The Changing Structure of Global Value Chains: Are Central Hubs Key for Productivity?

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Abstract

This article uses "centrality" metrics reflecting position within Global Value Chains (GVCs) to identify central hubs and peripheral European economies and sectors. We find evidence of large changes in the structure of European production networks, with rising importance of Eastern European economies coinciding with the timing of their EU accession. Using cross-country firm-level data from ORBIS, we find that changing structure of GVCs can play a role in the catch-up of firms, but the effects are heterogeneous across firms and countries. First, becoming more central is associated with faster productivity growth of firms in post-2004 EU members. Second, the average productivity (centrality weighted) of buyers/suppliers matters for the productivity of firms overall in other European economies, and particularly non-frontier (initially less productive) firms in both groups of countries. The results for post-2004 EU members suggest that policies to encourage integration into GVCs are particularly important for the productivity of emerging or less integrated economies, whereas for more advanced economies a more sophisticated policy is needed that encourages the formation of linkages with productive, frontier foreign firms and economies.

The productivity effects of Global Value Chains (GVCs) may stem from position within them and not just participation. It is well-established that GVC participation can increase productivity.[2] In addition, changes in the structure of GVCs and position within them may also matter for productivity. Firms and industries positioned at the

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2 On the relationship between Global Value Chains and productivity, see Criscuolo and Timmis (2017).

centre of complex production networks have access to a greater variety of foreign knowledge, compared to those at the periphery. Potential knowledge spillovers may be further reinforced when firms are part of networks connecting highly productive frontier suppliers or customers, with access to more advanced knowledge. Therefore whether firms and industries sit at the fringes of global production or are tightly knotted at the centre of a complex network, connecting highly productive foreign firms, is likely to affect economic outcomes.

The aim of this article is twofold. First, it shows there have been large changes in the structure of GVCs over the period 1995-2011. We present "centrality" metrics that go beyond GVC participation, reflecting central hubs and peripheral industries and countries within global production networks. Whilst some activities remain clustered around the same central hubs, as was the case at the start of the period, and some countries industries' remain relatively peripheral, for others there have been dramatic restructuring of the geography of economic activity. Many of these patterns in the data concord with anecdotal evidence concerning the shifting patterns of production. For example, European motor vehicle manufacturing remains centred around key hubs in Germany, but there has also been a pivot away from many traditional centres of manufacturing towards Eastern European countries. More generally, these countries have become more central to global production networks, with their growing importance coinciding with the timing of their EU accession.

Second, the article finds that the changing structure of GVCs can play a role in the catch-up of firms, but that the correlations are heterogeneous across firms and countries. We match our centrality metrics to cross-country firm-level data, to examine the effects of the structure of the GVC network on the diffusion of productivity. Becoming more central as a customer or supplier is associated with faster productivity growth of firms in post-2004 EU members, particularly those initially less productive firms. But we find either insignificant or even negative impacts for larger or frontier (initially more productive) firms and for firms more generally in other European countries. In addition, we find that being connected to more productive foreign sectors can also play a role in firm catch-up. We supplement the standard centrality metrics by examining changes in the average productivity (centrality weighted) of buyers/suppliers. Supplying or buying from faster growing foreign sectors is correlated with faster productivity growth of non-frontier (initially less productive) firms and of firms overall in other European economies. But again these correlations weaken with firm size or proximity to the frontier.

Our work draws heavily upon the growing body of work that uses centrality metrics to describe the structure of real-world production networks. We apply the "Bonacich-Katz" eigenvector centrality metric to the OECD ICIO 2015 edition data, which underlie OECD-WTO TiVA metrics. We focus on Europe because of the salient changes that have taken place, and the good coverage of both the trade flow and later firm-level data. Cerina *et al.* (2015) compute a range of centrality metrics using WIOD input-output (IO) data, and find that industries are highly asymmetrically connected and also that GVCs are regionally clustered. Other researchers have applied centrality metrics to trade in value-added data, rather than IO data. Santoni and Taglioni (2016) and Amador and Cabral (2017) find that foreign value added in exports became denser, more

complex and tightly connected over time. Gourdon *et al.* (2016) highlight the growing importance of China in electrical machinery manufacturing.

The literature has most often applied centrality metrics to study shock transmission and granularity, often within a single country, rather than productivity in a cross-country setting as we do here. This strand of work is based on the fact that in real-world production networks input flows are not distributed symmetrically and so well-connected agents, by linking remote parts of the network, can play a key role in the transmission of shocks (Acemoglu *et al.*, 2012). For instance, productivity growth in the 10 most central US sectors (out of 417 sectors in the U.S. Input-Output tables, approximately at the NAICS four-digit level) account for 80 per cent of the variation in U.S. aggregate output growth over the period 1959-2009 (Carvalho, 2014). Using novel firm-to-firm transaction data for Belgium, Magerman *et al.* (2016), find productivity shocks to the 100 most central Belgian firms (out of 80,000 firms in their sample) account for 91.3 per cent of Belgian aggregate volatility. Imbs and Pauwels (2017) find that GDP volatility between developed countries is explained by differences in foreign centrality, but not centrality due to domestic linkages, and that this link has strengthened over time.

A related stream of research considers the importance of centrality for the diffusion of knowledge or new technologies, often using social networks rather than production networks as in this article. Central players by definition have a high degree of connectivity (both directly and indirectly), more widespread and closer linkages to other agents, and therefore potentially broader access to knowledge that these other agents possess. Villagers in India consistently identify the most central person in terms of both direct and indirect social linkages as the person best-placed to spread information (Banerjee *et al.*, 2016). Students randomly allocated into groups of other students with high centrality tend to out-perform those randomly allocated to groups with lower centrality (Hahn *et al.*, 2015). Diffusion of participation in a weather insurance scheme reaches a greater proportion of farmers, when information on insurance is provided to those farmers that are more central, in terms of social linkages within the village (Caie *et al.*, 2015). Social linkages between farmers predict the diffusion of fertilizer technology in Ghana, with farmers copying neighbours who were unexpectedly successful in prior periods (Conley and Udry, 2010).

The article proceeds as follows. The first main section explains the centrality concept as applied to GVCs and presents graphical illustrations of key changes in the structure of value chains within Europe. The second section, briefly describes the firm-level data and empirical framework and present correlations between firm productivity and the changes in GVCs. The final section discusses our main conclusions.

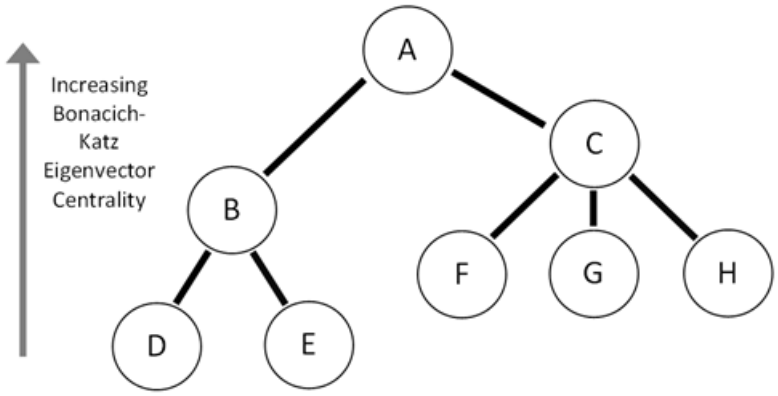
Central Hubs in GVCs

The first part of this article provides an overview of centrality and how this has changed over time for different countries and sectors within Europe. We focus on Europe because of the salient changes that have taken place, and the good coverage of both the trade and later firm-level data.

Measuring Centrality

Our work leverages standard network measures of Bonacich-Katz eigenvector centrality. These are measures of influence or connectivity within production networks that take into account both direct and indirect network linkages to identify central hubs. Thus centrality is determined not only based on direct trade linkages, but also

Figure 1: Bonacich-Katz Eigenvector Centrality Illustration



the linkages of your trade partners, and the trade partners of your trade partners and so on. To illustrate the Bonacich-Katz eigenvector centrality metric, consider the simplified production network of Figure 1, where we have neglected input flow weights for simplicity. Here C sources inputs from F, G and H, so has the highest number of direct connections. However, eigenvector centrality reflects the strength of both direct and indirect linkages. Although A only has two direct linkages (to B and C), it has five linkages one-indirect linkage away (D to H). A is a key hub in the network and would have highest centrality.

Specifically, we apply the theoretically-grounded centrality of Acemoglu *et al.* (2012) and Carvalho (2014).[3] This class of measure encompasses several variants applied in the sociology literature (such as eigenvector, Katz and Bonacich centrality) or in computer science, such as Google's PageRank search algorithm (Brin and Page, 1998). One key point is that input flows are scaled, such that we are concerned with input shares rather than absolute value of flows. This implies that centrality is a relative measure, relative to other country-industries in the network.[4]

Our centrality metrics are derived from the 2015 edition of the OECD-ICIO data that underlies the OECD-WTO TiVA indicators. The data employed here contain rich information of flows of goods and services across 34 ISIC revision three sectors and 62 economies for the 1995-2011 period. However, we focus upon the narrative for European economies for this article. The data have a broad coverage of the main actors in global production networks and also reflect flows of services as well as goods, with the former not captured for instance in network analysis of customs data (e.g. De Benedictis *et al.*, 2013). However, one limitation of the data is the relatively broad definition of sectors.

The centrality metrics we use distinguish between key suppliers and key customers, using forward export and backwards import linkages respectively, and report total centrality as the average of forwards and backwards centrality. Countries and industries can be central because of their linkages to domestic sectors or linkages to

3 Specifically, these models show the parameters used in the centrality calculation are proportional to the average share of intermediates in production. We use the same parameters as Carvalho (2014), since the average share in our data is close to that found by Carvalho (0.52 to 0.54 in our data, compared to 0.5).

4 A technical discussion of the centrality metric adopted in the article is detailed within Criscuolo and Timmis (2018a and 2018b).

foreign sectors. Given our concern with GVCs, this article focuses on the foreign component of centrality, where we find the majority of cross-section and time series variation (Criscuolo and Timmis, 2018a and 2018b). The domestic component of centrality is included as a control variable in our regressions.

Changing Structure of Factory Europe

At an economy-level we find that a minority of central hubs dominated European value chains in both 1995 and 2011. Chart 1 shows the aggregate centrality metrics for European economies. However, the underlying calculation relies on the full data dimensions of all countries and industries.[5] The size of nodes represents the total centrality from foreign sources; key hubs are denoted with large nodes and peripheral economies (of lower centrality) with small nodes. Overall, Germany is the most central economy in Europe both in 1995 and 2011, accompanied by several other central economies such as France, Italy and the UK. In contrast, there are several more peripheral economies, including those of a smaller market size such as Malta or Cyprus, but also Portugal, as well as Luxembourg and Eastern European economies at the start of the period.

However, there is rising centrality beyond the key hubs in European production networks. Several of the economies in Europe that were most peripheral (i.e. least central) in 1995 became increasingly central by 2011. This is particularly true of many Eastern European economies. One of the major changes within Factory Europe has been increasing centrality of the periphery and Chart 1 also shows increased production linkages between European economies over time, particularly Eastern European economies. Indeed, as we show later, for some industries such as computer and electronic or automotive manufacturing there is a particularly strong shifting influence from many developed economies to these emerging economies.

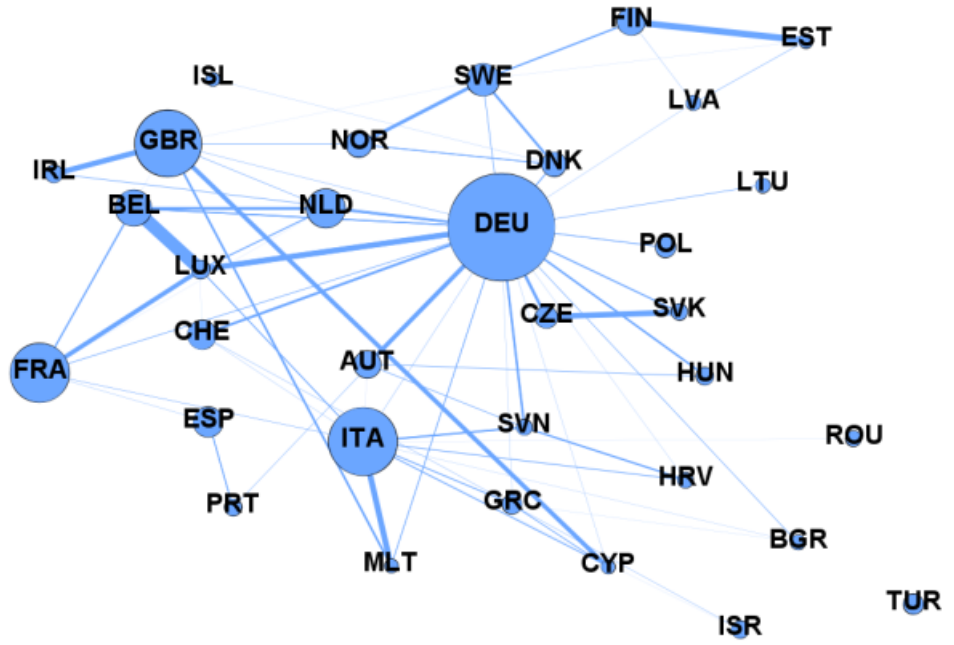
Several of most peripheral European sectors have become more central within Factory Europe, which has been mainly driven by post-2004 EU accession countries. Chart 2 shows the distribution of centrality across European country-industries in 1995 and 2011. For post-2004 EU member countries there has been a large rightward shift in this distribution, reflecting a general trend of increased centrality of their industries (Panel A in Chart 2). Conversely, for other European countries there is a much less noticeable change (Panel B). Note however that despite these changes, at the end of the period the post-2004 EU countries remain less central than other European economies on average (as reflected in Chart 1).

The centrality growth of post-2004 EU accession countries coincides with the timing of their EU accession. Chart 3 shows the centrality growth of various parts of the distribution of centrality over time for these economies, where centrality is normalized relative to the signing of the accession treaty in 2003. As in Chart 2, for these economies centrality increases over time across all parts of the distribution, reflecting a general trend of increasing centrality for post-2004 EU countries' industries. However, the centrality growth is particularly marked from 2004 onwards, with little obvious trend before that point. Surprisingly, centrality growth appears to be strongest for the most peripheral sectors of these post-2004 EU economies (10th and 30th percentiles),

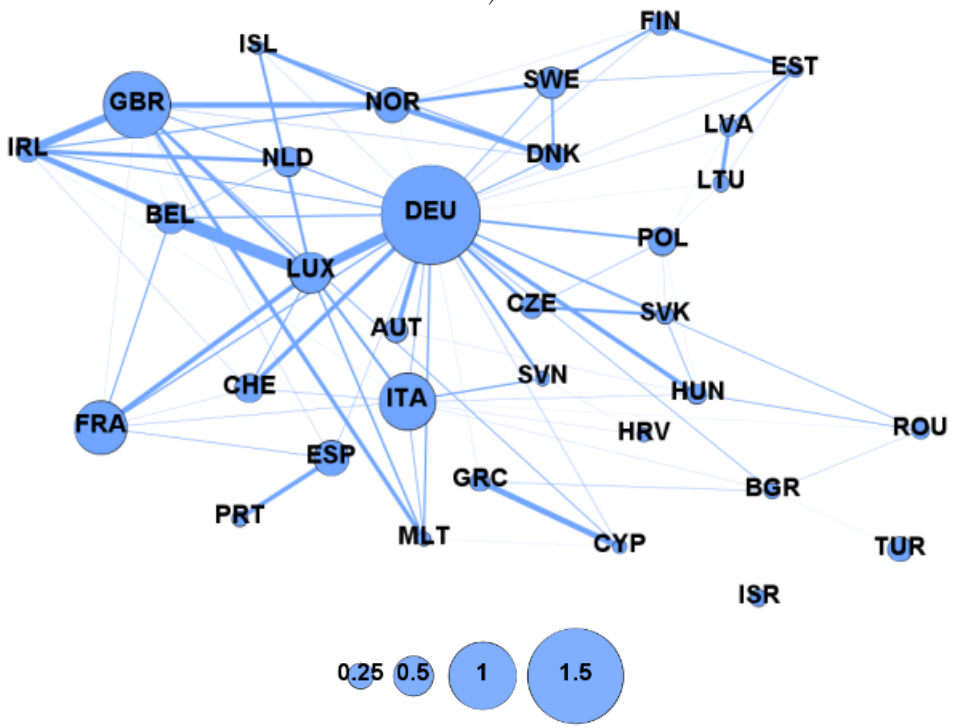
5 We aggregate industry metrics using their share of the economy's output as weights (results are also similar when using export weights).

Chart 1: Aggregate Central and Peripheral European Economies, 1995 and 2011

Panel A) 1995



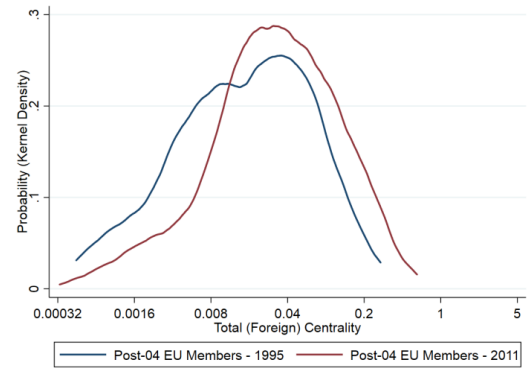
Panel B) 2011



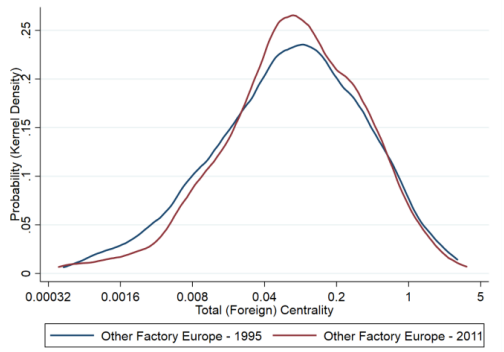
Economies are placed according to their location. Node size denotes total centrality (forward and backward) aggregated at an economy-level and includes all sectors within global production networks. Edges reflect direct input flows. For clarity only the largest input flows are reflected, those exceeding 2 per cent of total inputs used in the importing or exporting economy.

Chart 2: Increasing Centrality of Post-2004 EU Accession Members

Panel A) Post-2004 EU Members



Panel B) Other European Economies



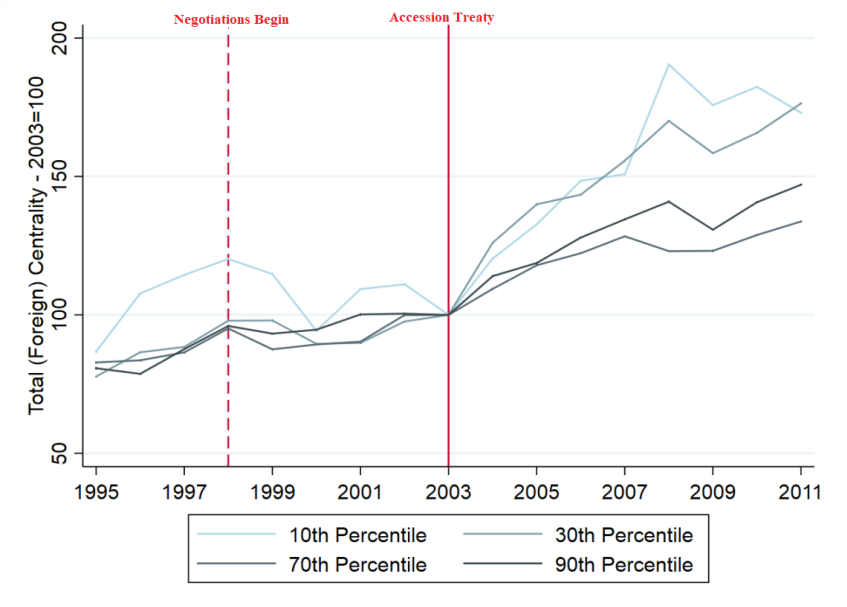
The charts show the distribution of foreign centrality across European country-industries in 1995 and 2011, with Panel A showing post-2004 EU accession countries and Panel B showing all other European countries. Comparing the two charts shows that most of the changes appear to reflect post-2004 EU countries, more so than other European countries. Total (foreign) centrality is measured at the country-industry level. Post-2004 EU Accession economies include: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Romania, Slovakia and Slovenia. Other Factory Europe economies include: Austria, Belgium, Croatia, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and UK.

rather than those sectors that were already more central and already more integrated into European value chains (70th and 90th percentiles). These same economies experienced large increases in FDI following their EU accession, suggesting there may be complementarities between ownership and input linkages. Indeed, other researchers have found that the entry of foreign firms into Eastern Europe has been an important factor affecting their integration into GVCs (e.g. Harding and Javorcik, 2012; Bajgar and Javorcik, 2016). These FDI inflows have been associated with increases in productivity both of the receiving country-industries, but also in supplier and customer industries (Bijsterbosch and Kolasa, 2010; Arnold *et al.*, 2011; Javorcik and Yue, 2013).

At an industry-level there are profound changes in the organization of some production networks, but some of the same central hubs persist throughout the period, mirroring the earlier findings at a country-level. Chart 4, Panel A shows the changes in centrality for one particular industry, motor vehicles manufacturing, over the period 1995-2011. The colour of the nodes reflects the sign of the change (green for positive, red for negative) and node size the absolute size of the change. For motor vehicles there has been a general eastwards shift, with declining importance of some traditional centres of production (such as the UK, France) and increasing influence of many Eastern European economies. This is consistent with a narrative of increasing offshoring of motor vehicle production. However, the narrative is not solely about offshoring of production. For instance, Germany was the most central hub for motor vehicles industry in 1995 yet actually increased influence over the period 1995-2011.

Service inputs are also becoming increasingly important to global production networks, in both emerging and high-income economies. We find that a number of economies specializing in services have become more influential in several services sectors, such as the UK or Luxembourg (see Figure 2). However, the growth of services in production networks is not

Chart 3: Centrality Growth of 2004 EU Accession Countries over the period of EU Accession, 1995-2011



The percentiles reflect different parts of the distribution of centrality for 2004 EU accession countries' industries. 2004 EU Accession economies include: Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Slovakia and Slovenia. The percentiles are defined afresh for each year and so represent different country-industries over time. Total (foreign) centrality is measured at the country-industry level.

simply a restructuring story for a minority high-income economies. For particular services industries, however, such as R&D and business services, these have become more important to production networks for the majority of economies for which we have data, as shown in Chart 4, Panel B. These trends are consistent with a rising importance of services for global value chains in general, and also for the performance of manufacturing firms even in emerging economies (e.g. Arnold *et al.*, 2011; 2016).

GVC Centrality and Productivity

The first part of this article has provided an overview of centrality and how this has changed over time for different countries and sectors within Europe. In the second part we analyze how centrality and its changes relate to the productivity of firms. We first briefly summarize the firm-level data, before outlining the empirical framework and presenting the results.

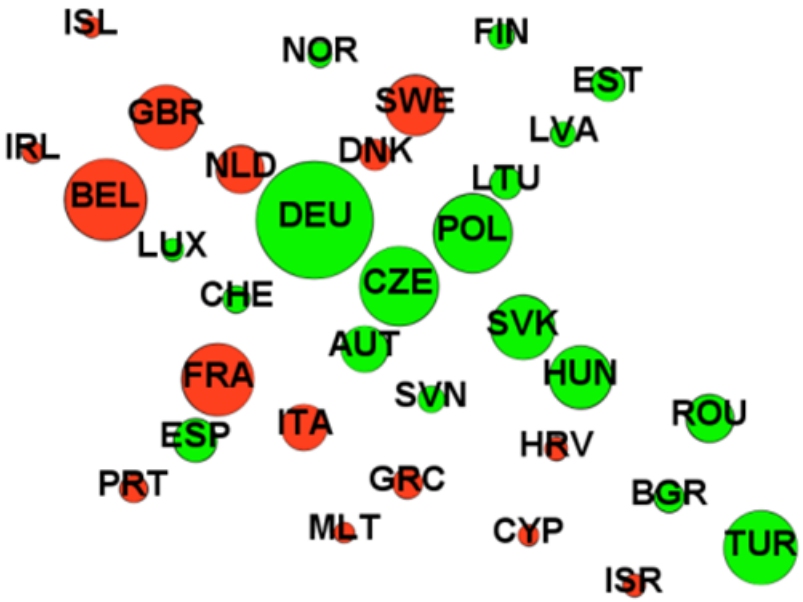
Measuring Firm Productivity

We use Orbis firm-level data, which is a harmonized cross-country dataset provided to the OECD by the commercial provider Bureau Van Dijk. The industry detail is at the two-digit in NACE (revision two) and comprise the non-farm non-financial business sector excluding mining, petroleum manufacturing and real estate activities (i.e. codes 10-82, excluding 19, 64-66 and 68). We retain 22 European countries with more than 500 (firm-year) observations

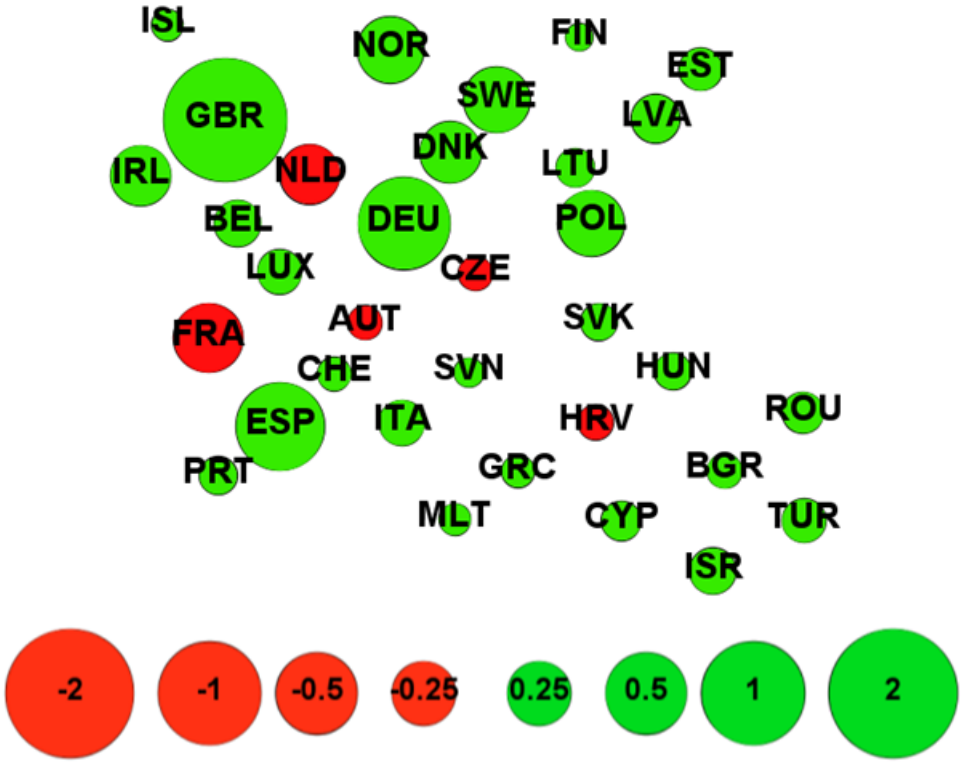
6 These economies are Austria, Belgium, Bulgaria, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Luxembourg, Netherlands, Poland, Portugal, Romania, Spain, Sweden, Slovenia, Turkey and the United Kingdom. The results are unchanged if we further restrict this to countries with more than 5000 observations, results are available upon request.

Chart 4: Changes in Centrality, 1995-2011

Panel A) Motor Vehicles



Panel B) R&D and Business Services



Economies are placed according to their location. The size of the nodes reflects the magnitude of the change (in levels) of total foreign centrality over the period 1995-2011. As reflected in the key, these changes are graphed using a log scale for readability. Green coloured nodes reflect increasing centrality and red denotes falling centrality. Motor vehicles manufacturing reflects ISIC rev.3, 34: Motor vehicles, trailers and semi-trailers. R&D and business services reflect ISIC rev.3, 73-74: R&D and other business activities.

in the matched data.[6] Since Orbis has relatively poor coverage of small firms, we restrict the sample to firms with more than 20 employees (on average over the sample period). We perform a number of cleaning steps to identify outliers and jumps, following the suggestions by Kalemli-Ozcan *et al.* (2015) and previous OECD analyses (Gal, 2013). We focus on unconsolidated data, out of a concern that consolidated data may consolidate information from subsidiaries in different industries and/or countries. To extend coverage, value-added has been internally imputed using the factor incomes given within Orbis, i.e. the cost of employees and earnings before interest, taxes, depreciation and amortisation, as suggested by Gal (2013).

We match firm-level Orbis data to the centrality metrics calculated using OECD ICIO data, using a firm's country, NACE (revision two) industry code and year. We employ a concordance between two-digit NACE (revision two) and 34 Trade in Value Added - TiVA (ISIC revision three) industries to account for differing industry definitions between Orbis and OECD ICIO data. The OECD ICIO data are available over 1995-2011, which ultimately determines the number of years of our analysis. We use one year lagged values of centrality, meaning that our period of analysis is 1996-2012.

Firm-level multifactor productivity (MFP) is estimated using the instrumental variable (IV) method proposed by Wooldridge (2009). To allow for technological differences across industries, the production function is estimated separately for each two-digit industry, controlling for year fixed effects.[7] Estimation uses a real value added-based production function estimation with the number of employees and real capital as inputs (deflated using two-digit country-specific deflators to 2005 PPP international dollars).[8]

The firms included in the final sample are predominantly of medium to large in size and older, with a mean employment of 248 employees and a mean age of 22 years (Table 1).[9] Therefore it is not possible to comment on the productivity of the smallest firms. Just under half these firms are in the manufacturing sector, reflecting that Orbis tends to have better coverage of manufacturing firms.

Empirical Framework

We focus on how productivity changes in foreign sectors diffuse through key hubs to influence the productivity of domestic firms. We consider two aspects of this diffusion. The first reflects the effect of becoming a central hub (for a given composition of sectors connected), and the second, the effect of connecting fast growing foreign sectors (for a given level of centrality). We measure the former using the centrality metric explained earlier, and the latter using the average productivity (centrality weighted) of buyers/suppliers.[10]

We first examine whether becoming more central within GVCs translates into firm productivity growth. Specifically, we consider whether firms in industries that

7 The results are robust to the use of mark-up adjusted firm MFP, which controls for unobservable firm markups using the method of De Loecker and Warzynski (2012). These results are available upon request.

8 We use the country-industry level purchasing power parity database of Inklaar and Timmer (2014).

9 The descriptive statistics for these larger firms is consistent with papers using similar data, for example, Andrews *et al.* (2015).

10 To remove noise, we measure each foreign sector's productivity as the 3 year moving average of log labour productivity (value-added per worker in international PPP dollars).

Table 1: Summary Statistics of Firm-Level Data

	Mean	Std. Dev	N
MFP (logs)	11.0	1.0	2,264,646
Employment (number)	248	3296	2,264,646
Sales (PPP$ millions)	76.5	978.0	2,235,358
Age (years)	22.2	18.3	2,264,646
Services	0.44	0.50	2,264,646

Note: Age is not included as a control variable in the regressions reported in the remainder of the paper as it is collinear with firm fixed effects.

become more central over time, increase productivity faster than those in industries that become more peripheral. As noted in the introduction, central hubs play a key role in linking agents throughout the network. Central hubs by definition have a high degree of connectivity (both directly and indirectly), more widespread and closer linkages to other buyers and suppliers, and therefore potentially broader access to knowledge that these other agents possess. This first metric therefore reflects whether becoming more or less influential within GVC networks matters for firm productivity.

Second, we examine whether who an industry connects with matters for firm productivity growth. We measure whether firms have faster productivity growth in industries connected to faster growing foreign buyers or suppliers. The diffusion path of new knowledge is unlikely to be determined solely by influence within GVC networks, but rather those sectors that are highly connected to new sources of knowledge are likely to benefit more. For instance, a central hub connecting highly productive, technologically advanced foreign buyers and suppliers is likely to have greater access to knowledge than a central hub connecting less productive ones. The diffusion of foreign knowledge may therefore depend upon the composition of buyer/supplier connections. We reflect this with the (centrality weighted) average productivity of foreign buyers/suppliers. The latter therefore reflects whether the productivity of a sector's more influential buyers or sellers matters for firm productivity.

Our empirical framework estimates the correlation between within-firm productivity growth and sector centrality or being connected to more productive (foreign) sectors:

$$\begin{aligned} MFP_{ist} = {} & \beta_1 c_{st-1} + \beta_2 PROD_{st-1} + \\ & \beta_3 IndustryControls_{st-1} + \\ & \beta_4 FirmControls_{st-1} + \\ & \delta_i + \delta t + \epsilon_{ist} \end{aligned} \tag{1}$$

where MFP_{ist} refers to the multifactor productivity of firm i, in sector s and time t. c_{st-1} is the centrality of sector s, which is lagged one period, and refers to either total, forwards or backwards centrality in the results below. $PROD_{st-1}$ is the average productivity (centrality weighted) of foreign buyers/suppliers, lagged one period, using either total, forward or backward linkages. Industry controls include domestic sources of centrality, total (forward and backward) GVC participation, Fally's (2011) GVC upstreamness measure, exports of intermediate goods and services, industry imports of intermediate goods and services, gross output (as a measure of industry size), Balassa's Gross Revealed Comparative Advantage and Koopman *et al.*'s (2014) Value-Added Revealed Comparative Advantage. Lagged firm employment is included as a control for firm size; firm age is not included since it

is reflected in the fixed effects. The model also includes both firm and year fixed effects while robust standard errors are clustered at the country-industry level, where industry reflects the 34 TiVA industries in the underlying centrality measure.

The inclusion of both firm and time fixed effects means we are comparing within-firm changes in productivity, due to industry-level changes in centrality or changes in productivity of their suppliers/customers. The firm fixed effects control for any time-invariant firm (and thus also industry or country) characteristics and year fixed effects control for any time-variant factors common across firms. We therefore reflected within-firm changes based on changes in centrality across country-industries.

As noted earlier, centrality is a relative measure such that it is relative to all other countries and industries in the network. Including further fixed effects, such as industry-year or country-year dummies, would depart from this. For example, including industry-year dummies would mean we are measuring changes across countries but within the same industry and year (e.g. computing and electronics manufacturing in 2000). We follow the approach of Imbs and Pauwels (2017) and do not include further fixed effects, but instead introduce a broad range of industry controls reflecting factors that may explain any link between centrality and firm productivity.

Although we do not claim a causal link, one obvious concern is that the network of input linkages underlying our measures may not be exogenously determined. For example, since more productive firms tend to trade more intensively and with more countries and trade partners (e.g. Bernard *et al.*, 2011; 2014), productivity increases themselves may lead to increased centrality within the GVC network, rather than the other way round. However, the use of firm-level data and industry-level centrality measures reduces the scale of the problem, as it is unlikely that many firms are able to influence the centrality of their entire industry within the GVC network. Centrality of the industry is therefore likely to be exogenous from a firm perspective, especially when considering small and medium sized firms. However, a minority of highly productive firms often account for the bulk of input flows across borders and a minority of multinationals are often found to drive GVCs (De Backer and Miroudot, 2017). To mitigate this concern, we examine our results separately for different firm types, isolating whether the productivity effects are driven by a minority of these frontier firms (those that are initially more productive) that may be able to influence industry centrality or those smaller and medium-sized firms, far from the frontier, that are not likely to be able to influence industry metrics. We leave further examination of causality as a direction for future research.

Firm Productivity and the Changing Structure of Factory Europe

Firms in post-2004 EU member countries show faster productivity growth in sectors that become more central, but this is not the case in other European economies (other than post-2004 EU members). Table 2 presents the baseline estimates of equation 1, examining the correlation between changes in (foreign) centrality and productivity of foreign suppliers/buyers on domestic firm productivity. For post-2004 EU members, firm productivity growth is correlated with becoming more central as a supplier through forward linkages (column 2), as a customer through backward linkages (column 3) or overall (column 1). The mean increase in (total) industry centrality for post-2004 EU economies is associated with 0.8 per

Table 2: Baseline Results

MFP Wooldridge	(1)	(2)	(3)	(4)	(5)	(6)
	Post-2004 EU Accession Economies			Other European Economies		
	Total	Forward	Backward	Total	Forward	Backward
Centrality	5.310***	3.503**	3.930***	0.157	0.205***	-0.057
	(1.491)	(1.540)	(1.190)	(0.097)	(0.071)	(0.055)
Average Productivity (Centrality Weighted) of Buyers / Suppliers	0.769**	0.816*	0.106	0.456***	0.407***	0.206**
	(0.333)	(0.427)	(0.240)	(0.121)	(0.111)	(0.087)
Observations	245,124	245,124	245,124	2,019,522	2,019,522	2,019,522

Robust standard errors clustered at country-(34 TiVA) industry level, *** p<0.01, ** p<0.05, * p<0.1

All regressions include year and firm fixed effects, as well as firm size and industry controls. Firm size control reflects lagged employment. Industry controls include GVC participation, domestic sources of centrality, Fally's (2011) GVC Upstreamness and GVC Length measures, Exports of intermediates, Imports of intermediates, Industry production (as a measure of industry size), Balassa's Gross Revealed Comparative Advantage, and Koopman *et al.*'s (2014) Value-Added Revealed Comparative Advantage. The post-2004 EU accession economies in our sample are Bulgaria, Estonia, Hungary, Latvia, Poland, Romania and Slovenia. Other European economies comprise Austria, Belgium, Germany, Denmark, Finland, France, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Sweden, Spain, Turkey and the United Kingdom.

cent annual firm productivity growth.[11] In contrast, we observe no correlation between the productivity growth of firms overall and changes in centrality for the rest of factory Europe (excluding post-2004 EU members), both in terms of total centrality and as a key supplier or customer (columns 4, 5 and 6 at Table 1 respectively). Thus becoming a central hub or becoming more peripheral does not seem to be correlated with productivity growth of European firms in general, but rather for emerging economies that are initially less integrated within value chains.

In contrast, the productivity of foreign buyers/suppliers matters for the productivity growth of firms in other European economies, but less so for firms in post-2004 EU member countries. The average productivity (centrality weighted) of buyers is weakly correlated with firm productivity in post-2004 EU members, but there is no discernible correlation with the productivity of sellers (columns 2 and 3 respectively). Conversely, the average productivity of suppliers but particularly buyers is strongly positively correlated with firm productivity in the rest of factory Europe (columns 6 and 5 respectively). A 1 per cent productivity growth of foreign buyers (through forward linkages) is correlated with a 0.4 per cent increase in domestic firm productivity. This is consistent with the notion that productive foreign buyers share knowledge with their suppliers, backwards through the value chain. A large literature on the productivity effects of FDI finds similar mechanisms, with evidence of spillovers from multinationals to their affiliate suppliers, with less evidence of forwards spillovers to their customers (Godart and Gorg, 2013; Havrnek and Irova,

11 An annual rate of 0.8 per cent productivity growth is equivalent to 14 per cent growth over 1995-2011, which is calculated as exp(0.025 * 5.310). Where 0.025 reflects the mean growth in total (foreign) centrality for industries of post-2004 EU economies over the sixteen year period 1995-2011 and the coefficient 5.310 is taken from Table 2.

2011).

Thus far we have examined productivity correlations for the "average" firm in our sample. However, it is not necessarily true that these correlations will be homogeneous across firm types. Further, if the positive correlations are present for only a subset of firms, they may not be revealed in the previous section. On the one hand, frontier firms are more likely to be directly engaged in GVCs through trade and FDI linkages, so will have the greatest direct exposure to foreign technologies. In addition, these larger firms are more likely to be able to overcome the sunk costs of the complementary organizational investments needed to benefit from exposure to new technologies (see for example Brynjolfsson and Hitt, 2000). On the other hand, those firms further from the frontier are most likely to have the largest catch-up potential productivity gains from knowledge spillovers from foreign sectors.

The correlation between firm productivity and centrality for post-2004 EU members is stronger for non-frontier firms and weakens with proximity to the productivity frontier. We examine whether there are heterogeneous effects by proximity to the frontier by interacting our variables of interest with initial firm productivity (MFP)[12]. The non-interacted term captures the correlation for those (initially) least productive firms in our sample, whereas the interaction captures additional impact for more productive firms. Table 3 shows that the earlier average result for post-2004 EU members masks substantial heterogeneity across firm types for both forward centrality (becoming a key supplier) and backward centrality (becoming a key customer), with the fastest productivity growth for those furthest from the frontier in each sample (columns 2 and 3). However, this is significantly weaker for more productive firms in either group of countries. Assuming this correlation weakens in a linear fashion suggests that this correlation becomes negative for the 7-9 per cent most productive, frontier firms in the post-2004 EU sample. In contrast, we find centrality is uncorrelated with productivity growth of either frontier or non-frontier firms in other European economies (columns 4 to 6).

The correlation between firm productivity and the average productivity of buyers/sellers is stronger for non-frontier firms in both post-2004 EU and other European economies. Previously, we found the productivity of buyers/suppliers is only correlated with average firm productivity in other European economies, but not post-2004 EU members. However, here we find the productivity of those least productive firms in both samples is positively correlated with both the productivity of buyers (forward linkages columns 2 and 5) and suppliers (backward linkages columns 3 and 6). Again we find that these positive correlations are concentrated within those least productive firms, with the correlation weakening for those closer to the frontier. Assuming a linear decay suggests that this becomes negative for the 9-25 per cent most productive firms in the post-2004 EU sample and for the 9-13 per cent most productive firms in other European economies.

Conclusion

This article presents new "centrality" metrics that go beyond GVC participation, reflecting central hubs and peripheral

12 We use firm characteristics at the start of the period, since these characteristics may be influenced by changes in the trade network over time. The term "frontier" as used here relates to the most productive firms in post-2004 EU Accession Economies or in Other European Economies in columns 1 to 3, and 4 to 6 respectively.

Table 3: Frontier vs Non-Frontier Firms

MFP Wooldridge	(1)	(2)	(3)	(4)	(5)	(6)
	Post-2004 EU Accession Economies			Other European Economies		
	Total	Forward	Backward	Total	Forward	Backward
Centrality	20.893***	31.453***	13.115***	0.214	0.258	0.452
	(1.887)	(4.443)	(1.607)	(0.315)	(0.232)	(0.320)
Centrality * Initial Firm MFP	-1.481***	-2.554***	-0.924***	-0.011	-0.006	-0.049*
	(0.275)	(0.374)	(0.213)	(0.027)	(0.018)	(0.028)
Average Productivity (Centrality Weighted) of Buyers/Suppliers	6.847***	5.254***	6.561***	4.127***	4.388***	3.425***
	(0.917)	(1.151)	(0.832)	(0.641)	(0.637)	(0.558)
Average Productivity (Centrality Weighted) of Buyers/Suppliers * Initial Firm MFP	-0.601***	-0.426***	-0.633***	-0.330***	-0.358***	-0.288***
	(0.078)	(0.106)	(0.076)	(0.054)	(0.053)	(0.048)
Observations	245,124	245,124	245,124	2,019,522	2,019,522	2,019,522

Robust standard errors clustered at country-(34 TiVA) industry level, *** p<0.01, ** p<0.05, * p<0.1

All regressions include year and firm fixed effects, as well as firm size and industry controls. Firm size control reflects lagged employment. Industry controls include GVC participation, domestic sources of centrality, Fally's (2011) GVC Upstreamness and GVC Length measures, Exports of intermediates, Imports of intermediates, Industry production (as a measure of industry size), Balassa's Gross Revealed Comparative Advantage, and Koopman *et al.*'s (2014) Value-Added Revealed Comparative Advantage. See Table 2 for a list of the countries in our sample.

industries and countries within production networks. We utilize well-established metrics from the network literature to identify those sectors and countries that are highly central hubs and those that are peripheral. Central sectors reflect those that are highly connected (both directly and indirectly) and influential within global production networks, and conversely, peripheral sectors exhibit weak linkages to other sectors and countries and so are less influential.

We illustrate profound changes in the structure of European production networks over the period 1995-2011. Whilst some activities remain clustered around the same key hubs as at the start of the period, for others there have been dramatic relocation of economic activity. We find that while motor vehicle value chains remain centred around Germany, there has also been a pivot away from many traditional centres of manufacturing towards increasing influence of Eastern Europe. In contrast, R&D and business services have become more important for production networks for many countries.

Policy can play a role in determining centrality and hence position within GVCs. Advances in communication technology have enabled the fragmentation of production, and permitted production to develop into the complex global network it is today. However, the changing structure of GVCs has not entirely been a technology story. We find that Eastern European economies have increased their overall importance within global production networks, with their growing importance coinciding with the timing of their EU accession.

We find that the changing structure of GVCs can play a role in the productivity catch-up of firms, although our empirical analysis reflects descriptive correlations, rather than causal effects. We match centrality metrics to cross-country firm-level data from ORBIS to examine how changes in centrality relate to domestic firm

productivity. Becoming more central as a customer or supplier is associated with faster productivity growth of firms in post-2004 EU member countries, particularly non-frontier firms. But we find either insignificant or even negative effects for frontier firms and for firms in other European economies. Consequently becoming more influential in GVCs appears to be important for the catch-up of those non-frontier firms and economies, whereas for those firms or economies that are already large or near the frontier, becoming more influential does not appear to impact productivity substantially. Further data are needed to examine the precise channels of productivity gains, for example, diffusion of technology or organizational practices or whether access to larger markets incentivises productive investments.

We find that the composition of buyers (in terms of their industry productivity) matters for firms in our data overall. This is particularly the case for the catch-up of non-frontier or smaller firms. We supplement the standard centrality metrics by examining changes in the (centrality weighted) average productivity of foreign buyers/suppliers. Supplying or buying from faster growing foreign sectors is correlated with faster productivity growth of non-frontier firms in both post-2004 EU members and other European economies, with these effects weakening with proximity to the frontier. But these correlations are only present for firms overall in the rest of Factory Europe (excluding post-2004 EU members).

Our results suggest that traditional policy measures to encourage integration into and influence within GVCs (such as trade facilitation and export guarantees) might be particularly important for the productivity of non-frontier firms, and also firms in emerging or less integrated economies. Although our work examines international input linkages, it is also suggestive that policies that strengthen the domestic linkages between domestic suppliers and foreign firms may also be important in the diffusion of productivity gains, such as local content requirements. However, our results also suggest the composition of buyer and supplier networks (in terms of their productivity) appear to also matter for spillovers to non-frontier firms and also for firms overall in higher-income economies. These results suggest that more sophisticated policy to facilitate GVC integration may be needed, which particularly encourages the formation of particular linkages that encourage the diffusion of spillovers from productive, frontier foreign firms and economies.

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