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The geographical and sectoral concentration of global supply chains

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ABSTRACT

Due to international fragmentation, production increasingly occurs in global supply chains (GSC). The common belief is that this leads to more specialization, which implies more concentration of imports and exports over time. In this paper, we empirically test this hypothesis by analysing the geographical and sectoral concentration of GSC over the period 1995–2011. We adapt the traditional Herfindahl's concentration indexes to a multi-regional input–output framework. Taking the information on intersectoral and interregional linkages into full account gives the concentration indexes of GSC. The indexes are at different aggregation levels, which enables us to examine both geographical and sectoral concentration patterns. After that, we analyse the effect a country's geographical and sectoral concentration on its gross domestic product (GDP) per capita. Our findings are: an increase of geographical and sectoral concentration of GSC from 1995 to 2011; a growing role in global production chains played by China and other Asian countries; less concentration for European Union countries; a significant positive effect of geographical concentration on GDP per capita; and a significant negative effect of sectoral concentration.

KEYWORDS

global supply chains, global multi-regional input–output table, geographical concentration, sectoral concentration, Herfindahl index

JEL F0, F10

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INTRODUCTION

The contemporary economy has increasingly become global and fragmented. The fragmentation meant that the production process of a certain good was split into ever smaller pieces. The consequence was that goods were now produced stepwise in supply chains or value chains (when focusing on the value that was added in each step). Globalization was defined by Giddens (1990, p. 64) as 'intensification of worldwide social relations which link distant localities in such way that local happenings are shaped by events occurring many miles away and vice

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versa'. As Sturgeon and Gereffi (2012, pp. 2–3) claim, current globalization 'underscores the growing interdependence between developed and developing countries' and 'there is a useful focus on how the chain of activities is organized across firms and country boundaries …'. This meant an increasing intensification of worldwide economic relations, linking distant regions through international trade. The progressive decline in transport and communication costs and fewer trade barriers allowed enterprises to obtain intermediate products from different parts of the world. The consequence of globalization was that the steps in the supply chains could easily cross borders. Therefore, fragmentation led to more complex supply chains and globalization led to supply chains becoming global. Hence, global supply chains (GSC).

Two aspects are crucial about GSC. First, its global nature; and second, the specialization in parts of the production process. The first aspect received a lot of attention in the literature on trade, input–output, international economics and international business. Whereas the underlying reasoning was at the firm level, the empirics took place at the level of sectors (or industries) in a global environment. The second aspect received much less attention in this area of the literature but was dealt with in the literature on business organizations (Casalin et al., 2017; Zhao & Zou, 2002). Although the underlying reasoning was again in terms of firms, in this paper we empirically focus on specialization at the level of sectors in a global framework.[1] These two aspects led to different (but complementary) processes of diversification and concentration of the chain simultaneously.

GSC (and international fragmentation) have been much discussed in recent years. Some papers examined internationalization of production and the consequences of an increasing role of exports for income generation (Baldwin, 2011; Fally, 2011; Inomata, 2016; Jouanjean et al., 2017). Other papers (Escaith & Inomata, 2013; Petri et al., 2014; Zhang & Minghui, 2012) focused on the 'geometry' behind supply chains and the implication for the economic upgrading of East Asia economies. Different studies have investigated the position of countries in GSC and the implication for economic growth (Zi, 2020). Also, various other effects of supply chains have been analysed, for example, on worldwide employment (García-Alaminos et al., 2020; Lakhani et al., 2013), on natural resources (Bolea et al., 2020) and on gender issues (Barrientos, 2019). The supply chain perspective has become more important with the emergence of Asian economies and their increasing presence in international trade in the last 30 years (Inomata, 2014; Suder et al., 2015). For many economies, the ability to effectively participate in GSC is imperative for their development (Barrientos et al., 2010).

The business organization literature has paid attention to the characteristic of outsourcing of parts of production processes and of niche specialization. In this context, this literature found that usually, within an industry, only one firm (or a small number of firms) achieves a large share of the market. This is also known as the 'winner takes the most' (Autor et al., 2020; Choi & Lee, 2018). There are many reasons why this happened, such as the creation of new competitive platforms or the increasing competition in international markets. In this way, the superstar model led to increased concentration of production in certain country sectors, as Autor et al. (2017) show for the United States from 1982 to 2012. As a result, both the number of sellers on the supply side and the number of buyers on the demand side are reduced. In this context, firms and sectors became more dependent on a few others. Besides, the studies on concentration focused on the tendency of certain sectors to locate primarily in specific geographical regions or countries, taking advantage of economic agglomeration (Parr et al., 2002; Porter, 2000; Shearmur & Polèse, 2005; Szanyi et al., 2010). This is the case, for instance, for the high-tech sectors in the United States, Japan, Taiwan and South Korea (Ernst & Guerrieri, 1998; Sturgeon et al., 2008).

In sum, the literature suggests different forces towards diversification and concentration in the context of globalization trends. It is thus a matter of empirics to check which ones have been more powerful in the last decades. In this paper, we measure concentration of GSC, for

which we use global multi-regional input–output (MRIO) tables. To the best of our knowledge, this measurement has never been done before. Global MRIO tables summarize all linkages between the countries and/or sectors involved in production and various sets of tables have become publicly available in the last 10 years (Tukker & Dietzenbacher, 2013). The research questions we want to answer are the following. Have GSC become geographically and sectorally more concentrated or diversified over time? What are the implications of the developments in the concentration of GSC for economic growth?

Indeed, this last question has not an easy answer, as both diversification and concentration have advantages and disadvantages (Shearmur & Polèse, 2005). On the one hand, concentration has positive effects on the efficiency in production processes. On the other hand, increased concentration makes firms and sectors more dependent on a few others, which makes them more vulnerable and creates a potential risk to production (Blome & Schoenherr, 2011; Cavinato, 2004; Tang, 2006; Thun & Hoenig, 2011; Wiengarten et al., 2016). For example, the difficulty of switching to contingency suppliers in the face of some disruptive event was painfully highlighted by the tsunami in Japan in 2011, impacting both high-tech sectors and car producers. Similar problems were caused by tropical storms and flooding in China, Thailand, South Korea and Taiwan (Wagner & Bode, 2006). In this context, the literature has pointed out that more diversification favours resilience in the long term (Brakman et al., 2015; Christopherson et al., 2010; Groot et al., 2011; Martin et al., 2016). Positive effects have also been reported for diversification of exports. For instance, Saviotti and Frenken (2008), Drucker (2011), Lei and Zhang (2014) and Freire (2017), among others, claim that more sectoral diversity leads to more economic growth. Indeed, diversity seems to induce cycle stability, as Martin et al. (2016) claim.

In our analysis, we will take the viewpoint of the buyer of inputs (which may be domestically produced or imported) and the viewpoint of the seller of products (for domestic or foreign markets). In both cases, the starting point will be a very general version of Herfindahl's concentration index, adapted to the global MRIO framework. Further refinements of the indexes are used to study geographical and sectoral concentration of GSC. We calculate the indexes for different levels of aggregation, to check for the robustness of the findings.

We will carry out two types of calculations. First, we look at the direct imports of a country. Therefore, the question is to what extent the imports of, for example, Canada are highly concentrated in a few origin countries (such as the United States) or very diversified over a large set of supplying countries? Similarly, are Canadian imports concentrated in a few products (delivered by a few supplying sectors abroad) or are they spread over a broad range of imported products? Second, we look at the imports that are embodied in the GSC of a country (e.g., Canada). That is, we look at how much US imports, and German imports, Japanese imports, etc., are embodied in the final products produced by Canada. A similar question is raised with respect to embodied imports by sector. This second type of calculation reflects the concentration of GSC.

The rest of the paper is structured as follows. The next section introduces the methodology used and explains how global MRIO tables can be used to calculate different concentration indexes depending on the aggregation. The third section applies this methodology to study annual changes in GSC between 1995 and 2011. For our calculations, we use the 2013 release of the World Input–Output Database (WIOD) (Dietzenbacher et al., 2013; Timmer, 2012; Timmer et al., 2014, 2015).[2] An econometric analysis is carried out to analyse the relationship between the changes observed in GSC and economic growth. The fourth section closes the paper with a summary of our main conclusions.

METHODOLOGY

Our main objective is to study the sectoral and geographical concentration of GSC. We would like to check and quantify whether globalization has made world production increasingly

dependent on an ever-smaller number of countries and/or sectors. The alternative is that GSC have become more diversified. Concentration will be measured by Herfindahl indexes for GSC that we develop in the last subsection. These indexes are multi-sectoral and multi-regional adaptations of the set of Herfindahl indexes that we develop in the second subsection to measure concentration of imports and exports. We start with introducing the type of data we use (i.e., global MRIO tables) and with a brief introduction to the Herfindahl index.

Global MRIO tables and Herfindahl indexes

Our starting point is the global MRIO table in Table 1 with n countries and m sectors in each country.[3] The $m \times m$ matrix $\boldsymbol{Z}^{rs}$ gives the intermediate deliveries from country r to country s. Its typical element z_{ij}^{rs} gives the value of goods and services shipped from sector i in country r for intermediate use by sector j in country s. The value of goods and services shipped from sector i in country r to country s for final use (household consumption, private investments, and government expenditures) is given by f_i^{rs}, the typical element of the vector $\boldsymbol{f}^{rs}$. The value of the output by sector i in country r is given by x_i^r, the typical element of the vector $\boldsymbol{x}^r$. The accounting identity is:

$$x_i^r = \sum_j \sum_s z_{ij}^{rs} + \sum_s f_i^{rs} \tag{1}$$

For the general definition of the Herfindahl index, consider a set of p shares. The shares are denoted by σ_i $(i = 1, \ldots, p)$ with $\sum \sigma_i = 1$. The standard Herfindahl concentration index (Kelly, 1981; Michelini & Pickford, 1985; Rhoades, 1993) is then given by:

$$H = \sum_i (100\ \sigma_i)^2 \tag{2}$$

This index has a maximum value of 10,000, which is achieved when one (and only one) share is 1 and all other shares are 0. When all shares have the same value (i.e., $\sigma_i = 1/p$), H reaches the minimum value, $10000/p$. In our MRIO framework, we will analyse both the geographical (country) and the sectoral concentration of imports and exports.

Because we consider concentration at different levels of aggregation (country sectors, countries, sectors, global), we will use a readjusted Herfindahl index (HR) to compare our results. The values for HR range from 0 to 10,000, irrespective of the number (p) of shares. For any $p > 1$,

Table 1. The global multi-regional input–output (MRIO) table.

	Intermediate use					Final use					Gross
	in 1	⋯	**in *r***	⋯	**in *n***	**in 1**	⋯	**in *r***	⋯	**in *n***	**outputs**
Country 1	$\boldsymbol{Z}^{11}$	⋯	$\boldsymbol{Z}^{1r}$	⋯	$\boldsymbol{Z}^{1n}$	$\boldsymbol{f}^{11}$	⋯	$\boldsymbol{f}^{1r}$	⋯	$\boldsymbol{f}^{1n}$	$\boldsymbol{x}^1$
⋮	⋮	⋱	⋮	⋰	⋮	⋮	⋱	⋮	⋰	⋮	⋮
Country *r*	$\boldsymbol{Z}^{r1}$	⋯	$\boldsymbol{Z}^{rr}$	⋯	$\boldsymbol{Z}^{rn}$	$\boldsymbol{f}^{r1}$	⋯	$\boldsymbol{f}^{rr}$	⋯	$\boldsymbol{f}^{rn}$	$\boldsymbol{x}^r$
⋮	⋮	⋰	⋮	⋱	⋮	⋮	⋰	⋮	⋱	⋮	⋮
Country *n*	$\boldsymbol{Z}^{n1}$	⋯	$\boldsymbol{Z}^{nr}$	⋯	$\boldsymbol{Z}^{nn}$	$\boldsymbol{f}^{n1}$	⋯	$\boldsymbol{f}^{nr}$	⋯	$\boldsymbol{f}^{nn}$	$\boldsymbol{x}^n$
Value added	$(\boldsymbol{w}^1)'$	⋯	$(\boldsymbol{w}^r)'$	⋯	$(\boldsymbol{w}^n)'$						
Total inputs	$(\boldsymbol{x}^1)'$	⋯	$(\boldsymbol{x}^r)'$	⋯	$(\boldsymbol{x}^n)'$						

HR is defined as follows:

$$HR = \frac{\sum_i (100\ \sigma_i)^2 - (10000/p)}{10000 - (10000/p)} 10000 = \frac{10000\ p}{p-1}\left[\sum_i (\sigma_i)^2 - (1/p)\right] \tag{3}$$

where $p/(p-1)$ is a normalization factor. If all shares are $1/p$, then $HR = 0$, which is the minimum. If one and only one share is 1 and all other shares are 0, then $HR = 10000$.

For this HR index, the definition for a 'market' to be concentrated is based on the rules of the US Department of Justice (n.d.). If the Herfindahl index is below 1500, the market is considered to display low concentration; if it is between 1500 and 2500, it is moderately concentrated; and if it is over 2500, it is highly concentrated.[4]

Herfindahl indexes for direct imports and exports

Because we focus on trade, we set $z_{ij}^{rr} = 0$, for all r. Let us consider the imports first. The question is: How are the imports concentrated in (or spread out over) the countries of origin? The immediate follow-up question is: What imports? We will look at four different aggregation levels: the imports of product i by sector j in country s; all imports by sector j in country s; all imports by country s; and all imports.

At the most detailed level of aggregation, we define the import shares as:

$$h_{ij}^{rs}(r) = \frac{z_{ij}^{rs}}{\sum_r z_{ij}^{rs}} \tag{4}$$

which considers the imports of product i by sector j in country s and gives the share of these imports that is delivered by country r. The letter r between parentheses indicates that we are interested in the concentration of imports in the countries of origin.[5] Herfindahl index is given by:

$$H_{ij}^{s}(r) = \frac{10000\ n}{n-1}\left[\sum_r (h_{ij}^{rs}(r))^2 - (1/n)\right] \tag{5}$$

At the next level, the question remains the same (i.e., the concentration of imports in the countries of origin) but we are looking at aggregated imports. That is, all imports by sector j in country s (i.e., $\sum_r \sum_i z_{ij}^{rs}$). The share of these imports coming from country r is given by:[6]

$$h_{\cdot j}^{rs}(r) = \frac{\sum_i z_{ij}^{rs}}{\sum_r \sum_i z_{ij}^{rs}} \tag{6}$$

The country sector-specific Herfindahl index for $h_{\cdot j}^{rs}(r)$ is given by:

$$H_{\cdot j}^{s}(r) = \frac{10000\ n}{n-1}\left[\sum_r (h_{\cdot j}^{rs}(r))^2 - (1/n)\right] \tag{7}$$

and indicates the geographical concentration (by origin) of imports of intermediate inputs by sector j in country s.

To obtain a Herfindahl index that describes the geographical concentration (by origin) of imports by country s, we have:

$$h^{rs}_{\cdot\cdot}(r) = \frac{\sum_j \sum_i z^{rs}_{ij}}{\sum_j \sum_i \sum_r z^{rs}_{ij}} \text{ and } H^{\cdot s}_{\cdot\cdot}(r) = \frac{10000\ n}{n-1}\left[\sum_r (h^{rs}_{\cdot\cdot}(r))^2 - (1/n)\right] \tag{8}$$

$$h^{r\cdot}_{\cdot\cdot}(r) = \frac{\sum_s \sum_i \sum_j z^{rs}_{ij}}{\sum_s \sum_i \sum_j \sum_r z^{rs}_{ij}}$$

Finally, we can also estimate the geographical concentration (by origin) of imports in the world market. In this case the shares and Herfindahl index are given by:

$$h^{r\cdot}_{\cdot\cdot}(r) = \frac{\sum_s \sum_i \sum_j z^{rs}_{ij}}{\sum_s \sum_i \sum_j \sum_r z^{rs}_{ij}}$$

$$H^{\cdot\cdot}_{\cdot\cdot}(r) = \frac{10000\ n}{n-1}\left[\sum_r (h^{r\cdot}_{\cdot\cdot}(r))^2 - (1/n)\right] \tag{9}$$

In the same way, we can derive four Herfindahl indexes for the geographical concentration of exports over the destination countries. This is done by simply swapping the indexes r and s in the summations.

Moreover, Herfindahl indexes of sectoral concentration of exports (or imports) are obtained by swapping r with j (or with i) in the summations. For example, the four types of shares that reflect the concentration of exports over the sectors of destination are given by:

$$h^{rs}_{ij}(j) = \frac{z^{rs}_{ij}}{\sum_j z^{rs}_{ij}},\ h^{rs}_{\cdot j}(j) = \frac{\sum_i z^{rs}_{ij}}{\sum_j \sum_i z^{rs}_{ij}},\ h^{\cdot s}_{\cdot j}(j) = \frac{\sum_r \sum_i z^{rs}_{ij}}{\sum_j \sum_r \sum_i z^{rs}_{ij}},\ h^{\cdot\cdot}_{\cdot j}(j) = \frac{\sum_s \sum_r \sum_i z^{rs}_{ij}}{\sum_j \sum_s \sum_r \sum_i z^{rs}_{ij}}$$

The corresponding Herfindahl indexes yield:

$$H^{rs}_{i\cdot}(j) = \frac{10000\ m}{m-1}\left[\sum_j (h^{rs}_{ij}(j))^2 - (1/m)\right],\ H^{rs}_{\cdot\cdot}(j) = \frac{10000\ m}{m-1}\left[\sum_j (h^{rs}_{\cdot j}(j))^2 - (1/m)\right]$$

$$H^{\cdot s}_{\cdot\cdot}(j) = \frac{10000\ m}{m-1}\left[\sum_j (h^{\cdot s}_{\cdot j}(j))^2 - (1/m)\right],\ H^{\cdot\cdot}_{\cdot\cdot}(j) = \frac{10000\ m}{m-1}\left[\sum_j (h^{\cdot\cdot}_{\cdot j}(j))^2 - (1/m)\right]$$

with m the number of sectors in each country. It should be mentioned that the 'chain of four Herfindahl indexes' depends on the ordering that has been used. As we have four parameters, r, s, i and j, we have $4! = 4 \times 3 \times 2 \times 1 = 24$ different chains, each providing a different kind of information.

So far we have focused on the shares and Herfindahl indexes for the imports and exports of intermediate deliveries. Similar expressions are given in Appendix A in the supplemental data online for trade in final products and for all trade (i.e., intermediate deliveries and final products).

Herfindahl indexes for GSC

Input coefficients are defined as $a^{rs}_{ij} = z^{rs}_{ij}/x^s_j$ and give the input of product i from country r necessary for the production of one unit (i.e., US$1 million in the WIOD tables) in sector j of country s. The accounting equation (1) thus becomes $x^r_i = \sum_j \sum_s a^{rs}_{ij} x^s_j + \sum_s f^{rs}_i$. In matrix notation we have:

$$\boldsymbol{x} = \boldsymbol{A}\boldsymbol{x} + \boldsymbol{y} \tag{10}$$

with:

$$\boldsymbol{A}=\begin{bmatrix}\boldsymbol{A}^{11} & \cdots & \boldsymbol{A}^{1n}\\ \vdots & \ddots & \cdots\\ \boldsymbol{A}^{n1} & \cdots & \boldsymbol{A}^{nn}\end{bmatrix},\ \boldsymbol{x}=\begin{pmatrix}\boldsymbol{x}^{1}\\ \vdots\\ \boldsymbol{x}^{n}\end{pmatrix},\ \boldsymbol{y}=\begin{pmatrix}\boldsymbol{y}^{1}\\ \vdots\\ \boldsymbol{y}^{n}\end{pmatrix}=\begin{pmatrix}\sum_{s}\boldsymbol{f}^{1s}\\ \vdots\\ \sum_{s}\boldsymbol{f}^{ns}\end{pmatrix}$$

The solution of the input–output model in (10) is given by $\boldsymbol{x}=(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{y}$, where $(\boldsymbol{I}-\boldsymbol{A})^{-1}$is the Leontief inverse. Next we define $\boldsymbol{Q}=(\boldsymbol{I}-\boldsymbol{A})^{-1}\hat{\boldsymbol{y}}$. Its typical element q_{ij}^{rs} gives the production of sector i in country r that is embodied in the final products sold by sector j in country s. In other words, this is the production of sector i in country r that is involved in the GSC of sector j in country s. In the same way as we did for the direct imports and exports of intermediate deliveries in the matrix $\mathbf{Z}$, we now consider the embodied imports and exports. That is, the foreign production that is embodied (through the supply chain) in certain final products sold by the home country and the home production that is embodied in the final products sold by foreign countries. The embodied imports are given in the columns of the matrix $\mathbf{Q}$ and the exports in the rows. The columns of matrix $\mathbf{Q}$ reflect the GSC dependence of sector j in country s on production in sector i in country r. The rows of matrix $\mathbf{Q}$ reflect the contribution of sector i in country r to the GSC of sector j in country s.

Under these embodied flows approach, we can now ask to what extent imports and exports are concentrated in the global chains. Taking $q_{ij}^{rr}=0$ for all i,j and r, in order to focus on foreign contributions to GSC (the imports perspective) or contributions to foreign GSC (the exports perspective). For example, the contributions of country r to the GSC of sector j in country s, can be measured as a share of all foreign contributions to the GSC of sector j in country s (i.e., the import perspective) or as a share of the contributions to all GSC in country s (i.e., the export perspective). These shares are, respectively, given by:

$$t_{\cdot j}^{rs}(r)=\frac{\sum_i q_{ij}^{rs}}{\sum_r\sum_i q_{ij}^{rs}},\ t_{\cdot j}^{rs}(j)=\frac{\sum_i q_{ij}^{rs}}{\sum_j\sum_i q_{ij}^{rs}}$$

and the corresponding Herfindahl are:

$$T_{\cdot j}^{\cdot s}(r)=\frac{10000\ n}{n-1}\left[\sum_r\left(t_{\cdot j}^{rs}(r)\right)^2-(1/n)\right],\ T_{\cdot\cdot}^{rs}(j)=\frac{10000\ m}{m-1}\left[\sum_j\left(t_{\cdot j}^{rs}(j)\right)^2-(1/m)\right]$$

RESULTS

Results at the global level

As indicated in the previous section, the multi-country and multi-sector nature of the global MRIO table allows us to obtain concentration indexes at several levels of aggregation. In this paper, we focus only on concentration at the global level and at the level of countries and sectors. More detailed results are available upon request.

First, we consider overall trade in the world by calculating Herfindahl concentration indexes for global imports and exports, both at the country and sector level and for matrices $\mathbf{Z}$ and $\mathbf{Q}$. The index $H_{\cdot\cdot}^{\cdot}(r)$ gives – for all direct imports – the concentration in origin countries and $H_{\cdot\cdot}^{\cdot}(i)$ gives the concentration in origin sectors. The concentration of all exports in destination countries is given by $H_{\cdot\cdot}^{\cdot}(s)$ and concentration in destination sectors by $H_{\cdot\cdot}^{\cdot}(j)$. Indexes $T_{\cdot\cdot}^{\cdot}(*)$ are used to reflect the concentration of countries' embodiment in foreign GSC (the import perspective, $*=r$) or the concentration of foreign embodiment in countries' GSC (the export

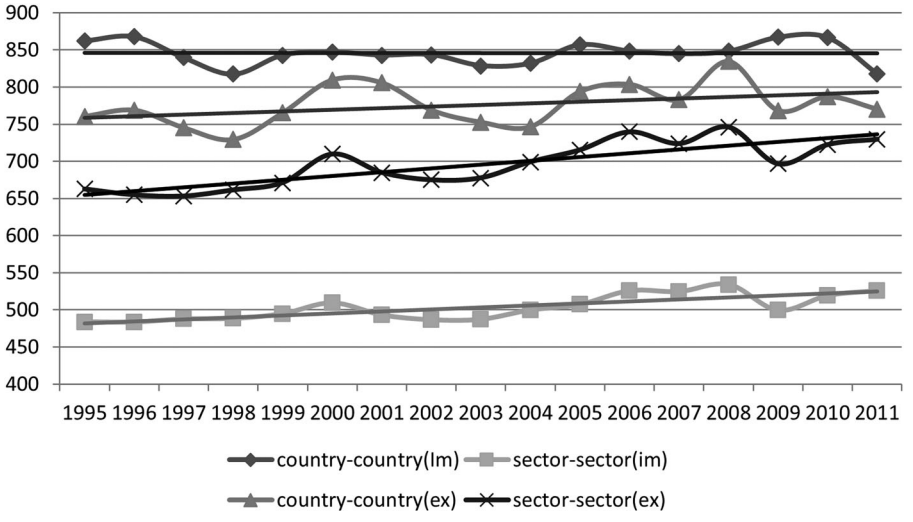

Figure 1. Sectoral and geographical concentration of direct global trade between 1995 and 2011 (Herfindahl indexes $H^{::}_{:}(r)$, $H^{::}_{:}(i)$, $H^{::}_{:}(s)$, and $H^{::}_{:}(j)$).

perspective, $* = s$). A larger concentration index for matrix $\mathbf{Q}$ than for $\mathbf{Z}$ indicates that GSC (which produce the final products that we consume) depend on fewer country sectors than the trade statistics suggest. In other words, if indexes obtained from $\mathbf{Q}$ are in general larger than those obtained from $\mathbf{Z}$ we have a sort of indirect dependence of countries which conditions their production chains even if it is not perceived in their direct purchases.

Figures 1 and 2 present the annual results for the eight indexes at the global level from 1995 to 2011. Several observations hold. First, all indexes are below 1500, indicating low levels of concentration. However, we also observe small yet significant increases over time in this period for almost all Herfindahl indexes. These increases are more significant for the T-indexes (between 5% and 9%) than for the H-indexes (between 1% and 7%). This implies that fewer countries

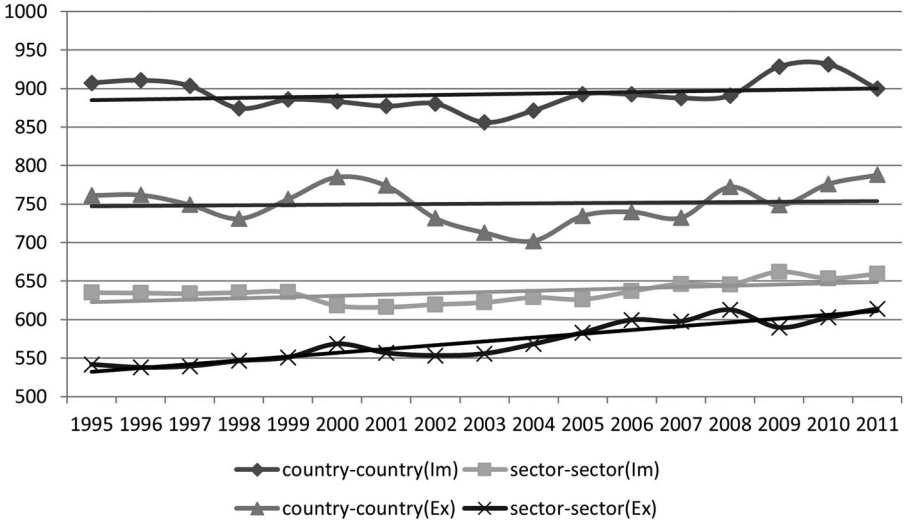

Figure 2. Sectoral and geographical concentration of global supply chain (GSC) participation between 1995 and 2011 (Herfindahl indexes $T^{::}_{:}(r)$, $T^{::}_{:}(i)$, $T^{::}_{:}(s)$, and $T^{::}_{:}(j)$).

play a larger role when looking at global imports (or global embodied imports) and exports. Second, we find larger increases in the period 2003–11. For instance, for the concentration in origin and destination countries we have $T_{\cdot\cdot}^{\cdot\cdot}(r)$ increased 9% and $T_{\cdot\cdot}^{\cdot\cdot}(s)$ increased 11%. These results reflect the important and increasing role of intermediate inputs from China after its accession to the WTO. We also did the same analysis for the case without China.[7] The tendency of $T_{\cdot\cdot}^{\cdot\cdot}(r)$ (concentration of the origins) then becomes negative, which reflects the important role of China. It suggests the coexistence of increasing multilateral trade primarily caused by a growing global dependence on China. We find this result for different levels of aggregation. Third, also the sectoral destinations of the direct and the embodied trade became more concentrated. For example, for the exports $H_{\cdot\cdot}^{\cdot\cdot}(j)$ increased 9% and $T_{\cdot\cdot}^{\cdot\cdot}(j)$ increased 11%. In contrast to what happened for geographical concentration, the sectoral results barely change when China is eliminated from the sample.[8]

This means that the number of relevant players involved in world trade is decreasing and that the existing players – and China in particular – are increasing their participation. The same applies to sectors, a larger part of world trade by less industries. In other words, there is a trend to concentrate imports and exports within a smaller group of countries and sectors. Looking at the detailed results, however, it seems that there is geographical diversification, but with an increasing and strong dependence on China. For instance, Chinese imports represented around 3% in 1995 and 14% in 2011, and the same pattern was observed for exports. This is true for both the direct links (measured through import and exports in **Z**) and for the involvement in GSC (measured through embodiment in **Q**). Also, there is a general trend towards more sectoral concentration of GSC. Together this implies more sectoral specialization and a large and increasing geographical dependence on China. If we run the unit root test for the time series,[9] we get a p-value of 0.31 for $T_{\cdot\cdot}^{\cdot\cdot}(r)$, 0.95 for $T_{\cdot\cdot}^{\cdot\cdot}(s)$, 0.67 for $H_{\cdot\cdot}^{\cdot\cdot}(i)$ and 0.64 for $H_{\cdot\cdot}^{\cdot\cdot}(j)$. This means that we cannot reject the hypothesis of a unit root, indicating that the series are not stationary. This corroborates the other findings so far.

It needs to be emphasized that caution is appropriate. This is because the database covers only 40 countries plus a rest of the world (RoW). Although the RoW is relatively small in terms of total gross domestic product (GDP), it contains a large number of countries and thus many potential trading partners. To check the sensitivity of our results to this aggregation of many countries into a single RoW we calculated the Herfindahl indexes without the RoW.[10] The results are between 300 and 550 lower than the results in Figures 1 and 2. This means that the RoW is big player in terms of trade and therefore increases concentration. This holds in particular for the concentration of destination countries. The increasing trends over time are also found when the RoW is left out of the analysis.[11]

Results at the level of countries and sectors

In this section we look at the results for the import concentration for a given country or sector. Similar results are found for export concentration and are not included here. Detailed results for export concentration are available from the authors upon request.

Import concentration for a given country

The top part of Table 2 gives for each country s and for the years 1995 and 2011 the index $H_{\cdot\cdot}^{\cdot s}(r)$ for the geographical concentration of direct imports (taken from **Z**). It measures how the intermediate inputs of country s are spread over the origin countries. Similarly, index $T_{\cdot\cdot}^{\cdot s}(r)$ gives the concentration in the origin countries of foreign production that is embodied in the final products made in country s (using **Q**). Because we want to compare the two types of Herfindahl indexes, we restrict the analysis to intermediate deliveries (and do not consider the indexes developed in Appendix B in the supplemental data online for trade in final products and for all trade).

Table 2. Herfindahl indexes for geographical and sectoral concentration of imports at the country level, 1995 and 2011.

		AUS	AUT	BEL	BGR	BRA	CAN	CHN	CYP	CZE	DEU	DNK	ESP	EST	FIN	FRA	GBR	GRC	HUN	IDN	IND
Geographical concentration																					
1995	**Z**	859	1,511	930	1,681	1,251	3,876	1,016	483	1,081	399	750	778	1,331	551	717	646	790	680	832	1,569
	Q	828	1,153	779	1,171	1,083	2,871	983	499	893	410	604	709	953	512	660	603	716	599	892	1,270
2011	**Z**	1348	1,240	689	738	1,228	2,709	1,260	710	873	363	568	774	474	573	628	626	578	611	1956	2,843
	Q	1295	834	526	543	957	1,982	1,079	639	678	415	516	648	464	495	577	583	541	505	1487	1,962
DIFZ		489	-271	-241	-942	-23	-1,167	244	227	-208	-36	-182	-5	-856	22	-89	-20	-213	-69	1124	1,274
DIFQ		467	-318	-253	-628	-127	-889	96	140	-215	5	-88	-60	-489	-17	-83	-20	-175	-94	595	692
Sectoral concentration																					
1995	**Z**	375	350	410	630	500	580	748	365	385	460	503	502	371	484	464	494	454	606	479	510
	Q	236	216	223	338	341	288	358	321	238	231	247	306	224	274	262	258	293	356	314	336
2011	**Z**	517	437	462	542	570	490	1,084	470	779	567	550	570	377	572	494	453	457	609	435	1,229
	Q	347	274	287	318	376	363	608	294	385	312	255	382	234	369	330	316	324	356	304	553
DIFH		142	88	52	-89	69	-90	336	105	394	107	47	68	6	89	30	-41	3	3	-44	719
DIFT		112	58	64	-20	35	75	249	-28	147	81	8	76	9	95	68	58	31	0	-10	217

		IRL	ITA	JPN	KOR	LTU	LUX	LVA	MEX	MLT	NLD	POL	PRT	ROM	RUS	SVK	SVN	SWE	TUR	TWN	USA	RoW	Average
Geographical concentration																							
1995	**Z**	1,445	679	1,227	1,274	1,326	1,293	743	4,613	1,269	945	887	860	891	931	1,148	883	700	879	1,228	887	1,090	1,145
	Q	1,142	652	1,194	1,284	1,032	1,112	746	3,792	762	782	773	760	726	679	853	736	654	776	1,141	834	993	966
2011	**Z**	1,651	855	1,868	1,616	1,848	1,447	520	2,558	689	729	714	1287	472	572	709	793	513	590	1,593	1015	439	1,055
	Q	1,181	739	1,637	1,392	944	763	476	1,787	508	655	593	946	418	592	558	642	487	646	1,253	976	525	840
DIFZ		206	176	641	342	522	154	-223	-2,055	-580	-216	-173	428	-419	-359	-439	-90	-188	-289	365	128	-651	-89
DIFQ		39	87	443	108	-89	-349	-270	-2,004	-254	-128	-181	186	-308	-86	-295	-94	-167	-130	112	142	-468	-126
Sectoral concentration																							
1995	**Z**	843	485	665	624	866	1,547	387	996	1,775	520	417	343	570	465	399	516	442	705	832	674	465	590
	Q	337	292	477	365	369	337	252	443	246	289	271	254	271	279	214	271	259	366	354	363	264	298
2011	**Z**	1,879	735	1,534	1,132	808	3,892	428	1,044	593	586	465	385	534	875	594	482	494	637	1,064	787	417	757
	Q	940	436	891	619	322	1,200	250	480	265	388	299	286	310	376	328	283	354	277	550	500	273	405
DIFH		1,036	250	869	508	-58	2,345	41	48	-1,182	67	48	42	-36	410	196	-34	52	-68	232	113	-48	166
DIFT		602	143	414	255	-47	863	-2	37	19	99	28	32	38	97	114	12	95	-88	196	138	10	107

Notes: rows **Z** $H^{s}_{\cdot\cdot}(r)$ list for geographical concentration and $H^{s}_{\cdot\cdot}(i)$ for sectoral concentration; rows **Q** list $T^{s}_{\cdot\cdot}(r)$ for geographical concentration and $T^{s}_{\cdot\cdot}(i)$for sectoral concentration. $DIFH = H^{s}_{\cdot\cdot}(*, 2011) - H^{s}_{\cdot\cdot}(*, 1995)$ and $DIFT = T^{s}_{\cdot\cdot}(*, 2011) - T^{s}_{\cdot\cdot}(*, 1995)$

The eight largest values in each row are coloured dark grey. They indicate the countries in which the production process is least dispersed internationally in the sense that their dependence is most concentrated. Following the guidelines of the US Department of Justice (n.d.), countries with a Herfindahl index larger than 2500 are highly concentrated. The only two countries to which this applies are Canada and Mexico (and India in 2011). On average, concentration is fairly low. Observe that concentration measured through direct imports (i.e., $H_{\cdot\cdot}^{\cdot\,s}(r)$) is in most cases slightly larger than when measured through embodied imports (i.e., $T_{\cdot\cdot}^{\cdot\,s}(r)$). It frequently occurs that a country imports relatively much from one country but when the entire supply chain is considered this dependence on one or a few countries is less outspoken. The increases between 1995 and 2011 are given in Table 2 by the rows $\mathrm{DIFH} = H_{\cdot\cdot}^{\cdot\,s}(r,\ 2011) - H_{\cdot\cdot}^{\cdot\,s}(r, 1995)$ and $\mathrm{DIFT} = T_{\cdot\cdot}^{\cdot\,s}(r,\ 2011) - T_{\cdot\cdot}^{\cdot\,s}(r, 1995)$. The eight largest increases are coloured dark grey and five of them are found in Asian countries (Indonesia, India, Japan, Taiwan and Korea). Again, we check the statistical significance of these changes using a unit root test. For the series of the different countries the p-values are between 0.61 and 0.98 indicating that structural change over time has occurred.

In contrast, the lowest values (light grey) are mainly observed for European countries such as Germany, Finland, Hungary and Sweden. This sketches the European Union (EU) as a well-functioning common market where countries are thoroughly integrated. The eight largest decreases are coloured light grey. Several of them are found in East European economies such as Bulgaria, Estonia, Romania and Slovakia. Note that these East European countries gained access to the EU in 2004 or 2007. Whereas their imports were moderately concentrated in 1995, the import pattern diversified considerably after their accession to the EU. The year 2011 is also a sign on trade diversity as consequence of their effective participation in the EU markets.

Two remarkable countries are Canada and Mexico. They had the largest concentration values (for both $H_{\cdot\cdot}^{\cdot\,s}(r)$ and $T_{\cdot\cdot}^{\cdot\,s}(r)$) in 1995 and showed the largest decreases between 1995 and 2011. The results reflect the development of the North American Free Trade Agreement (NAFTA) between the United States, Mexico and Canada. Mexico and Canada were very dependent for their imports on the United States in 1995. Although they have increased their trade with the United States, they have extended their direct and embodied links with other countries. This implies that they have become less dependent on the United States.

The average geographical concentration decreased between 1995 and 2011. At first sight, this may seem to contradict the increased Herfindahl indexes at the national level (i.e., $H_{\cdot\cdot}^{\cdot\cdot}(r)$ and $T_{\cdot\cdot}^{\cdot\cdot}(r)$). If the average country has an import pattern that becomes more diversified, is it possible that global imports become more concentrated? The answer is yes, which can be illustrated as follows. Suppose that each country buys its imports in one other country (implying maximum concentration in each and every country). At the same time, suppose also that each importing country buys its inputs from a different exporter. The suppliers of global imports (i.e., the exporters) are very diversified. Next take the case where each country buys a lot of inputs in China. The average concentration will then decrease (almost all countries are buying from two countries now) but the exporter shares in global imports may become more concentrated (with a larger weight for China). This is supported by the results which are obtained when China is eliminated from the analysis. In that case, we see decreasing concentration, both at global and country level. This especially holds for Asian countries, although they still report values close to or even above 1500.[12]

As we mentioned above, the results are to some extent determined by the aggregate nature of the RoW. If we leave the RoW aside, the Herfindahl indexes are lower, but the main conclusions remain the same. For instance, because Canada and Mexico remain very dependent on the United States, their indexes barely change. The largest drops in concentration are found for West European countries which depend more on the RoW than other countries. We also note that

Table 3. Herfindahl indexes for geographical and sectoral concentration of imports at the sector level, 1995 and 2011.

	Geographical concentration						Sectoral concentration					
	1995		2011				1995		2011			
	Z	Q	Z	Q	DIFH	DIFT	Z	Q	Z	Q	DIFH	DIFT
Agriculture, hunting, forestry and fishing	652	499	599	558	−53	59	1129	346	1254	366	124	21
Mining and quarrying	705	506	805	567	100	61	738	338	1141	519	403	180
Food, beverages and tobacco	662	497	628	580	−34	83	1591	384	1579	387	−12	3
Textiles and textile products	397	441	823	953	426	512	3232	1026	2149	590	−1083	−436
Leather, leather and footwear	515	512	493	539	−22	27	1443	362	968	272	−475	−90
Wood and products of wood and cork	567	440	573	505	6	65	1428	396	1253	346	−175	−50
Pulp, paper, paper, printing and publishing	476	447	451	472	−25	25	2726	921	1575	448	−1152	−473
Coke, refined petroleum and nuclear fuel	3357	1875	3104	2185	−253	310	5152	1249	5434	2441	282	1192
Chemicals and chemical products	544	529	627	590	83	62	3526	965	2716	836	−809	−128
Rubber and plastics	497	503	487	557	−10	54	2953	882	2794	720	−159	−162
Other non-metallic mineral	467	453	480	508	13	55	824	334	764	436	−60	102
Basic metals and fabricated metal	442	474	554	567	112	93	3325	1358	2918	1217	−407	−142
Machinery, nec	494	516	423	492	−71	−25	1649	724	1731	673	82	−51
Electrical and optical equipment	761	557	690	715	−72	158	4508	1106	4395	1082	−113	−24
Transport equipment	712	582	432	474	−280	−108	2729	695	2469	684	−260	−11
Manufacturing, nec; recycling	445	445	833	806	389	361	740	327	951	339	212	12
Electricity, gas and water supply	1580	949	1670	1316	89	367	2322	633	2932	1336	610	702
Construction	426	438	441	551	15	113	658	358	714	466	56	108
Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel	576	504	447	477	−130	−27	1676	370	1383	454	−293	84
Wholesale trade and commission trade, except of motor vehicles and motorcycles	659	446	390	467	−269	21	330	248	448	274	118	26

Retail trade, except of motor vehicles and motorcycles; repair of household goods	588	439	465	582	−123	142	385	242	399	299	14	57
Hotels and restaurants	510	469	589	617	80	148	1064	260	1135	314	71	54
Inland transport	632	524	492	657	−140	133	598	284	1088	419	490	135
Water transport	415	449	573	614	158	165	1800	352	1784	441	−16	90
Air transport	629	441	434	700	−195	259	1160	322	1263	551	103	229
Other supporting and auxiliary transport activities; activities of travel agencies	561	451	348	429	−213	−21	546	210	466	242	−80	32
Post and telecommunications	590	497	495	597	−96	99	1613	545	1441	499	−172	−45
Financial intermediation	761	468	794	567	33	99	1771	659	2832	737	1061	79
Real estate activities	565	449	547	512	−18	63	691	292	832	358	141	66
Renting of Maquinary and Equipment and other business activities	601	467	504	539	−98	72	963	368	1130	373	167	6
Public admin and defence; compulsory social security	527	455	416	584	−110	129	486	232	438	320	−48	87
Education	510	442	411	497	−99	56	364	229	446	283	82	53
Health and social work	563	511	515	581	−48	70	1749	546	1728	482	−21	−64
Other community, social and personal services	552	450	501	580	−51	130	422	256	415	280	−7	23
Private households with employed persons	978	700	800	718	178	18	1299	268	3049	445	1749	177
Average	683	538	696	678	12	140	1645	517	1657	569	12	53

Note: Columns Z list $H_{\cdot j}(r)$ for geographical concentration and $H_{\cdot j}(i)$ for sectoral concentration; and columns Q list $T_{\cdot j}(r)$ for geographical concentration and $T_{\cdot j}(i)$ for sectoral concentration. $DIFH = H_{\cdot j}(*, 2011) - H_{\cdot j}(*, 1995)$ and $DIFT = T_{\cdot j}(*, 2011) - T_{\cdot j}(*, 1995)$.

the sensitivity of the results to modifications in the dataset is larger at the global level than it is at the country level.

The bottom part of Table 2 presents the results for the sectoral concentration $H^{s}_{\cdot\cdot}(i)$ and $T^{s}_{\cdot\cdot}(i)$. $H^{s}_{\cdot\cdot}(i)$ gives the concentration of direct imports by country s in the sectors of origin. For example, the production processes in Ireland rely on just a very few foreign inputs (chemicals, wholesale trade, agriculture and food processing), which yields a large concentration. $T^{s}_{\cdot\cdot}(i)$ considers the embodiment of foreign production in the GSC of country s and how this foreign production is concentrated in the origin sectors.

Table 2 shows that the average concentration is low, substantially lower than the geographical concentration. The results also indicate that the values of the Herfindahl index are considerably larger in the case of $H^{s}_{\cdot\cdot}(i)$ (with direct relations) than in the case of $T^{s}_{\cdot\cdot}(i)$ when the whole GSC is considered. Taking the averages over the countries, $H^{s}_{\cdot\cdot}(i)$ is 590 and $T^{s}_{\cdot\cdot}(i)$ is 298 in 1995 (and 757 and 405, respectively, in 2011). This means that, from a sectoral viewpoint, the total (i.e., direct plus indirect) foreign dependence through GSC is less concentrated than suggested by the direct imports. This occurs when production depends strongly on a single input. For example, restaurants in country A depend on food products from country B. Directly, A does not import agricultural products from B. Indirectly, however, this is very likely because the food products in B are probably made with agricultural produce from the same country.

In contrast to the average geographical concentration, which slightly decreased between 1995 and 2011, the average sectoral concentration increased. In this regard, the results reveal a trend towards an increasing specialization. The sectors 'Transport equipment' and 'Electrical and optical equipment' are important drivers of the increasing concentration, especially in the case of Germany and China. In these countries, both sectors get more weight in the supply chains and show a large concentration in the period under consideration.

Import concentration for a given sector

This subsection considers the geographical and sectoral structure of imports for a given sector. The idea is to look at the average production process of a certain sector (where the average is taken over the countries) and check whether it has become more or less concentrated in terms of imported inputs. That is, we consider the concentration of the foreign supply of a given sector or the concentration of the foreign supply of a given supply chain. For the quantification, we use the following geographical and sectoral Herfindahl indexes: $H^{\cdot}_{\cdot j}(r)$, $T^{\cdot}_{\cdot j}(r)$, $H^{\cdot}_{\cdot j}(i)$ and $T^{\cdot}_{\cdot j}(i)$. For example, $H^{\cdot}_{\cdot j}(r)$ examines the imports of the average, say, food processing sector (j) and asks how concentrated the supplying countries are. $H^{\cdot}_{\cdot j}(i)$ does the same but looks at the concentration of supplying sectors. The T-indexes do not examine the imports of the food processing sector but the foreign contribution to the average food processing GSC. The results for these indexes are shown in Table 3 for 1995 and 2011.

As can be seen, the world geographical concentration is slightly larger for direct imports (using $H^{\cdot}_{\cdot j}(r)$) than for embodied foreign production (using $T^{\cdot}_{\cdot j}(r)$). Both concentrations have somewhat increased between 1995 and 2011. The geographical Herfindahl indexes are below 1000, indicating low concentration, in all but two sectors. Two of the exceptions are the energy related sectors of 'Coke, refined petroleum and nuclear fuel' and 'Electricity, gas and water supply'. Typically, these sectors depend strongly on oil and gas, which is found only in a few regions of the world. For the changes over time, remarkable sectors with substantial increases in their concentration of imports are 'Textiles and textile products', and 'Manufacturing nec and recycling'. On average, textile sectors all over the world import primarily (and approximately 50% of their total imports) from the RoW. The same holds for the other manufacturing sectors, with their imports from India.

The situation of sectoral concentration differs markedly from that of geographical concentration. The Herfindahl indexes for sectoral concentration are on average three times larger in

Table 4. Impact of geographical and sectoral concentration on gross domestic product (GDP) per capita.

	Geographical concentration				Sectoral concentration			
Variables	**(1) GDPpc**	**(2) GDPpc**	**(3) GDPpc**	**(4) GDPpc**	**(5) GDPpc**	**(6) GDPpc**	**(7) GDPpc**	**(8) GDPpc**
Herfindahl	3175**	−1069*	−1761*	−3690***	−3146*	−9321***	−10,379***	−6501**
	(1591)	(1181)	(1204)	(1093)	(1689)	(1529)	(1592)	(2408)
Herfindahl*DT		7656***	7549***	4773***		6597***	6658***	3859***
		(1270)	(1030)	(1148)		(1107)	(1114)	(1245)
Herfindahl*DEU			3843***	8367**			−2971**	−17,641**
			(1174)	(4047)			(1478)	(8343)
Herfindahl*DA				2900				19,263***
				(5144)				(1753)
Capital	−3.45e−06***	−5.22e−06***	−3.93e−06*	−2.23e−06***	−1.56e−06	−5.11e−06***	−6.13e−06***	−2.42e−06***
	(9.92e−07)	(1.15e−06)	(2.21e−06)	(6.18e−07)	(1.43e−06)	(1.05e−06)	(1.21e−06)	(5.72e−07)
High skill work	91,382***	79,376***	78,302***	126,891***	181,391***	76,624***	75,226***	124,422***
	(8161)	(7796)	(6684)	(18,042)	(7125)	(7891)	(7954)	(24,839)
Population	−5.397***	−7.160***	−4.352*	−45.02***	−15.96	−7.228***	−9.411***	−21.94
	(1.097)	(1.276)	(2.484)	(12.25)	(14.97)	(1.236)	(1.440)	(15.46)
VA in High Tech	1.08e−05	4.30e−06	6.76e−06	8.81e−06*	6.07e−06	6.29e−06	5.92e−06	4.49e−06
	(1.16e−05)	(1.16e−05)	(1.53e−05)	(4.97e−06)	(6.04e−06)	(1.19e−05)	(1.19e−05)	(5.12e−06)
Constant	40.63	3210	1442	−3919	−16,802***	12,275***	15,504***	9633
	(2451)	(2126)	(2021)	(4254)	(2832)	(2269)	(2544)	(7589)
Observations	608	608	608	608	608	608	608	608
R^2	0.312	0.53	0.607	0.646	0.308	0.583	0.608	0.629

Note: Standard errors are shown in parentheses. ***$p < 0.01$; **$p < 0.05$; and *$p < 0.1$.

the case of direct relations (using $H^{\cdot s}_{\cdot j}(i)$) than in case of embodied relations (using $T^{\cdot s}_{\cdot j}(i)$). This points at strong direct import dependencies of some sectors (as is the case for the manufacturing sectors) which become less intense when we consider the whole supply chain. The reason is that the input (on which a certain sector j crucially depends) is produced with intermediate goods from other sectors. And these intermediates are also produced with inputs, and so forth. A clear example is 'Electrical and optical equipment'. The direct imports often are components which mainly come from the sector itself, but these components are made with many other intermediate inputs, for example coming from 'Chemicals and chemical products', 'Rubber and plastics' or 'Transport equipment'.

We also observe a clear difference between the services sectors (with small Herfindahl indexes) and the manufacturing sectors (with large indexes). The exception for the services sectors is 'Financial intermediation', with large dependencies for the direct imports. This reflects its higher internationalization in comparison with the rest of services, whose demand is mainly domestic.

The development of the sectoral concentration over time is similar to that for geographical concentration. On average, concentration has slightly increased. For most sectors, the changes were minor, except for 'Financial intermediation' that further increased its concentration. In general terms, this sector has low input requirements and generates much value added (per unit of its output). The p-values for the unit root test are in each sector larger than 0.6, which is in line with the finding of an increase over time.

Complementary insights can be obtained by examining GSC from the viewpoint of the seller. That is, looking at the geographical and sectoral distribution of direct and embodied exports. This information is available in Appendix B in the supplemental data online. Briefly summarized, we see a trend towards a geographical concentration of direct and embodied exports, reflecting a regional specialization of GSC. We find more diversification of exports in European countries (when compared with the world average), which is even stronger for East European countries. Looking at sectors, significant differences are found. That is, much concentration for the primary sectors ('Agriculture, hunting, forestry and fishing' and 'Mining and quarrying') and some manufacturing sectors (such as 'Electrical and optical equipment', 'Transport equipment' and 'Textiles and textile products'). On the other hand, services sectors exhibit low concentration, implying a greater variety of export destinations.[13]

Concentration in the supply chains and economic growth

In the previous sections we have developed – in a MRIO framework – different indexes to measure the geographical and sectoral concentration of GSC. At the most aggregated level, these metrics consider the import dependence of the average country or the average sector, and they consider both direct imports and embodied imports. At the next level, the indexes consider the concentration of the import dependence of a particular country or of a particular sector. In this section, we focus on the question whether geographical or sectoral concentration of a country's GSC affects this country's development level.

We regress GDP per capita (GDPpc) in country s in year t on the geographical Herfindahl index $T^{s\cdot}_{\cdot\cdot}(r)$ in year t and on the sectoral Herfindahl index $T^{s\cdot}_{\cdot\cdot}(i)$ in year t. We have information for 16 years (1995–2011) and 38 countries.[14] We apply a panel data fixed effects approach and adopt the robust estimation to control for autocorrelation and heteroscedasticity. In order to control for the size of a country and its ability to take advantage of the cost–efficiency relationship between concentration and income (Kitsos & Bishop, 2018) we add control variables. These are: the share of high skilled workers (expressed as the percentage of people employed in tertiary education); the capital stock (expressed in millions of dollars); value added generated in high technology sectors (calculated as the sum of value added of 'Electrical and optical equipment', 'Transport equipment' and 'Chemicals and chemical products'); and population size. Data for

high skilled workers, capital stock and population size are obtained from Eurostat, while value added in high-tech sectors is calculated from WIOD input–output tables. These variables can be considered as proxies for technological development, economic structure, and size of the country. Some other papers considering these or similar variables are those by Lee (2014), Capello et al. (2015) or Kitsos and Bishop (2018). The results are presented in Table 4.

Columns (1)–(4) in Table 4 present the results for geographical concentration. Column (1) shows a positive and statistically significant coefficient for the geographical concentration. This suggests that more concentrated supply chains in a country are associated with a higher level of GDP per capita. From a cost-efficiency (and therefore income) perspective it is better to import from a select group of countries than to be risk-averse and spread the imports over a large group of countries. This is in accordance with one part of economic literature that explores the benefits of a concentration of supply in fewer suppliers, despite the possible risks (Hartman et al., 2017; Piatanesi & Arauzo-Carod, 2019).

Previous analyses showed that the concentration of supply chains accelerated from 2003 onwards, which is also confirmed by the Chow test. In the model in column (2) we control for that and introduce a slope dummy. That is, we use as an interaction variable the product of the Herfindahl index at time t and the value of time dummy DT in year t (which is 1 for the period 2003–11, and 0 otherwise). The effect of the geographical concentration on GDP per capita becomes negative for 1995–2002 but strongly positive for 2003–11. This confirms a change in the trend from 2003, intensifying the effect of the geographical concentration on per capita GDP.

Following the results in the previous subsection on regional aspects of GSC, we also control for the effect of belonging to the EU. The model in column (3) thus includes an interaction variable based on EU dummy (DEU = 1 if a country is part of Europe, and 0 otherwise). The net effect of Herfindahl concentration within this region is positive and significant. Being a European country thus intensifies the positive effect of concentration on GDP per capita (when compared with other countries). This can be associated with scale economies and their behaviour as a cluster, partially explained by their trade agreements (Goisis et al., 2009). In model (4) introduces a dummy for Asian countries (DA = 1 for Asian countries, and 0 otherwise). This dummy is not significant which means that belonging to Asia makes no difference in terms of the effect of geographical concentration on the GDP per capita of a country.

Columns (5)–(8) in Table 4 test the relationship between the sectoral concentration in the exports of a country and its per capita GDP. Model (5) shows a negative and significant effect of the Herfindahl sectoral index. More sectoral diversity of the exports (or less sectoral concentration) has a positive impact on GDP per capita. This result is in line with previous literature which conclude that sectoral diversity of exports (e.g., Lei & Zhang, 2014; Saviotti & Frenken, 2008; Freire, 2017) is an important factor to explain economic growth. This result is also in line with our own findings in the previous subsection. A high concentration was found in particular for the manufacturing sectors and low concentration for the services sectors. At the same time, services sectors generate more value added per dollar of output than manufacturing sectors. Note that, although manufacture sectors use more labour, services incorporate more high-skill workers. Therefore, countries with large services sectors and small manufacturing sectors will show on the one hand a relatively low concentration and on the other hand relatively much GDP per capita (i.e., when compared with countries with small services sectors and large manufacturing sectors).

As before, we control for time and place. Model (6) includes the time dummy DT (for 2003–11). The combined effect of concentration of GDP per capita is still negative but the effect is much smaller in size for 2003–11 than for 1995–2002. In other words, in the recent period the positive effect of import diversity on income is mitigated. In model (7), the EU dummy is significant and very negative. The combined effect shows that EU countries in the period

2003–11 increased their GDP per capita with more sectoral diversity (less concentration) in their exports. However, a different scenario appears for Asian countries in model (8). The dummy variable is in this case also significant and the effect of GDP per capita is positive. The results suggest that sectoral concentration of exports benefits the economy of Asian countries through the entire period.

As a robustness analysis, we carry out three additional exercises (the results of which are given in Appendix C in the supplemental data online). First, if we leave out China, concentration in Asian countries becomes non-significant. This points at the important role of this country. What is more, the sign for European concentration changes, becoming positive now. It might be indicating that, without considering China, the European trend towards more concentration is positive.

Second, we reproduce the calculus for WIOD 2016. This led us capture the effects of the crisis of 2008. However, the first year considered is 2000, thus, we are not able to capture the 2003 break. Despite that, we obtain the similar results with the same general trends over time.

These results are complementary, observing two moments of time in which the concentration trend increases. Moreover, the explicative capacity of the model is lower when using WIOD 2016. However, if we just consider the period 2000–09, R^2 becomes much more similar. This is telling that the correlation found between per capita GDP and concentration is more important during growth periods, while during years of crisis this relationship becomes weaker. This result would be in line with recent trends of back-shoring or reshoring as response to global crisis and the associated uncertainty, as well as the increasing adoption of decisions based on criteria such as shorter supply chains, confidence, closeness, etc. (Bettiol et al., 2017; Kinkel, 2014; Merino et al., 2021).

Third, we replicate our analysis using the concentration measure proposed by Van der Linden (1999), which is based on the well-known location quotient (Isard, 1960) and widely used in the input–output framework (Aghamohammadi et al., 2021; Jahn, 2017; Zhao & Choi, 2015). For most coefficients, we obtain similar results in terms of sign and significance.

In summary, our results suggest a significant relationship between concentration and the income level of countries. More geographical concentration and less sectoral concentration of imports favour economic growth. However, differences are found across years and countries. From 2003 onwards, concentration had a more positive dimension or less negative effect. EU membership has a positive effect on the impact of geographical concentration but a strong negative effect on the impact of sectoral concentration. In this context, we can conclude that more diversity does not always foster economic growth, as most of the economic literature seems to claim. Instead, the relationships are more complex, depending on several factors.

CONCLUSIONS

Supply chain concentration recently received renewed scholarly attention. Business studies reported an increase in the concentration of foreign supplies over the last decade, mainly in high-tech production. Typically, however, these studies focused on individual firms or products, not on sectors or entire countries. Economics studies related to global value chains suggested an increase in the international fragmentation of production. However, these studies (at the level of sectors and countries) did not consider concentration. Building on these two literatures, we hypothesized that trade and GSC participation have become more concentrated over time. This is because international fragmentation has led to more specialization in tasks and in niches of the production process. We developed Herfindahl indexes to measure geographical and sectoral concentration within a global MRIO framework.

At the global level, we asked how concentrated the imports are with respect to the countries and the sectors of origin. We also asked how concentrated the exports are with respect to the

countries and sectors of destination. The same four questions were answered for the embodiment in GSC. That is, instead of looking at the imports/exports we looked at the embodiment of foreign production in the average country's GSC. We found that all concentration indexes at the global level are low and that all increased between 1995 and 2011. At the same time, the increases were relatively small, which suggests that there is a more nuanced picture with differences across countries and sectors.

At the country and the sector level, our results were more varied. Asian countries showed a high geographical concentration in 1995 which increased further in until 2011 (in particular for Indonesia, India and Japan). In contrast, most EU countries had small geographical concentration indexes, which even slightly decreased. Our results suggest patterns that are similar within regional blocks but different across blocks. This is the case for the Asian economies, which tended to further concentrate their purchases, and for the EU, which tended to further diversify them. For the sectoral concentration of the imports, we found high levels for China and other Asian countries. China bought its imports from a small number of sectors, which was largely due to its strong dependence on processing imports. In contrast, the EU countries again showed low sectoral concentration, mainly because of intensive intra-EU trade.

Our analysis of the geographical import concentration of sectors showed low levels for the Herfindahl indexes. Exceptions were 'Coke, refined petroleum and nuclear fuel' and 'Electricity, gas and water supply'. Both sectors depend largely on the input of oil and gas, which many countries have to import from a small number of suppliers. Another finding was that the sectoral concentration was higher for the direct imports (H-indexes) than for the embodied imports (T-indexes). Sectors generally import from a few other sectors but their final products, however, require and embody inputs from a wide range of sectors. Also, the changes in concentration between 1995 and 2011 were extremely small and we observed (in particular for the sectoral concentration) a distinction between the services sectors (with low concentration) and the manufacturing sectors (with high concentration).

Finally, we have tested the impact of concentration on economic performance of countries. Broadly speaking, geographical concentration had a positive effect on the economy and sectoral concentration a negative (or, in other words, sectoral diversity was beneficial). In the period 2003–11, the positive effect of geographical concentration increased whilst the negative effect of sectoral concentration reduced in size. Looking at geographical areas, being a part of Europe reinforced the results obtained for the whole sample. That is, belonging to EU increased the positive effect of geographical concentration and the negative effect of sectoral concentration. The case of Asia was different from Europe, with a positive effect of sectoral concentration on GDP per capita and an insignificant effect of geographical concentration.

Diversification has usually been linked to a higher economic growth. However, our results suggest that in the last globalization wave, the impacts of concentration on economic growth have been heterogeneous over time and over countries. This suggests that there are different ways to take advantage of trade configurations and the composition of GSC. The heterogeneity of relations and patterns over time raise new questions and – in order to foster economic growth – may require adapting international policies, depending on the development stage of the countries. This creates many opportunities and challenges for policymakers.

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DISCLOSURE STATEMENT

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NOTES

[1] Specialization of countries in certain sectors, using multi-regional input–output tables (albeit not global) and based on extensions of the Balassa index, has received some attention in the literature (e.g., Oosterhaven, 1995; Van der Linden, 1999; Hoen, 2002). In the same vein, Van der Linden (1999) looked at the sectors in which outputs or exports were concentrated, which is a different question than the one we will address in this paper.

[2] The global MRIO tables in the WIOD provide information for 40 countries plus the rest of the world (as if it were a single country) and 35 sectors. The data are publicly available and can be downloaded for free from http://www.wiod.org.

[3] Bold-faced lower-case letters are used to indicate vectors, bold-faced capital letters indicate matrices, italic lower-case letters indicate scalars (including elements of a vector or matrix). Subscripts indicate sectors and superscripts indicate countries. Vectors are columns by definition, row vectors are obtained by transposition, denoted by a prime (e.g., $\mathbf{x}'$). Diagonal matrices are denoted by a circumflex (e.g., $\hat{\mathbf{x}}$).

[4] The specific values of the index depend on the characteristics of the database and, in particular, on the number of sectors. Our analysis, however, focuses on the trends over time of the indexes, using the same database and sector classification across the whole period.

[5] Alternatively, one might be interested in the concentration of the import bundle that goes from country r to sector j in country s. In this case, the shares $h_{ij}^{rs}(i) = z_{ij}^{rs} / \sum z_{ij}^{rs}$ would have been appropriate. It is also possible to look at the export shares and the concentration of countries or sectors of destination. The appropriate shares would be $h_{ij}^{rs}(s) = z_{ij}^{rs} / \sum_{s} z_{ij}^{rs}$ and $h_{ij}^{rs}(j) = z_{ij}^{rs} / \sum z_{ij}^{rs}$, respectively.

[6] The link between the import shares $h_{ij}^{rs}(r)$ and $h_{j}^{rs}(r)$ is that we can write $h_{j}^{rs}(r) = \sum_{i} w_{ij}^{\cdot s}(i) h_{ij}^{rs}(r)$. The weights $w_{ij}^{\cdot s}(i) = \sum z_{ij}^{rs} / \sum \sum z_{ij}^{rs}$ depend on i and reflect the relevance of imports of intermediate product i (from any country r) by sector j in country s.

[7] Detailed results of the analysis without China are available from the authors upon request.

[8] In our analysis, we eliminated China from the matrices Z and Q and calculated the indices without this country. The analysis may be slightly biased in the case of Q because this matrix still partially captures the role of China. An alternative would have been to apply the hypothetical extraction method. This method, however, as pointed out by Dietzenbacher et al. (2019), has other disadvantages and cannot be applied straightforwardly to world input–output tables, requiring making additional choices to redistribute the imports from China.

[9] The null hypothesis is that the time series has a unit root; the alternative hypothesis is that the series is stationary.

[10] The analysis without the RoW has done as in the case without China.

[11] In another set of calculations, we took also the domestic deliveries into account, and found that the geographical trends were negative. However, the domestic parts represent around 80% of the indexes. A negative trend therefore reflects more and increasing openness of trade during the period under consideration.

[12] Again, if the domestic inputs are included in the Herfindahl indexes, the indexes are higher, particularly for countries with a large share of domestic inputs. The average trend of decreasing concentration is, however, also found in this case.

[13] Contrary to our observations for geographical concentration, the results for sectoral concentration do not differ between the global and the country level. This confirms, in general terms, the competitive character of intermediate imports. The input requirements are determined by the production function and for sectoral concentration the source country is not important.
[14] We eliminate the RoW, Cyprus and Taiwan from the dataset due to a lack of appropriate data for GDPpc.

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