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

Miller, Ronald E.; Temurshoev, Umed

GGDC RESEARCH MEMORANDUM *133*

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

Ronald E. Miller and Umed Temurshoev

May 2013

university of groningen

groningen growth and development centre

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

Ronald E. Miller[†] Umed Temurshoev[‡]

May 3, 2013

Abstract

Using the world input-output tables available from the WIOD project (www.wiod.org), we quantify production line positions of 35 industries for 40 countries and the rest of the world region over 1996-2009. In contrast to the previous related literature we do not focus only on the output supply chain, but also consider sectors' input demand chain. 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 measure of Antràs et al. (2012) and our proposed input downstreamness measure to quantify industry relative position, respectively, along the global output supply chain and the global input demand chain. The results are examined in detail at the levels of the world, six aggregate economic branches, sectors and countries.

*We thank John Bensted-Smith, Lucian Cernat, Luís Delgado, Peter Eder, Nuno Sousa and João Rodrigues for their useful comments and suggestions. The views expressed in this paper are those of the authors and should not be attributed to the European Commission or its services.

[†]Regional Science Program (emeritus), University of Pennsylvania, Philadelphia, Pennsylvania. E-mail: remiller@sas.upenn.edu

[‡]European Commission, Joint Research Centre, Institute for Prospective Technological Studies, s/n 41092 Seville, Spain. E-mail: umed.temurshoev@ec.europa.eu

1. Introduction

Trade in intermediates has become an important issue in recent decades as nations across the world are becoming more and 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. 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., 2012).

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 (2012) model a firm's decision on whether to outsource inputs or produce them internally within the boundaries of the firm (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). 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 inputs purchases.

A sector's production line position is regarded ultimately with respect to households, government and investors (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. In this positioning also the size and complexity (i.e., existence of direct and indirect links) of the output supply network play crucial roles. Recently, 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 the Antràs et al. (2012) upstreamness indicator as "output upstreamness" (OU) measure of industries, where "output" is added to signify the fact that one is talking about industry production line position in 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 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 are buying a large amount of intermediate inputs from other firms. In this positioning also the size and complexity (i.e., existence of direct and indirect links) of the input demand chains is equally crucial. We propose an "input downstreamness" (ID) measure of industries which takes into account both these factors, 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.[1]

[1]It turns out that the ID measure presented here is (mathematically) exactly equivalent to Fally's (2012) measure of "the number of production stages embodied in each product" (p. 2). It is important to note that our work was developed entirely independently from that of Fally

Using the time series of the world input-output tables available from the EU-funded World Input-Output Database project (for details, see Timmer, ed, 2012), we compute the OU and ID measures of 35 industries for 40 countries and the rest of the world. This sheds light on the relative production line positions of sectors and countries in the global output supply and global input demand chains for the period of 1996-2009. The results are discussed in detail in the follow-up sections.

The proposed indicator of the relative production line position of industries in the input demand chain could be also quite useful in empirical studies of issues raised in the theory of the multinational firm, trade and business cycle literature, some of which are mentioned above. Another application of the OU and ID measures is related to the quantification of shared producer and consumer/worker responsibilities for generating pollution (Temurshoev and Miller, 2013). In general, both these indicators could contribute to a deeper understanding of any issue where industry production line positioning seems to be an important determinant.

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. Detailed empirical application of the OU and ID measures is carried out in Section 3 at the levels of the world, aggregate economic branches, sectors and countries. The development over time of the up/down-streamness indicators at these levels is also examined. Section 4 contains concluding remarks.

(2012), a consequence of which being different interpretations given to the same indicator in these studies. We are grateful to Thibault Fally for bringing our attention to his paper.

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 dollar 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 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

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

While the first term on the right-hand side of (1) indicates the value of industry i's *final sales*, the second term represents sector i's *direct intermediate sales* to all industries $j = 1, \ldots, n$ 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 i's output that is used in industry j's production by $b_{ij} \equiv z_{ij}/x_i$ (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 (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 (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 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 outputs, 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 (1), or from the *input demand chain* perspective which corresponds to point (ii) using the input-side accounting identity (2).

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

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

That is, since in the output supply chain (1) industry i is positioned upstream with respect to HGIs as final users, u_i in (3) quantifies industry i's average upstream position from HGIs. For this reason, Antràs et al. (2012) also refer to u_i as industry i's "average distance from final use" or "average production line position". It should be mentioned that in defining such average distance, in (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, emphasis added) is made. If u_i is large, then industry 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 assuming that $f_i \geq 0$ for all i) indicate that industry 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. That is, reasoning as for (3) but on the base of the round-by-round intermediate input decomposition (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 (2) it is clear that the shares in (4) sum up to one, as required. Since in the input demand chain (2) industry i is positioned downstream with respect to HGIs as its providers of primary inputs, d_i can be alternatively viewed as a measure of industry i's downstreamness. Note that a large value of d_i indicates that industry i is positioned rather downstream from its providers of primary inputs in the input demand chain with the majority of its inputs coming directly and indirectly from other production sectors. 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 in the input demand chain with a large share of its input coming directly from HGIs. In order not to confuse the up- and downstremness notions in connection with the output supply and the input demand chains, we refer to u_i in (3) and d_i in (4), respectively, as "output upstreamness" (OU) and "input downstreamness" (ID) measures of industry i.[2]

[2]Hence, a sector with low u_i (resp. low d_i) is an "output downstream" (resp. "input upstream") industry, where the extra term "output" (resp. "input") clarifies that industry relative position with respect to HGIs should be understood in connection with the output supply (resp. input demand) chain.

Table 1: Interpretation of the OU and ID measures

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

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 non-negligible intermediate output supply links with other industries. 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, for example, a large intermediate output supplier may provide inputs only to few domestic industries that in turn mainly produce final products); instead (3) fully captures the complexity and size of sector i's output supply network as well.

It is clear that obtaining the exact values of u_i from (3) and d_i from (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. 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 (1) in matrix form can be written as

$$\mathbf{x} = \mathbf{L}\mathbf{f}, \tag{5}$$

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 a typical entry b_{ij} and $\mathbf{v}$ be the vector of primary inputs. Then (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 zero 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 identities (5) and (7), the OU measures in (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 (8), the OU measures are exactly industries' *total forward linkages* (TFLs) – 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 industries) per stimulus euro, e.g., tax credits, than a sector with lower TFL.[3]

Similarly, using the fact that $\mathbf{I} + 2\mathbf{B} + 3\mathbf{B}^2 + \cdots = \mathbf{GG}$ and identities (6) and (7), the ID measures in (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, (9) shows that the ID measures are nothing else than the *total backward linkages* (TBLs), 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.[4]

It is clear that industries' "average distance from final use" and "average distance from primary inputs supply" become exactly equivalent to, respectively, TFL and TBL indicators because the distance between any two stages of production is assumed to be one in (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 finding av-

[3]The Ghosh IO model (6) when used in its *ex ante* causal interpretation is controversial in the IO literature. However, its use for the linkage analysis purposes underlying (8) is free from such a controversy because here it is employed strictly in its *ex post* descriptive interpretation of the input demand chain (2).

[4]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 simply "key-sectors" (Miller and Blair, 2009, pp. 559-560).

erage distance between individuals (as ultimate owners) and companies in the presence of cross-shareholding links (Dietzenbacher and Temurshoev, 2008). Understanding the aim of the use of the TFL and TBL indicators in IO analysis, what do we gain from this additional view (interpretation) 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, for example, from generating pollution. See Temurshoev and Miller (2013) for this application. For (potential) applications to the trade and business cycle literature see e.g., Alfaro and Charlton (2009); di Giovanni and Levchenko (2010); Antràs and Chor (2012); Antràs et al. (2012) and Zavacka (2012). In this paper we will simply provide the facts about the size of u_i and d_i and their development over time for 35 industries and 40 countries and the rest of the world in the next section.

Deriving the up/down-streamness measures based on a world IO table sheds light on the position of industries/countries in the global output supply and global input demand chains, both characterizing world production. Using one summary measure of the OU index and one summary measure of the ID indicator 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 up/down-streamness measures. However, this will not take into account the size of industries and/or countries in a considered IO system, particularly because different sectors/economies are highly heterogenous in terms of their economic size. Therefore, it seems reasonable to use a *weighted* average of the up/down-streamness 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 (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 (10) it does not matter whether the "average distance from final use" approach or the "average distance from primary inputs supply" 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,[5] for an *average sector solely representing the entire system* these two chains must be mirror images of each other.

3. Up/down-streamness in world production

We compute output upstreamness (OU) and input downstreamness (ID) measures using the 1996-2009 world input-output tables (WIOTs) as made available by the EU-funded World Input-Output Database project.[6] We use the WIOTs expressed in US dollars in previous year prices (in order to take the effect of price changes into account) with 35 industry classification. The input and output matrices are corrected with respect to net changes in inventories as proposed by Antràs et al. (2012). In comparison to that study, here we do not need to correct for exports and imports of final output, because WIOTs describe the entire world – a setting equivalent to a closed economy framework.

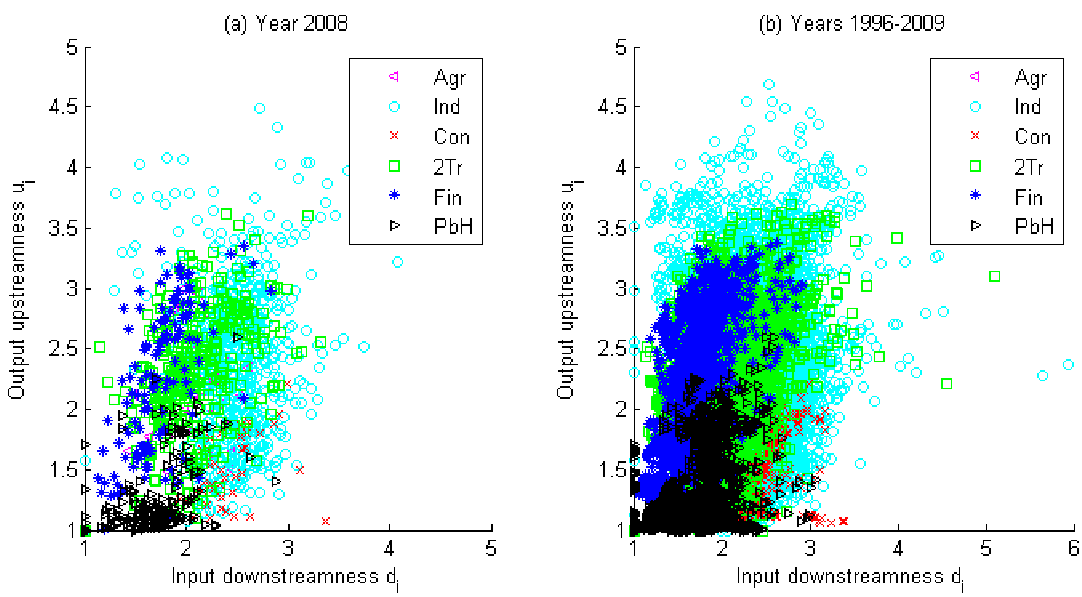
[5]That is, the IO matrix is *not* symmetric in terms of interindustry (output supply and input demand) transactions and their sizes.

[6]Apart from WIOTs, the database includes time series of (inter)national supply and use tables and various socio-economic and environmental accounts for 40 major economies and the rest of the world at the level of 35 industries and 59 products (for details, see Timmer, ed, 2012).

3.1. Global results

Figure 1 shows the relationship between the OU u_i and ID d_i measures of 1,435 ($= 35$ sectors $\times$ 41 regions) observations for the year of 2008 in subplot (a) and of 20,090 ($= 1,435 \times 14$ years) pairs of (u_i, d_i) for all years 1996-2009 in subplot (b).[7] The first important observation that we find from these scatterplots is that u_i and d_i 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 20,090 pairwise observations is 0.40, with all coefficients being highly statistically significant.

Figure 1: Scatterplots of the OU and ID measures



Note: Sectors' abbreviations "Agr", "Ind", "Con", "2Tr", "Fin" and "PbH" stand, respectively, for "Agriculture; fishing", "Industry, except construction", "Construction", "Wholesale and retail trade; hotels and restaurants; transport", "Financial intermediation; real estate" and "Public administration and community services; activities of households".

It might seem surprising that an upstreamness indicator would be positively associated with a downstreamness indicator as their (partial) labels suggest the contrary. However, recall that here we are looking at two different chains: u_i

[7] The data including all these indicators is available upon request from the authors.

characterizes the upstream position of industry i in the global output supply chain, while d_i quantifies the downstream position of industry i in the global input demand chain. And since both relative positions are examined ultimately with respect to households, government and investors (HGIs), the observed positive association simply indicates that a sector that is close to (resp. far away from) HGIs as its final users turns out to be, *on average*, also close to (resp. far away from) HGIs as its providers of primary inputs. Alternatively, sectors with a high (resp. low) proportion of direct final use of their gross outputs, on average, turn out to have significant (resp. low) share of primary inputs in their total inputs.

In Figure 1, however, we also distinguish between six broad categories, which correspond to the six-branch classification used by Eurostat. These are identified in the note to Figure 1 and their correspondence with the WIOD 35-industry classification is given in Appendix 1. Thus, the second observation made from these scatterplots is that, in general, "Public administration and community services; activities of households" (PbH) and "Financial intermediation; real estate" (Fin) are positioned closer to HGIs than the "Industry, except construction" (Ind) branch.

Further, if we had drawn the least-squares (LS) lines fitting the scatterplots of all six branches separately and compared them with the 45-degree line (these are not shown in Figure 1), we would have found that the LS line for Fin sectors is always higher than the 45-degree line, the LS lines for PbH and "Construction" (Con) sectors are always lower than the 45-degree line (even with much flatter slopes), and those of the other three branches intersect the 45-degree line from its top-left side within the range of $[2, 3]$ (mostly closer to 2.5) of both u_i and d_i. This implies that sectors making up Fin 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 sectors. This relative picture arises because generally primary inputs are a larger proportion of the total inputs of financial intermediation and real estate activities (Fin) if compared to the share of final outputs in total outputs of these industries, while the reverse situation holds for sectors making up the PbH and Con branches.

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

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
$\overline{u}$, $\overline{d}$	1.964	1.973	1.965	1.964	1.984	1.981	1.964	1.978	1.999	2.035	2.075	2.111	2.130	2.116
MeanU	2.060	2.069	2.053	2.057	2.080	2.084	2.073	2.086	2.101	2.108	2.126	2.146	2.155	2.125
MeanD	2.053	2.046	2.048	2.050	2.067	2.084	2.075	2.095	2.098	2.105	2.137	2.166	2.179	2.120
MaxU	4.107	4.112	4.162	4.128	3.998	4.087	4.093	4.224	4.310	4.424	4.546	4.694	4.485	4.549
MaxD	3.991	3.652	5.645	4.323	5.103	4.548	3.638	4.024	5.935	4.122	3.805	4.457	4.084	4.432
StdU	0.626	0.627	0.623	0.619	0.627	0.631	0.631	0.647	0.662	0.685	0.718	0.747	0.755	0.767
StdD	0.419	0.422	0.414	0.403	0.408	0.417	0.415	0.431	0.443	0.462	0.498	0.530	0.543	0.555

Note: $\overline{u}$ and $\overline{d}$ are the gross output-weighted averages of u_i and d_i, respectively. MeanU and MeanD (resp. MaxU and MaxD) are (unweighted) arithmetic averages (resp. maximum values) of u_i and d_i, respectively. The minimums are not reported as they all equal unity. StdU and StdD are the standard deviations of u_i and d_i, respectively, using sectors' gross output shares as weights.

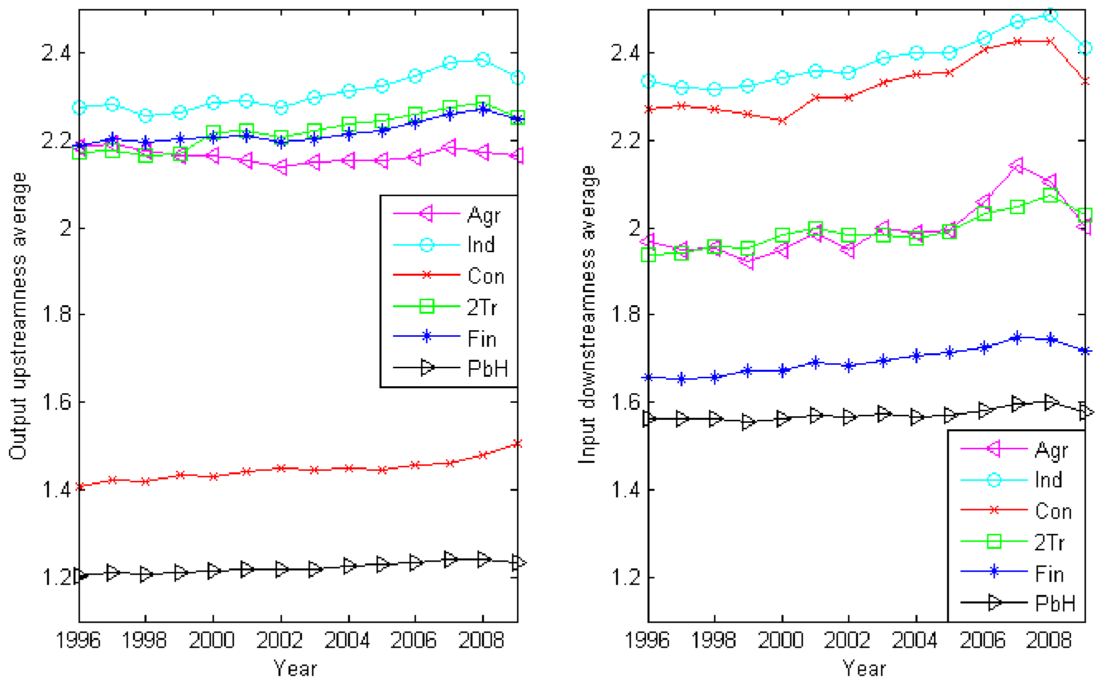
In Table 2 we provide a summary of the up/down-streamness indicators for all 14 years. The world output-weighted average of the OU/ID measure, $\overline{u} = \overline{d}$, (see Proposition 1) was 1.96 in 1996 and increased to 2.12 in 2009. However, the rounded $\overline{u}$'s imply that the average position of the *average industry* in the world production processes remained remarkably stable over the considered period. That is, the average industry in the global output supply chain is positioned roughly one stage away from final outputs use and, similarly, the average industry in the global input demand chain is positioned roughly one stage away from primary inputs supply. This is also true if we consider the unweighted averages of u_i and d_i, also reported in Table 2. Given that in Table 2 the unweighted means of u_i and d_i are always strictly larger than their weighted counterparts $\overline{u} = \overline{d}$, it follows that those industries having largest u_i and d_i are generally small sectors with low gross outputs/inputs.

Standard deviations of u_i and d_i, reported in Table 2, were calculated using the sectoral output shares in the world gross output as weights, and range between [0.62, 0.78] and [0.40, 0.58], respectively.[8] The ratio of the relative stan-

[8]For the OU u_i of 426 US industries in 2002, Antràs et al. (2012) report the average of 2.06 with

dard deviation (RSD, coefficient of variation) of u_i relative to the RSD of d_i over the considered years ranges from 1.37 to 1.45. Therefore, the OU measures are relatively more disperse across industries and/or countries than the ID measures.

Figure 2: Simple averages of the OU and ID measures by branch



Note: For abbreviations see the note to Figure 1.

In Figure 2 we show the simple arithmetic averages of the OU and ID indicators at the world level for each branch separately, from which the following observations are drawn.

1. According to both the OU and ID measures, the branch Ind (resp. PbH) consistently for all years is positioned farthest away from (resp. closest to) HGIs in the world output and input production chains.

a standard deviation of 0.85. The unweighted average and standard deviation for 2002 for the entire world are similar and equal 2.07 (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.

2. Consistently over the considered period, the construction branch ranks fifth according to the OU measure, but is the second largest ID branch.
3. The financial intermediation and real estate branch consistently ranks fifth according to the ID measure.
4. Three branches, Agr, 2Tr and Fin, are always positioned closer to Ind and have similar size and development patterns of their OU measures.
5. 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

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

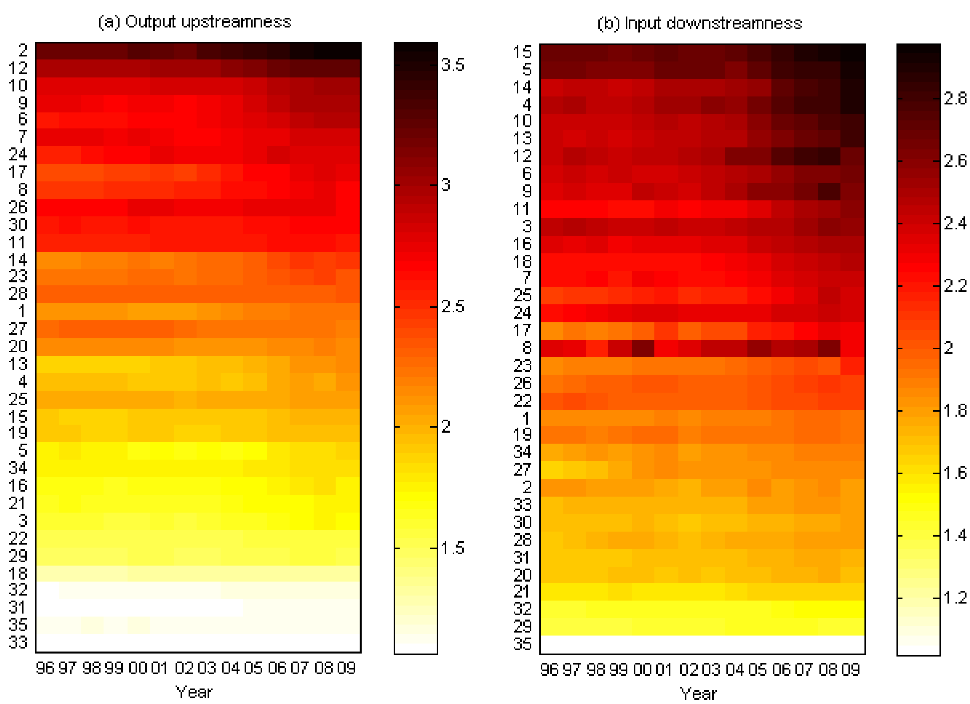
$$\text{Ind} \Leftarrow \text{Con} \Leftarrow\Longleftarrow \text{Agr, 2Tr} \Leftarrow\Longleftarrow \text{Fin} \Leftarrow \text{PbH} \Leftarrow\Longleftarrow\Longleftarrow \textbf{HGIs} \tag{12}$$

where the cumulative lengths of the arrows between the branches or between a branch and HGIs indicate the relative length roughly representing the values of the OU and ID averages illustrated in Figure 2. For example, we see that the distance between PbH and HGIs in the output supply chain (11) is much shorter than that in the input demand chain (12), because the corresponding OU and ID averages are approximately 1.2 and 1.6, respectively, for all years. All in all, the chains in (11) and (12) give the average picture of the positions of the considered branches in the world production processes in the period of 1996-2009.

3.2. Sector-specific results

Since individual sectors and countries could be quite heterogeneous with respect to their production structures, we now zoom in further and consider sector-specific OU and ID positions in the corresponding global production chains in this section and country-specific positions in the following section. Figure 3 presents the colormaps of the output-weighted OU and ID measures for each sector over the period of 1996-2009.[9] Industries are ordered according to the ranking of their weighted OU and ID measures for 2009. We find that in the global output supply chain the most upstream sector for all years is Mining and quarrying (WIOD code: 2) which had an OU measure of 3.23 in 1996 that has increased to 3.59 by 2009. Basic metals and fabricated metal (12) and Rubber and Plastics (10) consistently show, respectively, the second and third largest OU measures (the OU was 2.99 in 1996 and increased to 3.26 by 2009 for sector 12, and the corresponding numbers for sector 10 are 2.78 and 3.04, respectively).

Figure 3: Colormaps of the sector-specific OU and ID measures



If we take the arithmetic mean of the sector-specific OU measures, visualized in Figure 3, over the 14 considered years, the findings are as follows.

[9]For country and sector codes see Appendix 1. The sector-specific weighted OU and ID measures are derived as the weighted averages of, respectively, u_i's and d_i's of each sector across all countries with the corresponding country output shares as weights. This allows us to take into account countries' sizes in computing the OU and ID measures for each sector. For mathematical details of these indicators, see Appendix 2.

1. Twelve sectors are positioned roughly *two stages* away from final output use in the global output supply chain (i.e., their approximate OU measure is 3). These industries are (in descending order of their OU measures): Mining and quarrying; Basic metals and fabricated metal; Rubber and plastics; Chemicals and chemical products; Wood and products of wood and cork; Pulp, paper, printing and publishing; Water transport; Electricity, gas and water supply; Coke, refined petroleum and nuclear fuel; Other supporting and auxiliary transport activities, activities of travel agencies; Renting of machinery and equipment and other business activities; Other non-metallic mineral.
2. Five sectors have the lowest OU measure of roughly unity for all years, hence provide essentially all their outputs directly to HGIs. These are (in ascending order of their OU measures): Health and social work; Private households with employed persons; Public administration and defence, compulsory social security; Education; Construction.
3. The remaining 18 sectors represent the picture of the average industry position mentioned earlier: they are all positioned roughly one stage away from final outputs use in the global output supply chain.

We earlier found Industry to be the most upstream branch in the output supply chain (11) because it turns out that 75% of the sectors with the largest OU measures of approximately 3 (i.e., 9 of 12) come from this branch. The remaining three sectors with the highest OU measures, mentioned in the first point above, include two sectors from the 2Tr branch and one sector from the Fin branch. 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 – 38.9% (7 sectors), 2Tr – 38.9% (7), Fin – 11.5% (2), Agr – 5.6% (1), and PbH – 5.6% (1).

The second subplot of Figure 3 shows that Transport equipment (code: 15) was the most downstream sector in the global input demand chain for all years. Its ID measure was 2.69 in 1995 and rose to 2.98 by 2009. There is, however, no consistent ranking of all other sectors according to their ID measures for all years, except for the four least input downstream industries (i.e., sectors 21, 32, 29 and 35). Taking the mean of the sector-specific ID measures over the 14 years, we find the following.

1. Seven sectors – Transport equipment, Leather and footwear, Electrical and optical equipment, Textiles and textile products, Rubber and plastics, Machinery, and Basic metals and fabricated metal – are positioned roughly *two stages* away from primary input supply in the global input demand chain (i.e., their approximate ID measure is 3).
2. Three sectors have the lowest ID measures of roughly unity for all years, hence purchase almost all their inputs directly from HGIs. These are Private households with employed persons (its average ID measure: 1.03), Real estate activities (1.43) and Education (1.47).
3. The remaining 25 sectors represent the picture of the average industry position mentioned earlier: in the global input demand chain they are all positioned roughly one stage away from primary inputs supply.

These observations also explain the more aggregate picture of the input demand chain given in (12). That is, all seven sectors with ID measure of 3 come from the Ind branch, while the distribution of 25 sectors with the average OU 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).

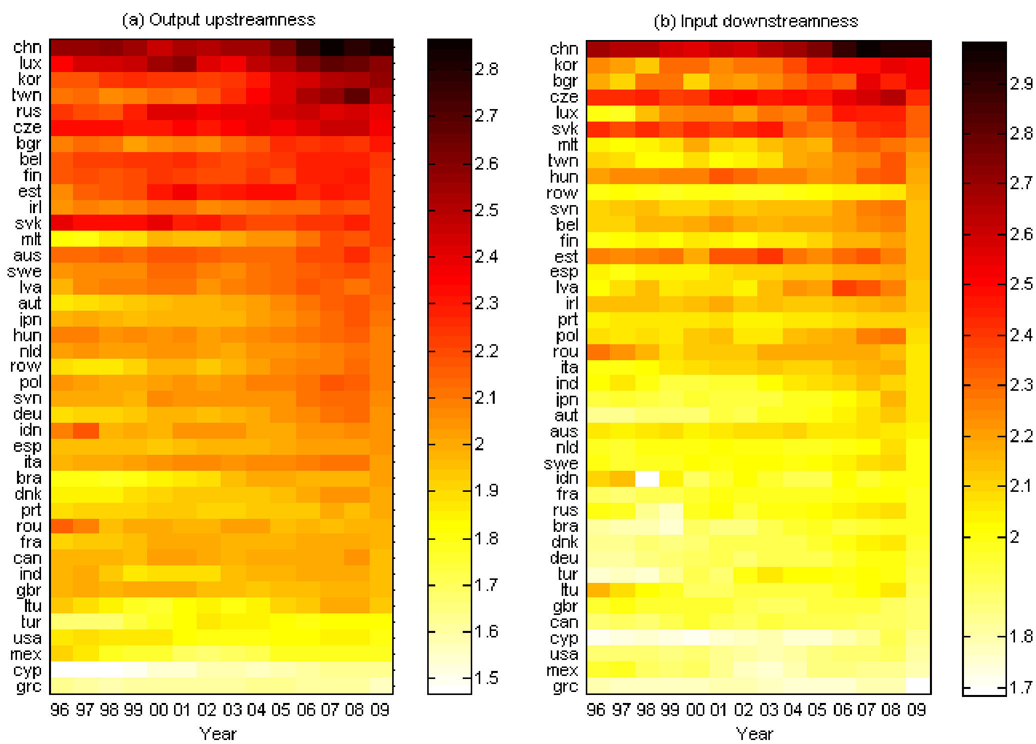
3.3. Country-specific results

Figure 4 presents the colormaps of the country-specific weighted OU and ID measures over the period, where countries are ordered according to their 2009 OU and ID rankings.[10] According to both measures, in all years, except for 2000

[10]The country-specific weighted OU and ID measures are derived as the weighted averages of, respectively, u_i's and d_i's of each country across all its sectors with the corresponding sectoral output shares as weights. This allows us to take into account sectors' sizes in computing the OU and ID measures for each country. For mathematical details of these indicators, see Appendix 2.

and 2001 OU measures, China was furthest away from HGIs in the global output supply chain. On the contrary, countries closest to HGIs in the output supply chain are Cyprus and Greece. According to the (rounded) overall average of the OU measures over the entire period, only two countries, namely China and Luxembourg, are positioned two stages away from HGIs as final output users, while all the rest have an average OU measure of 2. However, to observe the change over time, in 1996 the list of countries with the largest OU measure of 3 included only China, but by 2008 (pre-crisis year) three additional countries, namely, Luxembourg, Korea and Taiwan joined this ‘top’ list.

Figure 4: Colormaps of the country-specific OU and ID measures



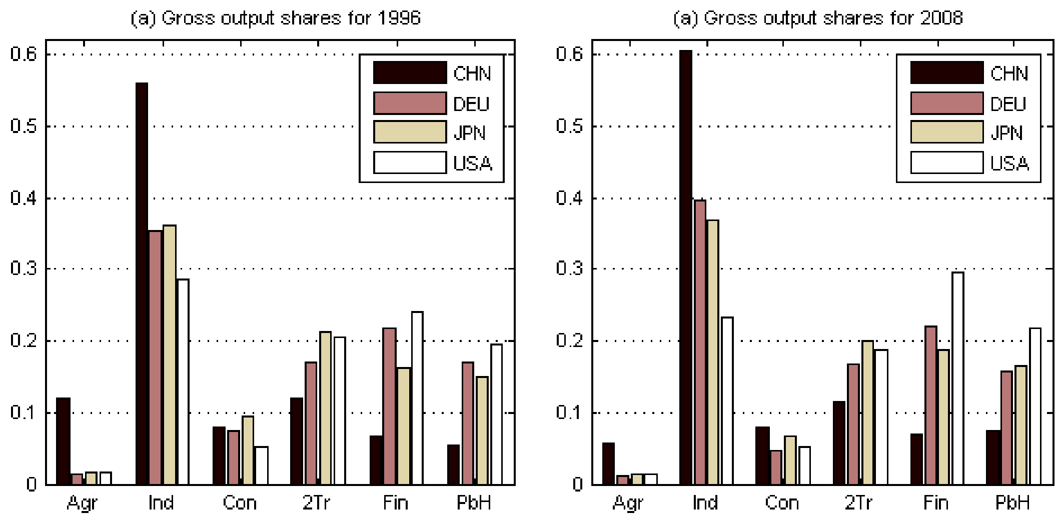
In the global input demand chain China consistently shows the largest ID measure, which was equal to 2.68 in 1996 and has increased to 2.93 by 2009. If we consider the average of the ID measures over 1996-2009, only China is positioned two stages away from HGIs as providers of primary inputs, while all other countries have the (rounded) average ID measure of 2 that represents the picture of the average country position in the global input demand chain. To see the change over time, while in 1996 only China had the largest ID measure of 3, in 2008 we have three such countries: China, Korea and Czech Republic.

Recalling the interpretation of the OU measure (3) given in Table 1, countries like China, Luxembourg, Korea, Taiwan, Russia and Czech Republic, should have (a) large share of intermediate output (or small share of final demand) in their gross outputs, and (b) highly interlinked and significant *intermediate output supply* links with other countries. On the contrary, countries like Greece, Cyprus, Mexico, USA and Turkey with the lowest average OU measures should have a relatively larger share of final output in their gross output and less interlinked intermediate output supply relations globally with other countries. One could also say that countries with the highest OU measures (i.e., listed in the top part of the first subplot of Figure 4) are mainly "specialized" in producing and selling goods of primary and/or secondary sectors with high OU indicators (i.e., those taking the top positions in the first subplot of Figure 3), while those with the lowest OU measures are "specialized" in sectors that are rather downstream along the supply chain (e.g., services). This is confirmed in Figure 5 for China, Germany, Japan and the USA as the four big economies of the world.

We observe that in China the share of Industry's gross output in total output was 56% in 1996 and increased further to 61% in 2009. Industry share in Germany, Japan and the USA was also largest in 1996, but its size was much lower ranging between 29% to 36%, hence leaving more room for other sectors with lower OU measures. Alternatively, while the share of PbH as the most downstream branch in the output supply chain in 1996 for China was only 5.4%, the corresponding figures for Germany, Japan and the USA were 16.9%, 15.0% and 19.6%, respectively. All these numbers for 2008 are 7.4%, 15.8%, 16.4% and 21.8%, 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.[11]

[11]Apparently, the absolute values of the economy-wide gross output matter. Normalizing

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



Similarly, sectors with high ID measures, listed in the top part of the second subplot of Figure 3, should have a rather large contribution to the gross outputs of countries with the largest ID measures, i.e., those listed in the top part of the second subplot of Figure 4. Again given the interpretation of the ID measure (4) in Table 1, countries with large ID measures like China, Korea, Bulgaria, Czech Republic, Luxembourg and Slovak Republic should have a large share of intermediate inputs (or a small share of value added) in their gross inputs, and highly interlinked *intermediate input demand* links with other countries. On the contrary, countries like Greece, Mexico, USA, Cyprus and Canada with the lowest average ID measures should generally have a relatively large share of value added in their gross inputs and rather less interlinked intermediate input demand relations with other countries.[12] Here again Figure 5 can explain part of

these numbers with respect to the Chinese total produces the following distributions of the normalized gross outputs, respectively, for China, Germany, Japan and the USA: (1, 2.07, 4.79, 6.65) for 1996, and (1, 0.52, 0.69, 2.14) for 2009. Hence, in terms of gross output while in 2009 the US was still producing more than double that of China, Germany and Japan were already lagging behind China.

[12]The observation that Canada, Mexico and the US are in similar positions according to both OU and ID measures also reflects the fact that these countries trade much more heavily among themselves than with any other WIOD countries. Baldwin and López-González (2012) term

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 2008 we observe that Fin is already contributing the most to its economy-wide output with the output share of 29.6% as opposed to 23.3% of Industry (PbH has the third largest share of 21.8%). All these facts contribute to the input upstream position of the USA as illustrated in Figure 4.

Since in Figure 4 the country-specific OU/ID measures 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 OU/ID indicators, it is interesting to see the country positions, similar to those illustrated in Figure 4, but considering *only* sectors in the Ind branch. The corresponding country-specific OU and ID measures for the Industry branch only are reported in Appendices 3 and 4, respectively, which we refer to as "country-specific Industry OU/ID measures".[13] As might be expected, we observe more heterogeneity across countries compared to that seen in Figure 4. In particular, while on average over 1996-2009 the number of countries with the largest OU (resp. ID) measure of 3 was only 2 (resp. 1) in the *overall* picture of Figure 4, now with a focus only on Industry it is much larger and equals 9 (resp. 14). Thus, the information in Appendices 3 and 4 show us exactly which countries mainly represent Industry and make it the most distant branch from HGIs.

The information in Appendices 3 and 4 is summarized in Table 3. To show the change over time we choose the years 1996 and 2008. The last year instead of 2009 is considered because this would allow us to take into account the fact that due to the global financial crisis the extent of international trade in intermediates and final goods largely decreased in 2009. The crisis turns out to have a dramatic effect on the input demand chain links in Industry, as the number of

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).

[13]That is, for each country these are weighted averages of OU/ID measures 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.

Table 3: Countries according to their Industry OU/ID measures

	OU≈3	OU≈2
	(a) 1996	
ID≈3	CHN, CZE, KOR, SVK	BGR, EST, HUN, MLT, ROU, TWN
ID≈2	AUS, FIN, LUX, RUS	The rest of the countries
	(b) 2008	
ID≈3	AUT, CHN, CZE, FIN, JPN, KOR, LUX, TWN	BEL, BGR, ESP, EST, FRA, HUN, IND, ITA, LVA, MLT, POL, PRT, SVK, SVN
ID≈2	AUS, RUS, RoW	The rest of the countries

countries with the largest Industry ID measures decreased from 22 in 2008 to 14 in 2009 (see Appendix 4). From Table 3 we observe that the number of countries with the largest Industry OU and ID measures of 3 increases from 4 in 1996 to 8 in 2008. Here Asia is represented by China, Japan, Korea and Taiwan (main players of Factory Asia as defined in Baldwin and López-González (2012)), and Europe by Austria, Czech Republic, Finland and Luxembourg. Note that Australia and Russia also have the largest Industry OU measure of 3, but their Industry ID measure is smaller and equals 2. This could be explained by the fact that these two countries are rich in natural resources, and hence are the main suppliers of natural resources to, at least, their neighboring nations.[14] From the input side, we also observe that 13 European countries and India in 2008 have Industry OU and ID measures of, respectively, 2 and 3, i.e., these nations are involved in more complex network of Industry goods purchase rather than sale. Note that Germany is closer in terms of its output and input structure to the US, both having an Industry OU/ID measure of 2.

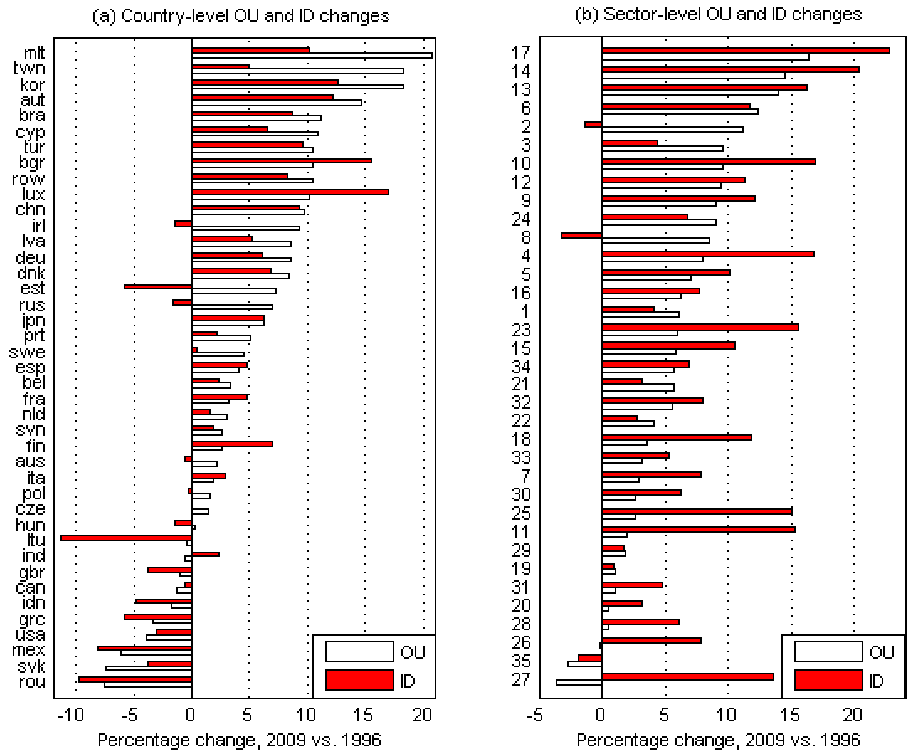
[14]One could also expect the OPEC countries to have patterns of the OU/ID indicators similar to those of Australia and Russia. These countries, however, are not separately included in the WIOD database. This expected similarity is partially shown by the fact that from 2004 and onwards the rest of the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

3.4. Changes in the up/down-streamness measures

The percentage changes of the country- and sector-specific OU and ID measures in 2009 relative to 1996 are presented in Figure 6. We observe that the overwhelming majority of countries and sectors have experienced an increase in their OU and ID indicators, which implies that over time the size of intermediate output and input interactions across countries and sectors increased and the corresponding linkages became more complex. This simply shows the continuing pace of the "second unbundling" where international competition operates at the level of stages of production that are being offshored to lower cost locations (Baldwin, 2006). Countries with the largest increase of at least 9% in their OU measures include (percentage changes are given in parentheses): Malta (20.8), Taiwan (18.3), Korea (18.3), Austria (14.7), Brazil (11.2), Cyprus (10.9), Turkey (10.5), Bulgaria (10.5), Rest of the World (10.4), Luxembourg (10.2), China (9.7) and Ireland (9.3). From these countries Austria, Bulgaria, China, Korea, Luxembourg, Malta and Turkey also experienced an increase in their ID measures of at least 9%. Hence, compared to 1996, in 2009 the production positions of these countries became more distant from final output users and/or primary inputs suppliers. We see the reverse trend for Indonesia, Greece, USA, Mexico, Slovak Republic and Romania. Estonia became more distant from its final output users, but closer to its primary inputs suppliers.

Without going into further details, from Figure 6 we observe that Electricity, gas and water supply (code: 17) and Electrical and optical equipment (14) have shown the largest increase in both of their OU and ID measures. The respective figures for sector 17 are 16.3% and 22.8%, and for sector 14 are 14.4% and 20.3%. On the contrary, only Private households with employed persons (35) shows a decrease in both its OU and ID measures of -2.7% and -1.9%, respectively. Post and telecommunications (27) became closer to final users (its OU changes by -3.6%), while much more distant from providers of primary inputs (its ID increases by 13.5%). The largest number of sectors experiencing the largest increase in their up- and down-streamness measures are observed along

Figure 6: Changes in the OU and ID measures, 2009 vs. 1996 (in %)



the input demand chain: while 15 sectors' ID measure increase by at least 10%, there are only five industries that experience a change in their OU measures 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: 91.4% of industries experienced positive changes in their output-weighted OU and ID measures. If we take the entire sample of 1,435 observations for years 1996 and 2009, we find that 60.5% of all 1,435 OU indicators and 63.1% of all ID measures increased in 2009 relative to their 1996 values. The corresponding figures are 67.7% and 72.3%, respectively, if we choose instead of 2009 the pre-crisis year of 2008.

4. Concluding remarks

In this paper we have examined industries' positions in the global production chain, ultimately relative to households, government 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, if a production chain is seen from the perspective of producers. These two chains are generally different, because at the sectoral level the output structure is not equivalent 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 because ultimately both sides are an essential part of the entire production process.

We quantified the relative positions of industries in the global output supply and the global input demand chains using the 1996-2009 time series of the world input-output tables available from the WIOD database that covers 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 outputs 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, trade in intermediates is 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 1996-2009.

- In terms of sectors, the Industry (resp. Public administration and activities of households) branch is positioned furthest away from (resp. closest to) HGIs. (Further details on finer sectoral disaggregation is given in the text.)

- China consistently occupies the most upstream (resp. downstream) position in the global output supply (resp. input demand) chain.

- By 2008 'Factory Asia' (i.e., China, Japan, Korea and Taiwan), Austria, Czech Republic, 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 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.

Finally we expect that the indicator of relative position of industries in the input demand chain, proposed in this paper, could be useful in empirical studies of issues where accounting for producing entities' positions with respect to the HGIs seems important. Such topics may include (but are not limited to) the determinants of the boundaries of the modern (multinational) firm, transmission of final demand shocks, and shared producer and consumer/worker responsibility for generating pollution.

References

Alfaro, Laura and Andrew Charlton, "Intra-industry foreign direct investment," *American Economic Review*, 2009, *99*, 2096–2119.

Antràs, Pol and Davin Chor, "Organizing the Global Value Chain," 2012. NBER Working Paper No. 18163.

— , — , Thibault Fally, and Russell Hillberry, "Measuring the upstreamness of production and trade flows," *American Economic Review: Papers and Proceedings*, 2012, *102*, 412–416.

— , Luis Garicano, and Esteban Rossi-Hansberg, "Offshoring in a Knowledge Economy," *Quarterly Journal of Economics*, 2006, *121*, 31–77.

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

— and Javier López-González, "Supply-chain trade: A portrait of global patterns and several testable hypothesis," 2012. Mimeo.

Burstein, Ariel, Christopher Kurz, and Linda Tesar, "Trade, production sharing, and the international transmission of business cycles," *Journal of Monetary Economics*, 2008, *55*, 775–795.

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

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

— and Umed Temurshoev, "Ownership relations in the presence of cross-shareholding," *Journal of Economics*, 2008, *95*, 189–212.

— , Isidoro Romero, and Niels Bosma, "Using average propagation lengths to identify production chains in the Andalusian economy," *Estudios de Economía Aplicada*, 2005, *23*, 405–422.

Fally, Thibault, "Production staging: Measurement and facts," 2012. Mimeo, University of Colorado-Boulder.

Ghosh, Ambica, "Input-output approach to an allocative system," *Economica*, 1958, *25*, 58–64.

Hummels, David, Jun Ishii, and Kei-Mu Yi, "The nature and growth of vertical specialization in world trade," *Journal of International Economics*, 2001, *54*, 75–96.

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

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

Jones, Ronald W. and Henryk Kierzkowski, "The role of services in production and international trade: A theoretical framework," in Ronald W. Jones and Anne Krueger, eds., *The Political Economy of International Trade*, Oxford: Basil Blackwell, 1990, pp. 31–48.

Koopman, Robert, William Powers, Zhi Wang, and Shang-Jin Wei, "Give credit where credit is due: Tracing value added in global production chains," 2011. NBER Working Paper No. 16426, Revised September 2011.

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

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

Miller, Ronald E. and Peter D. Blair, *Input-Output Analysis: Foundations and Extensions*, 2nd ed., Cambridge: Cambridge University Press, 2009.

Temurshoev, Umed and Ronald E. Miller, "Distance-based shared responsibility," 2013. Mimeo.

Timmer, Marcel, Bart Los, Robert Stehrer, and Gaaitzen de Vries, "Fragmentation, incomes and jobs. An analysis of European competitiveness," 2012. WIOD Working Paper No. 9.

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

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

Appendix 1: 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; fishing
Ind	2-17	Industry, except construction
Con	18	Construction
2Tr	19-27	Wholesale and retail trade; hotels and restaurants; transport
Fin	28-30	Financial intermediation; real estate
PbH	31-35	Public administration and community services; activities of households

Appendix 2: 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

$$x_s^{tot} = \sum_c x_s^c \quad \text{for each sector } s, \tag{A1}$$

$$x_{tot}^c = \sum_s x_s^c \quad \text{for each country } c. \tag{A2}$$

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

$$\overline{u}_s = \sum_c u_s^c \frac{x_s^c}{x_s^{tot}} \quad \text{for each sector } s, \tag{A3}$$

$$\overline{u}^c = \sum_s u_s^c \frac{x_s^c}{x_{tot}^c} \quad \text{for each country } c. \tag{A4}$$

Changing all u's in (A3) and (A4) 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 (A3)-(A4) 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.,*

$$\overline{u} = \overline{d} = \sum_s \overline{u}_s \frac{x_s^{tot}}{x^w} = \sum_s \overline{d}_s \frac{x_s^{tot}}{x^w} = \sum_c \overline{u}^c \frac{x_{tot}^c}{x^w} = \sum_c \overline{d}^c \frac{x_{tot}^c}{x^w}. \tag{A5}$$

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 (A3) 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 (A5) can be proved in the same way. *QED.*

Appendix 3: Country-specific Industry OU measures

Cnt.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean
AUS	2.51	2.52	2.53	2.50	2.55	2.57	2.53	2.53	2.55	2.58	2.75	2.78	2.87	2.74	3
AUT	2.14	2.18	2.19	2.20	2.22	2.25	2.23	2.26	2.32	2.36	2.42	2.46	2.53	2.53	2
BEL	2.24	2.28	2.25	2.29	2.32	2.31	2.27	2.25	2.28	2.31	2.39	2.42	2.42	2.36	2
BGR	2.31	2.31	2.30	2.24	2.39	2.36	2.27	2.34	2.37	2.52	2.39	2.45	2.45	2.49	2
BRA	2.10	2.11	2.11	2.13	2.17	2.20	2.23	2.31	2.32	2.32	2.31	2.30	2.29	2.35	2
CAN	2.33	2.33	2.29	2.23	2.28	2.31	2.30	2.29	2.32	2.37	2.40	2.42	2.48	2.38	2
CHN	2.91	2.88	2.94	2.91	2.84	2.91	2.89	2.94	2.94	3.01	3.15	3.26	3.13	3.23	3
CYP	1.64	1.67	1.68	1.75	1.81	1.81	1.83	1.81	1.80	1.84	1.93	2.00	1.99	1.98	2
CZE	2.54	2.52	2.48	2.46	2.43	2.46	2.43	2.46	2.50	2.49	2.54	2.55	2.55	2.46	2
DEU	2.06	2.07	2.07	2.06	2.12	2.11	2.10	2.11	2.15	2.17	2.23	2.26	2.29	2.24	2
DNK	1.94	1.97	1.95	1.99	2.04	2.05	2.05	2.04	2.09	2.11	2.20	2.25	2.27	2.20	2
ESP	2.23	2.21	2.19	2.21	2.23	2.28	2.30	2.32	2.35	2.38	2.42	2.42	2.44	2.45	2
EST	2.14	2.18	2.20	2.20	2.37	2.36	2.32	2.35	2.37	2.43	2.40	2.46	2.48	2.34	2
FIN	2.59	2.60	2.56	2.60	2.64	2.63	2.60	2.62	2.68	2.63	2.69	2.70	2.74	2.68	3
FRA	2.10	2.12	2.11	2.14	2.19	2.19	2.17	2.13	2.16	2.17	2.22	2.22	2.23	2.22	2
GBR	2.18	2.19	2.16	2.19	2.19	2.22	2.18	2.16	2.18	2.20	2.22	2.25	2.24	2.21	2
GRC	1.85	1.86	1.84	1.84	1.88	1.92	1.89	1.91	1.95	1.95	1.90	1.91	1.85	1.82	2
HUN	2.23	2.20	2.16	2.13	2.12	2.16	2.13	2.19	2.23	2.23	2.25	2.22	2.25	2.20	2
IDN	2.36	2.46	2.23	2.32	2.26	2.36	2.37	2.33	2.31	2.34	2.43	2.44	2.45	2.42	2
IND	2.25	2.31	2.25	2.17	2.21	2.24	2.22	2.30	2.30	2.29	2.29	2.30	2.34	2.28	2
IRL	2.02	2.09	2.09	2.13	2.18	2.17	2.06	2.13	2.16	2.17	2.19	2.26	2.25	2.30	2
ITA	2.15	2.17	2.15	2.17	2.20	2.21	2.21	2.21	2.23	2.25	2.28	2.31	2.33	2.22	2
JPN	2.45	2.45	2.42	2.39	2.44	2.44	2.45	2.47	2.55	2.58	2.64	2.70	2.73	2.71	3
KOR	2.59	2.60	2.67	2.65	2.60	2.63	2.63	2.66	2.78	2.92	2.98	3.04	3.10	3.15	3
LTU	2.11	2.08	2.05	1.95	1.93	2.00	1.99	1.99	2.01	2.08	2.14	2.22	2.21	2.08	2
LUX	2.62	2.61	2.56	2.64	2.62	2.58	2.54	2.51	2.54	2.52	2.64	2.69	2.76	2.69	3
LVA	2.14	2.21	2.21	2.26	2.24	2.22	2.21	2.29	2.30	2.37	2.43	2.42	2.38	2.38	2
MEX	2.15	2.10	2.01	1.96	1.97	1.92	1.91	1.94	1.99	2.07	2.07	2.09	2.10	2.12	2
MLT	2.06	2.03	2.14	2.17	2.27	2.19	2.18	2.26	2.30	2.29	2.39	2.47	2.46	2.48	2
NLD	2.22	2.24	2.22	2.22	2.22	2.24	2.22	2.22	2.26	2.29	2.33	2.38	2.40	2.37	2
POL	2.28	2.21	2.16	2.12	2.25	2.27	2.26	2.28	2.31	2.29	2.32	2.39	2.36	2.29	2
PRT	2.09	2.11	2.11	2.14	2.17	2.18	2.16	2.16	2.19	2.23	2.25	2.34	2.28	2.35	2
ROU	2.41	2.32	2.21	2.25	2.29	2.22	2.25	2.29	2.29	2.20	2.21	2.25	2.25	2.24	2
RUS	2.69	2.64	2.63	2.67	2.75	2.82	2.79	2.81	2.89	2.94	3.00	2.96	3.00	3.02	3
SVK	2.76	2.55	2.54	2.47	2.57	2.39	2.41	2.36	2.33	2.38	2.42	2.36	2.44	2.37	2
SVN	2.14	2.13	2.13	2.12	2.24	2.23	2.21	2.25	2.25	2.27	2.31	2.34	2.36	2.27	2
SWE	2.29	2.29	2.25	2.24	2.30	2.31	2.27	2.25	2.31	2.33	2.35	2.39	2.43	2.40	2
TUR	1.82	1.85	1.86	1.90	1.95	1.99	2.03	2.04	2.01	1.99	1.99	2.00	2.01	2.08	2
TWN	2.42	2.45	2.38	2.40	2.47	2.47	2.55	2.65	2.77	2.87	3.03	3.07	3.21	3.10	3
USA	2.25	2.25	2.22	2.20	2.19	2.15	2.13	2.12	2.12	2.16	2.17	2.21	2.25	2.16	2
RoW	2.30	2.27	2.28	2.33	2.44	2.44	2.41	2.48	2.55	2.63	2.68	2.71	2.80	2.73	3
OU≈3	8	8	7	5	7	6	7	7	9	10	10	10	11	10	9
OU≈2	33	33	34	36	34	35	34	34	32	31	31	31	30	31	32

Note: "Cnt." stands for country. "Mean" is the rounded arithmetic average of the OU measures over 1996-2009. "OU≈3" and "OU≈2" indicate the number of countries with the rounded OU measure of, respectively, 3 and 2.

Appendix 4: Country-specific Industry ID measures

Cnt.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Mean
AUS	2.30	2.26	2.28	2.32	2.31	2.29	2.31	2.33	2.41	2.33	2.26	2.28	2.27	2.28	2
AUT	2.15	2.14	2.20	2.18	2.18	2.26	2.26	2.34	2.35	2.37	2.45	2.50	2.56	2.47	2
BEL	2.40	2.40	2.49	2.50	2.54	2.55	2.52	2.54	2.58	2.57	2.64	2.69	2.70	2.43	3
BGR	2.60	2.36	2.70	2.70	2.33	2.48	2.47	2.54	2.62	2.66	2.47	2.87	2.67	2.92	3
BRA	2.21	2.22	2.21	2.19	2.37	2.29	2.27	2.40	2.38	2.40	2.35	2.37	2.44	2.37	2
CAN	2.21	2.22	2.19	2.24	2.30	2.20	2.19	2.24	2.23	2.21	2.17	2.16	2.20	2.14	2
CHN	2.93	2.89	2.88	2.85	2.81	2.86	2.83	2.91	2.95	3.05	3.19	3.28	3.25	3.21	3
CYP	2.21	2.20	2.28	2.26	2.16	2.25	2.28	2.31	2.25	2.18	2.26	2.33	2.45	2.39	2
CZE	2.62	2.64	2.74	2.64	2.66	2.78	2.77	2.75	2.76	2.73	2.83	2.88	2.93	2.71	3
DEU	2.14	2.15	2.20	2.21	2.25	2.28	2.24	2.29	2.29	2.31	2.36	2.42	2.43	2.34	2
DNK	2.15	2.10	2.13	2.10	2.14	2.16	2.15	2.16	2.16	2.21	2.23	2.29	2.33	2.15	2
ESP	2.42	2.37	2.41	2.41	2.44	2.48	2.50	2.51	2.53	2.52	2.57	2.61	2.65	2.58	3
EST	2.59	2.48	2.47	2.63	2.42	2.62	2.72	2.74	2.47	2.50	2.62	2.71	2.61	2.49	3
FIN	2.29	2.31	2.30	2.29	2.35	2.29	2.28	2.34	2.35	2.40	2.49	2.49	2.53	2.47	2
FRA	2.31	2.29	2.35	2.37	2.43	2.44	2.47	2.44	2.49	2.48	2.51	2.60	2.59	2.61	2
GBR	2.21	2.26	2.20	2.19	2.21	2.21	2.19	2.18	2.21	2.26	2.23	2.22	2.11	2.16	2
GRC	2.28	2.24	2.23	2.23	2.22	2.27	2.26	2.27	2.25	2.23	2.24	2.28	2.32	2.04	2
HUN	2.56	2.64	2.64	2.60	2.62	2.77	2.76	2.71	2.73	2.63	2.62	2.70	2.81	2.66	3
IDN	2.39	2.46	1.76	2.18	2.02	2.11	2.17	2.06	2.06	2.04	2.14	2.06	2.12	2.06	2
IND	2.48	2.57	2.49	2.42	2.46	2.45	2.45	2.56	2.60	2.59	2.61	2.68	2.62	2.55	3
IRL	2.38	2.37	2.32	2.27	2.26	2.33	2.28	2.28	2.28	2.29	2.35	2.37	2.44	2.37	2
ITA	2.38	2.39	2.41	2.43	2.49	2.50	2.50	2.55	2.54	2.56	2.62	2.65	2.69	2.53	3
JPN	2.33	2.37	2.34	2.32	2.38	2.37	2.36	2.39	2.44	2.46	2.55	2.60	2.78	2.57	2
KOR	2.68	2.60	2.51	2.68	2.68	2.63	2.69	2.71	2.82	2.93	2.95	2.97	3.08	3.00	3
LTU	2.48	2.49	2.32	2.39	2.30	2.20	2.29	2.32	2.30	2.27	2.25	2.33	2.42	2.27	2
LUX	2.22	2.33	2.40	2.25	2.35	2.46	2.33	2.47	2.51	2.48	2.65	2.63	2.65	2.40	2
LVA	2.25	2.33	2.44	2.33	2.41	2.39	2.42	2.63	2.53	2.62	2.84	2.75	2.59	2.48	3
MEX	2.36	2.38	2.27	2.25	2.30	2.20	2.16	2.15	2.21	2.28	2.28	2.24	2.26	2.14	2
MLT	2.53	2.52	2.55	2.62	2.70	2.67	2.61	2.72	2.71	2.64	2.76	2.77	2.73	2.64	3
NLD	2.28	2.28	2.32	2.32	2.35	2.34	2.30	2.36	2.34	2.35	2.38	2.41	2.49	2.24	2
POL	2.28	2.31	2.39	2.35	2.38	2.44	2.42	2.41	2.49	2.50	2.46	2.57	2.61	2.40	2
PRT	2.40	2.37	2.44	2.41	2.40	2.48	2.35	2.45	2.50	2.50	2.56	2.56	2.53	2.62	2
ROU	2.63	2.51	2.40	2.41	2.40	2.41	2.46	2.47	2.54	2.50	2.49	2.50	2.43	2.33	2
RUS	2.29	2.21	2.04	2.00	2.27	2.35	2.24	2.36	2.33	2.32	2.28	2.36	2.38	2.21	2
SVK	2.58	2.65	2.67	2.68	2.84	2.69	2.76	2.81	2.56	2.57	2.59	2.75	2.75	2.76	3
SVN	2.35	2.37	2.45	2.38	2.37	2.47	2.42	2.45	2.46	2.48	2.53	2.60	2.61	2.48	2
SWE	2.25	2.22	2.24	2.26	2.33	2.31	2.32	2.34	2.33	2.35	2.41	2.45	2.48	2.34	2
TUR	1.98	2.06	2.02	2.18	2.27	2.24	2.43	2.52	2.43	2.42	2.43	2.44	2.43	2.37	2
TWN	2.53	2.52	2.43	2.45	2.58	2.47	2.50	2.54	2.67	2.68	2.70	2.77	2.82	2.82	3
USA	2.34	2.35	2.32	2.30	2.34	2.30	2.23	2.25	2.26	2.35	2.34	2.34	2.41	2.18	2
RoW	2.32	2.34	2.36	2.29	2.26	2.29	2.25	2.23	2.23	2.24	2.25	2.26	2.26	2.38	2
ID≈3	10	9	7	8	8	9	10	15	15	16	18	20	22	14	14
ID≈2	31	32	34	33	33	32	31	26	26	25	23	21	19	27	27

Note: "Cnt." stands for country. "Mean" is the rounded arithmetic average of the ID measures over 1996-2009. "ID≈3" and "ID≈2" indicate the number of countries with the rounded ID measure of, respectively, 3 and 2.