{v}'\mathbf{GG}\hat{\mathbf{x}}^{-1} = \boldsymbol{\imath}'\hat{\mathbf{x}}\mathbf{G}\hat{\mathbf{x}}^{-1} = \boldsymbol{\imath}'\mathbf{L}. \tag{9}$$

Hence, Eq. (9) shows that the ID measures are nothing else than the *total backward linkages* (TBLs) expressed in terms of gross output, also widely used key-sector indicators in IO analysis. Here, similarly, the equivalence is not surprising. A large TBL sector purchases a significant part of its inputs in the form of intermediate inputs from other industries, and this is precisely what places a sector in a downstream position in the input demand chain with respect to many industries supplying inputs to that sector. In IO analysis, other things being equal, a sector with high TBL is interpreted as being a more suitable target for an economic stimulation, because this will lead other industries to also expand their outputs in order to meet that sector's increased intermediate demands.[9]

It is clear that industries' "average distance from final output users" and "average distance from primary inputs suppliers" become exactly equivalent to, respectively, TFL and TBL indicators because the distance between any two stages of production is assumed to be one in Eqs. (3) and (4). Such an assumption also has been adopted for quantifying average propagation length between industries (Dietzenbacher et al., 2005; Dietzenbacher and Romero, 2007) and average distance between individuals (as ultimate owners) and companies in the presence of cross-shareholdings (Dietzenbacher and Temurshoev, 2008). Understanding the aim of the use of the TFL and TBL in IO analysis, what do we gain from this additional view of these measures in terms of distance or up/down-streamness indicators? One of the applications that arises from these new interpretations of the TFL and TBL measures is on quantifying shared producer and consumer/worker responsibilities from generating pollution (Temurshoev and Miller, 2013). For applications to the trade and business cycle lit-

strictly in its *ex post* descriptive interpretation of the input demand chain as formalized in Eq. (2).

[9]Sectors with high TFL (resp. high TBL) are also classified as "dependent on interindustry demand" (resp. "dependent on interindustry supply"), while sectors with both high TFL and TBL are referred to as "generally dependent" or "key-sectors" (Miller and Blair, 2009, pp. 559-560).

erature see e.g., Alfaro and Charlton (2009); di Giovanni and Levchenko (2010); Antràs et al. (2012); Zavacka (2012) and Antràs and Chor (2013).

Deriving the OUs and IDs on a world IO table sheds light on the position of industries/countries along the global output supply and global input demand chains, both characterizing world production. Using one summary measure of the OU and one summary measure of the ID could be useful to see the development of the average industry (or country) relative position over time with respect to HGIs. One might use for this purpose a simple arithmetic average of the OUs and IDs. However, this will not take into account the differing sizes of industries and/or countries in a considered IO system. Therefore, it seems reasonable to use a *weighted* average of the OU/ID measures as a summary indicator of interest for a particular point in time. Total output (input) shares in the system can be considered as reasonable weights that account for the size of industries/countries. However,

**Proposition 1.** *The weighted averages of $u_i$ and $d_i$ with corresponding gross output (input) shares as weights are exactly equal to each other, i.e.,*

$$\overline{u} \equiv \sum_{i=1}^{n} u_i \frac{x_i}{\sum_k x_k} = \sum_{i=1}^{n} d_i \frac{x_i}{\sum_k x_k} \equiv \overline{d}. \tag{10}$$

*Proof:* Using Eqs. (7), (8) and (9), we obtain $\mathbf{x}'\mathbf{u} = \mathbf{x}'\mathbf{G}\boldsymbol{\imath} = \mathbf{x}'\hat{\mathbf{x}}^{-1}\mathbf{L}\hat{\mathbf{x}}\boldsymbol{\imath} = \boldsymbol{\imath}'\mathbf{L}\mathbf{x} = \mathbf{d}'\mathbf{x}$. Hence, $\overline{u} = \mathbf{u}'\mathbf{x}/\boldsymbol{\imath}'\mathbf{x} = \mathbf{d}'\mathbf{x}/\boldsymbol{\imath}'\mathbf{x} = \overline{d}$. *QED.*

Thus, for OU and ID summary measures that take account of the sizes of industries' gross outputs/inputs, due to Eq. (10) it does not matter whether the "average distance from final output users" approach or the "average distance from primary inputs providers" approach is used. The economic intuition of Proposition 1 could be the fact that although at the individual level each sector usually has different output supply and input demand chains,[10] for an *average sector solely representing the entire system* these two chains must be mirror images of each other.

[10]That is, the IO matrix is *not* symmetric in terms of the presence/absence of interindustry (output supply and input demand) transactions and their sizes.

## 3 Up/down-streamness in world production

We compute OU and ID measures using the 1995-2011 world input-output tables (WIOTs) as made available by the World Input-Output Database project. We use the WIOTs expressed in current US dollars with a 35-industry classification.[11]

### 3.1 Global results

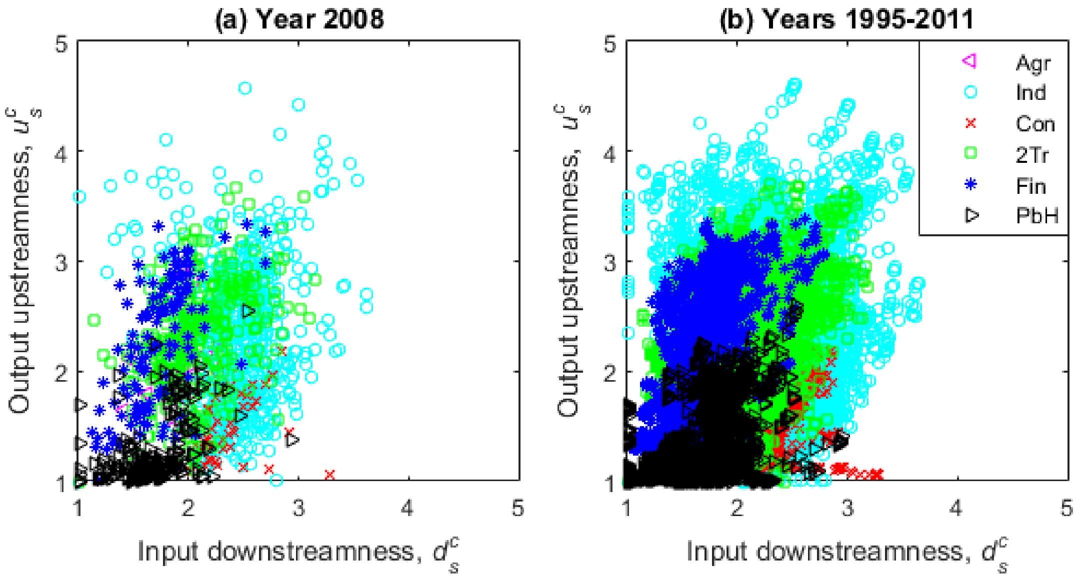
Figure 3 shows the relationship between the OU $u_s^c$ and ID $d_s^c$ measures of 1,435 (= 35 sectors × 41 countries/regions) observations for 2008 in subplot (a) and of 24,395 ($= 1,435 \times 17$ years) pairs of $(u_s^c, d_s^c)$ for all years 1995-2011 in subplot (b).[12] The first important observation is that $u_s^c$ and $d_s^c$ are (strongly) positively correlated. The corresponding correlations for each year range in the interval of [0.36, 0.43], while the overall correlation coefficient for all 24,395 pairwise observations is 0.40, and all coefficients are highly statistically significant (with zero p-values). How does it happen that an upstreamness indicator is positively associated with a downstreamness indicator as their *partial* labels suggest the contrary? Recall from Figures 1 and 2 that here we are looking at two different chains: $u_s^c$ characterizes the upstream position of sector $s$ in country $c$ along the global output supply chain, while $d_s^c$ quantifies the downstream position of sector $s$ in country $c$ along the global input demand chain. Since both relative positions are examined ultimately with respect to households, government(s) and investors (HGIs), the observed positive association indicates that a sector that is close to (resp. far away from) HGIs as final output users turns out to be, *on average*, also close to (resp. far away from) HGIs as providers of primary inputs.[13]

[11]Unlike Antràs et al. (2012), here we do not "correct" the input and output matrices for exports and imports of final goods, and net changes in inventories. The first is not needed as WIOTs describe the entire world – a setting equivalent to a closed economy framework. Intermediate transactions are not "corrected" for changes in inventories as for our decomposition analysis this would have implied adjusting final demand and value added figures as well, which we however want to keep as reported in national accounts. Nonetheless, the results are robust to such correction as the underlying OUs and IDs were found to be highly correlated with those presented here.

[12]Note that in this section we explicitly add extra dimension of countries (or regions) to the OU/ID notations, which were suppressed in the previous section for simplicity purposes and without loss of generality. Thus, $u_s^c$ and $d_s^c$ denote, respectively, the OU and ID measures of sector $s$ in country $c$. This data is available from `https://sites.google.com/site/umedtemurshoev/data`.

[13]Since the ID and OU indicators are, respectively, equivalent to total backward and forward linkages, in terms of IO key-sector studies the obtained positive correlation between $u_s^c$ and $d_s^c$

Figure 3: Scatterplots of the OU and ID measures




Note: Abbreviations "Agr", "Ind", "Con", "2Tr", "Fin" and "PbH" stand, respectively, for "Agriculture, fishing", "Industry, except construction", "Construction", "Wholesale & retail trade, hotels & restaurants, and transport", "Financial intermediation, real estate" and "Public administration, education, health, and activities of households".

In Figure 3, however, we also distinguish between six broad categories corresponding to the six-branch classification used by Eurostat. These are identified in the note to Figure 3 and their correspondence with the WIOD classification is given in Appendix A. Thus, the second observation made from these scatterplots is that, in general, "Public administration, education, health, and activities of households" (PbH) and "Financial intermediation, real estate" (Fin) are positioned closer to HGIs than the "Industry, except construction" (Ind) branch. Further, one can observe that a line passing through the Fin points is steep (i.e. above the 45-degree line), while that for PbH and "Construction" (Con) branches have flat slopes. This implies that Fin sectors are, on average, positioned more distant from their final users than from their providers of primary inputs, while the reverse is true for PbH and Con. This partly happens because primary inputs generally make a larger proportion of the total inputs in Fin sectors compared to the relevant final in gross output shares, while the reverse case holds for the PbH and Con branches.

In Table 2 we provide a summary of the OU and ID indicators for all 17 years.

implies that the majority of points representing TFL and TBL pairs fall into the diagonal (i.e. "high-high" and "low-low") blocks of the key-sector "high-low" classification table.

Table 2: Summary of the OU and ID measures at the global level

| | y95 | y96 | y97 | y98 | y99 | y00 | y01 | y02 | y03 | y04 | y05 | y06 | y07 | y08 | y09 | y10 | y11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\overline{u}$, $\overline{d}$ | 1.95 | 1.95 | 1.95 | 1.95 | 1.96 | 1.98 | 1.98 | 1.96 | 1.98 | 2.00 | 2.03 | 2.07 | 2.10 | 2.14 | 2.11 | 2.14 | 2.15 |
| MeanU | 2.04 | 2.03 | 2.04 | 2.04 | 2.05 | 2.06 | 2.06 | 2.06 | 2.07 | 2.08 | 2.09 | 2.10 | 2.12 | 2.14 | 2.14 | 2.14 | 2.14 |
| MeanD | 2.02 | 2.02 | 2.03 | 2.02 | 2.03 | 2.06 | 2.07 | 2.06 | 2.07 | 2.08 | 2.10 | 2.12 | 2.13 | 2.16 | 2.12 | 2.14 | 2.14 |
| MaxU | 3.87 | 3.92 | 4.03 | 4.03 | 4.02 | 3.97 | 4.02 | 3.97 | 4.13 | 4.20 | 4.35 | 4.46 | 4.61 | 4.57 | 4.61 | 4.55 | 4.48 |
| MaxD | 3.06 | 3.10 | 3.13 | 3.13 | 3.12 | 3.11 | 3.36 | 3.28 | 3.20 | 3.24 | 3.36 | 3.47 | 3.59 | 3.62 | 3.65 | 3.62 | 3.63 |
| StdU | 0.61 | 0.62 | 0.62 | 0.62 | 0.62 | 0.63 | 0.63 | 0.63 | 0.64 | 0.66 | 0.69 | 0.71 | 0.74 | 0.77 | 0.78 | 0.79 | 0.79 |
| StdD | 0.41 | 0.40 | 0.41 | 0.40 | 0.40 | 0.41 | 0.41 | 0.41 | 0.43 | 0.44 | 0.46 | 0.49 | 0.52 | 0.55 | 0.56 | 0.57 | 0.57 |

Note: Year shortcut of e.g. y95 denotes 1995. $\overline{u}$ and $\overline{d}$ are the output-weighted global averages of $u_s^c$ and $d_s^c$, respectively. MeanU and MeanD (resp. MaxU and MaxD) are arithmetic averages (resp. maximum values) of $u_s^c$ and $d_s^c$, respectively. The minimums are not reported as they all equal unity. StdU and StdD are the standard deviations of $u_s^c$ and $d_s^c$, respectively, using sectors' (in world) gross output shares as weights.

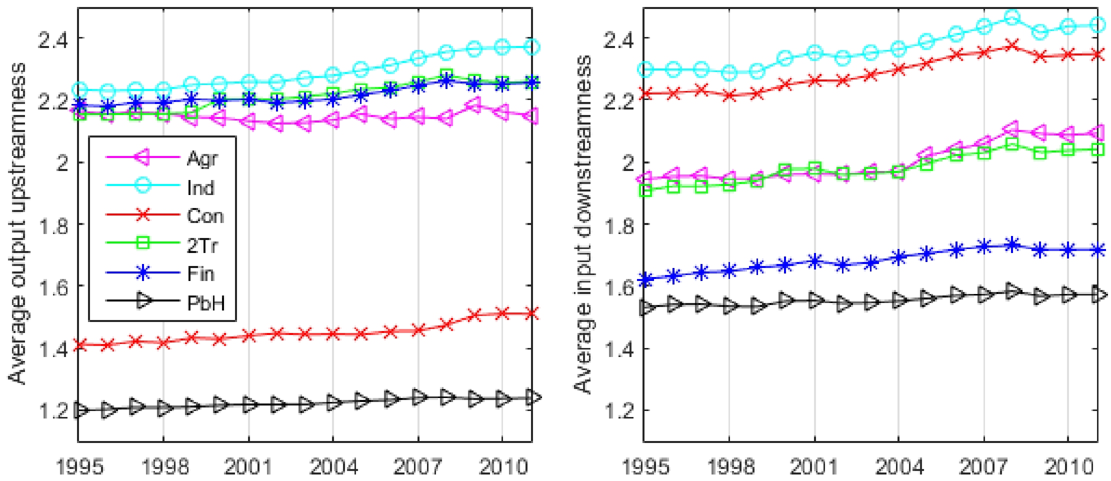
The world gross output-weighted average of the OU/ID measure, $\overline{u} = \overline{d}$,[14] (see Proposition 1) was 1.95 in 1995 and increased to 2.15 in 2011. However, the rounded $\overline{u}$'s imply that the average position of the *average industry* in the world production processes remained remarkably stable over the period. That is, the average sector along the global output supply (resp. input demand) chain is positioned roughly one stage away from final outputs use (resp. primary inputs supply). Output-weighted standard deviations of $u_s^c$ and $d_s^c$, reported in Table 2, range between $[0.61, 0.79]$ and $[0.40, 0.57]$, respectively.[15] The ratios of the relative standard deviation (RSD, coefficient of variation) of $u_s^c$ to the RSD of $d_s^c$ range from 1.41 to 1.49. Thus, the OUs are relatively more disperse across industries and/or countries than the IDs.

In Figure 4 we show the arithmetic averages of the OUs and IDs at the world level for each branch separately, from which the following observations are drawn. First, according to both the OUs and IDs, the branch Ind (resp. PbH) consistently for all years is positioned farthest away from (resp. closest to) HGIs along the world output and input production chains. This is not surprising as it indicates that compared to other industries the manufacturing sector is more engaged in the fragmentation of production, while service industries tend to use direct labor inputs more intensively. Second, consistently over the period, Construction ranks fifth according to the OU measure, but is the second largest ID branch. This is due to the fact that Con supplies output mainly to output downstream sectors and

[14] That is, the weighted global average of OU is defined as $\overline{u} = \sum_{s,c} u_s^c (x_s^c / \sum_{i,j} x_i^j)$, where $x_s^c$ is gross output of sector $s$ in country $c$.

[15] For 426 US sectors in 2002, Antràs et al. (2012) report the OU average of 2.06 with a standard deviation of 0.85. The unweighted average and standard deviation for 2002 for the entire world are similar and equal 2.06 (see Table 2) and 0.63, respectively. They are also similar to $\overline{u}$ and weighted standard deviation for 2002 reported in Table 2, which are, respectively, 1.96 and 0.63.

Figure 4: World (simple) averages of the OU and ID measures by branch




Note: For abbreviations see the note to Figure 3.

HGIs, but extensively uses inputs from Ind sectors that make Con distant from its suppliers of primary inputs. Third, the financial intermediation and real estate (Fin) branch consistently ranks fifth according to the ID measure. Fourth, three branches, Agr, 2Tr and Fin, are always positioned closer to Ind and have similar size and development patterns of their OU measures. And finally, branches Agr and 2Tr, taking intermediate positions between Ind and PbH, have similar size and development patterns of their ID measures. Given these results, the global output supply chain and the global input demand chain for the six broad categories with respect to HGIs can be roughly visualized, respectively, as

$$\text{Ind} \Rightarrow \text{2Tr, Fin, Agr} \Longrightarrow\Longrightarrow\Longrightarrow\Longrightarrow \text{Con} \Longrightarrow \text{PbH} \Longrightarrow \textbf{HGIs} \tag{11}$$

$$\text{Ind} \Leftarrow \text{Con} \Leftarrow\Longleftarrow \text{Agr, 2Tr} \Leftarrow\Longleftarrow \text{Fin} \Leftarrow \text{PbH} \Leftarrow\Longleftarrow\Longleftarrow \textbf{HGIs} \tag{12}$$

where the cumulative lengths of the arrows between the branches or between a branch and HGIs roughly indicate the relative values of the OU and ID averages illustrated in Figure 4. For example, the distance between PbH and HGIs in the output supply chain (11) is much shorter than that in the input demand chain (12) as the corresponding OU and ID averages are about 1.22 and 1.55, respectively, for all years. All in all, the chains in (11) and (12) give an average picture of the world production line positions of the considered branches over the period of 1995-2011.

### 3.2 World average sector-specific results

Since individual sectors and countries could be quite heterogeneous with respect to their production structures, we now zoom in and consider sector-specific OU and ID positions along the corresponding global production chains in this section and country-specific positions in the following section. Thus, *gross output-weighted* OUs and IDs for each sector over the period of 1995-2011 were computed.[16] We refer to Miller and Temurshoev (2013) for discussions of the details of these indicators per sector (covering the period up to 2009 as it was based on the earlier version of the WIOD database) and instead give a brief description of the average results. Taking the arithmetic mean of the computed sector-specific OUs and IDs over the 17 considered years and rounding them to the nearest integer, we end up with the results summarized in Table 3. Starting with the OU indicator, the table shows that twelve sectors are positioned roughly *two stages* away from final output users along the global output supply chain (i.e., their rounded world-average OU measure is 3), five sectors essentially provide all their outputs directly to HGIs and thus have the lowest OU measure of roughly unity for all years, and the remaining 18 sectors represent the picture of the average industry position mentioned earlier.

Table 3: World average sector-specific OU and ID results

| OU/ID | Number of sectors | Sectors (in descending order of their 1995-2011 average OU or ID values) |
|---|---|---|
| OU≈3 | 12 | Mining and quarrying; Basic metals and fabricated metal; Rubber and plastics; Chemicals and chemical products; Pulp, paper, printing and publishing; Wood and products of wood and cork; Pulp, paper, printing and publishing; Water transport; Other supporting & auxiliary transport activities, activities of travel agencies; Renting of machinery & equipment and other business activities; Coke, refined petroleum and nuclear fuel; Other non-metallic mineral; Electricity, gas and water supply |
| OU≈2 | 18 | The remaining sectors |
| OU≈1 | 5 | Construction; Education; Private households with employed persons; Public administration and defence, compulsory social security; Health and social work |
| ID≈3 | 7 | Transport equipment; Leather and footwear; Electrical and optical equipment; Textiles and textile products; Basic metals and fabricated metal; Rubber and plastics; Machinery |
| ID≈2 | 25 | The remaining sectors |
| ID≈1 | 3 | Education; Real estate activities; Private households with employed persons |

We earlier found Industry to be the most upstream branch along the output

[16]For country and sector codes see Appendix A. The sector-specific weighted OUs and IDs are derived as the weighted averages of, respectively, $u_s^c$'s and $d_s^c$'s of each sector across all countries with the corresponding country output shares as weights. This allows us to account for countries' size in computing the OU and ID measures for each sector. For details, see Appendix B.

supply chain (11) because, as can be seen from Table 3, 75% of the sectors with the largest OUs of approximately 3 (i.e., 9 of 12) come from this branch. The remaining three sectors with the highest OUs include two sectors from the 2Tr branch and one Fin sector. This also explains why these branches are positioned closer to Ind in (11). The distribution of 18 sectors with the average OU score of 2 is as follows: Ind, 39% (7 sectors); 2Tr, 39% (7); Fin, 11% (2); Agr, 6% (1); and PbH, 6% (1).

As for the ID measure, Table 3 shows that seven sectors are positioned two stages away from primary inputs providers along the global input demand chain, three sectors purchase almost all their inputs directly from HGIs, and the remaining 25 sectors represent the picture of the average industry position mentioned earlier. These findings also explain the global picture of the input demand chain in (12). That is, all nine sectors with an ID value of 3 come from the Ind branch, while the distribution of 25 sectors with the average ID score of 2 is as follows: Ind, 36% (9 sectors); 2Tr, 36% (9); PbH, 12% (3); Fin, 8% (2); Agr, 4% (1); and Con, 4% (1).

### 3.3 World average country-specific results

Similar to the world-average sector-specific results, weighted OU and ID measures were computed for each country.[17] We found that in all years, except for 2000 and 2001 OUs, China was located furthest away from HGIs along the global output supply chain,[18] while countries closest to HGIs along the output supply chain were Cyprus and Greece. According to the (rounded) *overall* average of the country-specific OU measures over the entire 1995-2011 period, only China and Luxembourg are positioned two stages away from HGIs as final output users, while all the remaining countries have an average OU score of 2. Starting from 2007 or 2008, the OU value of 3 was also observed for Korea and Taiwan.

In the global input demand chain China consistently shows the largest ID, equal

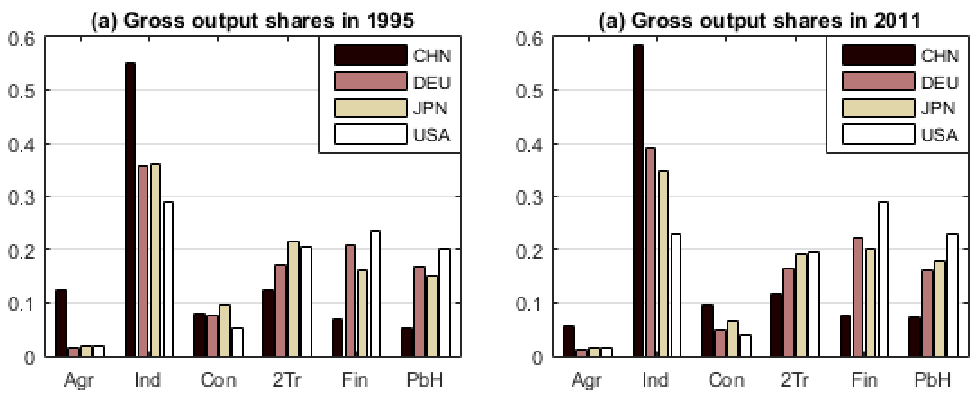
[17]The country-specific weighted OUs and IDs are derived as the weighted averages of, respectively, $u_s^c$'s and $d_s^c$'s of each country across all its sectors with the corresponding sectoral output shares as weights. This allows us to take into account sectors' size in computing the OUs and IDs for each country. For mathematical details, see Appendix B.

[18]This is consistent with Baldwin and López-González (2014) finding based on the importing-to-export (I2E) data, who conclude that "[t]he role of China is impressive – it is globally dominant as a *supplier of industrial inputs*. Its intermediate export pattern is the most globalised of all the Giant-4 manufacturers [i.e., the US, China, Germany and Japan]" (p. 23, emphasis added).

to 2.53 in 1995 and 2.91 in 2011. Focusing on the average of the IDs over 1995-2011, *only* China is positioned two stages away from HGIs as providers of primary inputs, while all other countries have the (rounded) average ID value of 2 which represents the worldwide average country ID position. In terms of changes over time, while in the beginning of the period only China had the largest ID of 3, starting from 2008 we have three such countries: China, Korea and Czech Republic.

Recalling the interpretation of the OU measure (3) given in Table 1, countries with the largest average OUs like China, Luxembourg, Czech Republic, Korea, Russia and Taiwan, should have (a) a large share of intermediate output (or a small share of final demand) in their gross outputs, *and* (b) extensive direct/indirect and significant *intermediate output supply* linkages to countries with more or less similar characteristics. On the contrary, countries like Cyprus, Greece, Mexico, Turkey and USA with the lowest average OUs should have a relatively larger final output share *and* weaker and less interlinked intermediate output supply relations globally with similar nations. Thus, one could also say that economies with the highest OUs are mainly "specialized" in producing and selling goods of primary and/or secondary sectors with high OUs, while those with the lowest OUs are "specialized" in rather more output downstream sectors (e.g., services). This is confirmed in Figure 5 for China, Germany, Japan and the USA as the four big economies of the world.

Figure 5: Output shares of branches in China, Germany, Japan and the USA




We observe that in China the share of Industry's gross output in total output was 55% in 1995 and increased further to 59% in 2011. Industry share in Germany, Japan and the USA was also largest in 1995, but with lower size of 36%, 36%

and 29%, respectively, hence leaving more room for other sectors with lower OUs. Alternatively, while the share of PbH – the most downstream branch along the output supply chain – in 1995 for China was only 5%, the corresponding figures for Germany, Japan and the USA were 17%, 15% and 20%, respectively. All these numbers for 2011 are, respectively, 7%, 16%, 18% and 23%, which again show that the contribution of the output downstream industries to the German, Japanese and the US economies is much higher than that to the Chinese economy.[19]

Similarly, high ID sectors listed in Table 3 should have a rather large contribution to the gross outputs of countries with the largest IDs like China, Czech Republic, Korea, Slovak Republic, Bulgaria and Hungary. Again given the interpretation of the ID measure (4) in Table 1, economies with large ID should have a large share of intermediate inputs (or a small share of value added) in their gross inputs, *and* strong and complex *intermediate input demand* linkages with countries of similar characteristics. The reverse should hold for countries with the lowest average IDs such as Greece, Cyprus, Mexico, USA, Brazil and Canada.[20] Here again Figure 5 can explain part of the story. From (12) we see that besides PbH, the finance and real estate branch (Fin) occupies the most input upstream position in the global input demand chain. In USA by 2011 Fin is contributing the most to its economy-wide output with the share of 29% as opposed to 23% of Industry (PbH also has a share of 23%). All these facts contribute to the USA input upstream position.

Since the above-discussed country-specific OUs/IDs are summary indicators for *all* sectors, it is not surprising to see the similarity of this all-products-encompassing average picture for countries. Given that in (11) and (12) the Industry branch is characterized by the largest OUs/IDs, it is interesting to see the country positions considering *only* sectors in the Ind branch.[21] As expected, we found that these

[19] Clearly, the size of the economy-wide gross output matters. Normalizing these numbers with respect to the Chinese total output, produces the following distributions of the normalized gross outputs, respectively, for China, Germany, Japan and the USA: (1, 2.27, 5.23, 7.13) for 1995, and (1, 0.30, 0.51, 1.21) for 2011. Thus, in terms of gross output while in 2011 the US was still producing 21% more than China, Germany and Japan were already largely lagging behind China.

[20] The observation that Canada, Mexico and the US are in similar positions according to both OUs and IDs also reflects the fact that these countries trade much more heavily among themselves than with any other WIOD countries. Baldwin and López-González (2014) term this trade network as Factory North America – one of the three regional blocks in the global production network they distinguish (the other two being Factory Asia and Factory Europe).

[21] The corresponding country-specific OUs and IDs for the Industry branch only are available

"country-specific Industry OUs/IDs" provide more heterogeneity across countries. Specifically, while on average over 1995-2011 the number of countries with the largest OU (resp. ID) of 3 was only 2 (resp. 1) in the *overall* picture, now with a focus on Industry only it is much larger and equals 9 (resp. 10). Thus, the information on Industry OUs/IDs, which is summarized in Table 4, shows us exactly which countries mainly represent Industry and make it the most distant branch from HGIs.

Table 4: Countries according to their Industry OU/ID measures

| | OU≈3 | OU≈2 |
|---|---|---|
| | (a) 1995 | |
| ID≈3 | CHN, CZE, KOR, SVK | BGR, EST, HUN, IND, MLT, ROU, TWN |
| ID≈2 | AUS, FIN, LUX, RUS | The rest of the countries |
| | (b) 2011 | |
| ID≈3 | AUT, BGR, CHN, FIN, JPN, KOR, LUX, TWN | BEL, CZE, ESP, FRA, HUN, IND, ITA, MLT, POL, PRT, SVK, SVN |
| ID≈2 | AUS, RUS, RoW | The rest of the countries |

From Table 4 we observe that the number of countries with the largest Industry OUs and IDs of 3 increases from 4 in 1995 to 8 in 2011. Here Asia is represented by China, Japan, Korea and Taiwan (main players of Factory Asia as defined in Baldwin and López-González, 2014), and Europe by Austria, Bulgaria, Finland and Luxembourg. Both Australia and Russia have the largest Industry OU of 3, but their Industry ID is smaller and equals 2. This could be explained by the fact that these countries are rich in natural resources, hence are the main suppliers of natural resources to, at least, their neighboring nations.[22] Eleven European countries and India in 2011 have Industry OUs and IDs of, respectively, 2 and 3, i.e., these nations are involved in more complex network of Industry goods purchases rather than sales.

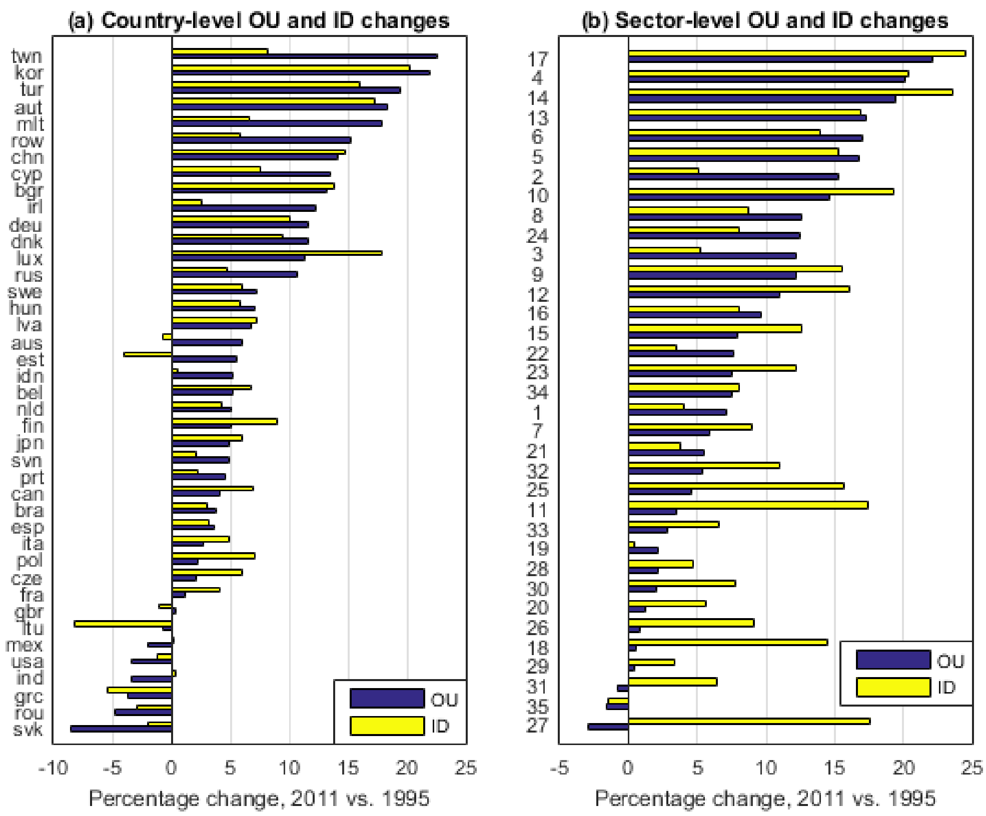
from the source mentioned in fn. 12 (see also Miller and Temurshoev, 2013, Appendices 3 and 4). For each country these are weighted averages of OUs/IDs of 16 sectors constituting Industry, where the weights indicate the proportions of gross outputs of included sectors in the total output of these sectors for each year and each country.

[22]One could also expect the OPEC countries to have patterns of the OU/ID indicators similar to those of Australia and Russia. These countries, however, are not separately included in the WIOD database. This expected similarity is partially shown by the fact that from 2004 and onwards the rest of the world (RoW) region enters the group {AUS,RUS}.

### 3.4 Changes in the OU/ID measures and their sources

The percentage changes of the world-average country- and sector-specific OUs and IDs in 2011 relative to 1995 are presented in Figure 6. The overwhelming majority of countries and sectors have experienced an increase in their OUs and IDs. Countries with the largest increase of at least 10% in both their OUs and IDs include Korea, Turkey, Austria, China, Bulgaria, Germany, and Luxembourg. Hence, compared to 1995, in 2011 the production positions of these countries became more distant from final output users and from primary inputs suppliers. The reverse (but weaker) trends are observed for Greece, Lithuania, Romania, Slovak Republic, and USA.[23]

Figure 6: Changes in the world-average OU and ID measures, 2011 vs. 1995 (in %)




Similarly, from Figure 6 we observe that the following sectors experienced an in-

[23]Note that our results are in line with the finding of Fally (2012) that "production staging" (or average ID in our terminology) declined in the US, though in our uncertainty analysis below the ID decrease is found to be insignificant from zero. The last difference is due to the fact that Fally: (a) covers much longer period of 1947-2002 using 11 US IO tables, and his relevant aggregate results for tradable goods show that almost all of the observed decrease took place between 1947-1987, while our data cover 1995-2011, (b) uses a finer level of sectoral disaggregation, and (c) employs national IO data, while we use global IO data that explicitly account for inter-country linkages.

crease of at least 10% in *both* of their OUs and IDs: Electricity, gas and water supply (code: 17), Textile and textile products (4), Electrical and optical equipment (14), Machinery (13), Wood and wood products (6), Leather and footwear (5), Rubber and plastics (10), Chemicals and chemical products (9), and Basic metals and fabricated metals (12). On the contrary, only Private households with employed persons (35) shows a decrease in both of its OU and ID of -1.6% and -1.5%, respectively. Post and telecommunications (27) and, to a lesser extent, Public administration and defence (31) became closer to final users (their OUs decrease), but much more distant from providers of primary inputs (their ID increase by 18% and 6%, respectively). The number of sectors experiencing the largest increase in their production position are found for the input demand chain: while 16 sectors' IDs increase by at least 10%, there are 13 industries that experience a change in their OUs of such a magnitude. In general, however, sectors within the global output supply and input demand chains have a clear tendency to be positioned further away from HGIs. In the entire sample of 1,435 observations for years 1995 and 2011, 65% of all 1,435 OUs and 73% of all IDs increased over the period. The corresponding figures are 67% and 77%, respectively, if we choose instead of 2011 the pre-crisis year of 2008.[24]

Given that IO data is measured with *uncertainty* caused by, e.g., sampling and measurement errors, aggregation errors, errors due to confidentiality issues, errors due to updating/balancing, and reporting errors, we ran a Monte Carlo analysis of significance of the obtained changes in the OUs and IDs across sectors and countries. We find that, from a practical perspective, the uncertainty bias is very negligible, which is in line with the stochastic IO literature findings, in particular, with the *error-compensating* properties of the IO system, first discussed by Evans (1954) and Christ (1955) (for further details, see Temurshoev, 2015). Most importantly, all our earlier discussions on the trends of country and sector average OU/ID changes based on the point-estimates remain (largely) valid with the uncertainty considerations as well. Insignificant results are found only for France, Great Britain and Lithuania in case of OUs, and for Australia, Great Britain, India, Indonesia, Mexico and USA

[24]See e.g., Bems et al. (2011) for the study of the effect of the 2008-2009 Great Recession on cross-border trade in intermediates.

in case of the IDs. Similarly, insignificant sector-specific OU/ID changes are found for Construction (18), Real estate activities (29), and to much lesser extent for Wholesale trade (20) and Other supporting and auxiliary transport activities (26) in case of OUs, and only for Sale, maintenance and repair of motor vehicles (19) in the case of the sector-level ID indicators. (For detailed discussions, see Appendix C; in particular, Figures C.1 and C.2 illustrate the margins of error for the percentage changes in OUs/IDs over time for countries and sectors, respectively.)

Given our result, also accounting for data uncertainty issues, that over time sectors along the global output supply and input demand chains have a clear tendency of being positioned further away from HGIs, the next relevant question is what is driving such increases in the OUs and IDs. As we have already noted in Table 1, there are two underlying sources of these changes: *final demand size/share* (FDS) effect and intermediate output sales or *intermediates supply network* (ISN) effect in the case of OUs, and *value added size/share* (VAS) effect and intermediate inputs purchases or *intermediates demand network* (IDN) effect in the case of IDs. The ISN and IDN effects, when capturing *inter*country linkages only, represent the "second unbundling" notion (Baldwin, 2006), where international competition operates at the level of stages of production that are being offshored to lower cost locations.[25]

Appendix D presents the structural decomposition analysis (SDA) for decomposing the OU changes into FDS, intra- and inter-country ISN effects, and the ID changes into VAS, intra- and inter-country IDN effects. Based on the detailed SDA results, the appropriate country-level factor contributions were obtained; these are presented in Table 5.[26] We find that at the world level an increase in the OU and ID measures is caused *solely* by the ISN and IDN effects, respectively. In fact, the FDS and VAS contributed to the *reduction* of the world-level OU and ID scores.

[25]Given that the ranges of the OU/ID changes distributions were found to be practically narrow and the relevant IO-based point estimates were almost identical to their distributions' means, in our decomposition analysis we do not further consider the uncertainty issue explicitly.

[26]These are weighted averages of the relevant factor contributions of all 1,435 OU and ID changes, where the averages of the 1995 and 2011 gross output shares within a country are used as weights. We have also obtained the FDS, ISN, VAS and IDN estimates using the *logarithmic mean Divisia index* (LMDI) decomposition approach (see e.g., Ang et al., 1998; Ang, 2005). Although these data are also available from the (internet) source mentioned earlier, we however do not report the LMDI results because they are (surprisingly) very similar to our SDA outcomes, with the correlation coefficients ranging between 0.9983 and 0.9998.

Table 5: Decomposition of the country-level OU and ID changes

| Cnry | Decomposition of the country-level OU changes | | | | | | | Decomposition of the country-level ID changes | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Factor contribution | | | | % of total change | | | Factor contribution | | | | % of total change | | |
| | FDS | ISN1 | ISN2 | Sum | FDS | ISN1 | ISN2 | VAS | IDN1 | IDN2 | Sum | VAS | IDN1 | IDN2 |
| AUS | -0.057 | -0.033 | 0.138 | 0.048 | -119 | -68 | 287 | -0.034 | -0.048 | 0.108 | 0.027 | -127 | -179 | 406 |
| AUT | -0.176 | 0.061 | 0.366 | 0.250 | -71 | 24 | 146 | -0.241 | 0.184 | 0.336 | 0.280 | -86 | 66 | 120 |
| BEL | -0.057 | -0.210 | 0.316 | 0.049 | -115 | -424 | 639 | -0.166 | -0.054 | 0.385 | 0.165 | -101 | -33 | 234 |
| BGR | -0.266 | 0.205 | 0.347 | 0.286 | -93 | 72 | 121 | -0.251 | 0.408 | 0.156 | 0.313 | -80 | 130 | 50 |
| BRA | -0.010 | -0.118 | 0.156 | 0.029 | -36 | -411 | 547 | -0.050 | -0.056 | 0.160 | 0.054 | -91 | -102 | 293 |
| CAN | -0.036 | 0.153 | -0.074 | 0.042 | -85 | 360 | -174 | -0.097 | 0.238 | -0.019 | 0.122 | -79 | 195 | -15 |
| CHN | -0.425 | 0.674 | 0.101 | 0.351 | -121 | 192 | 29 | -0.259 | 0.360 | 0.186 | 0.287 | -90 | 125 | 65 |
| CYP | -0.169 | 0.256 | 0.098 | 0.186 | -91 | 138 | 53 | -0.202 | 0.379 | 0.036 | 0.213 | -95 | 178 | 17 |
| CZE | -0.091 | -0.328 | 0.471 | 0.051 | -177 | -639 | 915 | -0.112 | -0.316 | 0.529 | 0.101 | -111 | -313 | 524 |
| DEU | -0.118 | -0.160 | 0.444 | 0.167 | -71 | -96 | 266 | -0.135 | -0.074 | 0.368 | 0.159 | -85 | -47 | 232 |
| DNK | -0.120 | -0.072 | 0.346 | 0.155 | -78 | -46 | 224 | -0.207 | 0.021 | 0.392 | 0.206 | -101 | 10 | 190 |
| ESP | -0.045 | -0.196 | 0.299 | 0.058 | -78 | -337 | 515 | -0.135 | -0.048 | 0.286 | 0.103 | -132 | -47 | 279 |
| EST | -0.027 | -0.085 | 0.147 | 0.035 | -76 | -242 | 418 | -0.033 | 0.025 | -0.031 | -0.039 | 84 | -65 | 81 |
| FIN | -0.164 | -0.038 | 0.352 | 0.150 | -109 | -25 | 234 | -0.210 | 0.115 | 0.293 | 0.198 | -106 | 58 | 148 |
| FRA | 0.008 | -0.164 | 0.163 | 0.006 | 128 | -2569 | 2541 | -0.094 | -0.040 | 0.231 | 0.097 | -97 | -41 | 238 |
| GBR | -0.028 | -0.276 | 0.315 | 0.011 | -259 | -2526 | 2885 | -0.082 | -0.097 | 0.223 | 0.044 | -187 | -221 | 508 |
| GRC | 0.072 | -0.254 | 0.111 | -0.070 | -102 | 360 | -158 | -0.002 | -0.245 | 0.196 | -0.052 | 4 | 475 | -379 |
| HUN | -0.083 | -0.536 | 0.699 | 0.080 | -104 | -666 | 869 | -0.129 | -0.449 | 0.675 | 0.097 | -134 | -463 | 697 |
| IDN | -0.172 | 0.065 | 0.250 | 0.143 | -120 | 45 | 174 | -0.147 | 0.077 | 0.143 | 0.074 | -200 | 105 | 195 |
| IND | 0.001 | -0.207 | 0.160 | -0.047 | -2 | 443 | -341 | -0.015 | -0.213 | 0.242 | 0.015 | -99 | -1427 | 1626 |
| IRL | -0.130 | -0.172 | 0.457 | 0.155 | -84 | -111 | 296 | -0.148 | -0.119 | 0.395 | 0.128 | -116 | -93 | 308 |
| ITA | -0.047 | -0.136 | 0.235 | 0.052 | -92 | -263 | 454 | -0.187 | 0.061 | 0.280 | 0.153 | -123 | 40 | 183 |
| JPN | -0.064 | -0.117 | 0.265 | 0.084 | -75 | -138 | 313 | -0.147 | 0.010 | 0.278 | 0.141 | -104 | 7 | 197 |
| KOR | -0.262 | 0.128 | 0.452 | 0.319 | -82 | 40 | 142 | -0.312 | 0.268 | 0.418 | 0.374 | -83 | 72 | 112 |
| LTU | 0.043 | -0.323 | 0.216 | -0.064 | -68 | 506 | -339 | 0.013 | -0.205 | 0.084 | -0.108 | -12 | 190 | -78 |
| LUX | -0.113 | -0.008 | 0.222 | 0.101 | -112 | -8 | 219 | -0.299 | 0.170 | 0.444 | 0.314 | -95 | 54 | 141 |
| LVA | -0.122 | 0.114 | 0.151 | 0.143 | -85 | 80 | 105 | -0.232 | 0.394 | 0.029 | 0.191 | -121 | 206 | 15 |
| MEX | 0.036 | -0.232 | 0.156 | -0.040 | -91 | 583 | -392 | 0.003 | -0.210 | 0.218 | 0.012 | 28 | -1802 | 1873 |
| MLT | -0.279 | 0.256 | 0.392 | 0.369 | -76 | 69 | 106 | -0.291 | 0.359 | 0.218 | 0.286 | -102 | 125 | 76 |
| NLD | -0.084 | -0.181 | 0.353 | 0.088 | -96 | -206 | 402 | -0.100 | -0.078 | 0.282 | 0.104 | -97 | -75 | 272 |
| POL | -0.050 | -0.377 | 0.455 | 0.027 | -183 | -1375 | 1658 | -0.128 | -0.334 | 0.604 | 0.141 | -91 | -237 | 428 |
| PRT | -0.041 | -0.085 | 0.193 | 0.067 | -61 | -128 | 289 | -0.133 | 0.125 | 0.112 | 0.104 | -128 | 120 | 108 |
| ROU | -0.024 | -0.245 | 0.246 | -0.023 | 106 | 1081 | -1087 | -0.051 | -0.270 | 0.314 | -0.008 | 674 | 3556 | -4130 |
| RUS | -0.100 | -0.033 | 0.302 | 0.169 | -59 | -19 | 179 | -0.102 | 0.153 | 0.068 | 0.119 | -86 | 128 | 57 |
| SVK | 0.077 | -0.581 | 0.342 | -0.162 | -47 | 359 | -211 | 0.012 | -0.456 | 0.371 | -0.074 | -16 | 620 | -504 |
| SVN | -0.110 | -0.185 | 0.399 | 0.104 | -106 | -178 | 384 | -0.100 | -0.103 | 0.274 | 0.071 | -141 | -145 | 386 |
| SWE | -0.116 | -0.105 | 0.353 | 0.132 | -88 | -80 | 267 | -0.129 | 0.003 | 0.249 | 0.123 | -105 | 3 | 202 |
| TUR | -0.312 | 0.349 | 0.323 | 0.360 | -87 | 97 | 90 | -0.294 | 0.433 | 0.175 | 0.315 | -93 | 138 | 56 |
| TWN | -0.261 | -0.197 | 0.795 | 0.337 | -77 | -59 | 236 | -0.172 | -0.142 | 0.483 | 0.169 | -102 | -84 | 286 |
| USA | 0.044 | -0.249 | 0.138 | -0.067 | -66 | 371 | -205 | -0.035 | -0.127 | 0.186 | 0.024 | -143 | -521 | 764 |
| RoW | -0.118 | 0.058 | 0.220 | 0.160 | -74 | 36 | 137 | -0.121 | 0.169 | 0.082 | 0.129 | -94 | 131 | 63 |
| World | -0.097 | -0.087 | 0.290 | 0.105 | -93 | -83 | 276 | -0.136 | 0.007 | 0.255 | 0.126 | -107 | 5 | 202 |

Note: The abbreviations are: FDS = final demand size/share effect, ISN1 = intra-country intermediates supply network effect, ISN2 = inter-country ISN, VAS = value added size/share effect, IDN1 = intra-country intermediates demand network effect, and IDN2 = inter-country IDN. The world-level contributions are simple averages of the corresponding output-weighted country-level factor contributions.

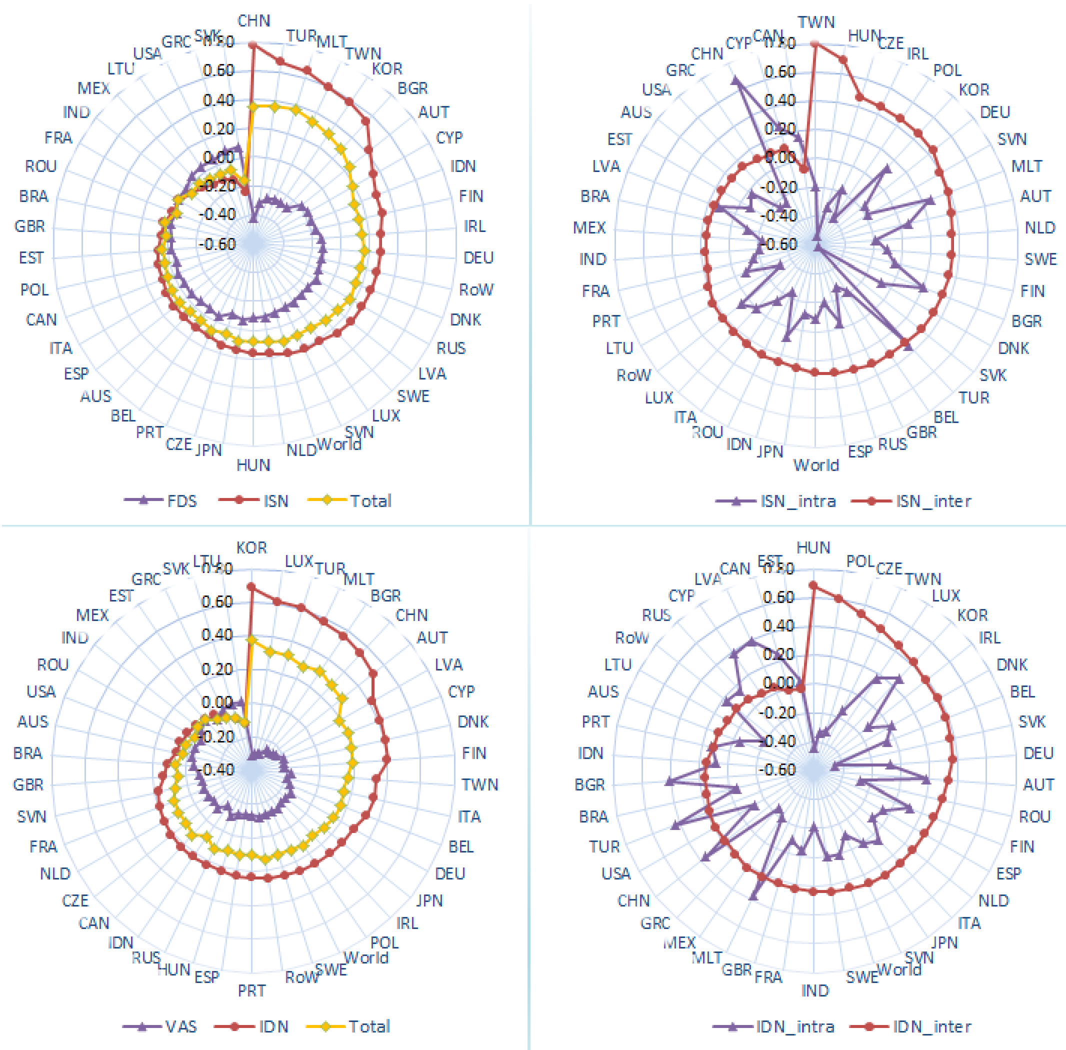
In particular, from Table 5 we see that FDS and ISN make, respectively, -93% and 193% of the average world OU change, and the VAS and IDN account, respectively, for -107% and 207% of the average world ID change. Looking deeper into the ISN components, we find that *intra*-country ISN also led to the reduction of the world average OU change, meaning that the intra-country output coefficients, on average, decreased over the 1995 to 2011 period. Thus, it is only the *inter*-country ISN factor that more than compensated the negative FSD and intra-country ISN effects that ultimately lead to the increase in the world OU measure. An almost similar picture is found for the IDN sub-effects. In this case both contributed to the increase of the world average ID, but the impact of the intra-country IDN was rather negligible: it contributed only 5% to the world ID increase, while the contribution of the inter-country IDN was 202%. Hence, we conclude that at the world level, on average, it is the increase in *inter-country intermediate* output and input coefficients (i.e. the inter-country network complexity effects) that caused industries to be located farther away from HGIs along the global output supply and input demand chains.

We use the radar charts in Figure 7, as visualization of the results in Table 5, in our analysis of country-level factor contributions (Appendix D explains in some detail the exact meaning of negative/positive factor contributions). The upper left chart depicts the FDS and ISN factors together with the overall average OU change per country, which are all presented according to the ISN ordering. This sub-plot shows that for all countries with positive average OU change (except France whose OU change is insignificant from zero, see Appendix C) the FDS contributions were always negative but those of the ISN effects were positive, overcompensating the FDS negative impact. The corresponding ISN values were larger than the relevant FDS (in absolute value) by factors ranging between 1.4 and 3.8, with the average factor of 2.2. On the other hand, for the remaining countries with a negative average OU change (SVK, GRC, USA, LTU, MEX and IND), the signs of the two factors are reversed, i.e. FDS effect was positive while the ISN contribution was negative and larger in absolute value than FDS. The only exception here is Romania, where the negative FDS overcompensated the relevant positive ISN effect. All in all, the general conclusion is that also at the country levels, the ISN effect solely contributed to the ultimate increase or decrease in the country-level average OU changes.

Now note, that e.g., in the US the FDS and ISN contributed, respectively, -66% and 166% to the average reduction of -0.067 of its OU change. This implies that, in the US, on average, the final output share increased over time that led to a decrease in average *direct* share of intermediate sales.[27] Looking further into the US intra- and inter-country ISN effects, we observe that the decrease in ISN is solely due to intra-country ISN effect. That is, intensification of inter-regional trade flows has

[27]However, given that the ISN is not only about the direct impact but also indirect impact coming from other countries, in general the ISN impact could be also positive. This may happen if intermediate inter-country sales increase in economies (also contributing to a rise in ISNs of other nations) with which US has strong intermediate trade links. Indeed, we find that all the main trading partners of the US, except Mexico, experienced an increase in their ISNs, but this positive indirect effect is not large enough to mitigate the decrease in the US intermediate sales shares. Thus, the US overall ISN contribution is negative.

Figure 7: Sources of changes in the country-level OUs and IDs, 2011 vs. 1995




also caused the average OU of the US to increase as the FDS impact, but these were overcompensated by the negative intra-country ISN effect.

The upper right radar chart presents the intra- and inter-country ISN effects for all countries according to the last ordering. It clearly shows that the inter-country ISNs are positive for all countries, except for Canada. Hence, indeed the increasing complexity of inter-country output supply chains was a common factor in making countries more output upstream. However, China – the top country with largest ISN – has *intra*-country ISN that is almost seven times as big as its *inter*-country ISN. Thus, for China the intra-country ISN factor is the most important source of locating it farthest away from HGIs in the global supply chain. To a large extent this should be due to a rise in direct output coefficients within China, especially for Industry sectors. Similar intra- vs. inter-country ISN patterns, albeit to much weaker degree, are observed for Canada, Cyprus and Turkey. Note that for the majority of countries intra-country ISN had a negative impact on their average OUs.

The bottom left chart in Figure 7 illustrates the VAS and IDN factors together with the average ID change per country, all presented according to the IDN ordering. Similar to the FDS vs. ISN effects, we find that for all countries with positive average ID change (except Mexico whose ID change is insignificant from zero, see Appendix C) the VAS contributions were always negative but those of the IDN effects were positive and overcompensated the VAS impact. The corresponding IDN values were larger than the relevant VAS (in absolute value) by factors ranging between 1.5 to 2.3, with the average factor of 2.0. Here we observe three countries for which the signs of VAS and IDN are *identical*: positive for Mexico, and negative for Estonia and Greece. For Slovakia and Lithuania the signs of the two factors are reversed, i.e. VAS was positive while the IDN contribution was negative and larger in absolute value. Note that all major developed countries have similar signs of their VAS and IDN factors, which was not the case with the FDS and ISN comparisons, where the US had different OU factor structure from that of e.g., Germany and Japan. All in all, the general conclusion again is that the IDN effect contributed to the ultimate increase (or decrease) in the country-level average ID changes.

Finally, the bottom right chart in Figure 7 presents all intra- and inter-country IDN effects, according to the last factor ordering. It again shows that the inter-country IDN effects are positive for all countries, except for Canada and Estonia. Hence, indeed the increasing complexity of inter-country input demand chains was a common factor for countries in taking more input downsteam positions. However, for China, Turkey and Bulgaria – included in the list of top countries with the largest IDNs – *intra*-country IDNs were larger than their *inter*-country IDNs by factors of, respectively, 1.9, 2.5 and 2.6. To a large extent this should be due to increasing direct input coefficients within these countries. Similar intra- vs. inter-country IDN relations are observed for Canada, Cyprus, Estonia, Latvia, Malta, and Russia. Note also that 21 countries experienced a negative intra-country IDN impact. In fact, some Eastern European countries like Hungary, Poland and Czech

Republic went through the largest decrease in *both* of their intra-country ISNs and intra-country IDNs, and end up in the list of countries with the largest increase in *both* of their inter-country ISNs and inter-country IDNs.

## 4 Concluding remarks

In this paper we have examined industries' positions along the global production chain, ultimately relative to households, governments and investors (HGIs) in their roles as buyers of final output from firms and as providers of primary inputs to firms. Thus, both the output supply chain and the input demand chain are considered, where the chain is seen from firms' perspective. These two chains are generally different, because at the sectoral level the output structure is not identical to the input structure. While previous related research has mainly focused on the output supply chain (see e.g., Antràs et al., 2012), here we also consider the input demand chain perspective as ultimately both sides are an essential part of the entire production process.

We quantified the relative positions of industries along the global output supply and the global input demand chains using the 1995-2011 time series of the world input-output tables from the WIOD database that distinguishes between 35 sectors, and 40 countries and the rest of the world. Some of our results are as follows:

- Industries that are positioned upstream in the global output supply chain are, on average, positioned downstream in the global input demand chain. That is, industries that are more distant from HGIs as buyers of final output are also, on average, more distant from HGIs as providers of primary inputs.
- The average industry/country is positioned roughly one stage away from HGIs; that is, transactions of intermediates are important and therefore total output is not produced mainly for final use purposes and total inputs do not include mainly primary inputs. This average picture stays stable for the period 1995-2011.
- In terms of sectors, the Industry (resp. Public administration, education, health, and activities of households) branch is positioned furthest away from (resp. closest to) HGIs along both production chains.
- China consistently occupies the most upstream (resp. downstream) position along

the global output supply (resp. input demand) chain, mainly due to a large share of Industry's output in its gross output.

- By 2011 'Factory Asia' (i.e., China, Japan, Korea and Taiwan), Austria, Bulgaria, Finland and Luxembourg make the Industry branch the most upstream (resp. downstream) in the global output supply (resp. input demand) chain. Natural resource-rich nations like Australia and Russia also contribute to the output upstreamness of the Industry position.
- An overwhelming majority of sectors and countries show a clear trend of positioning away from HGIs over time both along the global output supply and global input demand chains, which is robust to input-output data uncertainty issues.
- Positive changes in inter-country intermediate output and input coefficients – the inter-country network complexity effects – were found the be the most important drivers of the increase in countries OUs and IDs.
- For China, however, the *intra*-country intermediate output and input coefficients were found to be the most important source of locating it farthest away from HGIs along the global output supply and input demand chains. To a large degree, this should be due to increasing direct output and input coefficients within China, especially for Industry sectors.
- In contrast to China, for the US the *intra*-country intermediate output and input coefficients were found to be the most important source of locating it *closer to* HGIs along the global output supply and input demand chains. To a large degree, this should be due to decreasing direct output and input coefficients within the US, especially for services sectors.

Finally we expect that like the OU, the ID measure proposed in this paper as industry production line position along the (global) input demand chain could be useful in empirical studies of the determinants of the boundaries of the multinational firm, economy-wide transmission of demand/supply shocks, issues related to employees and firms co-agglomeration, and shared producer and consumer/worker responsibility for generating pollution, among other potential applications.

## References


Alfaro, L. and A. Charlton: 2009, 'Intra-industry foreign direct investment'. *American Economic Review* **99**, 2096–2119.

Ang, B.: 2005, 'The LMDI approach to decomposition analysis: a practical guide'. *Energy Policy* **33**(7), 867–871.

Ang, B., F. Zhang, and K.-H. Choi: 1998, 'Factorizing changes in energy and environmental indicators through decomposition'. *Energy* **23**(6), 489–495.

Antràs, P. and D. Chor: 2013, 'Organizing the global value chain'. *Econometrica* **81**, 2127–2204.

Antràs, P., D. Chor, T. Fally, and R. Hillberry: 2012, 'Measuring the upstreamness of production and trade flows'. *American Economic Review: Papers and Proceedings* **102**, 412–416.

Antràs, P., L. Garicano, and E. Rossi-Hansberg: 2006, 'Offshoring in a Knowledge Economy'. *Quarterly Journal of Economics* **121**, 31–77.

Baldwin, R.: 2006, 'Globalisation: the great undbundling(s)'. In: *Globalisation Challenges for Europe and Finland*. Helsinki: Secretariat of the Economic Council, Finnish Prime Minister's Office, Chapt. 1, pp. 5–47. Available at http://vnk.fi/hankkeet/talousneuvosto/tyo-kokoukset/globalisaatioselvitys-9-2006/en.jsp.

Baldwin, R. and J. López-González: 2014, 'Supply-chain trade: A portrait of global patterns and several testable hypotheses'. *World Economy*. doi: 10.1111/twec.12189.

Bems, R., R. C. Johnson, and K.-M. Yi: 2011, 'Vertical linkages and the collapse of global trade'. *American Economic Review: Papers and Proceedings* **101**, 308–312.

Burstein, A., C. Kurz, and L. Tesar: 2008, 'Trade, production sharing, and the international transmission of business cycles'. *Journal of Monetary Economics* **55**, 775–795.

Carvalho, V. M.: 2014, 'From micro to macro via production networks'. *Journal of Economic Perspectives* **28**, 23–48.

Christ, C. F.: 1955, 'A review of input-output analysis'. In: Conference on Research in Income and Wealth (ed.): *Input-Output Analysis: An Appraisal*. Princeton: Princeton University Press, pp. 137–169. Studies in Income and Wealth, vol. 18, A Report of the National Bureau of Economic Research.

di Giovanni, J. and A. A. Levchenko: 2010, 'Putting the parts together: trade, vertical linkages and business cycle comovement'. *American Economic Journal: Macroeconomics* **2**, 95–124.

Dietzenbacher, E.: 2006, 'Multiplier estimates: to bias or not to bias?'. *Journal of Regional Science* **46**, 773–786.

Dietzenbacher, E. and B. Los: 1998, 'Structural decomposition techniques: sense and sensitivity'. *Economic Systems Research* **10**, 307–324.

Dietzenbacher, E., B. Los, R. Stehrer, M. P. Timmer, and G. J. de Vries: 2013, 'The construction of world input-output tables in the WIOD project'. *Economic Systems Research* **25**, 71–98.

Dietzenbacher, E. and I. Romero: 2007, 'Production chains in an interregional framework: Identification by means of average propagation lengths'. *International Regional Science Review* **30**, 362–383.

Dietzenbacher, E., I. Romero, and N. Bosma: 2005, 'Using average propagation lengths to identify production chains in the Andalusian economy'. *Estudios de Economía Aplicada* **23**, 405–422.

Dietzenbacher, E. and U. Temurshoev: 2008, 'Ownership relations in the presence of cross-shareholding'. *Journal of Economics* **95**, 189–212.

Ellison, G. and E. L. Glaeser: 1997, 'Geographic concentration in U.S. manufacturing industries: A dartboard approach'. *Journal of Political Economy* **105**, 889–927.

Ellison, G., E. L. Glaeser, and W. R. Kerr: 2010, 'What causes industry agglomeration? Evidence from coagglomeration patterns'. *American Economic Review* **100**, 1195–1213.

Evans, W.: 1954, 'The effect of structural matrix errors on interindustry relations estimates'. *Econometrica* **22**, 461–480.

Fally, T.: 2012, 'Production staging: Measurement and facts'. Mimeo, University of Colorado-Boulder.

Ghosh, A.: 1958, 'Input-output approach to an allocative system'. *Economica* **25**, 58–64.

Holmes, T. J.: 1999, 'Localization of industry and vertical disintegration'. *Review of Economics and Statistics* **81**, 314–325.

Hummels, D., J. Ishii, and K.-M. Yi: 2001, 'The nature and growth of vertical specialization in world trade'. *Journal of International Economics* **54**, 75–96.

Jofre-Monseny, J., R. Marín-López, and E. Viladecans-Marsal: 2011, 'The mechanisms of agglomeration: Evidence from the effect of inter-industry relations on the location of new firms'. *Journal of Urban Economics* **70**, 61–74.

Johnson, R. C. and G. Noguera: 2012, 'Accounting for intermediates: Production sharing and trade in value added'. *Journal of International Economics* **86**, 224–236.

Jones, C. I.: 2011, 'Intermediate goods and weak links in the theory of economic development'. *American Economic Journal: Macroeconomics* **3**, 1–28.

Jones, R. W. and H. Kierzkowski: 1990, 'The role of services in production and international trade: A theoretical framework'. In: R. W. Jones and A. Krueger (eds.): *The Political Economy of International Trade*. Oxford: Basil Blackwell, pp. 31–48.

Koopman, R., W. Powers, Z. Wang, and S.-J. Wei: 2011, 'Give credit where credit is due: Tracing value added in global production chains'. NBER Working Paper No. 16426, Revised September 2011.

Krugman, P. and A. J. Venables: 1995, 'Globalization and the inequality of nations'. *Quarterly Journal of Economics* **110**, 857–880.

Leontief, W. W.: 1936, 'Quantitative input-output relations in the economic system of the United States'. *Review of Economics and Statistics* **18**, 105–125.

Leontief, W. W.: 1941, *The Structure of American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis*. Cambridge: Cambridge University Press.

Li, B. and Y. Lu: 2009, 'Geographic concentration and vertical disintegration: evidence from China'. *Journal of Urban Economics* **65**, 294–304.

Miller, R. E. and P. D. Blair: 2009, *Input-Output Analysis: Foundations and Extensions*. Cambridge: Cambridge University Press, 2nd edition.

Miller, R. E. and U. Temurshoev: 2013, 'Output upstreamness and input downstreamness of industries/countries in world production'. GGDC Research Memorandum 133, May.

Porter, M. E.: 1990, *The Competitive Advantage of Nations*. New York: Free Press.

Roland-Holst, D. W.: 1989, 'Bias and stability of multiplier estimates'. *Review of Economics and Statistics* **71**, 718–721.

Temurshoev, U.: 2015, 'Uncertainty treatment in input-output analysis'. In: T. ten Raa (ed.): *Handbook of Input-Output Analysis*. Edward Elgar Publishing Ltd., Chapt. 11. forthcoming.

Temurshoev, U. and R. E. Miller: 2013, 'Distance-based shared responsibility'. Mimeo.

Temurshoev, U. and J. Oosterhaven: 2014, 'Analytical and empirical comparison of policy-relevant key sector measures'. *Spatial Economic Analysis* **9**, 284–308.

Timmer, M., A. A. Erumban, B. Los, R. Stehrer, and G. J. de Vries: 2014, 'Slicing up global value chains'. *Journal of Economic Perspectives* **28**, 99–118.

Timmer, M., B. Los, R. Stehrer, and G. J. de Vries: 2013, 'Fragmentation, incomes and jobs. An analysis of European competitiveness'. *Economic Policy* **28**, 613–661.

Timmer, M. P. (ed.): 2012, *The World Input-Output Database (WIOD): Contents, Sources and Methods*. Available at: http://www.wiod.org/publications/source_docs/WIOD_sources.pdf.

Zavacka, V.: 2012, 'The bullwhip effect and the Great Trade Collapse'. European Bank for Reconstruction and Development Working Paper No. 148.

## A WIOD country acronyms and industry classification

| Acr. | Country | Code | Industry description |
|---|---|---|---|
| AUS | Australia | 1 | Agriculture, hunting, forestry and fishing |
| AUT | Austria | 2 | Mining and quarrying |
| BEL | Belgium | 3 | Food, beverages and tobacco |
| BGR | Bulgaria | 4 | Textiles and textile products |
| BRA | Brazil | 5 | Leather, leather and footwear |
| CAN | Canada | 6 | Wood and products of wood and cork |
| CHN | China | 7 | Pulp, paper, printing and publishing |
| CYP | Cyprus | 8 | Coke, refined petroleum and nuclear fuel |
| CZE | Czech Republic | 9 | Chemicals and chemical products |
| DEU | Germany | 10 | Rubber and plastics |
| DNK | Denmark | 11 | Other non-metallic mineral |
| ESP | Spain | 12 | Basic metals and fabricated metal |
| EST | Estonia | 13 | Machinery, nec |
| FIN | Finland | 14 | Electrical and optical equipment |
| FRA | France | 15 | Transport equipment |
| GBR | United Kingdom | 16 | Manufacturing, nec; recycling |
| GRC | Greece | 17 | Electricity, gas and water supply |
| HUN | Hungary | 18 | Construction |
| IDN | Indonesia | 19 | Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel |
| IND | India | 20 | Wholesale trade and commission trade, exc. of motor vehicles and motorcycles |
| IRL | Ireland | 21 | Retail trade; repair of household goods |
| ITA | Italy | 22 | Hotels and restaurants |
| JPN | Japan | 23 | Inland transport |
| KOR | Korea | 24 | Water transport |
| LTU | Lithuania | 25 | Air transport |
| LUX | Luxembourg | 26 | Other supporting and auxiliary transport activities; activities of travel agencies |
| LVA | Latvia | 27 | Post and telecommunications |
| MEX | Mexico | 28 | Financial intermediation |
| MLT | Malta | 29 | Real estate activities |
| NLD | Netherlands | 30 | Renting of machinery & equipment and other business activities |
| POL | Poland | 31 | Public admin and defence; compulsory social security |
| PRT | Portugal | 32 | Education |
| ROU | Romania | 33 | Health and social work |
| RUS | Russia | 34 | Other community, social and personal services |
| SVK | Slovak Republic | 35 | Private households with employed persons |
| SVN | Slovenia | | |
| SWE | Sweden | | |
| TUR | Turkey | | |
| TWN | Taiwan | | |
| USA | United States | | |
| RoW | Rest of the World | | |

| Abbr. | WIOD sectors | Description of six broad branches defined by Eurostat |
|---|---|---|
| Agr | 1 | Agriculture and fishing |
| Ind | 2-17 | Industry, except construction |
| Con | 18 | Construction |
| 2Tr | 19-27 | Wholesale & retail trade, hotel & restaurants, and transport |
| Fin | 28-30 | Financial intermediation, real estate |
| PbH | 31-35 | Public administration, education, health, and activities of households |

## B Sector- and country-specific weighted OU and ID measures

To spell out the distinction between sectors *and* countries, we denote $x_s^c$ as the gross output of sector $s$ in country $c$. Then *total output of each sector* and *total output of each country* are computed, respectively, as

$$x_s^{tot} = \sum_c x_s^c \quad \text{for each sector } s, \tag{B.1}$$

$$x_{tot}^c = \sum_s x_s^c \quad \text{for each country } c. \tag{B.2}$$

Similarly, now $u_s^c$ is the OU measure of sector $s$ in country $c$. Let us denote the *sector-specific weighted OU measure* of sector $s$ by $\overline{u}_s$ and the *country-specific weighted OU measure* of country $c$ by $\overline{u}^c$. These are defined, respectively, as

$$\overline{u}_s = \sum_c u_s^c \frac{x_s^c}{x_s^{tot}} \quad \text{for each sector } s, \tag{B.3}$$

$$\overline{u}^c = \sum_s u_s^c \frac{x_s^c}{x_{tot}^c} \quad \text{for each country } c. \tag{B.4}$$

Changing all $u$'s in (B.3) and (B.4) into $d$'s, gives us the sector-specific and country-specific weighted ID measures $\overline{d}_s$ and $\overline{d}^c$, respectively.

There is a direct link between the sector- and country-specific OU/ID measures given in (B.3)-(B.4) and the *system-wide* weighted OU/ID measures $\overline{u} = \overline{d}$ defined in (10). If we denote the system-wide (world) output by $x^w = \sum_c \sum_s x_s^c$, this relation is as follows:

**Proposition 2.** *The output-weighted averages of the sector- and country-specific OU/ID measures, where the shares of sector- and country-specific outputs in the world output are taken as respective weights, are exactly equal to the overall weighted OU/ID measures* $\overline{u} = \overline{d}$*, i.e.,*

$$\overline{u} = \overline{d} = \sum_s \overline{u}_s \frac{x_s^{tot}}{x^w} = \sum_s \overline{d}_s \frac{x_s^{tot}}{x^w} = \sum_c \overline{u}^c \frac{x_{tot}^c}{x^w} = \sum_c \overline{d}^c \frac{x_{tot}^c}{x^w}. \tag{B.5}$$

*Proof:* The proof is very simple, hence we show it for one of the above four mentioned cases only. Using the definition of $\overline{u}_s$ from (B.3) the output-weighted average of the sector-specific OU measure can be written as

$$\sum_s \overline{u}_s \frac{x_s^{tot}}{x^w} = \sum_s \left( \sum_c u_s^c \frac{x_s^c}{x_s^{tot}} \right) \frac{x_s^{tot}}{x^w} = \sum_s \sum_c u_s^c \frac{x_s^c}{x_s^{tot}} \frac{x_s^{tot}}{x^w} = \sum_s \sum_c u_s^c \frac{x_s^c}{x^w} = \overline{u}.$$

The remaining identities in (B.5) can be proved in the same way. *QED.*

## C A Monte Carlo analysis of significance of the OU/ID changes

The OUs and IDs are prone to uncertainty given that the underlying input and output coefficients are not 100% exact. It has been already shown in the IO literature that the bias caused due to data uncertainty has very negligible impact on the IO *output multipliers*, which are equivalent to the ID measures.[1] These studies consider solely ID uncertainty

[1] See e.g., Roland-Holst (1989) and Dietzenbacher (2006). There are different techniques that have been used by IO researchers in dealing with data uncertainty issues. For an extensive survey

and use national IO tables, while we focus on OU/ID differences over time which could be more prone to uncertainty in case of opposite biases of the OUs/IDs in the two time periods. Thus, here we pursue the same line of reasoning and run Monte Carlo simulations to understand the impact of uncertainties on the changes of country- and sector-specific OUs and IDs that are derived from global IO tables. Denote $z_{ij}^{rc,t}$ the value of intermediate transaction from industry $i$ in country $r$ to industry $j$ in country $c$ that is *observed* in year $t = 1995, 2011$. Similarly, $f_{ih}^{rc,t}$ denotes time $t$ observed final demand category $h$ (such as households consumption, government consumption, gross fixed capital formation, and changes in inventories) supplied by industry $i$ from country $r$ that is used in region $c$. For each simulation step $k = 1, 2, \ldots, 2500$, our Monte Carlo procedure runs as follows:

1. Draw the following indepedently normally distributed random variabes: $\Delta z_{ij,k}^{rc,t} \sim \mathcal{N}(0, [\rho \times z_{ij}^{rc,t}]^2)$ and $\Delta f_{ih,k}^{rc,t} \sim \mathcal{N}(0, [\rho \times |f_{ih}^{rc,t}|]^2)$, where $\rho$ represents a percentage deviation from the observed flows. Note that since changes in inventories can be negative, the variance of the final demand category deviation is proportional to the *absolute value* of the observed relevant figure.
2. Compute the randomized intermediate flows, final deliveries and gross outputs, respectively, as $\tilde{z}_{ij,k}^{rc,t} = z_{ij,k}^{rc,t} + \Delta z_{ij,k}^{rc,t}$, $\tilde{f}_{ij,k}^{rc,t} = f_{ij,k}^{rc,t} + \Delta f_{ij,k}^{rc,t}$, and $\tilde{x}_{i,k}^{r,t} = \sum_c \sum_j \left(\tilde{z}_{ij,k}^{rc,t} + \tilde{f}_{ij,k}^{rc,t}\right)$. In case an observed intermediate or final flow is zero, the corresponding randomized value is set to zero as well.
3. Compute the randomized direct input and output coefficients, respectively, as $\tilde{a}_{ij,k}^{rc,t} = \tilde{z}_{ij,k}^{rc,t} / \tilde{x}_{j,k}^{c,t}$ and $\tilde{b}_{ij,k}^{rc,t} = \tilde{z}_{ij,k}^{rc,t} / \tilde{x}_{i,k}^{r,t}$.
4. Compute the randomized OU and ID measures using Eqs. (8) and (9) based on the obtained randomized global Ghosh and Leontief matrices.
5. Derive the country- and sector-specific OU and ID averages (see Appendix B) and the corresponding percentage differences for year 2011 relative to 1995.

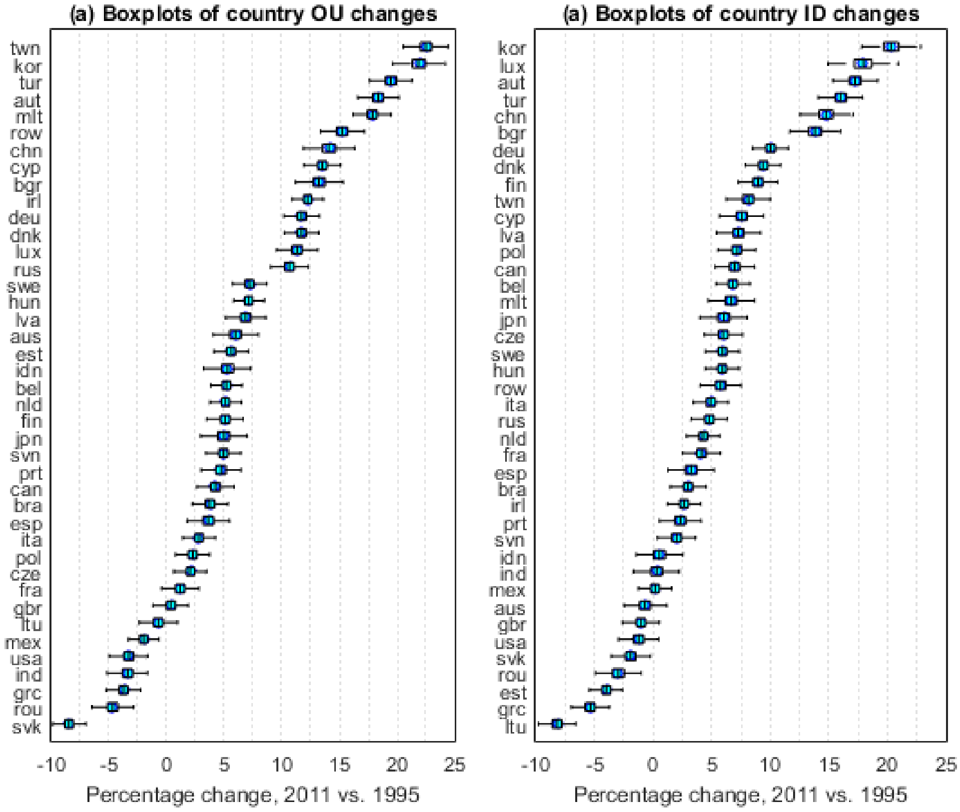
Following Roland-Holst (1989) and Dietzenbacher (2006), in the empirical analysis $\rho = 0.1$ is chosen. Figure C.1 illustrates the distribution of the 2011 to 1995 percentage differences of the country-specific OUs and IDs in terms of boxplots.[2] The derived *extremely few* outliers are not shown, because the 1.5 $IQR$ rule corresponds to approximately 99.3% coverage if the data are normally distributed, while using a one-sample Kolmogorov-Smirnov test we fail to reject the null hypothesis that the obtained differences come from a normal distribution per country. The same conclusion holds for sector-specific OUs and IDs, whose uncertainties are illustrated in Figure C.2. Both these figures also include the relevant *point estimates* as shown in Figure 6, denoted by cyan circles.

The following observations can be made from uncertainty ranges in Figures C.1 and C.2. First, there are biases of the changes in the country- and sector-specific OUs/IDs as shown by the width of the (roughly 99%) uncertainty intervals. However, practically the

of this literature, see Temurshoev (2015).

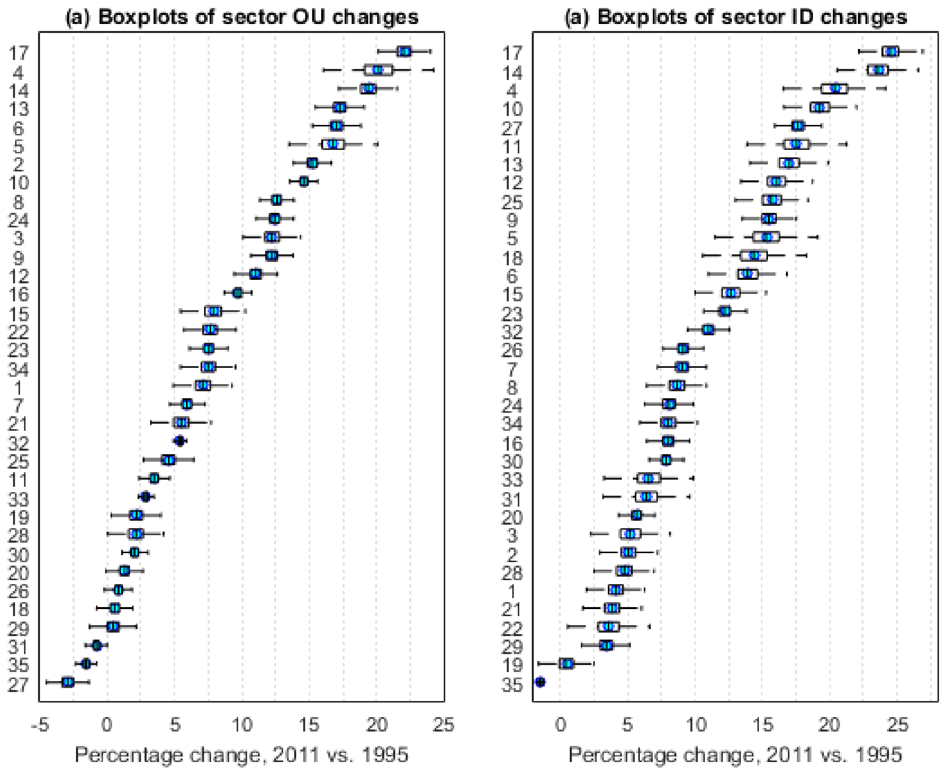
[2]The edges of each box represent the corresponding 25th and 75th percentiles (i.e., first and third quartiles, $Q_1$ and $Q_3$), the central mark is the median, and the whiskers extend to the most extreme datapoints determined by the so-called 1.5 interquartile range ($IQR = Q_3 - Q_1$) rule: all datapoints falling below $Q_1 - 1.5 \times IQR$ or above $Q_3 + 1.5 \times IQR$ are considered as outliers.

Figure C.1: Uncertainties of the differences in country-specific weighted OU and ID indicators, 2011 vs. 1995 (in %)




bias is very negligible given that (a) the point estimates of these changes always are almost identical to the median (and mean) of the illustrated distributions, and (b) 50% of the obtained changes fall within very narrow (i.e. $IQR$) ranges. This result is in line with the stochastic IO literature findings, in particular, with the *error-compensating* properties of the IO system, first discussed by Evans (1954) and Christ (1955) (for further details, see Temurshoev, 2015). Second, the OU and ID uncertainties' ranges are, on average, wider for sectors than for countries. As sector-specific OUs/IDs are weighted averages of the sector OUs/IDs across all countries, while country-specific OUs/IDs are weighted averages of OUs/IDs across all sectors within the country in question (see Appendix B), this finding suggests that the IO structure within one country is often less variable and more stable than that among different countries. Finally, all our earlier discussions on the trends of country and sector average OU/ID changes over time based on the point-estimates remain (largely) valid with the uncertainty considerations as well. Insignificant results are found only for France, Great Britain and Lithuania in case of OUs, and for Australia, Great Britain, India, Indonesia, Mexico and USA in case of the IDs, because the corresponding ($\approx 99\%$) distributions include zero change as follows from Figure C.1. Similarly, insignificant sector-specific OU/ID changes are found for Construction (18), Real estate activities (29), and to much lesser extent for Wholesale trade (20) and Other supporting and auxiliary transport activities (26) in case of OUs, and only for Sale, maintenance and repair of motor vehicles

Figure C.2: Uncertainties of the differences in sector-specific weighted OU and ID indicators, 2011 vs. 1995 (in %)




(19) sector in case of the sector-level ID indicators.

## D Structural decomposition analysis of the OU and ID changes

The output-side accounting identity $\mathbf{Z}\boldsymbol{\imath} + \mathbf{f} = \mathbf{x}$, if premultiplied by the inverse of gross outputs as diagonal matrix, yields $\hat{\mathbf{x}}^{-1}\mathbf{f} = \boldsymbol{\imath} - \hat{\mathbf{x}}^{-1}\mathbf{Z}\boldsymbol{\imath} = (\mathbf{I} - \mathbf{B})\boldsymbol{\imath}$. Premultiplying the last expression by the Ghosh inverse gives $\mathbf{G}\hat{\mathbf{x}}^{-1}\mathbf{f} = \boldsymbol{\imath}$. Hence, the OU measure in (8) can be alternatively written as

$$\mathbf{u} = \mathbf{G}\boldsymbol{\imath} = \mathbf{G}\mathbf{G}\hat{\mathbf{x}}^{-1}\mathbf{f} = \mathbf{S}\mathbf{f}_c, \tag{D.1}$$

where $\mathbf{S} \equiv \mathbf{G}\mathbf{G}$ and $\mathbf{f}_c \equiv \hat{\mathbf{x}}^{-1}\mathbf{f}$.[3] Similarly, the input-side accounting identity $\boldsymbol{\imath}'\mathbf{Z} + \mathbf{v}' = \mathbf{x}'$, if postmultiplied by $\hat{\mathbf{x}}^{-1}$, gives $\mathbf{v}'\hat{\mathbf{x}}^{-1} = \boldsymbol{\imath}'(\mathbf{I} - \mathbf{A})$. Postmultiplying the last equation by the Leontief inverse yields $\mathbf{v}'\hat{\mathbf{x}}^{-1}\mathbf{L} = \boldsymbol{\imath}'$. Therefore, the ID measure in (9) can be alternatively written as

$$\mathbf{d}' = \boldsymbol{\imath}'\mathbf{L} = \mathbf{v}'\hat{\mathbf{x}}^{-1}\mathbf{L}\mathbf{L} = \mathbf{v}_c'\mathbf{D}, \tag{D.2}$$

where $\mathbf{v}_c' \equiv \mathbf{v}'\hat{\mathbf{x}}^{-1}$ and $\mathbf{D} \equiv \mathbf{L}\mathbf{L}$.

Equations (D.1) and (D.2) are exactly expressions we need in understanding the sources of the OUs and IDs changes. In particular, in (D.1) changes in $\mathbf{S}$ capture the intermediate output sales, or *intermediates supply network* (ISN) effect and changes in $\mathbf{f}_c$ account for

[3] Subscript $c$ stands for "direct *coefficient*", and not to be confused with "country".

*final demand size/share* (FDS) effect in explaining the changes of OUs over time. Similarly, in (D.2), changes in $\mathbf{D}$ account for the intermediate inputs purchases or *intermediates demand network* (IDN) effect and changes in $\mathbf{v}_c$ capture the *value added size/share* (VAS) effect in explaining the changes of IDs over time. We use structural decomposition analysis (SDA) to quantify the individual contributions of these factors.

Using (D.1), the change in OU measures between two points in time, i.e. $\Delta\mathbf{u} \equiv \mathbf{u}^1 - \mathbf{u}^0$, may be decomposed in two ways as follows:

$$\Delta\mathbf{u} = \Delta\mathbf{S}\mathbf{f}_c^0 + \mathbf{S}^1\Delta\mathbf{f}_c, \tag{D.3}$$

$$= \Delta\mathbf{S}\mathbf{f}_c^1 + \mathbf{S}^0\Delta\mathbf{f}_c, \tag{D.4}$$

where $\Delta\mathbf{S} \equiv \mathbf{S}^1 - \mathbf{S}^0$ and $\Delta\mathbf{f}_c \equiv \mathbf{f}_c^1 - \mathbf{f}_c^0$. Following the usual SDA practice (see e.g., Dietzenbacher and Los, 1998), we take the mean of the two decompositions in (D.3) and (D.4) to obtain the estimates of the ISN and FDS effects as follows:[4]

$$ISN = 0.5 \times \Delta\mathbf{S}(\mathbf{f}_c^0 + \mathbf{f}_c^1), \tag{D.5}$$

$$FDS = 0.5 \times (\mathbf{S}^0 + \mathbf{S}^1)\Delta\mathbf{f}_c. \tag{D.6}$$

In order to distinguish between *intra-country* and *inter-country* ISN effects, (D.5) can be further decomposed as follows. Note that since $\Delta\mathbf{S} = \mathbf{G}^1\mathbf{G}^1 - \mathbf{G}^0\mathbf{G}^0 = \Delta\mathbf{G}\mathbf{G}^0 + \mathbf{G}^1\Delta\mathbf{G} = \Delta\mathbf{G}\mathbf{G}^1 + \mathbf{G}^0\Delta\mathbf{G}$, as earlier we take the average of the last two decompositions to write changes in $\mathbf{S}$ in terms of changes in $\mathbf{G}$:

$$\Delta\mathbf{S} = 0.5 \times \Delta\mathbf{G}(\mathbf{G}^0 + \mathbf{G}^1) + 0.5 \times (\mathbf{G}^0 + \mathbf{G}^1)\Delta\mathbf{G}. \tag{D.7}$$

The final trick is writing changes in the Ghosh inverse $\mathbf{G}$ in terms of changes in the underlying direct output coefficients matrix $\mathbf{B}$. It can be shown that $\Delta\mathbf{G} = \mathbf{G}^0\Delta\mathbf{B}\mathbf{G}^1 = \mathbf{G}^1\Delta\mathbf{B}\mathbf{G}^0$ (see e.g., Miller and Blair, 2009, Chapter 13). Again since there is no particular reason for choosing either of these expressions, we take their mean, i.e. $\Delta\mathbf{G} = 0.5 \times (\mathbf{G}^0\Delta\mathbf{B}\mathbf{G}^1 + \mathbf{G}^1\Delta\mathbf{B}\mathbf{G}^0)$. The last expression together with (D.5) and (D.7) give the ISN effect in terms of changes in the direct output coefficients as follows:

$$\begin{aligned} ISN =& 0.125 \times \big[(\mathbf{G}^0\Delta\mathbf{B}\mathbf{G}^1 + \mathbf{G}^1\Delta\mathbf{B}\mathbf{G}^0)(\mathbf{G}^0 + \mathbf{G}^1) \\ &+ (\mathbf{G}^0 + \mathbf{G}^1)(\mathbf{G}^0\Delta\mathbf{B}\mathbf{G}^1 + \mathbf{G}^1\Delta\mathbf{B}\mathbf{G}^0)\big](\mathbf{f}_c^0 + \mathbf{f}_c^1). \end{aligned} \tag{D.8}$$

Thus, in (D.8) by summing only over selected elements of interest of $\Delta\mathbf{B}$, the underlying ISN effects can be obtained. For example, if one is interested in *intra*-country ISN effects only, nullifying all off-block diagonal matrices (i.e. all interregional trade coefficients) in $\Delta\mathbf{B}$ when applying (D.8) gives the estimates of the required impact.

Analogous to (D.3) and (D.4), using (D.2) the two-way decompositions of the changes

[4] Note that even if we would have had interaction terms $\Delta\mathbf{S}\Delta\mathbf{f}_c$ in (D.3) and (D.4), their mean would still give us equations (D.5) and (D.6).

in ID measures between two points in time are:

$$\Delta\mathbf{d}' = \Delta\mathbf{v}_c'\mathbf{D}^0 + (\mathbf{v}_c^1)'\Delta\mathbf{D}, \tag{D.9}$$

$$= \Delta\mathbf{v}_c'\mathbf{D}^1 + (\mathbf{v}_c^0)'\Delta\mathbf{D}, \tag{D.10}$$

where $\Delta\mathbf{d} \equiv \mathbf{d}^1 - \mathbf{d}^0$, $\Delta\mathbf{v}_c \equiv \mathbf{v}_c^1 - \mathbf{v}_c^0$, and $\Delta\mathbf{D} \equiv \mathbf{D}^1 - \mathbf{D}^0$. Thus, the VAS and IDN effects can be quantified as the mean of the corresponding factors in (D.9) and (D.10), i.e.:

$$VAS = 0.5 \times \Delta\mathbf{v}_c'(\mathbf{D}^0 + \mathbf{D}^1), \tag{D.11}$$

$$IDN = 0.5 \times (\mathbf{v}_c^0 + \mathbf{v}_c^1)'\Delta\mathbf{D}. \tag{D.12}$$

To distinguish between the *intra-* and *inter*-country IDN effects, we need to write (D.12) in terms of changes in the direct input coefficients matrix $\mathbf{A}$. Using the identities $\Delta\mathbf{D} = \mathbf{L}^1\mathbf{L}^1 - \mathbf{L}^0\mathbf{L}^0$ and $\Delta\mathbf{L} = \mathbf{L}^0\Delta\mathbf{A}\mathbf{L}^1 = \mathbf{L}^1\Delta\mathbf{A}\mathbf{L}^0$, and going through similar transformations as above, we arrive at the final expression for the IDN effects as follows:

$$\begin{aligned} IDN = & 0.125 \times (\mathbf{v}_c^0 + \mathbf{v}_c^1)'\big[(\mathbf{L}^0\Delta\mathbf{A}\mathbf{L}^1 + \mathbf{L}^1\Delta\mathbf{A}\mathbf{L}^0)(\mathbf{L}^0 + \mathbf{L}^1) \\ & + (\mathbf{L}^0 + \mathbf{L}^1)(\mathbf{L}^0\Delta\mathbf{A}\mathbf{L}^1 + \mathbf{L}^1\Delta\mathbf{A}\mathbf{L}^0)\big]. \end{aligned} \tag{D.13}$$

That is, the IDN impact of changes in selected elements of the input matrix can be quantified using (D.13) by the appropriate choice of positive entries in $\mathbf{A}$ (or by summing over the corresponding elements). For example, by nullifying all intra-country input coefficients (i.e., all block diagonal input matrices), the outcome of (D.13) estimates the magnitude of the *inter*-country IDN effects.

To fully understand the country-level decomposition results, it is worthwhile to explain what exactly the negative/positive factor contributions mean. For example, a negative FDS effect for country C does not necessarily imply that only the share of final demand in gross output in country C decreased over the considered period. It could be also due to similar trends in final demand shares experienced by (direct and indirect) trade partners of C.[5] Similarly, any change in the IDN (resp. ISN) effect for country C does not only reflect the relevant direct intermediate input (resp. output) coefficients changes in C itself, but also accounts for such changes in intra- and inter-country input (resp. output) coefficients of all countries. The extent of these "hidden" impacts will depend on the size of the direct and indirect trade links of C with all other countries. In fact, this is also true for the *intra*-country ISN/IDN effect, because we consider the impact of changes in intra-country output/input coefficients for all countries simultaneously. Hence, given the trade structure, changes in output/input coefficients within one country will also have an impact on the intra-country ISN/IDN values of another country indirectly through international trade links.[6] Of course, the impact on intra-country ISN/IDN effects for all countries due

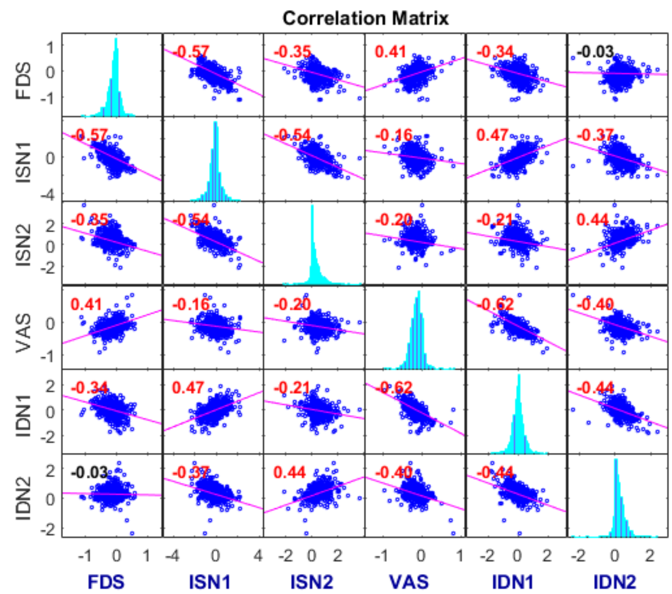
[5] Thus in interpretations of OUs/IDs in Table 1 we have "links with *similar* countries".

[6] Mathematically, all this can be explicitly seen if the relevant formulas of this Appendix D are written in partitioned matrix form (for a simple two-country setting), where the partitions refer to

to changes in output/input coefficients in only one country can be examined separately (which also holds for any other individual effect of interest), but doing such an extensive analysis falls outside the scope of the current paper.

Our SDA results indicate that, in general, all three sources of the OU and ID changes are significantly positively correlated. At the country level, the correlation between FDS and VAS, intra-country ISN and intra-country IDN, and between inter-country ISN and inter-country IDN are, respectively, equal to 0.83, 0.92 and 0.77. The respective figures for all 1,435 observations are 0.41, 0.47 and 0.44 as shown in the correlation plot illustrated in Figure D.1. It also shows that the following pairs of variables are rather strongly negatively correlated: {FDS, intra/inter-country ISN}, {VAS, intra/inter-country IDN}, {intra-country ISN, inter-country ISN} and {intra-country IDN, inter-country IDN}. Thus, on average, those sectors or countries that have positive FDS (resp. VAS) effect, tend to have lower (or more negative) intra- and inter-country ISN (resp. IDN) effects. At the same time, intra- and inter-country ISN (or IDN) are strongly negatively correlated, implying that these sources contribute, on average, very differently to the changes in OUs (or IDs). That is, for sectors or countries with strong positive inter-country ISN/IDN effects, on average, we observe smaller positive or even negative intra-country ISN/IDN effects.

Figure D.1: Correlation plot of the OU and ID determinants




*Note*: Histograms of the variables appear along the matrix diagonal; scatter plots of variable pairs appear off-diagonal. The slopes of the least-squares reference lines in the scatter plots are equal to the displayed correlation coefficients. Significant correlations are highlighted in red. For variables abbreviations see the note to Table 5.

countries. Then the results for a selected country will show that it is not only the related changes in the country in question that determine the outcome, but also the relevant changes in other countries and/or relevant inter-country changes among all countries that influence the results.