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Made in Europe? Trends in International Production Fragmentation

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Abstract

In a world dominated by the emergence of global value chains, production processes increasingly fragment across a variety of countries. We provide new macro-economic evidence on this phenomenon, using a Theil-type distribution index of value added, which we call the international production fragmentation (IPF) index. In contrast to the well-known Feenstra and Hanson (1999) measure, this novel index does not suffer from a country size-bias and double counting due to re-imported intermediates. Moreover, it is sensitive to changes in the country-distribution of value added. We identify global value chains (GVCs) by the country-industry in which the last stage of production takes place. Using a new dataset of world input-output tables covering 40 countries, we find that since 1995 production processes for most manufacturing goods in Europe increasingly fragmented across countries, although at different paces. In 2008, GVCs of electrical products and transportation equipment were generally most internationally fragmented, while food products and minerals production the least. Averaged across products, Belgium, Ireland and the Netherlands had the most fragmented GVCs in 2008, followed by Germany, the Czech Republic, and Hungary, where fragmentation increased at a high pace since 1995. We also find that in 1995, European value chains were mainly fragmented across other EU countries. Afterwards, however, there has been a strong trend towards increased participation of non-European countries. The financial crisis in 2008 led only to a temporary reduction in international production fragmentation.

Keywords: International fragmentation of production; global value chains; Theil index; World input-output tables

JEL classification: F14, F60, O19

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1. INTRODUCTION

In 2006, Hans-Werner Sinn labeled Germany a "Bazaar Economy" (Sinn, 2006). He argued that national institutional arrangements led to wages becoming so high as compared to other countries that Germany had specialized in capital-intensive activities, while labor-intensive activities had been offshored. While German exports were booming, the domestic value added declined, leading to sluggish economic growth and high unemployment. For illustration, Sinn referred to a study estimating that only 33 per cent of the value of a Porsche luxury car was added on German soil (Dudenhöffer, 2005). German firms like Porsche relocated substantial parts of their production processes to cheaper foreign locations, enabled by reductions in the costs of transportation and fast progress in information and communication technology (Baldwin, 2006a). Case studies like this and others (such as in Dedrick et al., 2010, on high-tech electronics) have been the inspiration of much of the burgeoning literature on the causes and consequences of international fragmentation of production.[1] This literature covers a wide set of perspectives, ranging from international business scholars who studied issues of governance in global value chains (Sturgeon et al., 2008), development economists and sociologists who focused on ways in which backward countries and regions could use global value chains to foster development (Humphrey and Schmitz, 2002; Gereffi et al., 2005), to trade economists who focused on the extent to which these tendencies affect international trade patterns at a more macroeconomic level, both empirically (Feenstra and Hanson, 1999; Koopman et al., 2012; Johnson and Noguera, 2012a,b) and theoretically (e.g., Grossman and Rossi-Hansberg, 2008; Costinot et al., 2013).

Empirical work that actually measures the degree of international fragmentation of production is however, limited. This paper aims to contribute by generalizing the type of results obtained in the case study approach towards macro-economic insights. We propose a new index of international production fragmentation, named the IPF index, which builds upon the broad offshoring measure proposed by Feenstra and Hanson (1999). This measure was simply defined as the share of imports in the intermediate inputs used in production of a good. While straightforward and simple to calculate, this measure suffers from a number of shortcomings if used as an indicator of international production fragmentation. First, it suffers from a country-size bias as larger countries can source from a wider variety of domestic input producers than smaller countries and hence will have lower import shares. Importantly, it includes just the total value of imports irrespective of the country of origin. Sourcing a similar value of imports but from a wider set of countries should have an impact on a meaningful fragmentation measure. In addition, the Feenstra and Hanson measure disregards the fact that imports are often themselves part of an international production process that might involve multiple countries, including the country under consideration. With increasing back and forth trade across borders, double-counting of imports will occur.[2]

Our index of international production fragmentation is more general than the Feenstra-Hanson measure and does not suffer from these shortcomings. It is based on an entropy index that measures the distance between the actual cross-country distribution of value directly and indirectly added in the production of a particular good and the cross-country distribution of world GDP. According to this measure, fragmentation will be low if most value is added in the economy that also sells the product to the final user.

[1] This term was introduced by Jones and Kierzkowski (1990) and will be used in this paper to denote the phenomenon in which production processes are increasingly fragmented in separate activities that are carried out in several countries.

[2] These double-counting issues are highlighted in the work of Koopman et al. (2013).

If, however, materials, parts and components are increasingly imported and sourced from an increasing number of countries, fragmentation as measured by the IPF index will increase. The IPF index does not suffer from a country-size bias and it takes into account the full distribution of value added in all stages of production. It is related to the work by Dietzenbacher and Romero (2007), Fally (2011) and Antras et al. (2012) who focus on physical aspects of production processes by computing the average number of transactions a given product will go through before being sold for final use. If this number of transactions goes up, they consider production processes to have become more fragmented. Instead of measuring numbers of transactions, our measure will focus on the distribution of value added in the chain.

We use the IPF index to address three basic questions on the fragmentation processes of global values chains for European products. First, how fast was the international fragmentation process of European value chains since 1995, both across countries and products? Second, are these trends mainly due to increasing fragmentation within the EU27, or due to increased sourcing from non-EU27 countries? And third, did the global financial crisis that started in 2008 cause a structural change in the pace of increasing production fragmentation (see, e.g. Bems et al., 2011, for an account of the trade collapse immediately following the crisis)?

To implement the IPF index empirically, it is crucial to define and identify the set of value adding activities that constitutes the production process of a particular good. In case studies this is done by assessing the values and production locations of all components and services that go into a narrowly defined good, such as an iPod produced in China (Linden et al., 2011).[3] In order to provide a comprehensive macro-economic overview instead, we have to work at a more aggregate level and focus on sets of narrow classes of final products. These will be identified by the industry and country in which the last production stage takes place (such as the transport equipment manufacturing industry in Germany), before the good is delivered to the final consumer. We will label the industry in which the last stage of production takes place the "country-industry-of-completion". The computation of the value added in the production in each of the intermediate inputs of first-tier suppliers and suppliers further upstream requires international input-output tables that cover the world economy. We use the new World Input-Output Database (see Timmer, ed., 2012; Dietzenbacher et al., 2013b) for the years 1995-2009 and projections based on this database for 2010 and 2011.

The rest of this paper is structured as follows. In Section 2, we introduce our IPF index and compare it to the Feenstra-Hanson index, and show how it can be decomposed to provide relevant additional information about the drivers of changes in international production fragmentation. Section 3 gives a brief description of the data used. In Section 4, trends in IPF indices, various decompositions and a regression analysis will be presented, providing answers to the above-mentioned research questions. Section 5 concludes.

[3] Linden et al. (2011) found that about 70% of all wage income related to the production of an iPod in 2006 was earned on U.S. soil, while workers in China earned only 2%, despite the product being labeled as "Made in China". They also found that workers in Japan, Korea, Singapore and Taiwan earned substantial shares of the iPod's global value chain wage income, which illustrates the geographical dispersion of income related to the iPod's production chain.

2. AN INDEX OF INTERNATIONAL PRODUCTION FRAGMENTATION (IPF)

How can international production fragmentation be measured in a macroeconomic setting? The study by Feenstra and Hanson (1999) was one of the first to introduce a measure of fragmentation at the industry level. Their aim was to indicate the extent of offshoring of activities by US firms in particular. They proposed two indicators of what they labeled "international outsourcing": a narrow and a broad one. Their "broad" measure is defined as the share of imported intermediate inputs in the value of all intermediate inputs used in a particular industry. In computing their "narrow" measure, they take the import share in the value of intermediate inputs from all foreign and domestic industries *in the same 2-digit SIC* as the industry considered.[4] These shares basically measure the degree of offshoring of intermediate input production, but are often also interpreted as measures of international fragmentation. But while straightforward and simple to calculate, these indicators suffer from a number of shortcomings from the latter perspective. First, the Feenstra and Hanson (FH) measures suffer from country-size bias invalidating comparisons across countries. Large countries typically have lower import shares than small countries as a wider variety of inputs is domestically available, and this should be corrected for. Second, FH only measure the total value of imports irrespective of the country of origin. Sourcing a similar value of imports but from a wider set of countries should have an impact on the fragmentation measure. In addition, their measure disregards the fact that the production of imported intermediates in turn requires intermediates that might involve production in multiple countries, including the country under consideration. With increasing back and forth trade across borders, double-counting of imports will occur. Our index of international production fragmentation is more general than the FH measure and does not suffer from these shortcomings.

We propose an index that uses information from global input-output tables to describe the international fragmentation of production in specific value chains. It does not only take the value added generated by the immediate suppliers of materials, parts and components to the manufacturer of the final good into account, but also valued added by second-tier suppliers and suppliers even further upstream. We label our indicator the IPF (international production fragmentation) index.[5]

As the point of departure, we take the global value chain (GVC) income perspective on international production networks, as introduced by Los et al. (2012) and Timmer et al. (2012). This perspective defines the global value chain of a specific industry i located in a specific country j as the activities in industries s=1,…,S in each of the countries n=1,…,N required to produce the final output of industry i in country j. Final output is output delivered for household consumption and investment demand. We will label (i,j) the "country-industry-of-completion". Industries that create margins between basic prices and purchasers' prices (such as industries producing wholesale and retail services, and transport services industries) are not considered as industries-of-completion. An example of a GVC is the GVC for German transport equipment. This GVC contains all the activities (ranging from mining activities to basic metals production to the delivery of business services and transport equipment manufacturing itself) required to meet final demand for transport equipment completed in Germany. These activities can be located in each of the countries,

[4] Imports of steel by German car manufacturers are considered as a form of international outsourcing in Feenstra and Hanson's (1999) broad measure, but are not seen as such in their narrow measure.

[5] In refining the approach pioneered by Hummels et al. (2001), Koopman et al. (2013) and Johnson and Noguera (2012a,b) also used global input-output tables. Their analyses yield measures of vertical specialization, which focus on the role a country plays in international networks of global value chains. The IPF index has a global value chain as the unit of analysis instead, and aims at measuring its fragmentation.

including Germany itself. To measure this, we need to start with finding the levels of gross output associated with these activities. This can be estimated by applying standard input-output methods (see Miller and Blair, 2009) to global input-output tables.

Global input-output tables contain information on the values of intermediate input flows among all country-industries in the world, as well as on the values of flows from each of these country-industries to final use in each of the countries. These tables also contain information on value added generated in each of the country-industries. Combining information on values of sales and value added per dollar of sales leads to estimates of value added in each of the *SN* industries as a consequence of final demand of the products of industry-of-completion *i* in country *j*. If we aggregate these value added figures over industries-of-completion within each country, we obtain the *Global Value Chain Income* (GVCI) of each of the *N* countries for the global value chain considered.

INSERT FIGURE 1 ABOUT HERE

The details regarding the computation of GVCI can be elucidated by referring to Figure 1, which is an extension of a diagram in Hummels et al. (2001). It refers to a simplified world economy consisting of three countries and depicts a set of global value chains for which country 3 is the country-of-completion. To complete its final products (which are sold domestically and exported), it uses domestic capital and labor, which generate value added and hence income. Next to these production factors, it uses intermediate inputs. Some of these intermediate inputs are produced within country 3 itself, which implies that additional value added is generated domestically. Other intermediate inputs are imported from country 2. To produce these, country 2 in its turn adds value in its own industries. This value added generation does not remain limited to the industries producing the exported intermediate products (the first-tier suppliers of country 3's producers of final products), but value added will also be generated in industries in country 2 that act as second-tier suppliers to country 3 by producing materials and components that are essential for the production by country 2's first-tier exporters. Finally, second-tier suppliers of the final products of manufacturing industries in country 3 are not only located in country 2, but also in country 1. Because the production of these second-tier suppliers involves domestic labor and capital, country 1 also adds value in the GVCs with country 3 as the country-of-completion.

A global input-output table can be seen as a description of the worldwide network of internationally fragmented production processes, which are much more complicated than depicted in Figure 1. We can derive GVCI from such tables, using an equation that has been a standard tool in input-output analysis for over decades (see Miller and Blair, 2009):

$$\mathbf{g} = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-1}(\tilde{\mathbf{F}}\mathbf{e}) \qquad (1)$$

In this equation, **g** is the vector of value added created in each of the *SN* country-industries within a global value chain. The choice for a specific final demand matrix $\tilde{\mathbf{F}}$ determines which value chain(s) is considered. **e** is a summation vector. $(\mathbf{I}-\mathbf{A})^{-1}$ is the well-known Leontief inverse, the use of which ensures that value added contributions in all tiers of suppliers are taken into account. **v** is a vector with value added over gross output

ratios, for each of the country-industries.[6] Appendix 1 contains a technical discussion of the derivation of Equation (1). To arrive at what we label a "country's GVCI" below, we first aggregate over the elements of **g** corresponding to the industries within that country. Shares in GVCI are then obtained by dividing the country's GVCI by GVCI summed over all countries. Note that all final demand is considered, irrespective of the location of the customers, so including both domestic and foreign demand.

As an illustration, Table 1 shows the shares of all value added generated within the global value chain with the German transport equipment industry as country-industry-of-completion, in 1995 and 2008, respectively. As stated above, we refer to these as shares in Global Value Chain Income (GVCI), following Timmer et al. (2012). For reasons of exposition, we aggregated over countries to arrive at GVCIs for three "regions".[7] The table indicates that Germany itself lost a considerable share of GVCI, while "Other EU27" and "Non-EU27" enjoyed growing shares. Intuitively, these results suggest that the production process of German transport equipment has become more internationally fragmented in the period 1995-2008.

INSERT TABLE 1 ABOUT HERE

The construction of a suitable index of international production fragmentation requires the determination of a distribution of GVCI that can be seen as "maximal" or "perfect" fragmentation. If most value added in the GVC for German transport equipment would have been generated in Germany itself, international fragmentation would be low. In our approach, international production fragmentation is similarly low if most value was added by activities in the Slovak Republic, and only marginally in Germany. This suggests that "excessive" value added shares in both the country-of-completion and other countries should yield index values pointing towards imperfect fragmentation. A question that follows immediately is how to define "excessiveness". In view of the differences in size of the German and Slovakian economies, a GVCI share of 60% for Slovakia should be considered as much more excessive than an identical share for Germany. We might thus view international production fragmentation as the extent to which GVCI shares deviate from the relative sizes of economies. In a situation of perfect fragmentation, all countries contribute an amount of value added to each of the GVCs that is proportional to their GDP, irrespective of the country-of-completion. In such a case, the share of Germany in an American GVC should be the same as in a German GVC. Comparison of the GVCI-shares and GDP-shares of the three regions in Table 1 shows that GVC-shares in the German transport equipment manufacturing GVC converged towards GDP-shares, over the period 1995-2008. In 2008, the "other EU27" region had a GVC-share that matched its GDP-share, but Germany's share in this GVC is still considerably higher than its GDP share. The mirror image applies to "non-EU27", which is still underrepresented in this global value chain. This is not surprising given the well-known home-bias in trade. Due to historical path-dependency and remaining barriers to trade, the country of completion still has a major share in its "own" GVCs' incomes.

This definition of perfect fragmentation suggests that we should adopt an index that aggregates differences between the country distributions of GVCI in a particular value chain and world GDP. This context therefore calls for a cross entropy approach, in a similar vein as studies of income inequality use cross entropy indicators to aggregate deviations in income shares of population subgroups from the shares

[6] Matrices are indicated by bold capital symbols and (column) vectors by bold lowercases. Primes indicate transposition and hats denote diagonal matrices with the corresponding vector on the main diagonal.

[7] The results are based on the World Input-Output Database. See Section 3 for a brief description, or Timmer (ed., 2012) and Dietzenbacher et al. (2013b) for extensive account of sources and methods.

that these subgroups have in the overall population. The two most popular indexes in inequality research within the class of generalized entropy statistics are the regular Theil index and the related "Mean Log Deviation" (MLD) index, both introduced in Theil (1967).[8] The difference between the two indexes relates to the weighting of the ratios between the shares implied by both distributions when aggregating these into a single figure. In the regular Theil index, the logs of these ratios are weighted by the income shares, while the logs of the ratios are weighted by the population shares in the MLD index. As such the regular Theil index is relatively sensitive to income changes in the richer parts of the population, while the MLD is more sensitive to income changes in larger population subgroups. Translating these differences to the context of the present study, the regular Theil would be dominated by countries with a large GVCI share (often the country-of-completion, like in Table 1's illustration), while the MLD index would be affected more by countries with a high GDP. The latter is more attractive for our purposes, since the fragmentation index will be much less sensitive to the size of the country-of-completion. Hence, we define the IPF-index as

$$IPF^{ij} = \sum_{n=1}^{N} \left(\frac{GDP_n}{GDP_{world}}\right) \ln\left(\frac{GDP_n/GDP_{world}}{GVCI_n^{ij}/GVCI_{world}^{ij}}\right) \quad (2)$$

As stated before, *i* and *j* together denote the country-industry-of-completion, so IPF^{ij} stands for the international production fragmentation of the global value chain of which industry *i* in country *j* delivers the final product. Applying Equation (2) to the GVCI-shares and GDP-shares in Table 1 yields IPF indexes of 1.48 and 1.10 for 1995 and 2008 respectively, revealing increased international production fragmentation of the GVC for German transport equipment.

The choice to adopt an index that is grounded in entropy statistics has the advantage that we can use the decomposability of the index into between-set and within-set inequality stressed by Theil (1967) already. In the context of the present analysis, we would like to know more about the geographic scope of fragmentation. Is fragmentation of European value chains mainly due to increasing contributions of value from an increasing number of faraway countries? Or are such decreases in IPF the consequence of other countries in Europe capturing value added that was previously earned in the country-of-completion itself? We will refer to the first tendency as "global fragmentation" and to the latter as "regional fragmentation".

As is shown in Appendix 2, the total IPF index can be decomposed into four components, according to Equation (3).

$$IPF^{ij} = IPF_{GF}^{ij} + IPF_{RF}^{ij} + IPF_{WE}^{ij} + IPF_{WO}^{ij} \quad (3)$$

The components of the decomposition are weighted IPFs themselves. Figure 2 graphically shows to which distributions of GVCI and GDP the four terms in Equation (3) refer. IPF_{GF} focuses on global fragmentation and indicates to which extent the EU27 share in GVCI income for a European GVC matches the EU27 share in world GDP. The stronger this match, the higher the degree of global fragmentation.

IPF_{RF} is based on comparisons of the shares of the country-of-completion and the rest of the EU27, in total EU27 GVCI and GDP. Offshoring stages of production in the global value chain for German transport

[8] See, for example, Jenkins and Van Kerm (2009) for a discussion of the information-theoretic properties of both indexes.

equipment to other EU27 countries (irrespective of the particular EU27-countries to which relocation takes place) is measured as an increase in regional fragmentation.

INSERT FIGURE 2 ABOUT HERE

IPF_{WE} measures the fragmentation within the "Other EU27"region (a situation in which a limited number of countries generate virtually all GVCI accruing to "Other EU27" results in a high IPF_{WE}), while IPF_{WO} refers to fragmentation across countries within "Other" (the non-EU27 countries in the database, including the Rest of the World).

3. THE WORLD INPUT-OUTPUT DATABASE[9]

The computation of Global Value Chain Income (GVCI) according to Equation (1) requires the availability of a global input-output table. Such data have become available only very recently. By linking GTAP input-output tables to bilateral trade data from the same source (see Narayanan and Walmsley, 2008), Johnson and Noguera (2012a) and Koopman et al. (2013) constructed global input-output tables.[10] These tables are not publicly available, however, and only cover one year. We use the newly constructed World Input-Output Database, which has the main advantage that it provides time-series of global input-output tables, covering 35 industries in 40 countries in the world plus a region called "Rest of the World", for the period 1995-2009.[11] For the purpose of this paper we have extended the data to 2011 using methodologies that were also applied for 1995-2009, but based on more limited and often preliminary data. In addition, we revised the 2008 and 2009 tables to include recent revisions in the export and import statistics of India and in particular China.

Basically, a world input-output table (WIOT) is a combination of national input-output tables in which the use of products is broken down according to country-industry of origin. This is illustrated by the schematic outline for a WIOT in Figure 3. It illustrates a simplified WIOT with *N* countries, which together constitute the world economy. The rows in the WIOT indicate the value of deliveries of output from a particular industry in a country. This can be used for intermediate use (in the blocks labeled **Z**) or final use (in the blocks labeled **F**), either domestically or abroad. A fundamental accounting identity is that total use of output in a row equals total output of the same industry as indicated by the sum of inputs in the respective column in the left-hand part of the tables. The columns convey information on the technology of production as they indicate the amounts of intermediate inputs needed for production. Intermediate inputs are either sourced from domestic industries or imported. The residual between total output and total

[9] For a more elaborate discussion of construction methods, practical implementation and detailed sources underlying the WIOD database, see Timmer (ed.) (2012).

[10] A notable early effort to construct international input-output tables (for the EU 1965-1985) led to a series of publications in the regional science literature. See e.g., Van der Linden and Oosterhaven (1995), Dietzenbacher and Van der Linden (1997), Oosterhaven and Hoen (1998) and Dietzenbacher et al. (2000). Furthermore, the Japanese government agency IDE-JETRO has a long tradition of constructing international input-output tables for East Asia (see e.g., Meng et al., 2013).

[11] All WIOTs and underlying data sources are publicly available for free at www.wiod.org.

intermediate inputs is value added (**w**), which measures the direct contribution of domestic factors to output.

INSERT FIGURE 3 ABOUT HERE

WIOTs have been specifically constructed to allow for both cross-country and intertemporal comparisons, by benchmarking them to the concepts and statistics from the National Accounts, and a common industrial classification (ISIC rev. 3). All national tables have been harmonized, removing idiosyncrasies regarding price concepts, treatment of financial services, and negatives in the intermediate blocks. Typically, input-output tables are only available for a limited set of years (e.g. every five years) and once released by the national statistical institute revisions are rare. To remedy problems related to the introduction of new statistical methodologies and accounting rules, which usually do not lead to revised input-output tables, WIOTs have been constructed on the basis of National Accounts time series and benchmark Supply and Use tables.[12] This treatment ensures consistency of the tables, both in the intertemporal and intercountry dimensions.

A second characteristic of the WIOTs is that the supply of products is broken down by country and industry of origin. This type of information is not available in any input-output table published by national statistical offices. To allow for differences in the intensity of use of imported products (relative to domestically produced products) across intermediate use and final use, national SUTs in the WIOD were linked through a classification of bilateral import flows by three end-use categories using detailed international trade statistics (UN COMTRADE at the 6-digit product level). WIOTs also cover trade in services collected from various international data sources (including OECD, Eurostat, IMF and WTO), checked for consistency and integrated into a bilateral service trade database.

The WIOTs have been expressed in current US$ using official exchange rates from the IMF to convert tables in national currencies. All tables are expressed in basic prices, which is a price concept that excludes net taxes and trade and transportation margins.[13] This fits our purpose to measure the distribution of value added in the production process of a good.

4. TRENDS IN INTERNATIONAL PRODUCTION FRAGMENTATION

This results section is divided into three parts. First, we examine trends in international production fragmentation of European GVCs. We show that international fragmentation has been increasing for the vast majority of GVCs, irrespective of the country-of-completion and of the nature of the final goods produced in the GVC. Second, we use the decomposability of the IPF to study to what extent increased production fragmentation of GVCs in the European Union is due to “regional fragmentation” as other EU countries capture growing shares of GVC Income, or to “global fragmentation” as more value is added outside the EU. We find that both types of fragmentation contributed to the tendency towards more fragmented GVCs, but conclude that global fragmentation has caused the largest effects. Third, we

[12] Supply and use tables have been used if available, rather than input-output tables. Input-output tables are of the industry-by-industry or product-by-product type. Supply and use tables are of a product-by-industry nature and hence provide a better linking with product-based trade data and industry-based value added data.

[13] Trade and transport margins have been allocated as output to the respective trade and transport industries.

investigate whether the global financial crisis in 2008 only led to temporary decreases in international production fragmentation or had effects in the longer run as well.

Increasing fragmentation over time

Figure 4 shows a scatter plot of IPF indexes for manufacturing global value chains in 1995 and 2008 based on Equation (2). All industries and countries-of-completion in the European Union have been included, so we have 14 x 27 = 378 GVCs.[14] If production processes would have remained equally fragmented over the period, the observations would have clustered around the 45-degree line. The vast majority of observations are below the 45-degree line, however, reflecting an increase in fragmentation. A simple OLS regression through the origin yields an estimated slope coefficient of only 0.78.[15] On average global value chains became almost 22% more fragmented over the 13-year period considered.

INSERT FIGURE 4 ABOUT HERE

In section 2 we argued that the Feenstra and Hanson indices do not allow for useful comparisons of fragmentation levels across countries of different sizes. This is illustrated in Table 2, which presents country-specific weighted means over manufacturing GVCs for the narrow and broad measures of offshoring (Feenstra and Hanson, 1999), and the IPF index, for 2008. The countries have been grouped by region, and sorted on GDP in current US dollars at market exchange rates in 2008. As explained in section 2, the broad measure of offshoring is the share of imported intermediate inputs in total intermediate inputs. [16] The narrow measure of offshoring is the share of imported intermediate inputs in intermediate inputs from the same industry. Note that a lower value for the FH index indicates less fragmentation. A lower value of the IPF index, however, corresponds to a higher degree of fragmentation.

The last row of Table 2 clearly shows that large economies tend to have low values for the indicators proposed before. Correlation coefficients between GDP levels on the one hand and the broad and narrow measures of offshoring on the other are sizable, at -0.53 and -0.43, respectively. For our IPF index, the correlation coefficient is much lower (-0.14 and insignificant at conventional levels). These results provide evidence that IPF indexes can indeed be meaningfully compared across countries-of-completion.

INSERT TABLE 2 ABOUT HERE

Table 2 also shows that the IPF index and the offshoring measures tend to indicate similar differences in fragmentation across countries when GDPs are comparable.[17] Comparing pairs of EU15-countries of about the same size, like Belgium-Sweden or Finland-Ireland, reveals that low levels of international production fragmentation according to the IPF index are also reflected in low values for the FH measures. As the

[14] Two observations have been dropped in the graph, since we did not observe final output in 1995 for leather manufacturing and petroleum manufacturing in Luxembourg.

[15] A Wald test rejects the hypothesis that the slope coefficient is equal to one at the 1 percent significance level.

[16] Feenstra and Hanson (1999) excluded energy inputs from total intermediate inputs. We included these. Prices of energy inputs are typically much more volatile compared to prices of other inputs. Since we include energy inputs in the IPF-index (because natural resources play an important role in many global value chains), a useful comparison requires the inclusion of energy inputs in the narrow and broad measures of offshoring as well.

[17] The correlation coefficients between the IPF index on the one hand and the narrow and broad measure of offshoring, are -0.43, and -0.27 respectively.

discussion of the indicators in Section 2 suggested already, the correlation between the indicators is not perfect, however, if only because they measure different aspects of the roles that countries play in networks of global value chains. Portugal and Ireland, for example, have comparable offshoring values, while the IPF index shows that Irish global value chains are considerably more fragmented than Portuguese ones.

Our first results focus on industries-of-completion, averaging over countries-of-completion. To what extent are GVCs of say final chemical products less fragmented than GVCs producing transportation equipment? Or, have fragmentation tendencies been much more pronounced for some products than for others? Answers to such questions provide information with regard to the extent to which the stories of fragmentation from case studies as discussed in the introduction can be generalized to manufacturing products in general. The IPF indices of products are shown in Table 3. Products are grouped into the main industry of final production. The average IPF index for global value chains by manufacturing product group are given for 1995 and 2008. They have been averaged over countries-of-completion and weighted by the value of final output.

INSERT TABLE 3 ABOUT HERE

Table 3 clearly shows that the production processes related to all goods became more fragmented over time. But we also observe substantial differences in international production fragmentation of GVCs across products, which appear to be quite persistent over time. The production processes of transport equipment and electrical and electronic products have been most fragmented. These are also important industries in terms of their final output value. The production processes of non-metallic minerals and of food products are at the opposite end of the spectrum. These differences in international production fragmentation across manufacturing goods are most likely related to trade barriers and transport costs. Upstream intermediate inputs (like many natural resources) often cross multiple borders, which implies that tariffs and transport costs are incurred repeatedly (Yi, 2003). Non-tariff barriers on food products are known to be relatively high (Lee and Swagel, 1997) and so are transport costs. Similarly, transportation costs for products like stone and cement are high, given their low value-to-weight ratios. These ratios are considerably more favorable for electronic parts and components, as a consequence of which GVCs for electrical and electronics products are more internationally fragmented than those for food products and non-metallic mineral. Such differences were highlighted in Hummels (2007) who found that transportation costs dropped faster for products that tend to be shipped by air. Besides cost differences, differences in the importance of timeliness of delivery can also have an impact on the choice for a domestic supplier or a supplier abroad. In a study of car manufacturing, Sturgeon et al. (2008) stress additional factors. National car manufacturing industries are considered to be of such an importance by national governments that protectionist policies focusing on high degrees of “local content” lead companies to locate assembly facilities near their end-markets. In addition, the car manufacturers often urge their main first-tier suppliers of parts and components to move to those locations as well, while second-tier suppliers often tend to benefit from economies-of-scale by producing in only a few locations.

Are there also differences in GVC fragmentation across countries-of-completion? This can be investigated by averaging across industries in each country. Table 4 provides insights into differences in degrees of international production fragmentation across countries in 1995 and 2008, and changes over

this period. The country-level IPF indexes have been constructed as averages of IPF indexes of manufacturing GVCs, weighted with the values of final output of these GVCs.

INSERT TABLE 4 ABOUT HERE

The increase in international fragmentation that was evident in Figure 4's scatter plot is also apparent from the columns in Table 4, which presents the changes in international production fragmentation over time. GVCs of all countries became more fragmented. The regional figures in the last row do not only hide a lot of heterogeneity with respect to levels, but also regarding changes over time. The biggest changes within the EU are observed for Eastern European global value chains, with the largest increase in fragmentation in Polish value chains. For the large European Union countries, we find that British value chains processes were more fragmented in 1995 than their German and French counterparts. Thereafter, however, production fragmentation increased at a fast pace in Germany and France. As a result, production in 2008 was more fragmented in German and French GVCs than in GVCs with the United Kingdom as the country-of-completion. Small EU15-countries with relatively unfragmented GVCs in 1995 (such as Austria and Denmark) experienced relatively fast reductions in their IPF indexes, although their GVCs were still less internationally fragmented in 2008 than those of Belgium and the Netherlands. These are specific cases of a more general pattern: on average, GVCs of countries-of-completion with little fragmentation in 1995 experienced stronger increases in fragmentation in 1995-2008 than those that were initially very fragmented already. This finding of convergence of fragmentation levels is supported in regression analysis where we find a significant negative effect of initial levels on changes in the IPF index.[18]

The increases in fragmentation by country-of-completion as reported in Table 4 could be caused by two effects. GVCs for many industries-of-completion can have become more fragmented, and final output of fragmented GVCs can have grown faster than final output of less fragmented GVCs (a product-mix effect) Shift-share analysis suggests that changes in fragmentation are mainly driven by increased fragmentation within GVCs. On average, about 90 percent of changes in country-level IPF indexes is explained by this. Only for some Eastern European countries, such as the Czech Republic and Hungary, we find that changes in the product mixes account for a considerably larger share of changes in the IPF index (32 and 28 percent respectively).

[18] We estimated an OLS regression for manufacturing industries, clustering standard errors by country and weighing observations by final output. The effect of initial levels on changes in the IPF index is significant at the 1 percent level. Regression results are available upon request.

Global versus regional fragmentation in European value chains

In his study on bilateral vs. multilateral free trade agreements, Baldwin (2006b) made a distinction between international economic integration within regions and global economic integration. The relative magnitudes of international (gross) trade flows within regions (like the EU or NAFTA) are still much larger than those of trade flows between regions. Given integration of markets within the EU and the simultaneous fast growth of emerging economies outside Europe, it is interesting to investigate what shares in the trends toward fragmentation of European GVCs as quantified above can be attributed to global fragmentation and regional fragmentation, respectively.

Before turning to the decomposition results based on the IPF index, we first present some statistics based on Feenstra and Hanson's broad measure of offshoring, as this provides an intuitive background to our decomposition. Table 5 shows this measure for each EU country (column (1)) and also presents splits into the percentage of imported intermediates from EU countries and the percentage imported from non-EU countries, for 1995 and 2008. The rightmost columns in the table indicate that shares of imported intermediate inputs from EU27 countries have generally grown faster than corresponding shares from outside the EU27. This pattern is most pronounced for the EU12 countries. In this set of countries, the Czech Republic and Estonia appear to be the only countries for which the share of non-EU27 intermediate inputs increased more than the share from EU27 countries. An analysis based on the FH broad measure of offshoring thus suggests that regional fragmentation has been the main driver of international production fragmentation.

INSERT TABLE 5 ABOUT HERE

In Section 3, we argued that one of the main disadvantages of the FH measures of offshoring in measuring production fragmentation relates to the neglect of trade in intermediate inputs in upstream industries. The results in columns (2) and (5) in Table 5 are computed on the basis of the intermediate inputs imported from within the EU27, but is not sensitive to the degree to which the production of these products required intermediate inputs from outside the EU27. This so-called double counting problem was highlighted by Johnson and Noguera (2012a) and Koopman et al. (2013). To get some preliminary insights into the potential consequences of this phenomenon, we computed GVCI in UK manufacturing value chains for "Other EU27" and for "Non EU27", and considered the growth in these shares over 1995-2008. The GVCI share of "Other EU27" remained stable at 12%, while the GVCI share of "Non EU27" grew from 10% to 14%. This is due to the increased non-EU 27 content of EU27 exports to the UK, which is not picked up by the FH indices in Table 5. Similar observations apply to other countries and stress the need to correct for the double counting of intermediates.

To quantify the respective contributions of global fragmentation and regional fragmentation of European value chains more systematically, we decompose the IPF indexes for 1995 and 2008 along the lines sketched in Figure 2, using Equations (A2.2). We focus our analysis on the changes over this period. In Table 6, the first column shows the changes in the average IPF index by country-of-completion. The second column reports the contribution from changes in global fragmentation (IPF_{GF}). The third column documents the contribution of regional fragmentation in the EU27 (IPF_{RF}). Columns (4) and (5) show changes in fragmentation within "Other EU27" (IPF_{WE}) and "Other" (IPF_{WO}). These terms capture the

fragmentation due to changes in the GVCI-shares for each of the other EU27 countries in "Other EU27"'s GVCI and for each of the non-EU27 countries in "Other"'s GVCI, respectively.

INSERT TABLE 6 ABOUT HERE

The bottom rows in Table 6 show weighted averages for GVCs with countries in the EU15 and EU12 as countries-of-completion, respectively. For both sets of GVCs, we find that changes in global fragmentation have been the dominant driver of the overall change in the IPF-indexes. In EU15 GVCs, global fragmentation accounted for almost 90% of the total change in fragmentation, while regional fragmentation contributed 19%. The negative effects of the two "within"-terms are small (9%) for these value chains. For the EU12 value chains, almost half of the increase in overall production fragmentation was contributed by global fragmentation, while regional fragmentation accounted for slightly more than 15%. GVCs of sizable countries like the Czech Republic and Poland appear to rely increasingly on upstream activities outside Europe. These findings complement Marin's (2006) results about increasing integration of Eastern European countries in European value chains. The positive contribution of regional fragmentation in EU15 GVCs is partly a reflection of EU12 countries capturing increasing shares of GVCI in these chains, which is a confirmation of Marin's findings based on EU12 exports of intermediate inputs to Austrian and German firms. The dominance of increasing global fragmentation for the Czech Republic and Poland reflect that their value chains increasingly rely on imports of (low-tech) materials and parts from non-EU27, rather than on activities in the EU15. Our results thus indicate that integration of EU12 countries into the European economy is not a symmetric process. A very substantial part of the fast rates of increase in international production fragmentation of EU12 GVCs is accounted for by changes in the extent to which contributions of individual non-EU27 countries have been in proportion to their GDP-levels (column (5)). This is a consequence of the fact that a number of EU12 countries were still highly dependent on Russia in the early years of the 1995-2008 period. Over time, other non-EU27 countries (like China, Japan and the US) also started to supply intermediate inputs to EU12 value chains (often as second- or third-tier suppliers, via EU15 first-tier suppliers), which led to a more even distribution of GVC income over non-EU27 countries.[19]

We also investigated whether the relative importance of changes in global fragmentation and regional fragmentation varied across GVCs for the product groups listed in Table 3. The (undocumented) results show that increases in global fragmentation dominated for all product groups. For textile products and electronics, changes in global fragmentation completely drove the overall increase in fragmentation, while this was less evident for food products and leather products.

Production fragmentation after the crisis

Is the long-run trend towards fragmentation in European GVCs a particular historical period that ended with the financial crisis, or has it continued? The immediate consequences of the crisis were studied in a global input-output framework by Bems et al. (2011), who concluded that international trade declined considerably more than world GDP when the crisis started. This was explained by demand uncertainty leading firms to use existing stocks of materials and components, instead of ordering usual amounts of

[19] The share of Russian GVC income in Hungarian global value chains, for example, decreased from 5.0% in 1995 to 3.7% in 2008. Among the six biggest EU12 economies, Poland is the only one for which the Russian income share in its GVCs increased considerably (from 2.3 to 4.2 per cent).

intermediate inputs. It might also indicate a more structural break in the process of international fragmentation, however, as firms experienced the vulnerability of long production chains. Other factors like increasing transport costs (as fuel prices continue rising) and an upward drift in Chinese wages might be additional drivers towards a long-term decline in fragmentation. To investigate this, we have updated the WIOD to 2011 using recent data on international trade and (mostly preliminary) data on gross output and value added by industry. We obtain insights into what happened in the first three years after the start of the crisis by regressing our time-series of IPF indexes for all EU27 manufacturing GVCs by OLS on country-of-completion, industry-of-completion and year dummies. The inclusion of the first two sets of dummies allows us to isolate year-specific effects in the variation in IPF indexes. These effects give us insights into long-run trends, but also into the effects of the crisis. The sample consists of 6,351 observations, which have been weighted by the GVCs' values of final output. Following Feenstra and Hanson (1999), the regressions are based on IPFs in which value added generated in mining activities has been excluded from both GVCI and GDP, because prices of energy inputs are typically unstable and lead to volatile value shares. The coefficients on the year dummies will indicate possible trends in the process of international fragmentation.

INSERT FIGURE 5 ABOUT HERE

Figure 5 shows the estimated coefficients for the year dummies and the associated 95 percent confidence intervals. The dummy for 1995 has been omitted, so all point estimates have to be viewed as relative to 1995. The figure clearly reflects the across-the-board increase in international fragmentation that was discovered throughout the empirical part of this study. The year dummies were found to be statistically larger than 0 at a 5% level of significance from 1997 onwards. The point estimates show a decreasing trend in the IPFs (reflecting increasing fragmentation) until the onset of the crisis. Splitting the sample into subsamples related to specific final products (like in Table 3), we found this tendency for all product groups. Nevertheless, we also observed differences, since the value chains for transport equipment got increasingly fragmented in the second part of the 1990s already. Fragmentation of European GVCs for electronics products, on the other hand, did not start to get increasingly fragmented until 2003.

The effects of the onset of the financial crisis in 2008 are clearly visible. The IPFs show an upward jump between 2008 and 2009. This appears to have been a short-run effect, though. Fragmentation rebounded almost equally fast between 2009 and 2010 and a Wald test on the equality of the year dummies for 2008 and 2011 reveals that the IPFs in 2011 were already lower than those in 2008, which is proof that the tendency towards more fragmentation seems to have set in again.[20] This result is found for virtually all product groups. We should stress that these results only convey information about the fragmentation effects of the crisis in the period immediately following the start of the crisis. It remains to be seen whether the prolongation of the crisis through 2012 might have more structural effects, also for shares in GVC income earned in non-EU27 countries. Our present data do not allow us to examine to what extent crisis-induced protectionist government policies and "re-shoring" decisions by multinational companies as debated in the popular press (see The Economist, 2013) lead to changes that can also be observed in our IPF index and related indicators.

[20] The *p*-value implied by the Wald test statistic is considerably lower than 0.01.

5. Concluding remarks

Driven by rapid advances in information and communication technology and the opening up of China and Eastern Europe in the 1990s, companies increasingly moved parts of their production activities to benefit from location advantages of other countries. This paper provides a new index that quantifies the speed and extent of this process of international production fragmentation, called the IPF index. Put loosely, it measures the distribution of value added generated in the production of a final good across countries and regions. It is a variant of Theil's Mean Log deviation index which is rooted in entropy theory. In the empirical application we show how the IPF index can be computed on the basis of world input-output tables as contained in the recent World Input-Output Database (WIOD).

The empirical analysis shows that the IPF index is not sensitive to the size of countries, unlike related measures such as Feenstra-Hanson's indicator of offshoring. This implies that levels of international production fragmentation can be compared across countries. We find a strong tendency towards increased fragmentation for most production processes, irrespective of the country-of-completion or the final product generated by a GVC. Global value chains for electrical and electronic products are most fragmented, followed by those for transportation equipment. We find that fragmentation of EU15 GVCs is mainly due to a shift in the value added in chains from the EU15 countries to non-European countries. Finally, we find that the upward trend in international fragmentation before the onset of the financial crisis in 2008 continued after a strong once-off reduction between 2008 and 2009. We did not find evidence of a long-run structural effect on production fragmentation. It should be stressed, though, that the crisis was not over by 2011 and that protectionist policies induced by the crisis might have effects that will only be visible in the longer run.

We believe that our new index for international production fragmentation provides insights that were not available using existing measures related to economic globalization. The quality of future empirical research based on the IPF index will obviously depend on the quality of the available underlying data. We are confident that the main trends depicted in this paper reflect actual tendencies. Nevertheless, future research would benefit from further improvements in the global input-output tables required for the computation of global value chain income shares and the IPF index. More disaggregated industry data would improve the quality of the results as it better represents heterogeneity in production processes. It would also be very helpful if the implicit assumption that exporting firms and non-exporting firms use the same shares of inputs could be relaxed. The recent Trade in Value Added initiative by the OECD and the WTO (OECD and WTO, 2013) has ambitions into these directions. This initiative also aims at constructing global input-output tables containing more countries than the World Input-Output Database. Such tables would allow for deeper analyses of the roles of other Asian countries, such as Malaysia, Thailand and Vietnam, in global production systems.

At the same time, other directions of research can be explored. The World Input-Output Database does not only contain information on total value added generated in country-industries, but also provides information about the value added and income captured by owners of capital and labor of various skill categories. This type of information has extensively been used in Timmer et al. (2012, 2013) to study the competitiveness of European countries and to document stylized facts about the distributional consequences of the emergence of global value chains. It can also be used to answer questions like "Are low-skilled stages of production processes becoming much more internationally fragmented than high-skilled stages?" Observations such as Sinn's (2006) that Germany is becoming a country that only designs,

markets and sells manufacturing products, activities that are generally thought to be high-skilled , could be tested empirically. Another dimension along which more insights can be gained is the increase of regional detail at the subnational level. Cherubini and Los (2013) and Dietzenbacher et al. (2013a) have pioneered regional disaggregation of the Italian and Brazilian parts of WIOD's world input-output tables. This allows them to study to what extent regional economies benefit from participation in national and global value chains, offering macro-economic perspectives on the case study-based evidence that has been amassed, such as in Humphrey and Schmitz (2002). This would improve our understanding of the drivers of regional development in a world characterized by global value chains.

Finally, future research might focus on the role of potential determinants of international production fragmentation. Our analysis showed that the degree of fragmentation varies across product groups, but we could only speculated about the causes of these differences. For example, Johnson and Noguera (2012b) found that participation in bilateral free-trade agreements positively affects the vertical specialization of countries in trade. A similar analysis for global value chains could lead to complementary insights by linking to what is probably the most important question to be pursued: "How can countries benefit from the increased international fragmentation of production processes?" The recent study by Baldwin and Evenett (2012) gives an extensive overview of the issues at stake for the UK. Policy insights like theirs combined with high-quality data and new indicators should lead to well-founded industrial and trade policies.

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Appendix 1: Derivation of Global Value Chain Incomes

To compute the GVCI income related to the value chain with industry *j* in country *i* as the country-of-completion as generated in each of the countries, a global input-output table as depicted in Figure 3 is taken as the point of departure. The number of industries in each of the countries is *S*, the number of countries is *N*. The number of final demand categories per country is indicated by *C*. The (*SN*x*SN*)-matrix **A**

and the (*SN*)-vector **v** are obtained as $\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1}$ and $\mathbf{v}' = \mathbf{w}'(\hat{\mathbf{x}})^{-1}$, respectively.[21] **A** gives the intermediate inputs required per unit of gross output, while **v** represents the value added generated per unit of gross output. As a first step in computing the income generated in the GVCs for (*i,j*)'s final products, we derive the payments for capital and labor in the country-industry-of-completion. This equals $\mathbf{g}^{tier0} = \hat{\mathbf{v}}\tilde{\mathbf{F}}\mathbf{e}$, in which **e** is an (*CN*)-summation vector and $\tilde{\mathbf{F}}$ stands for a final demand matrix (of dimensions (*SN*x*CN*)) in which only the row representing final demand for country-industry (*i,j*) have their actual value and all other final demand is set to 0. This implies that $\tilde{\mathbf{F}}\mathbf{e}$ is an (*SN*)-vector with a single positive element, which is obtained by adding domestic and foreign final demand for (*i,j*)'s products. The elements of $\mathbf{g}^{tier0}$ (which is an (*SN*)-vector with GVC income in the final production stage) equal zero for all industries other than (*i,j*). As the stylized example in Figure 1 shows, the production of these final product deliveries does not only require labor and capital inputs, but also intermediate inputs from (domestic and foreign) first tier suppliers. The gross outputs of these industries attributable to final demand for country 3's products equals $\mathbf{A}\tilde{\mathbf{F}}\mathbf{e}$ and the global value chain income in first-tier suppliers can be expressed as $\mathbf{g}^{tier1} = \hat{\mathbf{v}}\mathbf{A}\tilde{\mathbf{F}}\mathbf{e}$. The intermediate products ($\mathbf{A}\tilde{\mathbf{F}}\mathbf{e}$) delivered by first-tier suppliers in their turn require intermediate inputs, from second-tier suppliers. These output levels equal $\mathbf{A}(\mathbf{A}\tilde{\mathbf{F}}\mathbf{e})$ and the associated second-tier global value chain income levels are $\mathbf{g}^{tier2} = \hat{\mathbf{v}}\mathbf{A}(\mathbf{A}\tilde{\mathbf{F}}\mathbf{e})$. Continuing this line of reasoning for higher-tier suppliers and adding over tiers, we can write for the vector of *total* GVC income levels (see Miller and Blair, 2009, for the mild conditions under which the summation converges):

$$\mathbf{g} = \mathbf{g}^{tier0} + \mathbf{g}^{tier1} + \mathbf{g}^{tier2} + \mathbf{g}^{tier3} + \ldots = \hat{\mathbf{v}}(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \ldots)(\tilde{\mathbf{F}}\mathbf{e}) = \hat{\mathbf{v}}(\mathbf{I} - \mathbf{A})^{-1}(\tilde{\mathbf{F}}\mathbf{e}) \qquad \text{(A1.1)}$$

Equation (A1.1) is identical to Equation (1) in the main text. The matrix $(\mathbf{I} - \mathbf{A})^{-1}$ is the well-known Leontief inverse. **g** contains the value added (income) in each of the industries in each of the countries that can be attributed to the global value chains for country-industry (*i,j*)'s final products. In order to obtain Global Value Chain Income by country, the elements of the (SN)-vector **g** that correspond to industries in a country are simply added.

[21] **Z** contains all submatrices $\mathbf{Z}^{11}$, $\mathbf{Z}^{1.}$, $\mathbf{Z}^{NN}$. in Figure 3. **x** should be interpreted in the same vein.

Appendix 2: Decomposition of IPF index

To outline our IPF index decomposition approach as depicted in Figure 2 in mathematical terms, we follow Akita (2003) in adopting a notation in which GVCI related to industry-of-completion *i* in country *j* and GDP both have three sub-indexes. We first split the world into super-regions, indicated by *l* = 1, …, *L* (*L*=2). These super-regions are "EU27" and "Other". The number of regions (indicated by *m* = 1, …, M_l) contained in these super-regions varies. The super-region "EU27" contains two regions: "home" (the country-of-completion itself) and "Other EU27". The super-region "Other" contains just a single region ("Other"). Finally, each of the 41 countries that potentially add value belongs to a single region. As before, the countries are indicated by *n* (*n* = 1, …, N_m, with N_m the number of countries in region *m*). Equation (2) can now be expanded into:

$$IPF^{ij} = \sum_{l=1}^{L}\sum_{m=1}^{M_l}\sum_{n=1}^{N_m}\left(\frac{GDP_{lmn}}{GDP_{world}}\right)\ln\left(\frac{GDP_{lmn}/GDP_{world}}{GVCI_{lmn}^{ij}/GVCI_{world}^{ij}}\right) \quad \text{(A2.1)}$$

Equation (A2.1) can be decomposed into the terms contained in the right-hand side of Equation (3) in the main text:

$$IPF^{ij} = IPF_{GF}^{ij} + IPF_{RF}^{ij} + IPF_{WE}^{ij} + IPF_{WO}^{ij} \quad (3)$$

The first term on the right hand side (IPF_{GF}^{ij}) stands for the degree of global fragmentation of the value chain with (*i,j*) as the country-industry-of-completion. We define global fragmentation as the fragmentation between the two super-regions. It is defined as

$$IPF_{GF}^{ij} = \sum_{l=1}^{L}\left(\frac{GDP_l}{GDP_{world}}\right) ln\left(\frac{GDP_l/GDP_{world}}{GVC_l^{ij}/GVC_{world}^{ij}}\right) \quad \text{(A2.2a)}$$

with $GDP_l = \sum_{m=1}^{M_l}\sum_{n=1}^{N_m} GDP_{lmn}$ and $GVCI_l^{ij} = \sum_{m=1}^{M_l}\sum_{n=1}^{N_m} GVCI_{lmn}^{ij}$)

The second term (IPF_{RF}^{ij}) indicates the level of regional fragmentation of value chain (*i,j*) between the country-of-completion and the rest of the EU27 considered as a single region:

$$IPF_{RF}^{ij} = \left(\frac{GDP_1}{GDP_{world}}\right)\sum_{m=1}^{M_1}\left(\frac{GDP_{1m}}{GDP_1}\right) ln\left(\frac{GDP_{1m}/GDP_1}{GVC_{1m}^{ij}/GVC_1^{ij}}\right) \quad \text{(A2.2b)}$$

with ($GDP_{1m} = \sum_{n=1}^{N_m} GDP_{1mn}$; $GVCI_{1m}^{ij} = \sum_{n=1}^{N_m} GVCI_{1mn}^{ij}$)

The last two terms in Equation (3) relate to the distribution of GVCI over countries within regions. These so-called "within"-terms are computed as

$$IPF_{WE}^{ij} = \left(\frac{GDP_{12}}{GDP_1}\right)\sum_{n=1}^{N_1}\left(\frac{GDP_{12n}}{GDP_{12}}\right) ln\left(\frac{GDP_{12n}/GDP_{12}}{GVCI_{12n}^{ij}/GVCI_{12}^{ij}}\right) \quad \text{and} \quad \text{(A2.2c)}$$

$$IPF_{WO}^{ij} = \left(\frac{GDP_2}{GDP_{world}}\right)\sum_{n=1}^{N_2}\left(\frac{GDP_{21n}}{GDP_2}\right) ln\left(\frac{GDP_{21n}/GDP_2}{GVCI_{21n}^{ij}/GVCI_2^{ij}}\right) \quad \text{(A2.2d)}$$

Table 1. Regional shares in German transport equipment GVCI and world GDP

	1995		2008	
	GVCI	GDP	GVCI	GDP
GER	0.789	0.080	0.660	0.049
Other-EU27	0.132	0.210	0.186	0.187
non-EU27	0.079	0.711	0.154	0.764
Total	1.000	1.000	1.000	1.000

Source: Authors' calculations on World Input-Output Database (revised April 2012 release).
Note: GVCI is global value chain income expressed in US dollars at market exchange rates. GDP is world gross domestic product expressed in US dollars at market exchange rates.

Table 2. Comparison of the IPF index to alternative measures, 2008

	GDP	Broad offshoring	Narrow offshoring	IPF index
EU 15				
Germany	3,272,236	0.46	0.49	1.32
France	2,574,694	0.41	0.44	1.45
United Kingdom	2,451,686	0.51	0.61	1.46
Italy	2,072,559	0.28	0.34	1.56
Spain	1,464,933	0.30	0.36	1.54
the Netherlands	778,522	0.66	0.75	1.17
Belgium	453,502	0.77	0.84	1.10
Sweden	431,143	0.50	0.59	1.38
Austria	377,310	0.62	0.71	1.52
Greece	308,371	0.49	0.49	1.78
Denmark	293,005	0.65	0.64	1.47
Finland	237,540	0.35	0.42	1.51
Ireland	235,018	0.51	0.53	1.05
Portugal	219,403	0.47	0.54	1.68
Luxembourg	52,737	0.86	0.92	1.40
EU 12				
Poland	469,601	0.45	0.51	1.64
Czech Republic	195,961	0.54	0.59	1.36
Romania	183,465	0.49	0.44	1.98
Hungary	134,007	0.72	0.84	1.18
Slovakia	86,138	0.71	0.78	1.37
Slovenia	48,156	0.68	0.74	1.37
Lithuania	42,587	0.61	0.62	2.11
Bulgaria	40,790	0.59	0.56	1.56
Latvia	30,342	0.66	0.56	1.92
Cyprus	22,483	0.59	0.53	1.51
Estonia	21,047	0.73	0.76	1.52
Malta	7,613	0.85	0.88	1.30
correlation with GDP		-0.53	-0.43	-0.14

Source: Authors' calculations based on World Input-Output Database (revised April 2012 release).

Notes: GDP in millions of current US dollars at market exchange rates. All indicators represent appropriately weighted averages over manufacturing industries. A low IPF index corresponds to a high degree of fragmentation.

Table 3. International Production Fragmentation by product, 1995 and 2008, and change over 1995-2008

Industry	ISIC rev. 3 code	1995	2008	Change 1995-2008	Final output
Transport products	34,35	1.51	1.14	0.37	675,330
Electronic products	30-33	1.47	1.20	0.27	361,055
Basic and fabricated metals	27,28	1.74	1.30	0.44	162,697
Chemical products	24	1.74	1.30	0.44	321,191
Manufacturing n.e.c.	36	1.76	1.39	0.37	502,591
Rubber and plastics	25	1.75	1.39	0.36	59,048
Petroleum products	23	1.81	1.50	0.30	224,278
Machinery n.e.c.	29	1.92	1.55	0.37	192,184
Textile products	17,18	1.89	1.61	0.28	160,962
Leather products	19	1.97	1.67	0.30	46,971
Paper and printing products	21,22	2.01	1.70	0.32	160,827
Wood products	20	2.08	1.70	0.38	26,577
Food products	15,16	2.07	1.71	0.36	791,960
Other non-metallic minerals	26	2.16	1.72	0.45	41,442

Source: Authors' calculations based on the World Input-Output Database (revised April 2012 release).

Notes: Average IPF for the global value chains of manufacturing products for European countries, weighted by the values of final output across countries. Products ordered by degree of international fragmentation in 2008. Last column shows total final output in EU 27 in millions of current US dollars at market exchange rates, in 2008.

Table 4. International Production Fragmentation by country, 1995 and 2008 and change over 1995-2008

Country	1995	2008	Change 1995-2008	*Country*	1995	2008	Change 1995-2008
Austria	2.07	1.52	0.54	Bulgaria	2.36	1.56	0.79
Belgium	1.34	1.10	0.24	Cyprus	1.66	1.51	0.15
Denmark	2.07	1.47	0.60	Czech Republic	2.01	1.36	0.65
Finland	1.84	1.51	0.34	Estonia	2.06	1.52	0.54
France	1.78	1.44	0.33	Hungary	1.90	1.18	0.71
Germany	1.77	1.32	0.45	Latvia	2.49	1.92	0.56
Greece	2.30	1.78	0.52	Lithuania	2.21	2.11	0.11
Ireland	1.35	1.05	0.30	Malta	1.54	1.30	0.24
Italy	1.91	1.56	0.34	Poland	2.54	1.64	0.90
Luxembourg	1.70	1.40	0.30	Romania	2.57	1.98	0.59
Netherlands	1.41	1.17	0.24	Slovakia	2.23	1.36	0.86
Portugal	1.97	1.68	0.29	Slovenia	1.89	1.37	0.51
Spain	2.00	1.54	0.45				
Sweden	1.75	1.38	0.36				
United Kingdom	1.68	1.46	0.22				
EU 15	1.78	1.42	0.37	EU 12	2.27	1.55	0.72

Source: Authors' calculations based on the World Input-Output Database (revised April 2012 release);
Notes: Average IPF for manufacturing global value chains, weighted by the value of final output. IPF indexes by regions are weighted averages over the countries considered.

Table 5. Shares of imports in total intermediate inputs

	Import share	*other EU*	*non EU*	Import share	*other EU*	*non EU*
	1995	1995	1995	change 1995-2008	change 1995-2008	change 1995-2008
	(1) =	(2) +	(3)	(4) =	(5) +	(6)
EU 15						
Austria	0.44	0.27	0.17	0.18	0.09	0.08
Belgium	0.67	0.39	0.27	0.10	0.01	0.09
Denmark	0.55	0.33	0.23	0.10	0.04	0.06
Finland	0.28	0.23	0.05	0.07	0.06	0.00
France	0.33	0.24	0.09	0.08	0.05	0.02
Germany	0.30	0.14	0.16	0.17	0.09	0.08
Greece	0.34	0.21	0.13	0.15	0.07	0.09
Ireland	0.68	0.59	0.10	-0.18	-0.12	-0.05
Italy	0.24	0.16	0.07	0.04	0.04	0.00
Luxembourg	0.88	0.67	0.21	-0.02	-0.05	0.03
the Netherlands	0.61	0.32	0.29	0.05	-0.01	0.07
Portugal	0.33	0.18	0.14	0.14	0.12	0.02
Spain	0.23	0.14	0.09	0.07	0.03	0.03
Sweden	0.40	0.23	0.16	0.10	0.08	0.03
United Kingdom	0.36	0.16	0.20	0.15	0.10	0.05
EU 12						
Bulgaria	0.35	0.24	0.11	0.24	0.13	0.11
Cyprus	0.60	0.49	0.11	-0.01	0.01	-0.01
Czech Republic	0.36	0.19	0.17	0.18	0.05	0.13
Estonia	0.64	0.40	0.24	0.09	0.02	0.07
Hungary	0.35	0.23	0.11	0.37	0.35	0.02
Latvia	0.53	0.38	0.15	0.13	0.08	0.05
Lithuania	0.61	0.32	0.29	0.00	0.00	-0.01
Malta	0.79	0.63	0.16	0.06	0.09	-0.02
Poland	0.24	0.14	0.10	0.21	0.11	0.10
Romania	0.27	0.20	0.06	0.23	0.13	0.10
Slovakia	0.36	0.29	0.07	0.35	0.33	0.03
Slovenia	0.53	0.35	0.17	0.16	0.11	0.05
Average EU 15	*0.34*	*0.20*	*0.14*	*0.10*	*0.06*	*0.04*
Average EU 12	*0.34*	*0.22*	*0.12*	*0.22*	*0.13*	*0.08*

Source: Authors' calculations based on the World Input-Output Database (revised April 2012 release).

Notes: Import share is the share of imported intermediates in total intermediate use. This import share is split in the subsequent columns into the share from EU countries and non-EU countries. Columns might not sum due to rounding.

Table 6. Decomposition of the change in the IPF index (1995-2008)

	Change in IPF index	Change in global fragmentation	Change in regional fragmentation	Change in fragmentation within Other EU27	Change in fragmentation within non-EU27
	(1) =	(2) +	(3) +	(4) +	(5)
EU 15					
Austria	0.54	0.34	0.11	-0.02	0.11
Belgium	0.24	0.31	0.04	-0.03	-0.08
Denmark	0.60	0.37	0.08	0.01	0.14
Finland	0.34	0.35	0.08	0.00	-0.09
France	0.33	0.32	0.05	0.00	-0.04
Germany	0.45	0.42	0.03	-0.01	0.01
Greece	0.52	0.70	0.03	-0.01	-0.21
Ireland	0.30	0.18	0.11	0.00	0.01
Italy	0.34	0.33	0.04	-0.01	-0.01
Luxembourg	0.30	0.21	0.07	0.00	0.02
the Netherlands	0.24	0.23	0.05	-0.01	-0.03
Portugal	0.29	0.28	0.05	-0.02	-0.03
Spain	0.45	0.38	0.10	-0.01	-0.02
Sweden	0.36	0.35	0.09	-0.02	-0.05
United Kingdom	0.22	0.18	0.05	0.00	-0.01
EU 12					
Bulgaria	0.79	0.20	0.18	0.01	0.40
Cyprus	0.15	0.09	-0.01	-0.01	0.08
Czech Republic	0.65	0.36	0.12	0.02	0.14
Estonia	0.54	0.21	-0.03	0.08	0.27
Hungary	0.71	0.26	0.18	0.00	0.28
Latvia	0.56	0.08	0.10	0.03	0.36
Lithuania	0.11	0.08	0.03	-0.01	0.01
Malta	0.24	0.20	-0.03	0.02	0.05
Poland	0.90	0.62	0.18	0.00	0.11
Romania	0.59	0.22	0.14	0.00	0.24
Slovakia	0.86	0.41	0.16	0.08	0.22
Slovenia	0.51	0.41	0.04	0.01	0.06
Average EU15	*0.37*	*0.33*	*0.07*	*-0.01*	*-0.02*
Average EU12	*0.55*	*0.26*	*0.09*	*0.02*	*0.18*

Source: Authors' calculations based on the World Input-Output Database

Notes: Change in the average IPF for the global value chains of manufacturing industries weighted by final output by country. Decomposition of the IPF index in subsequent columns has been calculated using Equations (A2.2). Columns might not sum due to rounding.

Figure 1

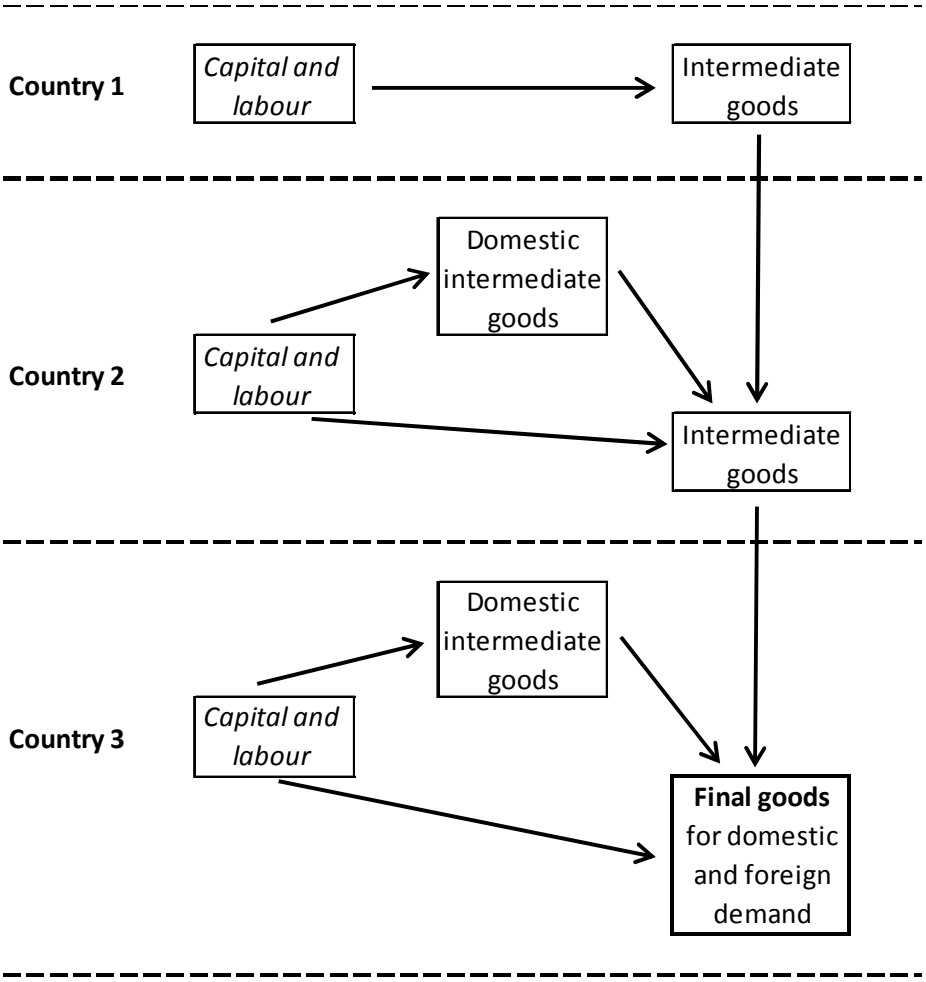
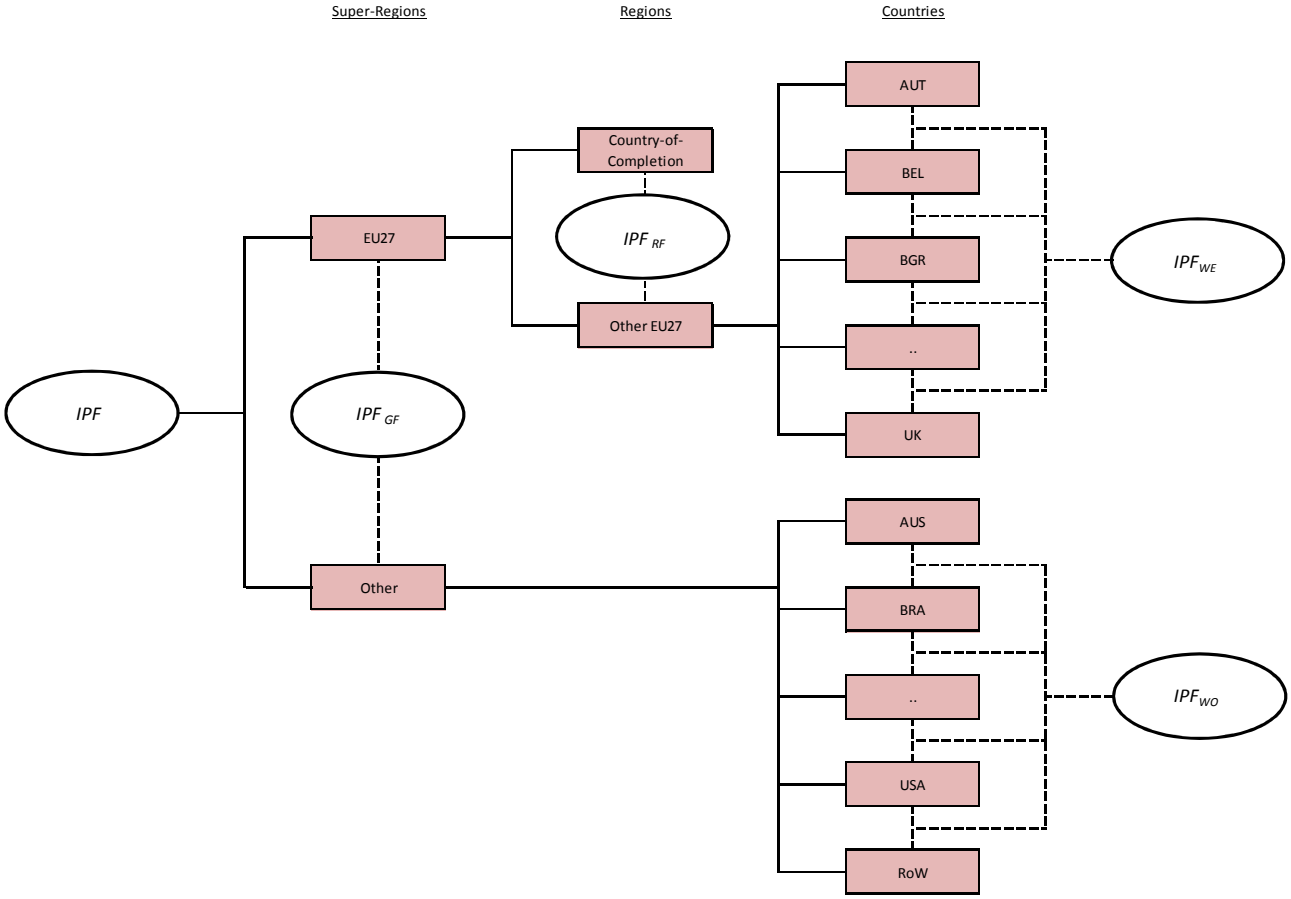

Country 1
Capital and labour
Intermediate goods
Country 2
Capital and labour
Domestic intermediate goods
Intermediate goods
Country 3
Capital and labour
Domestic intermediate goods
Final goods for domestic and foreign demand

Figure 2. Decomposition of IPF index

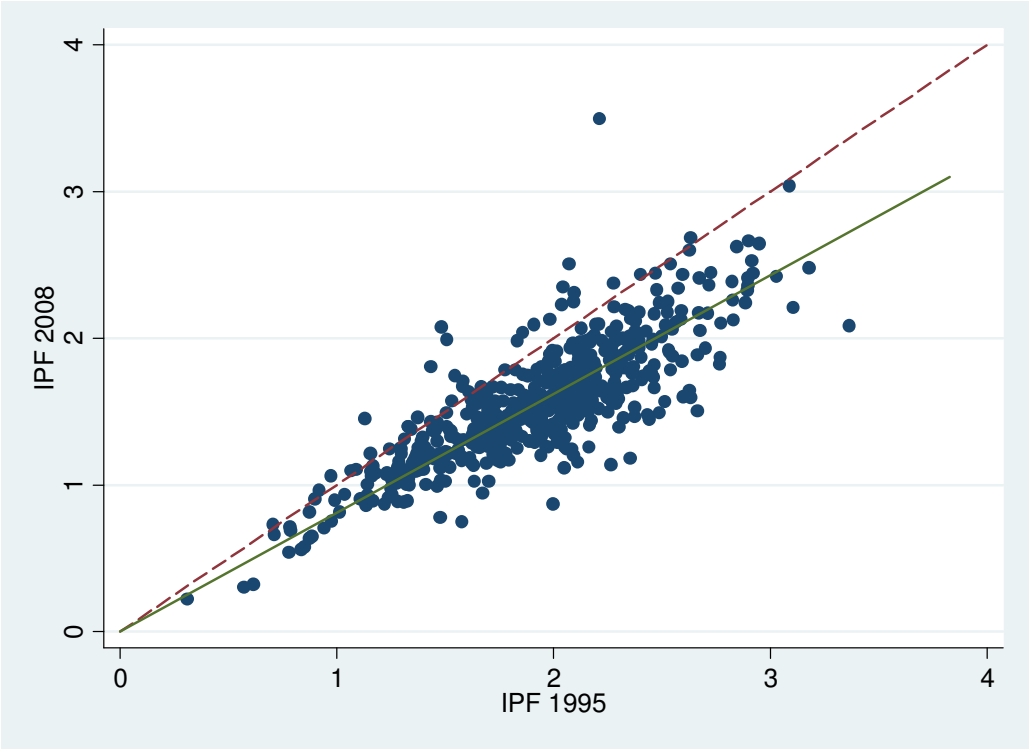


Note: *IPF* (total fragmentation) computed according to Equation (2). IPF_{GF} (global fragmentation), IPF_{RF} (regional fragmentation), IPF_{WE} and IPF_{WO} computed according to Equations (A2.2a-A2.2d) in Appendix 2.

Figure 3. A stylized world input-output table

	Intermediate use (*S* columns per country)			Final use (*C* columns per country)			Total
	1	…	*N*	1	…	*N*	
S Industries, country 1	$\mathbf{Z}^{11}$	$\mathbf{Z}^{1\cdot}$	$\mathbf{Z}^{1N}$	$\mathbf{F}^{11}$	$\mathbf{F}^{1\cdot}$	$\mathbf{F}^{1N}$	$\mathbf{x}^{1}$
…	$\mathbf{Z}^{\cdot 1}$	$\mathbf{Z}^{\cdot\cdot}$	$\mathbf{Z}^{\cdot N}$	$\mathbf{F}^{\cdot 1}$	$\mathbf{F}^{\cdot\cdot}$	$\mathbf{F}^{\cdot N}$	$\mathbf{x}^{\cdot}$
S Industries, country *N*	$\mathbf{Z}^{N1}$	$\mathbf{Z}^{N\cdot}$	$\mathbf{Z}^{NN}$	$\mathbf{F}^{N1}$	$\mathbf{F}^{N\cdot}$	$\mathbf{F}^{NN}$	$\mathbf{x}^{N}$
Value added	$(\mathbf{w}^{1})'$	$(\mathbf{w}^{2})'$	$(\mathbf{w}^{N})'$				
Output	$(\mathbf{x}^{1})'$	$(\mathbf{x}^{2})'$	$(\mathbf{x}^{N})'$				

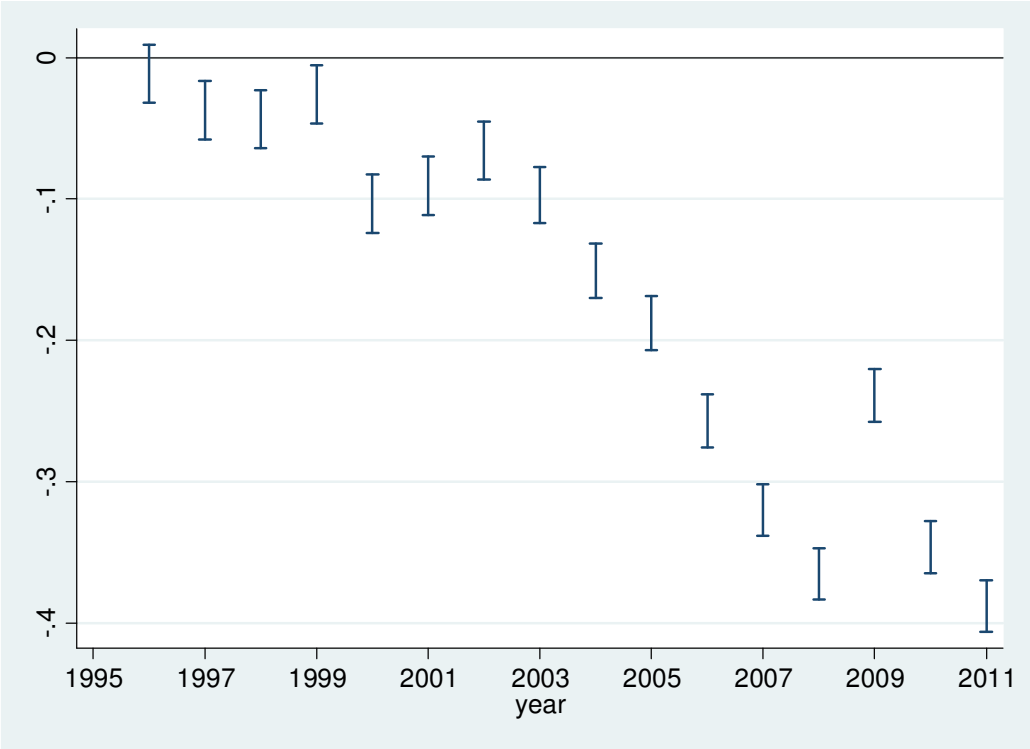
Figure 4. International production fragmentation indexes, 1995 and 2008



Source: Authors' calculations based on the World Input-Output Database (revised April 2012 release).

Notes: Each dot represents the IPF indexes for the global value chain of a manufacturing industry in a particular country in 1995 and 2008. The IPF indexes have been estimated according to Equation (2). 376 observations, from the 27 European countries-of-completion, have been included. The dashed line is the 45 degree line. The solid line has been obtained by OLS regression through the origin; the slope coefficient is 0.78.

Figure 5. International production fragmentation before and after the 2008 financial crisis



Source: Authors' calculations based on the World Input-Output Database (revised April 2012 release).

Notes: Regression of IPF index on country-of-completion dummies, industry-of-completion dummies and year dummies. The figure provides estimated coefficients and 95 percent confidence intervals of year dummies. The observations (6,351) are weighted by final output. Value added generated in mining industries has been excluded in computing the IPF indexes for this regression analysis.