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ARTÍCULO

MEASURING UPSTREAMNESS AND DOWNSTREAMNESS BASED ON EXPORTS

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In this paper I discuss and develop measures of upstreamness and downstreamness to describe the position of countries and sectors in global value chains. Both measures are defined as the distance between exports and either final demand (upstreamness) or primary factors (downstreamness). When added together, they create a single measure of chain length, and reveal the position of the chain in international trade. I show the usefulness of these measures for highlighting aspects of international participation in value chains that cannot be deduced from measures developed previously. In particular, the measures proposed here better describe the specialization of countries along value chains.

Keywords: Global value chains; upstreamness; downstreamness.
JEL: D57, F14.

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Lalanne, A. (2023). Medición de *upstreamness* y *downstreamness* a partir de las exportaciones. *Cuadernos de Economía*, *42*(90), 429-464.

Este artículo discute y desarrolla medidas de *Upstreamness* y *Downstreamness* para describir la posición de los países y sectores en las cadenas globales de valor. Las medidas están definidas como distancia entre exportaciones y demanda final (*Upstreamness*) o con los factores primarios (*Downstreamness*) y pueden resumirse en medidas simples de largo y posición en cadenas en el comercio internacional. Estas medidas muestran aspectos de la participación en cadenas de valor que no se obtienen con las medidas de referencia. En particular, la especialización de los países a lo largo de las cadenas queda mejor reflejada con las medidas propuestas aquí.

Palabras clave: cadenas globales de valor; *upstreamness*; *downstreamness*.
JEL: D57, F14.

INTRODUCTION

Literature on the measurement of global value chains based on multi-country input-output tables (MCIO) has undergone significant development in recent years. Among the most important lines of research are the measurement of trade in value added (Johnson, 2018; Johnson & Noguera, 2012; Los & Timmer, 2020), the decomposition of gross exports to identify domestic and foreign valued-added and double-counted components (Arto *et al*., 2019; Borin & Mancini, 2019; Koopman *et al*., 2014; Los *et al*., 2016; Nagengast & Stehrer, 2016; Wang *et al*., 2013), which create measures of participation of countries or country- sectors in value chains (Borin & Mancini, 2019; Los *et al*., 2015; Wang *et al*., 2013), and finally, measures of length and position in chains, commonly defined as upstreamness and downstreamness (Antrás & Chor, 2018; Miller & Temurshoev, 2017; Wang *et al*., 2017a).

Measures of the position of sectors or countries in chains are becoming increasingly important. Some studies use them as an explanatory variable to include type of participation in the analysis (Reshef & Santoni, 2022). Theoretical models pertaining to offshoring decisions also distinguish between industry type based on these concepts (Alfaro *et al*., 2019).

When measuring the length of value chains or a position within them, there is a recognized conceptual difference between measures that are based on a decomposition of gross exports (Arto *et al*., 2019; Borin & Mancini, 2019; Los & Timmer, 2020; Wang *et al*., 2013) and those based on countries' total production or value added (Knez *et al*., 2021; Wang *et al*., 2017b). In the latter approach, a distinction is made between the value added (or the final output) that is related to international production and that which is not.

However, the measures of length and position in chains that are most widely used are calculated based on total production, while measures based directly on exports are underused. In earlier studies, measures were calculated using the U.S. domestic input output table (Antràs *et al*., 2012; Fally, 2012) with an adjustment for international trade. Once MCIO became available, they were calculated on total production without distinguishing international trade from local-driven production (Antràs & Chor, 2018; Miller & Temurshoev, 2017).

Antràs *et al*. (2012) define *upstreamness* as the distance from production to final demand, measured as the number of times production is accounted for until it is incorporated into a final good. Antràs and Chor (2013) define *downstreamness* as the distance from primary factors of production, measured as the number of times value added is accounted for in a production process until it is incorporated into a country's output.[1] The definitions of Antràs and Chor (2018) consolidate previous

[1] To provide greater clarity, Miller and Temurshoev (2017) define 'Output Upstreamness' as the distance to the final product (*i.e.*, focusing on the forward linkages of a given product) and 'Input Downstreamness' as the distance of production from primary factors, *i.e.*, focusing on backward linkages. They show that, at the aggregate level, both measures coincide, and that they differ at

ones and coincide with those proposed by Miller and Temurshoev (2017). Accordingly, in this paper, measures based on these definitions will be labeled 'AC-MT'.

Wang *et al*. (2017a) define their measures based on a matrix that tracks the value added from its origin in each country-sector to its inclusion in the final demand of a given country-sector. To better distinguish domestic chains from global chains, these authors decompose the matrix according to participation in both domestic and global chains, following the method they proposed previously in Wang *et al*. (2017b). The characterization of the countries' positions is performed on the last term, either by measuring forward, adding up the value added included in chains across a row, or backward, decomposing the final production of goods down a column.

While both contributions are valuable, they have certain limitations that prevent them from providing a full description of the role of countries in the chains. AC-MT measures do not distinguish international from domestic trade, and therefore it is not possible to interpret differences in positions solely by the indices. While it is true that more than three quarters of the world's output is consumed in the same country where it is generated and therefore is not traded internationally (Wang *et al*., 2017b; Dollar *et al*., 2017), in certain types of analyses, having a global view of a country's production can be useful. When conducting specific analyses of international trade it can be advantageous to work with the reference of gross exports, as this data can be found in the statistics. Given that none of the measures that Wang *et al*. (2017a) propose are based on gross exports, they also lack an easy or directly indicative interpretation for international trade. Wang *et al*. (2017a) categorize international trade into intermediates and final goods. In the forward perspective (in which linkages are tracked to final consumption) only the former is integrated into chains. Therefore, a part of what is commonly considered participation in chains is determined by the domestic component. Furthermore, the measures of position defined by these authors, calculated using the ratio between forward and backward lengths, can lead to erroneous interpretations. This is because the denominator and numerator are defined based on different sets of information, specifically, on different chains.

One notable advantage of the method proposed by Wang *et al*. (2017b) is that it shows that upstreamness and downstreamness are concepts that are relative to a given chain length. As a result, measures of distance cannot be compared without taking this into account. However, the main drawback to their method is that they define a forward and a backward length and then find the position by calculating the ratio between these two, so that the notion of absolute length is overshadowed by their measure of position.

In this article, I define upstreamness as the average number of stages that exports undergo before they are transformed into a final good or service. For gross exports,

the country, sector or country sector level because the sales structure (at a given level) does not coincide with the input supply structure.

the measure starts at zero when gross exports are at the final use stage, and it increases according to the distance to final demand. Downstreamness is defined as the average number of stages that primary factors (value added) have undergone before being exported by a country. It starts at one when exports are solely obtained from value added without intermediate inputs and it increases based on the cumulative importance of inputs. Total downstreamness can be divided into its domestic or international contributions. This division is useful when describing countries with similar downstreamness. Given that both upstreamness and downstreamness are based on the same information but refer to different flows, the measurements can be easily added together to create a new measure of length of chain defined at a country-sector level. The contribution that the stages before exports (downstreamness) make to total length is a measure of the relative position of a country sector in each chain. Every measure defined for country-sectors can be added together to find the measure for country, sector, and overall levels. Then, the position of the countries can also be described according to the interaction of a structural position (the relative importance of each sector for their exports) and idiosyncratic performance.

The methodology followed in this paper aligns with the approach that decomposes gross exports previously developed in studies by Borin and Mancini (2019), Koopman *et al.* (2014), Los and Timmer (2020), and Wang *et al.* (2013). While these prior works produce measures of depth or participation in chains using forward or backward biases, here, I aim to create measures of length and position in chains. The advantage of using gross exports instead of production or value added is that their interpretation is straightforward and familiar in the context of international trade, and it is through gross exports that countries are inserted into global chains. They also allow a direct and more integrated analysis of the measures created to describe forward and backward participation.

In that sense, gross exports also bear a resemblance in their interpretation to that of GVC participation where there is a total value that can be decomposed into its forward and backward terms (Borin & Mancini, 2019; Borin *et al.* 2021). While both families of measures are similar in their starting points and logic, they measure different aspects of value chains. Borin and Mancini (2019) and other related studies consider the instances in which value added crosses a border, and define GVC-trade as the value added that crosses a border more than once. The measures defined in the present study depart from the notion of one border crossing (the export itself) and take into account the distance to final demand or primary factors, rather than the number of borders crossed. In this sense, the measures used in this study are more inclusive because they account for single value chains (according to the definition followed by many authors such as Antràs, 2020; Wang *et al.*, 2017b; and Baldwin *et al.*, 2022). It should be noted that the larger the chain in which the country-sector participates (distance from primary factors or final demand) the higher the probability that the value will cross a second border, so it is obvious that both families of measures are positively correlated.

Following this introduction, the article has three more sections. The second section presents the benchmark measures for determining position and length in chains using MCIO according to total output (Antràs & Chor, 2018; Miller & Temurshoev, 2017) and for distinguishing trade in value chains from traditional trade (Wang *et al*., 2017a); it goes on to present the alternative measures proposed for this study. The third section compares the results obtained from the three sets of measures using data from the World Input Output Database (WIOD) (Los *et al*., 2015). Common and diverging outcomes are discussed, and a more complex analysis performed using the measure proposed for this article. Finally, the fourth section outlines some of the conclusions derived from the analysis.

MEASURES OF UPSTREAMNESS, DOWNSTREAMNESS AND RELATIVE POSITION IN VALUE CHAINS

General notation and definitions

Multi-country input-output (MCIO) tables organize the world output according to destination (in the columns) and the source of value (across the rows), as can be seen in Table 1. The global economy is organized into G countries, and production and use in each country is organized into N sectors.

Table 1.
Multi-country input-output table

Destination	Intermediate use			Final use			Output
Source	1	…	G	1	…	G	
1	Z^{11}	…	Z^{1t}	Y^{11}	…	Y^{t1}	X^1
s	Z^{S1}	…	Z^{St}	Y^{S1}	…	Y^{St}	X^S
⋮	⋮	⋱	⋮	⋮	⋱	⋮	⋮
G	Z^{t1}	…	Z^{tt}	Y^{t1}	…	Y^{tt}	X^t
Value Added	Va^1	…	Va^t				
Output	(X^1)T	…	(X^t)T				

Source: Created by the author.

Where Z^{St} is an NxN matrix of intermediate inputs produced in country s and used in country t, Y^{St} is an *Nx1* vector of final goods produced in country and consumed in country t, X^S is an *Nx1* vector of output of country s and Va is a 1xN vector of direct value added in country s. T is the transpose operator. All intermediate transactions can be arranged in an *NGxNG* matrix: Z. Final demand is divided into two vectors: Y^D is a vector of NGx1 that accounts for domestic demand (every Y^{St} where $s = t$) and Y^F is a vector of NGx1 that combines all foreign final demand of every country-sector (every Yst where s). Then, total final demand can be split into domestic and foreign ($Y = Y^D + Y^F$). Also, X is a vector of NGx1 that accounts for production in each country-sector and Va is 1xNG vector of direct value added in every country sector.

The Leontief matrix $A = Z\hat{X}^{-1}$ facilitates use of the standard notation in input-output analysis. The operator ˆ indicates that the vector is expressed as a diagonal matrix. The usual decomposition of production is:

$$X = AX + Y \tag{1}$$

The International Leontief inverse matrix is defined by:

$$B = (I - A)^{-1} \rightarrow X = BY \tag{2}$$

Analogously, the Gosh matrix $J = \hat{X}^{-1}Z$ expresses intermediate use as shares of total use. The alternative decomposition of output is:

$$X^T = X^T J + Va \tag{3}$$

Then, the International Gosh inverse matrix is defined by:

$$H = (I - J)^{-1} \rightarrow X^T = (Va)H \tag{4}$$

It will be useful to express the value added as shares of output: $V = Va\hat{X}^{-1}$. Taking the data from the columns, the output is the result of the combination of intermediate inputs plus the value added. This equation illustrates the Leontief function of production:

$$X^T = u\hat{X} = uZ + Va = uA\hat{X} + V\hat{X} \tag{5}$$

Where is a 1xG vector of ones. Post multiplying by $\hat{X}^{-1}$ the expression is $u = uA + V$. This results in the decomposition formula for production.

$$uI - uA = u(I - A) = V \rightarrow u = V(I - A)^{-1} = VB \rightarrow u = u\hat{V}B \tag{6}$$

A unit of output can be decomposed according to the value's country and sector of origin. $\hat{V}B$ has useful properties, as when post multiplied by a diagonal matrix of final demand, it will result in a complete decomposition of all the value added that has been included in it.[2] $\hat{V}B$ can also be used to split vectors other than final demand, such as output or exports.

A contains both the domestic and foreign coefficients of input utilization, which can be split into a matrix of domestic requirements (A^D) and a matrix of international requirements (A^F) (Wang *et al.*, 2017b). Then $A^F X$ will represent the international trade in intermediates.

$$A^D = \begin{bmatrix} A^{ss} & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & A^{tt} \end{bmatrix};\ A^F = A - A^D = \begin{bmatrix} 0 & A^{su} & A^{st} \\ A^{us} & \ddots & \vdots \\ A^{ts} & \cdots & 0 \end{bmatrix}$$

2 $\hat{V}B\hat{Y}u^T = Va$ and $u\hat{V}B\hat{Y} = Y^T$

The Local Leontief Inverse matrix partition of A should also be defined.

$$L = (I - A^D)^{-1}$$

Relevant definitions from the literature

Definitions based on of world production

Dietzenbacher and Romero (2007) used the notion of Average Propagation Length to measure the distance between two sectors. Antràs *et al*. (2012) and Fally (2012) then used it to create a definition of the upstreamness of a sector that counts the number of stages involved in the production of a sector before reaching final demand. Analogously, Antràs and Chor (2013) define downstreamness as the distance between output and the productive factors. Then, Antràs and Chor (2018) and Miller and Temurshoev (2017) applied these concepts to an MCIO to measure the degree of upstreamness and downstreamness of global production.[3]

Using the algebra and terminology of Miller and Temurshoev (2017), the 'Output Upstreamness' of AC-MT is defined by:[4]

$$OU = \hat{X}^{-1}(I + 2A + 3A^2 + \cdots)Y = \hat{X}^{-1}BBY = \hat{X}^{-1}B\hat{X}u^T = Hu^T$$

And 'Input Downstreamness' by:[5]

$$ID = Va(I + 2J + 3J^2 + \cdots)\hat{X}^{-1} = VaHH\hat{X}^{-1} = u\hat{X}H\hat{X}^{-1} = uB$$

Definitions based on value added included in final demand

The definitions produced by Wang *et al*. (2017a) start from the matrix of value added included in the final demand: $\hat{V}B\hat{Y}$. Each cell of this *NGxNG* matrix contains the direct and indirect value added of a sector-country of origin included in the final demand of a given sector-country. This calculation includes the direct relationships between row and column and also the total of the indirect relationships connecting these two sectors. The output used in this value-added flow is the number of times that value has been counted as output in that relationship. Again, the method of counting stages applies.

$$\hat{V}BB\hat{Y}$$

[3] Antràs and Chor (2018) go on to propose simpler measures of upstreamness and downstreamness that are highly correlated with U and D. These basic measures are simply the ratio between final demand and production for upstreamness (the higher the ratio the lower the upstreamness) and the ratio between direct value added and production for downstreamness (the higher the ratio the higher the downstream ness), both at sector level.

[4] The first equation uses the equivalence $(1 + 2A + 3A^2 + \cdots) = BB$ and the last uses the equivalence between the Leontief and Gosh inverse matrices: $\hat{X}^{-1}B\hat{X} = H$ (see Appendix for a demonstration of both equivalences).

[5] Again, the first equation uses the equivalence $(1 + 2J + 3J^2 + \cdots) = HH$ and the last uses the equivalence between the Leontief and Gosh inverse matrices: $B = \hat{X}H\hat{X}^{-1}$ (see Appendix).

The ratio between the production stages counted and the value added in each cell is the average length of each relationship.

$$\frac{\hat{V}BB\hat{Y}}{\hat{V}B\hat{Y}}$$

Wang *et al*. (2017a) define the upstreamness measure for total output using the ratio between the sum of each row of the numerator and the denominator.

$$U_W^{Tot} = \frac{\hat{V}BB\hat{Y}u^T}{\hat{V}B\hat{Y}u^T} = \frac{\hat{V}BBY}{\hat{V}BY}$$

When the value added is simplified, and X = BY tused, it can be observed that the total forward chain length measure calculated by Wang *et al*. (2017a) matches that of AC-MT: $U_W^{Tot} = OU$

Wang *et al*. (2017a) define the downstreamness measure for total output as the ratio of the aggregation of each column of the numerator and the denominator. It once more coincides with the 'Input Downstreamness' measure.

$$D_W^{Tot} = \frac{u\hat{V}BB\hat{Y}}{u\hat{V}B\hat{Y}} = \frac{VBB\hat{Y}}{VB\hat{Y}} = \frac{VBB}{VB} = \frac{uB}{u} = uB = ID$$

However, Wang *et al*. (2017a) do not apply their measures to total output, rather, they estimate a measure for each of the components of total output according to the decomposition of total output developed previously in Wang *et al*. (2017b):

$$\hat{V}B\hat{Y} = \hat{V}L\hat{Y}^D + \hat{V}L\hat{Y}^F + \hat{V}LA^F B\hat{Y}$$

The first component is the term that includes the value added integrated into exclusively domestic chains that are consumed domestically, the second term is domestic value added that is included in the final production that is exported, and the third term is value added integrated into value chains. The analysis of global value chains in Wang *et al*. (2017a) focuses on the third term. As for total production, length is identified for each term and divided by the value added included in that flow. For domestic and final goods chains the average length is simply:

$$AL_{dom} = \frac{\hat{V}LL\hat{Y}^D}{\hat{V}L\hat{Y}^D};\ AL_{fin} = \frac{\hat{V}LL\hat{Y}^F}{\hat{V}L\hat{Y}^F}$$

However, for the term representing the length of the global value chains it is necessary to distinguish domestic stages, *i.e.*, the linkages that occur before the value-added crosses the border, and international stages, *i.e.*, the linkages that occur after the value added has left the country of reference.

$$AL_{CGV} = \frac{\hat{V}LLA^F B\hat{Y} + \hat{V}LA^F BB\hat{Y}}{\hat{V}LA^F B\hat{Y}}$$

Once more, in the forward perspective, the sum of the rows of both matrices defines the upstreamness measure. In the backward perspective, the sum of the columns defines the downstreamness measure.

Wang *et al*. (2017a) establish the position of a sector-country in a value chain through the quotient of both ratios. A value greater than one indicates that the country-sector has a longer forward than backward length, *i.e.*, that the sector is further away from final consumption than from primary factors and is therefore positioned upstream in the value chain. Adding together all sectors generates measures for the countries.

It is important to note that the measure that Wang *et al*. (2017a) use for the position in value chains is defined based on two sets of information that refer to different flows. The upstreamness measure quantifies the average number of stages that the value added of a sector in a country went through before becoming a final good. This, provided that there is international trade of intermediates (represented by the matrix A^f) between the reference value added and final production. The downstreamness measure is calculated by counting the average number of stages between the point at which a sector's value added was incorporated and the final goods production of a country sector. Here, only value added that entered the country of reference through international trade in intermediates is counted, while domestic value added that is combined with these inputs is not integrated into the chains.

In the measures proposed by both AC-MT and Wang *et al*. (2017a), the length of a chain is a concept that cannot be shown as a number, since there is still a forward (upstreamness) and a backward (downstreamness) measurement to be found. A proposed solution to this problem is set out in the next subsection.

Measures based on gross exports

Starting with a study by Koopman *et al*. (2014), an important strand of the literature has developed concerned with measuring participation in global value chains by decomposing the vector of gross exports. This method allows interpretation guided by terms such as "domestic content of trade", "foreign value", "double-counted term" or "back-and-forth" trade. All these measures can combine the origin of value together with the use after they have been separated from each other. The measures outlined in this section begin from the same starting point, but differ thereafter.

In the following methodology, two measures for gross exports will be defined. Three equations for the direct combination of these measures will output measures for length and position of exports in global value chains.

Distance from exports to final demand: Upstreamness

This measure counts the average number of times a sector or country's exports are factored into stages of production until they are incorporated into final demand.

Similar to the concept of forward linkages discussed in the literature on measuring chain participation (Borin & Mancini, 2019; Koopman *et al.*, 2014; Los & Timmer, 2020), this measure of upstreamness depends on the type of good being exported and the use made of the good at its destination, rather than in the country from which it is exported.

Eq. 1 divides total production into intermediate and final production. Likewise, gross exports can be divided into intermediate and final exports:

$$E = A^F X + Y^F \tag{7}$$

Using the Leontief inverse matrix and Eq. 2, exports then can be decomposed as follows:

$$E = A^F BY + Y^F = A^F (I - A)^{-1} + Y^F = Y^F + A^F (I + A + A^2 + A^3 + \cdots)Y \tag{8}$$

Exports are divided according to the a number of stages to final demand. The first term represents the final demand, so no additional stage is required. The number of additional stages is zero. The second term ($A^F Y$) represents exports of intermediates that are directly included in final demand. The number of stages is one. The third term ($A^F AY$) corresponds to two additional stages before being included in the final demand. Then, the total production is measured as follows:

$$U_E = 0.Y^F + A^F (1.I + 2.A + 3.A^2 + 4.A^3 + \cdots)Y \tag{9}$$

Antràs *et al.* (2012) explain that the term in parentheses is (BB), and can be incorporated into the equation that shows the average number of stages that exports undergo before being included in the final demand:

$$U_e = \frac{U_E}{E} = \frac{A^F BBY}{E} \tag{10}$$

Now, U_e represents a vector that is produced from a ratio of vectors. Its size is generally defined by NGx1, and each row shows the average forward-facing length of exports of sector N from country G. U_e is defined only for each sector that produces exports. By adding together U_E and E for the sectors of a country, U_e can also be expressed as a vector of Gx1, in which the average length of exports in a forward direction of each country is indicated. Also, an alternative method of aggregation of U_e can result in a vector of $Nx1$, indicating the average length of exports of each sector globally.

Distance from exports to primary factors: Downstreamness

This backward-looking measure counts how many stages on average the value added underwent until it was incorporated into a country's gross exports. These stages may have been domestic or international.

To estimate downstreamness it is necessary to track the sector-country of origin of the value added included in gross exports. V is defined as a row vector that includes coefficients from value added to output. Any output vector can be split using VB to identify the sector of origin of the value added (Borin & Mancini, 2019).

$$E^T = VB\hat{E} = V(I + A + A^2 + A^3 + A^4 + \cdots)\hat{E} \tag{11}$$

Each of the terms is a row vector and corresponds to value added in exports at a production stage. The first term is $V\hat{E}$, that is, a row vector that contains the value added by the producer of exports. The second term, $VA\hat{E}$ is the value added by all input producers, purchased in each sector by the exporter for its production (which can be domestic or international). The third term, $VAA\hat{E}$, is the value added by the input producers and then used by the input producers, then by the exporters, and so on. It is possible to weigh each term by the number of times the value is accounted for in production. Furthermore, the sum of the value added by all producers at each stage is the value of exports. Then, the distance from exports to value added can be defined by:

$$D_e = \frac{D_E}{E^T} = \frac{V\left(1.I+2.A+3.A^2+4.A^3+5A^4+\cdots\right)\hat{E}}{E^T} = \frac{VBB\hat{E}}{E^T} \tag{12}$$

It is useful to divide the numerator of the backward length of exports according to whether production occurred in domestic or international stages.

$$D_E = VBB\hat{E} = D_{E\_dom} + D_{E\_int} = VLL\hat{E} + VBA^F LL\hat{E} + \ VBBA^F L\hat{E} \tag{13}$$

The first term accounts for the domestic value-added chain in exports with no stages abroad. It measures the circulation of domestic value added in the export production structure before it is included in exports. The second term accounts for the circulation of imported inputs in the domestic economy. Each time an imported input is included in a stage in an export chain, this value is counted. The first and second terms together represent the domestic contribution to the backward length of chains (D_{E_dom}). The third term accounts for the stages that international inputs underwent before entering into the productive structure of the exporting country. This is the international contribution to downstreamness (D_{E_int}).

It should be noted that the definition of domestic is limited to the value that is included within the domestic economy after importing inputs. Domestic value can also encompass value that is contained within imported inputs (Koopman *et al.*, 2014), but for the purpose of manipulating international matrices it is important to clarify at what moment domestic and international considerations are taken into account. Accordingly, I will follow the source-based perspective (Borin & Mancini, 2019, Nagengast & Stehrer, 2016) in which the definition of domestic will be reduced to the last time that a portion of value is added inside the country of reference. An alternative approach is to use a Sink-based perspective, where all value generated in a country should be counted as domestic, irrespective of its circulation. See Borin and Mancini (2019) for a discussion of the advantages and drawbacks of using these methods. The proper definition is key when value must be divided between domestic value, foreign value and double counted. When analyzing length and position in chains however, the definition is not important.

It is also possible to use $D_{e_{dom}} = {}^{D_{E_{dom}}}/_{E^T}$ and $D_{e_{int}} = {}^{D_{E_{int}}}/_{E^T}$ to define the domestic and international contribution to downstreamness. This method reflects the average of the relative importance of domestic value added and imported inputs, as well as the complexity of the productive structure of the exporting country and its suppliers.

Length of chains in which exports are involved

The sum of the domestic and international contribution measures equals the length of global value chains in a country's exports. U_e is a vector of NG rows defined between zero and infinity, yielding zero if a country sector exports final goods exclusively. D_e is a vector of NG columns defined between one and infinity, equaling one if the country sector does not use inputs from other sectors. Both measures can be calculated for countries by aggregating all sectors of a country.

These measures have an advantage over the previous ones in that they are defined for exports, and therefore dialogue better with measures of participation in international trade. In addition, unlike previous measures, those defined here can be aggregated into a single measure of total chain length for chains in which exports are involved.

The total length of chains in which exports participate, measured from primary factors to the production of final goods, is calculated as follows:

$$LC = U_e + D_e^T \tag{14}$$

LC is a row vector of dimension *NG* and ranks between one and infinity. The minimum length of one corresponds to an export of a final good undertaken exclusively by value added in the exporting sector, that is, without using inputs from another sector. By aggregating every sector in a country, it can be transformed into a vector of dimension *G*.

Relative position of exports in a value chain

Once the total length is defined, the Relative Position can be laid out as a ratio:

$$RP = \frac{D_e^T}{LC} \tag{15}$$

The relative position of a country-sector in a value chain ranks between zero and one. A value close to zero indicates a country-sector that is located towards the beginning of a chain, that is, the country-sector is used several times by other country-sectors before being included in final demand, but the country-sector itself uses relatively low inputs from other sectors. This is the case of a country-sector with long upstreamness and short downstreamness. A value close to one indicates that the value added was included in the export which was transited through a high number of intermediate sectors and it is close to the end of the chain. This type of country-sector has short upstreamness and long downstreamness.

It will be useful to this study to build a measure of relative position that can be compared with those produced in other studies.

Balanced relative position of exports in value chains

$$BRP = \frac{D_e^T}{U_e+1} \tag{16}$$

When upstreamness is defined as starting at zero, adding one to it allows for comparability with measures of position such as those developed by AC-MT and Wang *et al*. (2017a). It is important to note that Wang *et al*. define their measure inversely to Eq. 16, as the ratio between upstreamness and downstreamness. BRP ranks between zero and infinity. Values above one represent a downstream biased position, and below one an upstream biased position.

To measure the position of a country (or sector-country) in the chain, it is necessary to take into account both the total length of the chain in which it is located and the contribution made by each of the two measures that make up its length. Downstreamness is defined by the country's production function and its supply structure (and that of its suppliers), while upstreamness is determined by the use that other countries make of the country's production. This way of decomposing the results has several advantages. Since the final position and length is a weighted average of the position and length in each sector, a country's position can be divided into 'structural' and 'idiosyncratic' positions. The 'structural' position is the result of the composition of exports. The 'idiosyncratic' position is the difference between the country's overall position and its structural position, and is determined by the country's own production and supply structure and the characteristics of the markets supplied. Countries may shift upstream or downstream simply because of what they export, or they may have their own idiosyncrasy.

EMPIRICAL APPLICATION: MEASURING SPECIALIZATION ALONG VALUE CHAINS

The purpose of this section is twofold. First, it describes the most relevant results related to the evolution of the measures of upstreamness, downstreamness, length and position at overall, country, sector, and country-sector levels. It also shows the usefulness of the new measures developed. Second, it shows that the measures developed in previous studies have produced somewhat different results than those presented here. This disparity can lead to misleading conclusions being drawn regarding specialization in global value chains.[6]

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[6] Since the objective of this paper is not to survey the empirical literature on participation in global value chains, this section does not include analysis of widely cited works such as de Backer and Miroudot (2014), World Bank (2019), or Xing *et al.* (2021).

In the first subsection, the application of measures at an overall level is presented to quantify the evolution of the fragmentation of global production. The second subsection applies metrics based on gross exports to describe the length and position of countries and their evolution. The third compares these results with the reference measures from prior studies, and highlights the differences found. A fourth subsection describes the structural and idiosyncratic position results. The section concludes by showing sector and country-sector level results, highlighting differences in position and length among countries within bigger exporting sectors.

The estimation of the results was performed on the 2016 version of WIOD data for the period 2000-2014 (Los *et al.*, 2015). 56 sectors (based on ISIC 4, compatible with SNA version 2008) from 44 countries are surveyed.

General evolution of chain length

Table 2.
Chain length measures. Selected years from 2000-2014

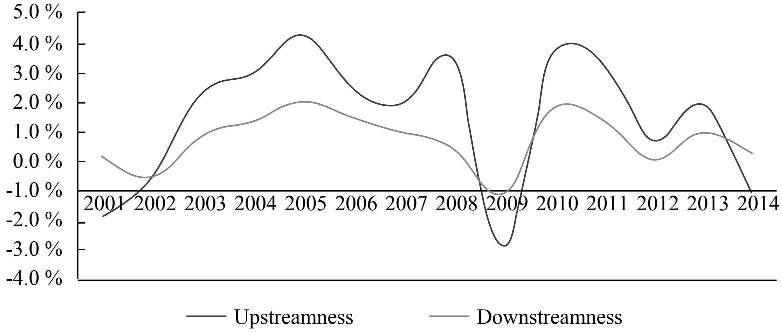
	Measure	2000	2002	2004	2006	2008	2010	2012	2014	Annual growth
Measures	AC-MT Total	2.01	1.98	2.04	2.13	2.19	2.20	2.26	2.31	1.0%
from the	Wang *et al.*: Total	1.93	1.90	1.94	2.01	2.06	2.05	2.10	2.13	0.7%
literature	Wang *et al.*: Domest	1.69	1.67	1.67	1.69	1.71	1.73	1.75	1.78	0.4%
	Wang *et al.*: GVC	4.01	3.98	4.05	4.18	4.24	4.30	4.37	4.43	0.7%
Based on	Upstreamness	1.32	1.28	1.35	1.45	1.53	1.54	1.60	1.62	1.5%
Gross	Downstreamness	2.29	2.29	2.34	2.42	2.46	2.48	2.52	2.55	0.8%
Exports	Length	3.61	3.57	3.69	3.87	3.99	4.01	4.12	4.16	1.0%

Source: Own calculations based on WIOD version 2016.

All measures reported an increase in the total length of global value chains. It should be noted that the measures of upstreamness and downstreamness developed by AC-MT and Wang *et al.* (2017a) yield equivalent results when calculated for a total MCIO. This means that differences between upstreamness and downstreamness only arise at the country-sector, country or sector level (Miller & Temurshoev, 2017; Wang *et al.*, 2017a). The AC-MT measure (of both U and D) shows a growth rate of 1% per year over the period. The total Wang *et al.* (2017a) measure, weighted by value added instead of by production, shows a lower increase of 0.7% per year. The breakdown produced by the Wang *et al.* (2017a) measure between domestic chains (including exports of final goods) and global value chains indicates that the latter are the driving force behind productive fragmentation, since they increased at a faster rate than domestic chains (especially in the first part of the period).

The gross export-based measures also indicate that chains have increased in length. The growth rate they calculated coincides with that of AC-MT (1% per year). The division of growth between upstreamness and downstreamness indicates that the chains grew more upstream. In total, the upstreamness of exports increased from 1.32 to 1.62, while the backward length increased from 2.29 to 2.55. It is important to remember that the first measure starts at 0 (if all exports are final goods) and the second starts at 1 (if all exports are composed of value added directly incorporated by the exporting firm). In total, the length of chains defined using gross exports rose from 3.61 to 4.16 in the study period. The relative position measure reduced from 0.64 to 0.61. This growth in chain length skewed toward an increase in forward length implies that exports moved "backward" in the chain in relative terms. Figure 1 also shows that the lengthening of chains occurred mainly between 2003 and 2008.

Figure 1.
Annual growth rate of world upstreamness and downstreamness based on gross exports.



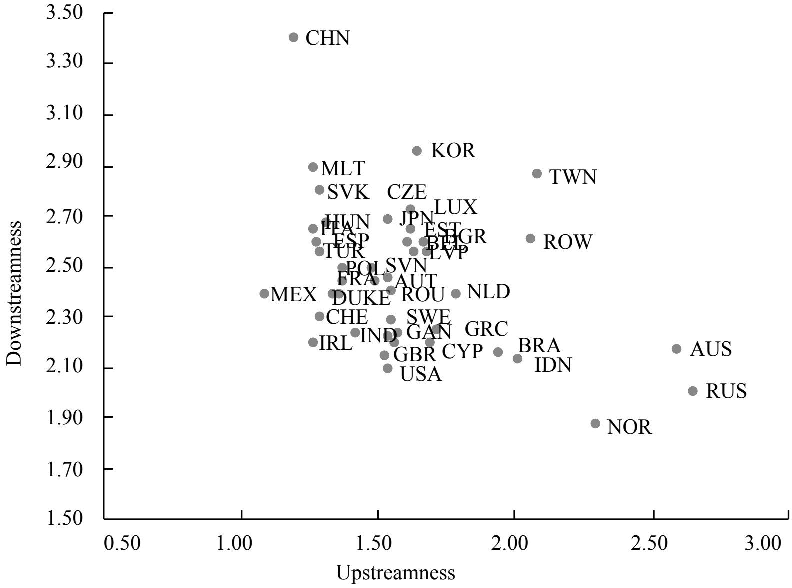
Source: Created by the author based on WIOD.

Evolution of upstreamness, downstreamness, length and position at country level

This section examines how the measures of the countries show their evolution. All measures are calculated as ratios, with the aggregation performed on the numerator and denominator to produce the result. The position of a country is a weighted average of the positions of its country-sectors.

Figure 2 depicts the upstreamness and downstreamness of gross exports as well as the measures of length and position. The further from the origin a country is, the larger the length of its exports. Taiwan, Australia, Rest of the World, Russia, Rep. of Korea and China are the countries with the largest measured export length. The negative correlation between upstreamness and downstreamness result in less variation in the length of chains than when the measures are defined separately.

Figure 2.
Upstreamness and downstreamness of exports, 2014.

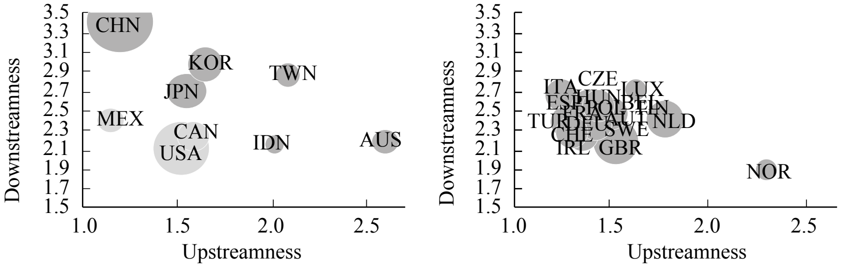


Source: Created by the author based on WIOD.

Australia, Russia, and Norway (although it has a shorter chain), show a strong bias towards forward participation. Meanwhile, China stands out for its considerable backward participation. The graph also highlights other commodity producers with high upstreamness such as Brazil and Indonesia, and also identifies some European end-of-chain countries. Mexico stands out as a country with short chains and very low forward linkages. The position of Mexico and its evolution has been well documented using alternative measures (Chiquiar & Tobal, 2019). Countries with strong services sectors, such as USA, Great Britain, Ireland, and Switzerland, also have particularly short export chains. For example, USA and Switzerland have a total length of 3.6, 0.6 below the world average.

Figure 3 shows the positions of the main countries within the world's three global factories: the Americas (6a), Asia-Pacific (6a) and Europe (6b). The Asia-Pacific factory is more specialized and has a higher length. The Americas exhibit lower levels of fragmentation, resulting in shorter chains, while Europe occupies an intermediate position in this regard. Countries such as Czech Republic, Hungary, Poland and Turkey stand out in the graph as economies based on assembly of goods. Similarly, the graph highlights countries like Ireland, Switzerland and United Kingdom in their role as exporters of services.

Figure 3.
Upstreamness and downstreamness of countries in the global factories.



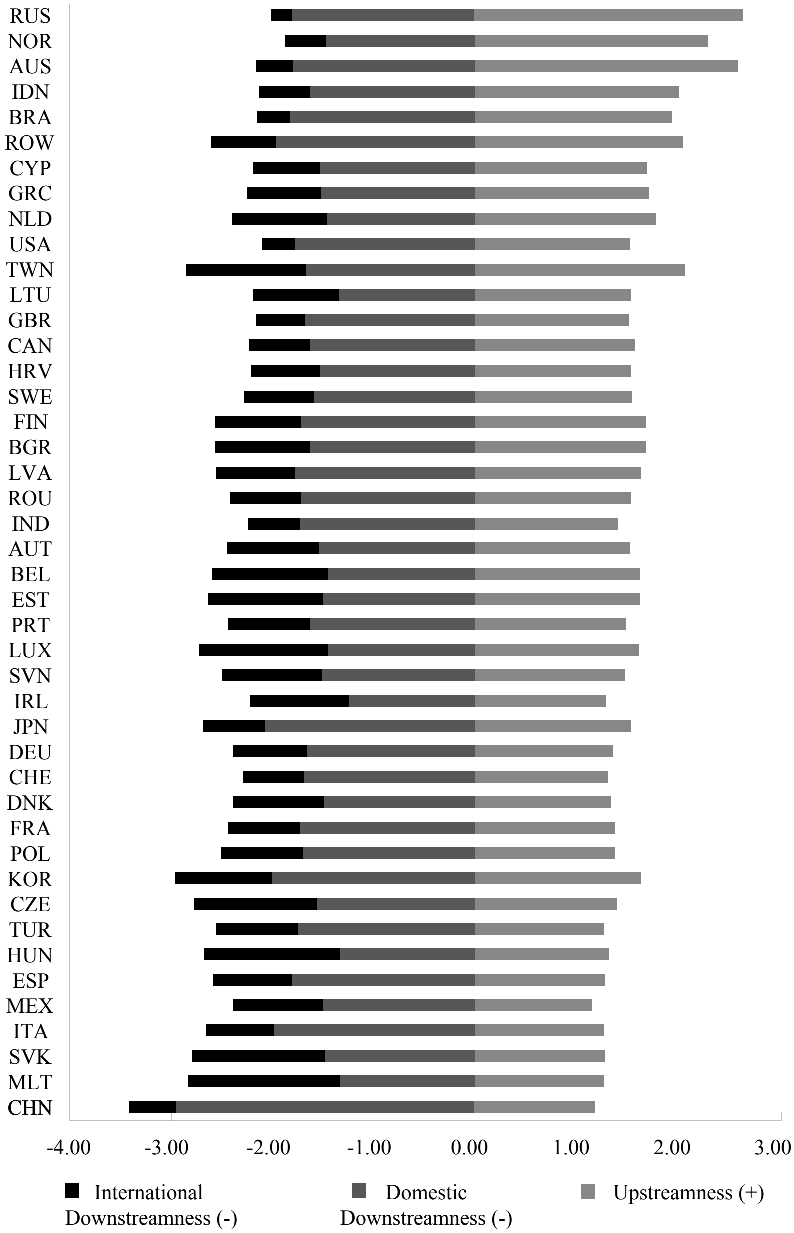
(a) Americas (light grey) and Asia-Pacific (dark grey) (b) Europe
Source: Created by the author based on WIOD.

Figure 4 shows the same information but with an emphasis on chain length and the contributions of its components. Downstreamness is graphed on the negative axis. Black bars show the proportion of length claimed by production in the exporting country and dark grey bars show the length of the chain before production enters the reference country (see Eq. 13). Relative position is given by the ratio between downstreamness and total length (Eq. 15). The countries are ordered by position, from the most upstream (Russia) to the most downstream (China). Russia, the most upstream country in the sample has a relative position of 0.43, *i.e.*, 57% of Russia's chain length occurs after its product is exported. Surprisingly, USA and Taiwan are among the countries closest to the beginning of their chains. For these countries, 58% of length occurs before export, but 42% of length – a relatively high number – occurs after export. At the other extreme is China, which, as we mentioned earlier, is one of the countries with the longest chains. The graph shows that 74% of production stages occur before China exports its products. The comparative size of the black and dark grey bars shows that almost all of China's chain length is given over to domestic production. Other countries that are positioned further along their chains (except for Italy, Spain, and Rep. of Korea) tend to rely on imported intermediate inputs, adding length to their supply chains, and contributing relatively little domestically (see, *e.g.*, Hungary and Slovakia).

Figure 5 shows the change in upstreamness and downstreamness over the period analyzed. As mentioned, this change was biased towards an increase in forward length. Australia, Brazil and Taiwan strongly increased their distance from final goods, moving towards the center of the value chain. While Taiwan increased distances in both directions, the others two reduced their backward length. USA and Canada also became more upstream over the period, by basically not increasing their backward length and moving further away from final demand. On the other hand, Slovakia, Czech Republic, Bulgaria, Romania and Spain increased their backward length without changing their forward length in practical terms.

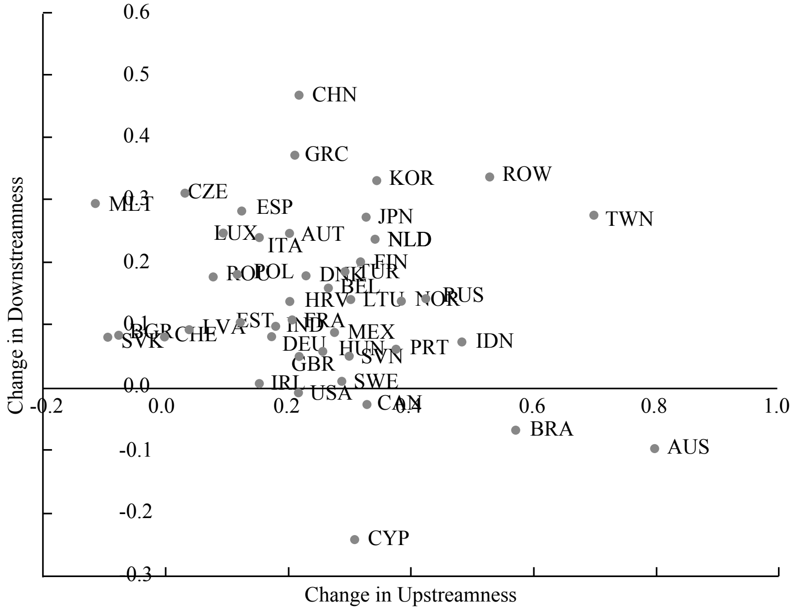
Figure 4.

Length of chains based on exports and the relative contributions of upstreamness and (domestic and international) downstreamness, 2014.



Source: Created by the author based on WIOD.

Figure 5.
Change in upstreamness and downstreamness between 2000 and 2014.



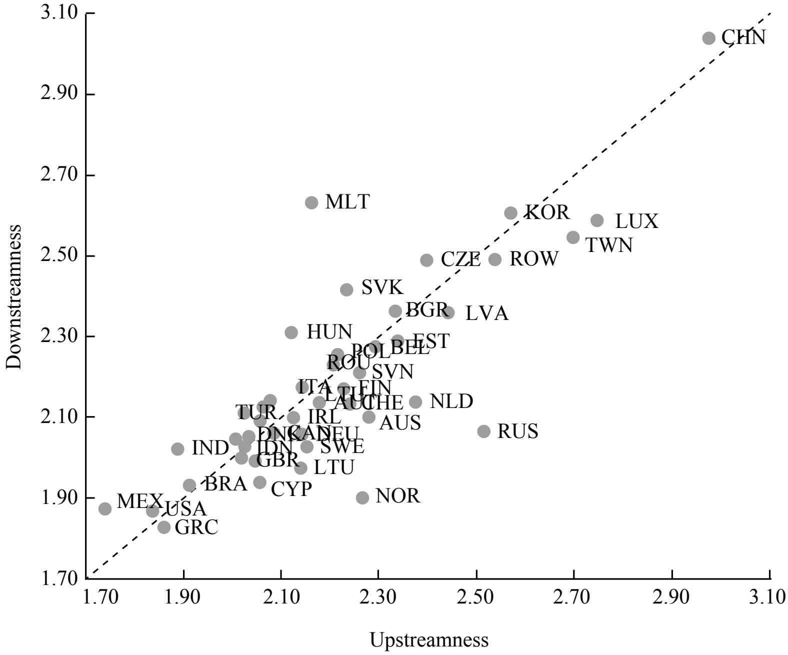
Source: Created by the author based on WIOD.

Czech Republic became the most downstream European country in the sample, displacing Hungary, which grew in the opposite direction. Mexico exhibited a similar evolution to the average, although with a certain bias away from downstream demand. Japan and Rep. of Korea experienced fairly high and balanced growth in the length of their chains.

Comparison with measures from prior studies

The measures developed in this article yield results that, to some extent, align with previous studies. However, they also reveal other aspects of the international position of countries in GVC that the prior literature does not explore. Figure 6 shows the AC-MT measures. As both of these studies (AC & MT) point out, both measures are strongly correlated. This high correlation, seen as "puzzling" by Antràs and Chor (2018), shows that countries with a large distance to final demand also have a large distance to value added. It is clear from Miller and Temurshoev's (2017) observations that both measures are two sides of the same coin. As Antràs and Chor (2018) point out, if a country's total value added is equal to final output, as is the case for closed economies, a country will produce identical results for both measures. Antràs and Chor (2018) indicate that as countries become more integrated into world trade, greater specialization is expected and thusly, less cor-

Figure 6.
AC-MT measures of upstreamness and downstreamness at a country level, 2014.



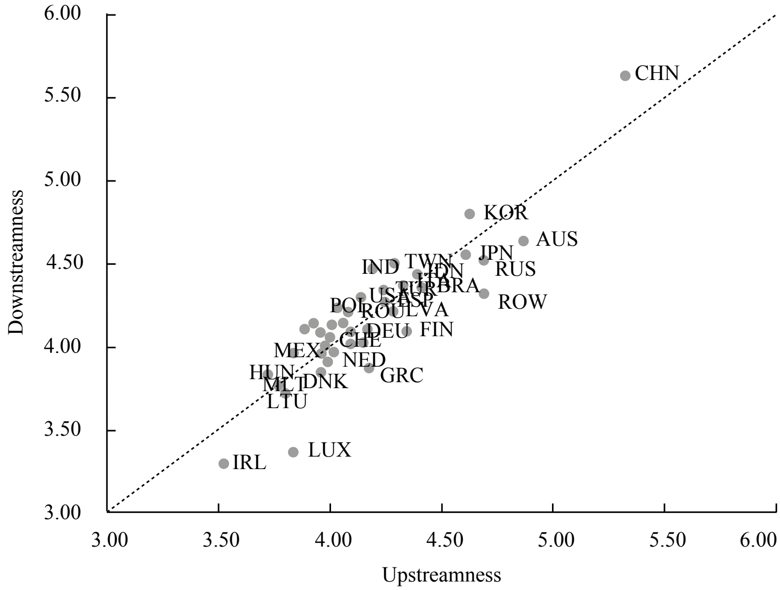
Source: Created by the author based on WIOD.

relation between the two measures will occur. However, as they also point out, the evidence shows an increasing correlation over the period studied.

As can be seen in Figure 6, China is different from the rest of the countries. The country has a length of 3 and little bias towards downstreamness. Mexico and USA are positioned at the opposite end to China, with a chain length of less than 2. Although Brazil is a major exporter of primary minerals, this is not reflected in these measures, where the country appears close to both final demand and value added. Figure A1 in the appendix is the same graph for the period between 2000 and 2014. This graph shows that Taiwan, China and Rep. of Korea are the countries that most increased the length of their total production in this period.

Figure 7 shows the measure of length in forward and backward value chains according to the method by Wang *et al*. (2017a). Again, China stands out from the rest, exhibiting a considerably longer length than the rest. Rep. of Korea and Taiwan also have a longer length in the GVC component than the rest as well as a backward bias, while Australia, Russia and Rest of the world have significant forward length. The graph also shows that USA is situated in longer chains than those suggested by the measure based solely on total production. This could be due to a high weighting of non-integrated production in chains.

Figure 7.
Wang *et al*. (2017a) measures of upstreamness and downstreamness at country level for GVC component, 2014.

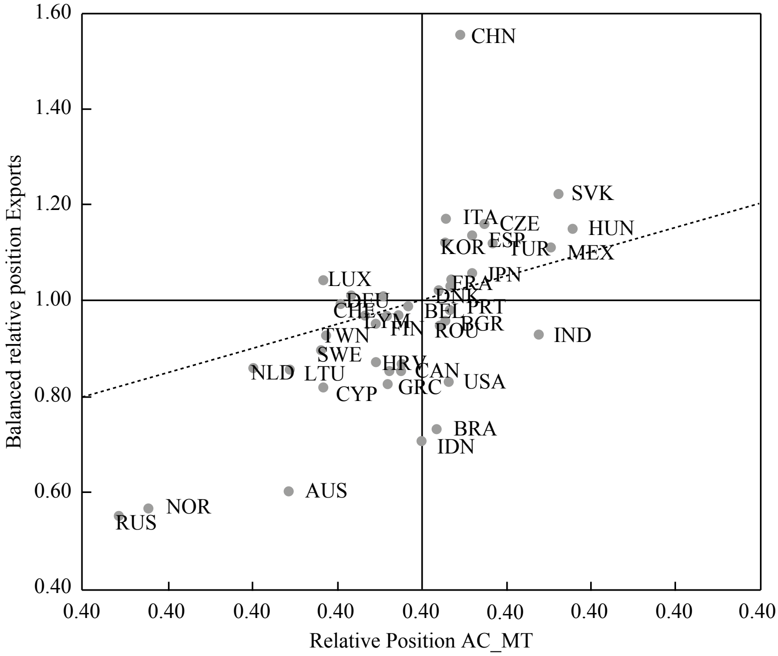


Source: Created by the author based on WIOD.

The balanced relative position defined in the previous section (see Eq. 16) allows the position of the countries according to each of the methodologies tested to be compared. The BRP will be compared to the ratio between downstreamness and upstreamness derived from the measures proposed by AC-MT and Wang *et al.* (2017a).

Figure 8 compares the BRP based on gross exports with those derived from the AC-MT measures. The positive correlation indicates that the measures tend to place countries in the same space. However, there are some differences. First, export measures naturally generate less balanced positions. Secondly, the countries located in quadrants 2 and 4 exhibit relative positions that differ in direction based on the measure used. Brazil, USA and Indonesia stand out as having higher downstreamness according to AC-MT, but according to the export-based measures, should be positioned higher upstream. On the other hand, Germany, Switzerland and Luxembourg should be positioned upstream according to AC-MT but appear balanced when defined by the export-based measure. The comparison between China and Mexico is also useful. Both measures agree that the countries are downstream, but Mexico should be further downstream according to AC-MT and China further upstream according to the BRP.

Figure 8.
Balanced relative position of exports and ratio of upstreamness to downstreamness according to AC-MT, 2014.



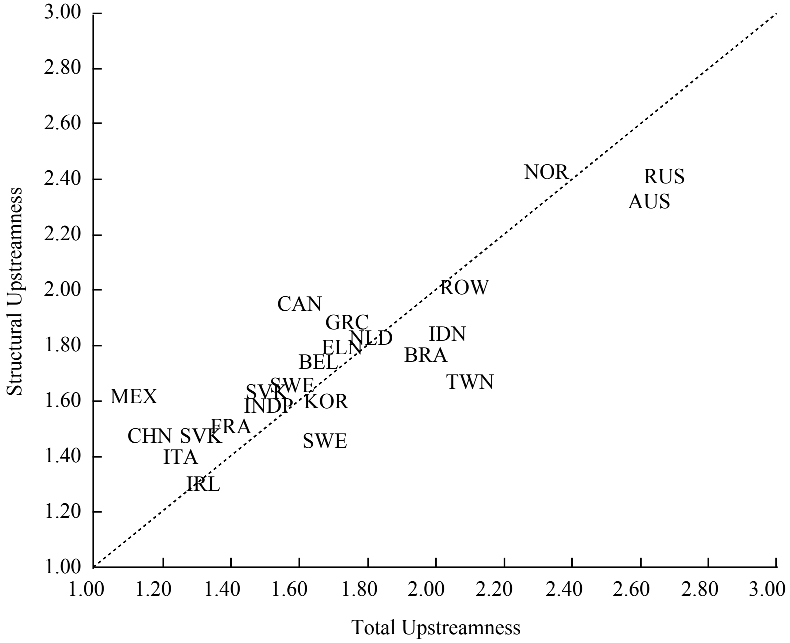
Source: Created by the author based on WIOD.

Figure A3 in the appendix shows the comparison between the BRP based on exports and the inverse of the relative position measure developed by Wang *et al.* (2017a). The results are similar. The countries that the different approaches disagree on, classified as downstream according to Wang *et al.* (2017a) and upstream according to the BRP, are USA, Canada, Indonesia, India, Taiwan and United Kingdom.

Countries with idiosyncratic performance

The information constructed and presented above is useful for assessing the performance of countries in value chains beyond their export basket. In each of the two possible directions, ‘idiosyncratic’ performance is determined as the difference between the length achieved and the ‘structural’ length. The ‘structural’ length is the length that would indicate an average performance based on the sectoral structure exported by the country. To evaluate this result, each performance will be analyzed separately. Figure 9 shows the measure of total (effective) upstreamness versus structural performance, *i.e.*, the expected upstreamness based on the weight of each sector in its exports. The distance to the 45-degree line measures the size of the ‘particularity’. Russia, Australia and Norway have

Figure 9.
Structural and total upstreamness, 2014.

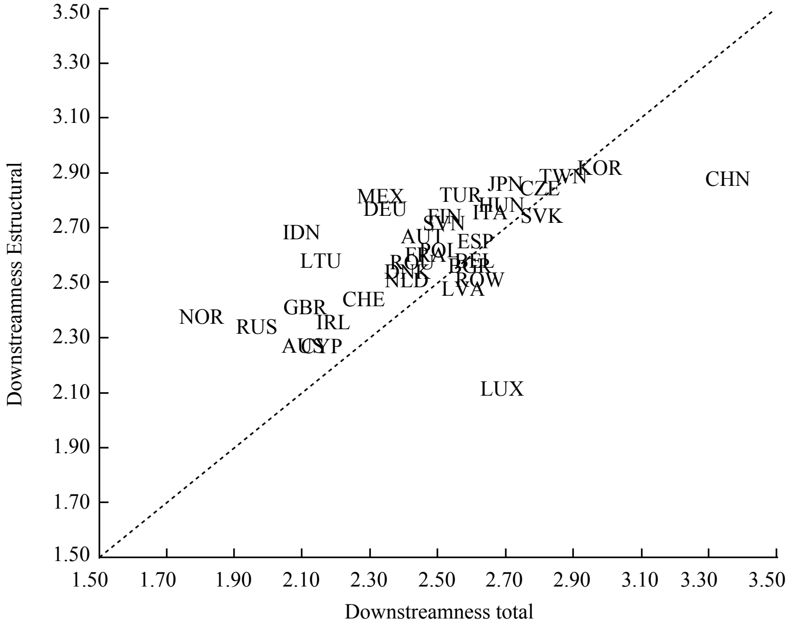


Source: Created by the author based on WIOD.

an export structure that positions them far from final demand. However, while Russia and Australia have a larger effective distance than their structure indicates, Norway has a smaller effective distance. It is possible then that Australia and Russia behave this way because their sales are more concentrated in the longer Asian markets, while Norway sells to shorter markets, typically in the Americas and Europe. Taiwan, Brazil and Indonesia also import part of their length because of their exposure to the Asian market. Meanwhile, although Mexico and Canada's structures would indicate a close-to-average upstreamness, they in fact have a much greater proximity to final demand. This must be related to the fact that they sell mainly to the United States, a market close to final demand. On the other hand, China also has a greater proximity to final demand than would be expected given its structure.

Figure 10 shows the same information for downstreamness. It highlights the performance of China, which has a much longer backward length than its trade indicates. This is because this country has the highest domestic linkages of all countries. Most countries have a shorter distance to productive factors than their structure indicates. China's heavy weight and its structural difference compared to the rest of the countries explains this difference. Among the countries that are furthest away from their structural downstreamness are large exporters of manufac-

Figure 10.
Structural and total downstreamness, 2014.



Source: Created by the author based on WIOD.

tured goods, such as Mexico, Germany, USA and Indonesia. Asian countries that have a similar structure do not move away from their structural position, mainly due to the greater length of Asian production.

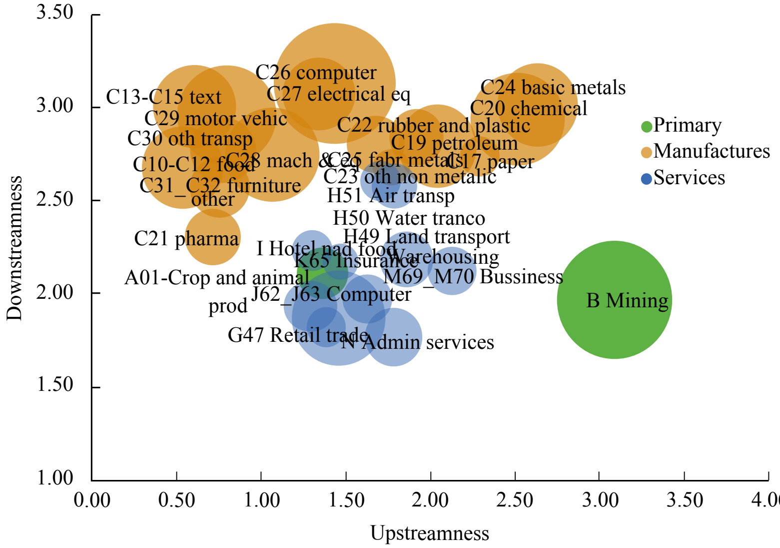
The total length of chains can also be broken down into their particular and structural lengths. Graph A3 in the Appendix shows their evolution. Mexico stands out as the country whose total length deviates furthest from the length suggested by its structure, since it is shorter both forwards and backwards. Mexico has a structural length identical to Rep. of Korea. However, due to its sales structure and production function, its length is one step shorter than that of Rep. of Korea.

Sector and country-specific length and position

Upstreamness and downstreamness at a sector level

Figure 11 shows the upstreamness and downstreamness of the top 30 exporting sectors (out of a total of 56). The size of bubbles represents importance in total exports. As shown in the graph, the differences in the distance to final demand (upstreamness) are very large, while the distances to value added (downstreamness) are quite similar. All manufacturing sectors report an average distance of between 2.6 and 3.1, except pharma. Primary and tertiary sectors have a distance

Figure 11.
Upstreamness and downstreamness of exporting sectors, 2014.



Source: Created by the author based on WIOD.

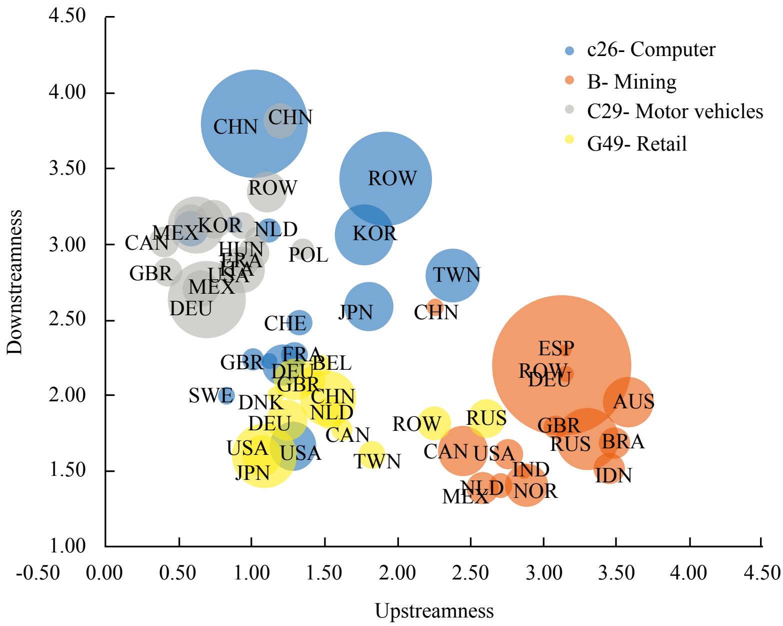
to value added of between 1.8 and 2.2, except for transportation where it is higher. Upstreamness reports large differences. Mining stands out for its larger than average distance to final demand. Additionally, base metals, chemicals, petroleum and fabricated metals report significant distances, while electrical materials, computers and machinery and equipment have an intermediate distance to final demand. Finally, motor vehicles, textiles, pharma and food sectors are situated very close to the final consumer. For services, the closest sectors to the final consumer are computer programming, accommodation and food, financial services and trade, while business and administrative services are further away.

Sector-country analysis of position

The information at the country-sector level completes the description. Figure 12 shows the position of the four main exporting sectors in the database and the top ten exporting countries in each sector. The size of the bubbles represents the importance of each country-sector in exports. The top four sectors have quite different positions.

In the computer equipment sector, China appears as the country with the highest downstreamness and one of the lowest upstreamness, contrasting strongly with the position of the USA, in close proximity to value added. The other Asian countries in the sample have a much greater downstreamness than China, and also less distance to value added. The European countries are in an intermediate position and

Figure 12.
Upstreamness and downstreamness of top 10 exporting countries in top 4 exporting sectors, 2014.



Source: Created by the author based on WIOD

do not have any major differences between them, except for the Netherlands and Sweden. The second largest sector is mining, which, as we saw in Figure 12, is particularly far from final demand. There are no major differences between countries, although the three North American countries have less upstreamness. The third most important sector in international trade is motor vehicles, where Germany appears as the main exporter. There, the countries are similarly positioned, close to final demand in relatively long backward chains. China differs from the rest in that it has a much longer backward portion, although it does not stand out for its proximity to final demand, as it has in other sectors. The fourth most important sector is retail, which is a short chain. USA has great weight in this sector, and its chain is also shorter than the other countries. This sector contributes to USA's short position, both in terms of its structural and idiosyncratic positions.

CONCLUSIONS

Specialization through international trade organized in global value chains tends to place countries in different segments of the supply chain. Using the information produced from the construction of multi-country input-output tables, in recent years there have been improvements in the metrics for measuring the participation and depth of trade in value chains. The vast majority of the literature on chain measurement uses gross exports to calculate the measures.

However, the literature measuring the location of sectors and countries in value chains has taken as the benchmark a country's production (Antràs & Chor, 2018; Miller & Temurshoev, 2017) or only a portion of international trade (Wang *et al.*, 2017a). The measures proposed in this paper, based on gross exports, show some particularities of the international fragmentation of production the benchmark measures have been unable to reveal. Based on WIOD between 2000 and 2014, I have found that, on average, exports are integrated into value chains that elongate forward (*i.e.*, away from final demand) and backward (*i.e.*, away from value added) but do so in a way that is biased toward greater forward distance. While previous measures produced a strong positive correlation between the two measures, the measures proposed in this paper exhibit a negative correlation. This means that countries with longer forward length tend to have shorter backward length, which is consistent with countries located in different segments along chains of a given length.

The Asian factory has longer value chains than the European or American factories, and over the period studied they increased their distance from the rest. Differences between the countries within the factories were identified. China's exports are located a long way from primary factors (due to the length of its domestic chains) and close to final demand. On the other hand, while the other Asian countries are also distant from primary factors, they are less distant than China. They are also distant from final demand. China also stands out because most of its backward distance is explained by domestic production stages, while in the rest of the countries (especially the smaller ones), the international circulation of foreign inputs is an important part of the length of their chains. The greater length of Chinese chains is not necessarily due to the composition of their exports, which mainly derive from traditionally long sectors, but the analysis at the country-sector level shows that China is consistently closer to final demand, but especially further away from primary factors.

The Americas factory (consisting of USA, Mexico and Canada) is particularly short both forward and backward, and countries are positioned differently according to the measures used. For example, according to Wang *et al.* (2017a), the three countries are downstream, and for AC-MT only Canada is upstream. But these results are not consistent with specialization within the bloc. The measures based on exports indicate that Mexico is downstream, and the United States and Canada are upstream.

European manufacturing holds an intermediate rank in terms of position and length. Czech Republic, Slovakia, Italy, Spain and Poland are the countries furthest downstream, while the Netherlands and Great Britain are upstream. The analysis also places far upstream countries with a significant presence of mining in their exports, such as Australia, Norway, Russia, Canada and Brazil.

The analysis of the idiosyncratic components of chain participation indicates that Australia, Russia and Brazil, as suppliers to China, inherit their long forward length, while Norway and Canada, suppliers to the shortest factories in the Americas and Europe, inherit their low forward length.

While USA, Brazil and Indonesia may appear to be countries positioned close to final demand if all production is considered, examination of their exports profiles reveals that they are actually further upstream in the chain.

This analysis inherits the limitations of the multi-country input-output tables and the techniques associated with them. The most original aspect of these tables is the identification of intermediate trade flows between sectors-country of origin and sectors-country of use. However, this is constructed in an approximate way through proportionality assumptions (Ahmad *et al.*, 2013; Puzzello, 2012) as there are no detailed statistics to indicate the origin of an input according to the sector of use. Another limitation of the analysis lies in the assumption of the homogeneity of firms within sectors, which combined with a relatively high level of aggregation (56 sectors) may bias the results. This, given that exporting firms tend to have a different supply structure and value added than domestic firms (Bernard *et al.*, 2007). For this reason, for sector- or country-specific analyses, the information should be complemented with more specific data on the type of goods exported and the use of imported inputs (Sanguinetti *et al.*, 2021).

The literature on downstreamness and upstreamness does not yet produce very clear policy recommendations. However, it is clear that upstream and downstream industries have quite different policy requirements in terms of trade facilitation, infrastructure, capabilities or rules of origin. It is important to bear in mind that the evolution towards a certain type of insertion will have implications for the direction of the required policies.

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APPENDIX

A.1 - Algebra

A.1.1- Demonstration of $D_E = D_{E_{dom}} + D_{E_{int}}$

$$D_E = VBB\hat{E}$$

$$D_{E_{dom}}: VLL\hat{E} + VBA^F LL\hat{E}$$

$$D_{E_{int}}: VBBA^F L\hat{E}$$

$$VBB\hat{E} = VLL\hat{E} + VBA^F LL\hat{E} + VBBA^F L\hat{E}$$

$$VBB\hat{E} = V(LL + BA^F LL + BBA^F L)\hat{E}$$

Using the following equality:

$$BA^F L = B(A - A^D)L = (I - A)^{-1}(A - A^D)(I - A^D)^{-1} =$$

$$= [(I + A + A^2 + A^3 + \cdots)A - (I + A + A^2 + A^3 + \cdots)A^D]\left(I + A^D + {A^D}^2 + {A^D}^3 + \cdots\right) =$$

$$= (A + A^2 + A^3 + A^4 + \cdots) - (I + A + A^2 + A^3 + \cdots)A^D +$$

$$(A + A^2 + A^3 + A^4 + \cdots)A^D - (I + A + A^2 + A^3 + \cdots){A^D}^2 +$$

$$(A + A^2 + A^3 + A^4 + \cdots){A^D}^2 - (I + A + A^2 + A^3 + \cdots){A^D}^3 +$$

$$(A + A^2 + A^3 + A^4 + \cdots){A^D}^3 - (I + A + A^2 + A^3 + \cdots){A^D}^4 + \cdots =$$

$$= (A + A^2 + A^3 + A^4 + \cdots) - (I + \cancel{A + A^2 + A^3 + \cdots})A^D +$$

$$\cancel{(A + A^2 + A^3 + A^4 + \cdots)A^D} - (I + \cancel{A + A^2 + A^3 + \cdots}){A^D}^2 +$$

$$\cancel{(A + A^2 + A^3 + A^4 + \cdots){A^D}^2} - (I + \cancel{A + A^2 + A^3 + \cdots}){A^D}^3 +$$

$$\cancel{(A + A^2 + A^3 + A^4 + \cdots){A^D}^3} - (I + \cancel{A + A^2 + A^3 + \cdots}){A^D}^4 + \cdots =$$

$$= I + A + A^2 + A^3 + A^4 + \cdots - I - A^D - {A^D}^2 - {A^D}^3 - {A^D}^4 - \cdots =$$

$$= (I - A)^{-1} - (I - A^D)^{-1} = B - L$$

Replacing $BA^F L$ por $(B - L)$ in $V(LL + BA^F LL + BBA^F L)\hat{E}$

$$VBB\hat{E} = V(LL + (B - L)L + B(B - L))\hat{E} = V(LL + BL - LL + BB - BL))\hat{E} = V(BB)\hat{E}$$

A.1.2- Demonstration of $(I + 2A + 3A^2 + 4A^3 + \cdots) = BB$

Using the equivalency: $(I + A + A^2 + A^3 + \cdots) = (I - A)^{-1} = B$

$$(I + 2A + 3A^2 + 4A^3 + \cdots)$$
$$= I + A + A^2 + A^3 + A^4 + \cdots + A + A^2 + A^3 + A^4 + \cdots + A^2 + A^3 + A^4 + \cdots + A^3 + A^4 + \cdots =$$

$$(I - A)^{-1} + A(I - A)^{-1} + A^2(I - A)^{-1} + A^3(I - A)^{-1} + \cdots =$$

$$(I + A + A^2 + A^3 + A^4 + \cdots)(I - A)^{-1} = (I - A)^{-1}(I - A)^{-1} = BB$$

Using the equivalency $(I + J + J^2 + J^3 + \cdots) = (I - J)^{-1} = H$, demonstration of $(I + 2J + 3J^2 + 4J^3 + \cdots) = HH$ is analogous.

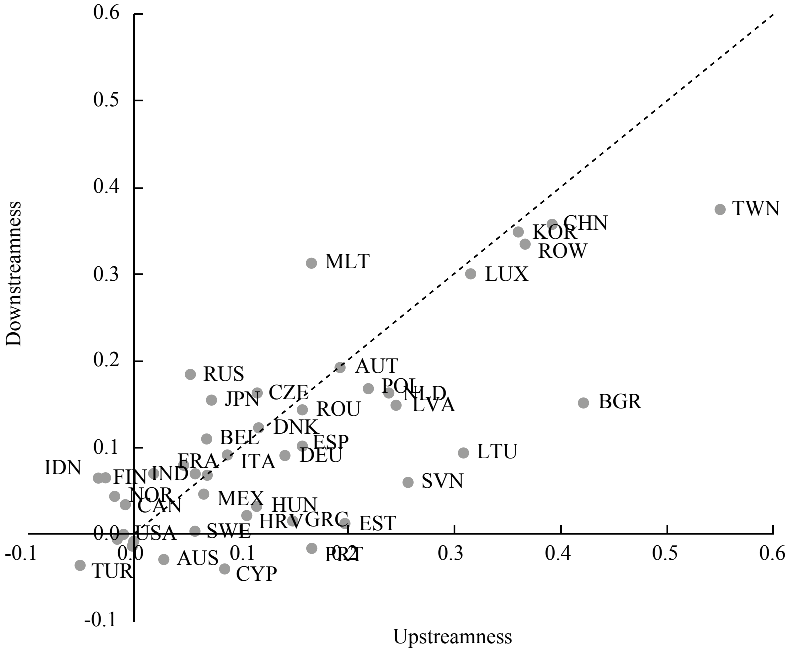
A.1.3- Demonstration of $\hat{X}^{-1}B\hat{X} = H$

$$\hat{X}^{-1}B\hat{X} = H \rightarrow B\hat{X} = \hat{X}H \rightarrow (I - A)^{-1}\hat{X} = \hat{X}(I - J)^{-1} \rightarrow \hat{X}(I - J) = (I - A)\hat{X}$$
$$\rightarrow \hat{X} - \hat{X}J = \hat{X} - A\hat{X} \rightarrow \hat{X} - Z = \hat{X} - Z$$

A.2 Additional Figures

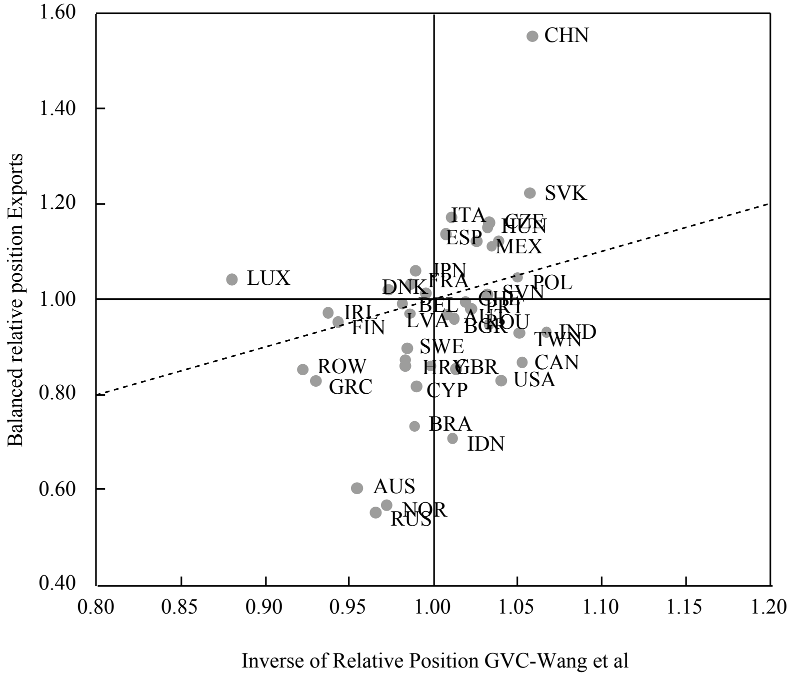
Figure A.1.

Change in Upstreamness and Downstreamness Based on Output (AC-MT). Years 2000-2014



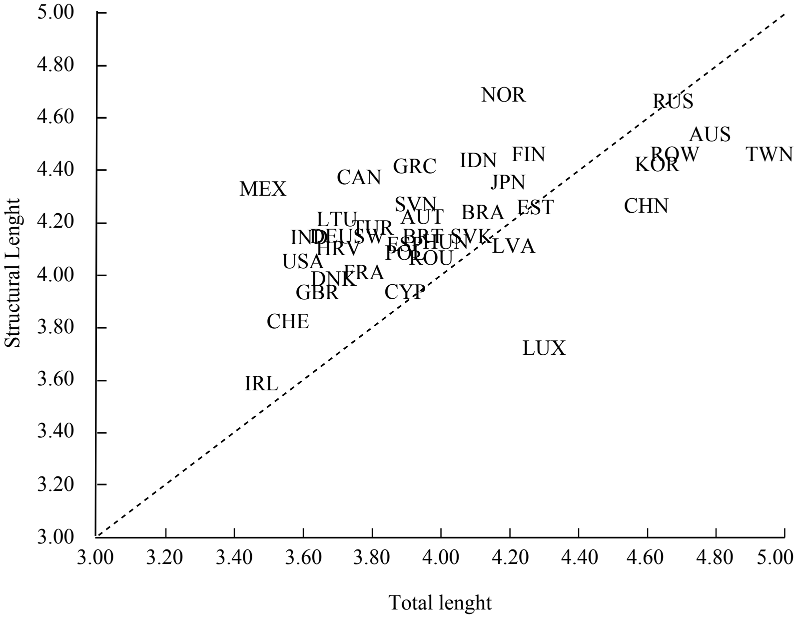
Source: Created by the author based on WIOD.

Figure A.2.
Balanced relative position of exports and ratio of upstreamness to downstreamness according to Wang *et al*. (2017a). Year 2014



Source: Created by the author based on WIOD.

Figure A.3.
Structural and total length of chains. 2014



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90

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