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Håkan Nordström, Harry Flam

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Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
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Production Integration in the European Union

Abstract

Measured by trade in intermediate inputs, economic integration has increased between 2000 and 2014 between members of the European Union and even more with non-members. Integration is negatively related to economic size and positively to the number of years as a member. Germany is the largest hub in the production network and the centre of gravity has moved eastward. Older member states are increasingly exporting service inputs and new member states primary and manufacturing inputs. Wages are increasing faster in countries with low initial wages, indicating wage convergence as a result of production integration.

JEL-codes: E100, F100, F600, J310.

Keywords: global value chains, economic integration, input-output models, wage convergence.

*Håkan Nordström**
National Board of Trade / Sweden
hakan.s.nordstrom@gmail.com

Harry Flam
Stockholm University / Sweden
harry.flam@iies.su.se

*corresponding author

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1. Introduction

The European Union has succeeded in creating a common market even if some obstacles to the free flow of goods, services, capital and labour still remain. For a brief history and analysis of the Single Market and for a follow-up on subsequent measures taken to complete the Single Market, see Flam (1992) and Flam (2015). As shown in Flam (2015), there exists surprisingly little research on the amount of economic integration achieved by the Single Market. In this paper, we use tools from the global value chain (GVC) [1], spatial networks[2] and income convergence[3] literatures to provide a description of the anatomy of integration in the European Union and how integration has changed and intensified over time and as additional countries have joined the Union. The questions we ask are: Are all countries equally integrated? What is the pattern of specialization across countries? What countries serve as hubs or nodes in the European production network? What changes can be observed over time? And – as an indicator of the success of integration – have incomes converged across countries as a result of integration?

Trade associated with production networks in the European Union– so-called supply-chain trade – makes up roughly two-thirds of trade in the Single Market.[4] Such trade will continue to increase as man-made trade barriers and transportation and communication costs continue to fall. The European Union is a recurrent object of study in the GVC literature. For example, Timmer et.al. (2013) use GVC tools to analyse production fragmentation in the European Union, and Leitner and Stehrer (2014) links the economic performance of new member states to the participation in global value chains. As far as the network literature is concerned, we cannot find any studies that focus specifically on the European Union. However, there is a growing number of network papers that use input-output datasets to analyse the structure of the global trade network, many of which point to the European Union as a regional hub in the global economy.[5] The network paper that is most similar to ours is Lejour et.al. (2017), which proposes a new method for identifying hubs in a production network by looking at the value-added content of the output vector of the last processing country before final demand.

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[1] The GVC literature was born as a concept in 2001 [Hummels et.al. (2001) and Gereffi et.al. (2001)] and as an empirical field in 2007 owing to a set of new inter-country input-output datasets, including the World Input Output Database (WIOD), the Trade in Value Added (TiVA) dataset, and the GTAP dataset. Important contributions include Dietzenbacher and Romero (2007); Johnson and Noguera (2012); Antràs et.al. (2012), Los and Temurshoev (2012), Timmer et.al. (2013); Koopman et.al. (2014); and Los et.al. (2015).

[2] To the best of our knowledge, the first paper that studies the global trade system from a network perspective is a 1942 report of the League of Nations (the predecessor to the UN) entitled *The World Trade Network*. The report includes a graph (sociogram) of the structure of world trade in 1928 before the Great Depression and the outbreak of protectionist policies. A main point of the report was that trade is much more than the exchange of final goods – it is a network of supply links on which production itself rests. If the system breaks down because of ill-conceived policies, such as the Smoot-Hawley Tariff Act of 1930 that exacerbated the depression it was meant to fight, the cost to society is much larger than the foregone trade. The modern network analysis of trade started in the 1970´s and focused on the position and centrality of individual countries in the world trade network, using tools developed in sociology. The early literature made no distinction between intermediate and final goods since international input-output data were not available at that time. One of the most cited papers from the early years is Snyder and Kick´s (1979) study on the linkage between economic growth and the structural position of a country in the global trade network.

[3] Baumol (1986), Barro and Sala-i-Martin (1992) and Mankiw et.al. (1992).

[4] Our calculation is based on the November 2016 edition of the World Input-Output Database (WIOD).

[5] Cerina et.al. (2015); Amador and Cabral (2016); and Lejour et.al. (2017).

The contribution of our paper is both methodological and substantive. One methodological contribution is the combination of network and GVC tools, including a value-chain based definition of hubs in the input-output system. Our index is similar to the index of Lejour et.al. (2017).[6] In addition, we offer a new value-chain definition of the density of the input-output system, which in the at network literature is defined as the share of potential links that exist. Adapted to a value chain context, we define the density as the share of intermediate exports of value added that is supplied directly to the ultimate user (as opposed to via a hub in the system). The third methodological contribution is our use of forward and backward integration indices to study whether supply-chain trade facilitates the convergence of wages at the sector level in the European Union. Our analysis builds on the research of Leitner and Stehrer (2014), who established a positive link between the economic performance of the new member states (in terms of exports, employment and productivity growth) and participation in global value chains (measured as the foreign value-added content of exports).

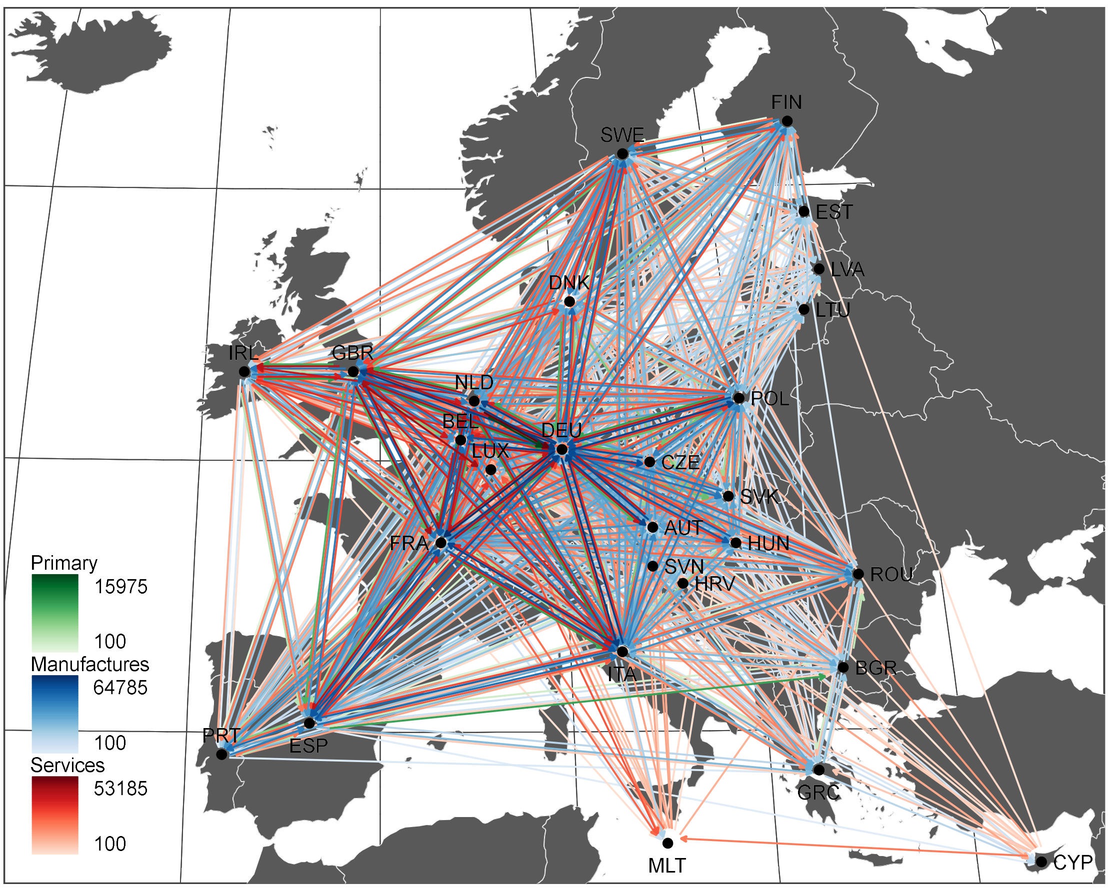
The remainder of the paper is organized as follows: In section 2 we construct a graph of the input-output structure of the production network in the European Union. Section 3 gives a short description of the World Input Output Database (WIOD) that underlies our study. Section 4 presents empirical results on the specialization pattern and backward and forward integration of the member states into supply chains in the European production network, plus results on how supply chains relate to economic size and years of membership. Section 5 takes a network perspective and shows that Germany is the central hub in the European production system, with France, Italy and the United Kingdom as important but lesser hubs. The analysis also shows that the network has become denser - has more direct supply links between the member states – and has moved eastward over time as new member states have become more integrated. Section 6 finds that supply-chain trade causes convergence of wages at the sector level across countries. Section 7 concludes.

[6] Our measure is a GVC adaptation of the so-called betweenness centrality index used in the network literature. The derivation is different from Lejour et.al. (2017) but the indices are similar.

2. A first look at European Union integration

Let us first look at in Figure 1 which is a map of the European Union production network. The input-output data used to construct the map are taken from the November 2016 edition of the World Input-Output Database (WIOD) described in section 3. Arrows show gross flows of primary (green), manufactured (blue) and services inputs (red) between the member states in 2014. For clarity we only include bilateral trade worth more than 100 million USD. (The WIOD database is denominated in USD). Arrows between member states are colour coded and divided into 100 steps using a logarithmic scale. More intense colours signify larger trade flows.

Figure 1. Gross flows of primary, manufactured and services inputs in 2014 between EU countries worth more than 100 million USD



As one may expect, trade in intermediate inputs in absolute terms is most intensive between the largest economies in the European Union and Germany is the central hub in the production network. The supply-chain trade is particularly intensive in the triangle formed by Germany, France, and the Benelux countries, all of which are original members of the EU. Colours show the basic pattern of specialization. The old member states trade relatively more services and the new member states relatively more primary and manufactured inputs, with the exception of Cyprus and Malta that specialize in services.

3. Data

Our data are from the November 2016 edition of WIOD, which was put together by a research group coordinated by members of the Economics and Business faculty of University of Groningen, Netherlands. WIOD is constructed from national IO-tables and bilateral trade data and covers all current member states and 15 key trading partners to the European Union listed in Table 1. The rest of the world (RoW) is aggregated into one region that is calibrated to balance the global accounts. WIOD contains data for 56 sectors divided into 4 primary, 19 manufacturing and 33 services sectors listed in Table 2. Annual data are available from 2000 to 2014. [7]

Table 1. Country coverage of WIOD 2016

EU members	Year of entry	Other countries	Region
Belgium (BEL)	1958, Euro (1999)	Norway (NOR)	Europe
France (FRA)	1958, Euro (1999)	Switzerland (CHE)	Europe
Germany (DEU)	1958, Euro (1999)	Turkey (TUR)	Near East
Italy (ITA)	1958, Euro (1999)	Russian Federation (RUS)	Europe/Asia
Luxembourg (LUX)	1958, Euro (1999)	Brazil (BRA)	Americas
Netherlands (NLD)	1958, Euro (1999)	Canada (CAN)	Americas
Ireland (IRL)	1973, Euro (1999)	Mexico (MEX)	Americas
Denmark (DNK)	1973	United States (USA)	Americas
United Kingdom (GBR)	1973	China (CHN)	Asia
Greece (GRC)	1981, Euro (2001)	Chinese Taipei (TWN)	Asia
Portugal (PRT)	1986, Euro (1999)	India (IND)	Asia
Spain (ESP)	1986, Euro (1999)	Indonesia (IDN)	Asia
Austria (AUT)	1995, Euro (1999)	Japan (JPN)	Asia
Finland (FIN)	1995, Euro (1999)	Korea (KOR)	Asia
Sweden (SWE)	1995	Australia (AUS)	Oceania
Slovenia (SVN)	2004, Euro (2007)		
Cyprus (CYP)	2004, Euro (2008)	Rest of World (ROW)	
Malta (MLT)	2004, Euro (2008)		
Slovak Republic (SVK)	2004, Euro (2009)		
Estonia (EST)	2004, Euro (2011)		
Latvia (LVA)	2004, Euro (2014)		
Lithuania (LTU)	2004, Euro (2015)		
Czech Republic (CZE)	2004		
Hungary (HUN)	2004		
Poland (POL)	2004		
Bulgaria (BGR)	2007		
Romania (ROU)	2007		
Croatia (HRV)	2013		

[7] See Dietzenbacher et.al. (2013), Timmer et.al. (2015), and Timmer et.al. (2016) for details on how WIOD is constructed and can be used.

Table 2. Sector coverage of WIOD 2016

ISIC Rev. 4	Sector	Aggregate
Primary production		
A01	Crop and animal production, hunting and related service activities	PP
A02	Forestry and logging	PP
A03	Fishing and aquaculture	PP
B	Mining and quarrying	PP
Manufacturing		
C10-C12	Manufacture of food products, beverages and tobacco products	RBM
C13-C15	Manufacture of textiles, wearing apparel and leather products	RBM
C16	Manufacture of wood and of products of wood and cork, except furniture; …	RBM
C17	Manufacture of paper and paper products	RBM
C18	Printing and reproduction of recorded media	RBM
C19	Manufacture of coke and refined petroleum products	RBM
C20	Manufacture of chemicals and chemical products	RBM
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	RBM
C22	Manufacture of rubber and plastic products	RBM
C23	Manufacture of other non-metallic mineral products	RBM
C24	Manufacture of basic metals	RBM
C25	Manufacture of fabricated metal products, except machinery and equipment	RBM
C26	Manufacture of computer, electronic and optical products	CE
C27	Manufacture of electrical equipment	CE
C28	Manufacture of machinery and equipment n.e.c.	MVTO
C29	Manufacture of motor vehicles, trailers and semi-trailers	MVTO
C30	Manufacture of other transport equipment	MVTO
C31-C32	Manufacture of furniture; other manufacturing	MVTO
C33	Repair and installation of machinery and equipment	MVTO
Services		
D35	Electricity, gas, steam and air conditioning supply	OS
E36	Water collection, treatment and supply	OS
E37-E39	Sewerage; waste collection, treatment and disposal; materials recovery; …	OS
F	Construction	OS
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	OS
G46	Wholesale trade, except of motor vehicles and motorcycles	OS
G47	Retail trade, except of motor vehicles and motorcycles	OS
H49	Land transport and transport via pipelines	TS
H50	Water transport	TS
H51	Air transport	TS
H52	Warehousing and support activities for transportation	TS
H53	Postal and courier activities	TS
I	Accommodation and food service activities	OS
J58	Publishing activities	BS
J59-J60	Motion picture, video and tv production, sound recording and music publishing, …	BS
J61	Telecommunications	BS
J62-J63	Computer programming, consultancy; information service activities	BS
K64	Financial service activities, except insurance and pension funding	FI
K65	Insurance, reinsurance and pension funding, except compulsory social security	FI
K66	Activities auxiliary to financial services and insurance activities	FI
L68	Real estate activities	BS
M69-M70	Legal and accounting activities; head offices; management consultancy activities	BS
M71	Architectural and engineering activities; technical testing and analysis	BS
M72	Scientific research and development	BS
M73	Advertising and market research	BS
M74-M75	Other professional, scientific and technical activities; veterinary activities	BS
N	Administrative and support service activities	BS
O84	Public administration and defence; compulsory social security	OS
P85	Education	OS
Q	Human health and social work activities	OS
R-S	Other service activities	OS
T	Activities of households as employers …	OS
U	Activities of extraterritorial organizations and bodies	OS

PP = Primary products; RBM = Resource based manufacturing; CE = Computer and electronic equipment; MVTO = Machinery, veichles, transport equipment and other manufacturing; TS = Transportation services; FI = Finance and insurance; BS = Business services; OS = Other services.

4. The pattern of trade in intermediate inputs

As a preliminary step, we need to describe the structure of a closed economy input-output model and then of the multi-country input-output model of WIOD.

4.1 Closed economy input-output model

The input-output table of a closed economy is depicted in Table 3. The first $n \times n$ elements of the input-output table record intra- and inter-industry flows of intermediate goods and services, where sales from sector *i* to *j* are recorded horizontally and purchases by sector *j* from sector *i* vertically. The *n+1* column ("Final demand") records sales to final consumers and the *n+1* row ("Value added") outlays on labour and capital used to process intermediate inputs into next-stage ("downstream") inputs in the value-chain. The right-most column reports total output (supply) by industry and the bottom row total input (use) by industry, which in equilibrium are equal in monetary terms.

Table 3. Input-output table of a closed economy

Using sector *j = 1, 2, …, n*

		Intermediate demand Sector 1	Sector 2	…	Sector n	Final demand	Total output
Supplying sector *i =1, 2 ,… , n*	Sector 1	z_{11}	z_{12}	…	z_{1n}	f_1	y_1
	Sector 2	z_{21}	z_{22}	…	z_{2n}	f_2	y_2
	…	…	…	⋱	…	…	…
	Sector n	z_{n1}	z_{n2}	…	z_{nn}	f_n	y_n
	Value added	w_1	w_2	…	w_n		
	Total input	y_1	y_2	…	y_n		

The production side of this Leontief model is the simplest possible, with fixed input coefficients and constant returns to scale (CRS),

(1) $y_i = \min\left(\frac{z_{1i}}{a_{1i}}, \frac{z_{2i}}{a_{2i}}, \dots, \frac{z_{ni}}{a_{ni}}; \frac{w_i}{b_i}\right),$

where y_i denotes the output of sector *i*, z_{ji} inputs from sector *j* and w_i inputs of primary production factors (which in equilibrium equals $1-\sum a_{ij}$ under the CRS assumption). As there is no substitutability between different types of inputs in the Leontief model, firms will employ just the minimum amount of inputs to produce the output demanded by the market,

(2) $z_{ij} = a_{ij} y_j.$

The model is closed by treating final demand as an exogenous vector. Under these assumptions, the model boils down to a linear equation system of supply and demand,

(3) $$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}}_{\boldsymbol{y}} = \underbrace{\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}}_{\boldsymbol{A}} \underbrace{\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}}_{\boldsymbol{y}} + \underbrace{\begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix}}_{\boldsymbol{f}}.$$

where $\boldsymbol{y}$ denotes the production vector, $\boldsymbol{A}$ the input-output matrix per unit of output and $\boldsymbol{f}$ the final demand vector. The equation system has the following solution (general equilibrium),

(4) $$\boldsymbol{y} = [\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{f},$$

where $[\boldsymbol{I} - \boldsymbol{A}]^{-1}$ is the so-called Leontief inverse that computes total input requirement from each sector to produce the final demand vector.

4.2 Multi-country input-output model

Extending the Leontief model into a multi-country input-output model is a matter of scaling up the model, since the world as a whole is a closed economy. Using block-matrix notation, the multi-country version of the Leontief model takes the form

(5) $$\underbrace{\begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \boldsymbol{y}_{28} \\ - \\ \boldsymbol{y}_{29} \\ \boldsymbol{y}_{30} \\ \vdots \\ \boldsymbol{y}_{44} \end{bmatrix}}_{\boldsymbol{y}} = \underbrace{\left[\begin{array}{cccc|cccc} \boldsymbol{A}_{1,1} & \boldsymbol{A}_{1,2} & \cdots & \boldsymbol{A}_{1,28} & \boldsymbol{A}_{1,29} & \boldsymbol{A}_{1,30} & \cdots & \boldsymbol{A}_{1,44} \\ \boldsymbol{A}_{2,1} & \boldsymbol{A}_{2,2} & \cdots & \boldsymbol{A}_{2,28} & \boldsymbol{A}_{2,29} & \boldsymbol{A}_{2,30} & \cdots & \boldsymbol{A}_{2,44} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_{28,1} & \boldsymbol{A}_{28,2} & \cdots & \boldsymbol{A}_{28,28} & \boldsymbol{A}_{28,29} & \boldsymbol{A}_{28,30} & \cdots & \boldsymbol{A}_{28,44} \\ \hline \boldsymbol{A}_{29,1} & \boldsymbol{A}_{29,2} & \cdots & \boldsymbol{A}_{29,28} & \boldsymbol{A}_{29,29} & \boldsymbol{A}_{29,30} & \cdots & \boldsymbol{A}_{29,44} \\ \boldsymbol{A}_{30,1} & \boldsymbol{A}_{30,2} & \cdots & \boldsymbol{A}_{30,28} & \boldsymbol{A}_{30,29} & \boldsymbol{A}_{30,30} & \cdots & \boldsymbol{A}_{30,44} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{A}_{44,1} & \boldsymbol{A}_{44,2} & \cdots & \boldsymbol{A}_{44,28} & \boldsymbol{A}_{44,29} & \boldsymbol{A}_{44,30} & \cdots & \boldsymbol{A}_{44,44} \end{array}\right]}_{\boldsymbol{A}} \underbrace{\begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \boldsymbol{y}_{28} \\ - \\ \boldsymbol{y}_{29} \\ \boldsymbol{y}_{30} \\ \vdots \\ \boldsymbol{y}_{44} \end{bmatrix}}_{\boldsymbol{y}} + \underbrace{\begin{bmatrix} \sum_j \boldsymbol{f}_{1,j} \\ \sum_j \boldsymbol{f}_{2,j} \\ \vdots \\ \sum_j \boldsymbol{f}_{28,j} \\ \hline \sum_j \boldsymbol{f}_{29,j} \\ \sum_j \boldsymbol{f}_{30,j} \\ \vdots \\ \sum_j \boldsymbol{f}_{44,j} \end{bmatrix}}_{\boldsymbol{f}}$$

where $\boldsymbol{y}_i$ is the output vector of country *i*; $\boldsymbol{A}_{ij}$ is the input-output block between country *i* and *j*; and $\sum_j \boldsymbol{f}_{ij}$ is the global demand vector for the final products of country *i.* The dashed lines in (5) mark the division between the European Union and the rest of the world.

The global input-output model can be expressed in compact form as a two-region model with the European Union as one region (subscript $\boldsymbol{e}$) and the rest of the world as the other region (subscript $\boldsymbol{w}$),

(6) $$\underbrace{\begin{bmatrix} \boldsymbol{y}_e \\ \boldsymbol{y}_w \end{bmatrix}}_{\boldsymbol{y}} = \underbrace{\begin{bmatrix} \boldsymbol{A}_{ee} & \boldsymbol{A}_{ew} \\ \boldsymbol{A}_{we} & \boldsymbol{A}_{ww} \end{bmatrix}}_{\boldsymbol{A}} \underbrace{\begin{bmatrix} \boldsymbol{y}_e \\ \boldsymbol{y}_w \end{bmatrix}}_{\boldsymbol{y}} + \underbrace{\begin{bmatrix} \boldsymbol{f}_e \\ \boldsymbol{f}_w \end{bmatrix}}_{\boldsymbol{f}},$$

where $\boldsymbol{A}_{ee}$ records input-output linkages within the European Union, $\boldsymbol{A}_{ew}$ forward (downstream) linkages to the rest of the world, and $\boldsymbol{A}_{we}$ backward (upstream) linkages to the rest of the world. The general equilibrium of the world economy can be solved as a function of the four blocks of $\boldsymbol{A}$ through block inversion,

(7) $$\underbrace{\begin{bmatrix} \boldsymbol{y}_e \\ \boldsymbol{y}_w \end{bmatrix}}_{\boldsymbol{y}} = \underbrace{\begin{bmatrix} (\boldsymbol{I} - \boldsymbol{A}_{ee} - \boldsymbol{R}_{ewe})^{-1} & (\boldsymbol{I} - \boldsymbol{A}_{ee} - \boldsymbol{R}_{ewe})^{-1}\boldsymbol{A}_{ew}(\boldsymbol{I} - \boldsymbol{A}_{ww})^{-1} \\ (\boldsymbol{I} - \boldsymbol{A}_{ww} - \boldsymbol{R}_{wew})^{-1}\boldsymbol{A}_{we}(\boldsymbol{I} - \boldsymbol{A}_{ee})^{-1} & (\boldsymbol{I} - \boldsymbol{A}_{ww} - \boldsymbol{R}_{wew})^{-1} \end{bmatrix}}_{[\boldsymbol{I} - \boldsymbol{A}]^{-1}} \underbrace{\begin{bmatrix} \boldsymbol{f}_e \\ \boldsymbol{f}_w \end{bmatrix}}_{\boldsymbol{f}},$$

where $\boldsymbol{R}_{ewe} \equiv \boldsymbol{A}_{ew}[\boldsymbol{I} - \boldsymbol{A}_{ww}]^{-1}\boldsymbol{A}_{we}$ and $\boldsymbol{R}_{wew} \equiv \boldsymbol{A}_{we}[\boldsymbol{I} - \boldsymbol{A}_{ee}]^{-1}\boldsymbol{A}_{ew}$ measure the circular flows of inputs between the regions (known as "returning value added" in the GVC literature). The upper left block of the global Leontief inverse measures the supply-chain trade within the European Union (including returning inputs that re-enter the supply chains after a processing stage outside the European Union), the upper right block the sales of inputs to the rest of the world and the lower left block the purchases of inputs.

4.3 Supply-chain decomposition

To analyse the supply chains we need additional tools that can split them into their country components, or specifically, to split total value added into country contributions. In this context we may call supply chains value added chains (the two concepts are used interchangeably in the literature). The decomposition of value added can either be done by following the value chains forward (downstream) from each sector to the final demand vector, or backward (upstream) from each sector to the different tiers of suppliers and sub-suppliers. We will use the backward decomposition technique, as illustrated in Figure 3.

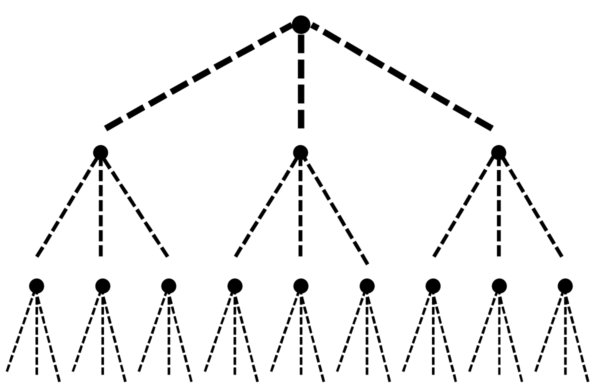
The backward decomposition technique introduced by Mirodout and Nordström (2015) starts with the accounting identity

$$(8) \qquad \boldsymbol{i} = \boldsymbol{A}'\boldsymbol{i} + \boldsymbol{v},$$

where $\boldsymbol{i}$ is a unit vector of output, $\boldsymbol{A}'\boldsymbol{i}$ is the cost share of non-primary inputs (using primes to denote the transpose of matrix or vector) and $\boldsymbol{v}$ the value-added share, i.e. the compensation received by the primary factors of production, labour and capital, per unit of output. By iterating the accounting identity backward in the supply chain (that is, replacing the $\boldsymbol{i}$ on the right hand side with $\boldsymbol{A}'\boldsymbol{i} + \boldsymbol{v}$) we get an infinite series that decomposes the value-added by stage of production:

$$(9) \qquad \boldsymbol{i} = \underbrace{\boldsymbol{v}}_{\substack{\textbf{final}\\ \textbf{assembly}}} + \underbrace{\boldsymbol{A}'\boldsymbol{v}}_{\substack{\textbf{1:st tier}\\ \textbf{suppliers}}} + \underbrace{\boldsymbol{A}'^{2}\boldsymbol{v}}_{\substack{\textbf{2:nd tier}\\ \textbf{suppliers}}} + \cdots = \underbrace{\boldsymbol{v}}_{\substack{final\\ assembly}} + \underbrace{\boldsymbol{A}'[\boldsymbol{I} - \boldsymbol{A}']^{-1}\boldsymbol{v}}_{\substack{upstream\\ production\ stages}} .$$

Figure 3. Supply chain decomposition (per unit of output)



production stage	gross output	value added
final assembly	$\boldsymbol{i}$	$\boldsymbol{v}$
1:st tier suppliers	$\boldsymbol{A}'\boldsymbol{i}$	$\boldsymbol{A}'\boldsymbol{v}$
2:nd tier suppliers	$\boldsymbol{A}'\boldsymbol{A}'\boldsymbol{i}$	$\boldsymbol{A}'\boldsymbol{A}'\boldsymbol{v}$
…	…	…
Cumulated	$[\boldsymbol{I} - \boldsymbol{A}']^{-1}\boldsymbol{i}$	$\boldsymbol{i}$

The share of an individual country is found by setting all coefficients to zero in the $\boldsymbol{v}$-vector except for the country under consideration. These calculations can be done for one country at the time or in one computational step by redefining $\boldsymbol{v}$ as a *block-diagonal* matrix,

$$(10) \quad \boldsymbol{V} = bdiag(\boldsymbol{v}) + \boldsymbol{A}'[\boldsymbol{I} - \boldsymbol{A}']^{-1} bdiag(\boldsymbol{v})$$

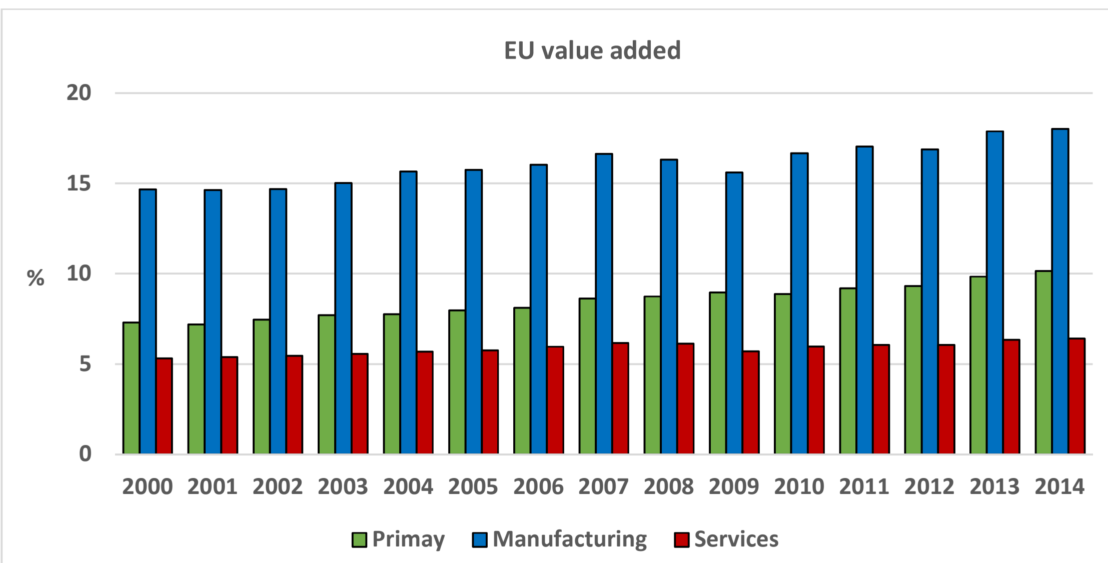
$$= \underbrace{\begin{bmatrix} \mathbf{v_1} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{v_2} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \mathbf{v_m} \end{bmatrix}}_{\substack{\text{value added} \\ \text{final assembly}}} + \underbrace{\begin{bmatrix} \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_1 \mathbf{v_1} & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_1 \mathbf{v_2} & \cdots & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_1 \mathbf{v_m} \\ \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_2 \mathbf{v_1} & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_2 \mathbf{v_2} & \cdots & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_2 \mathbf{v_m} \\ \vdots & \vdots & \ddots & \vdots \\ \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_m \mathbf{v_1} & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_m \mathbf{v_2} & \cdots & \langle \mathbf{A}'[\mathbf{I}-\mathbf{A}']^{-1}\rangle_m \mathbf{v_m} \end{bmatrix}}_{\substack{\text{upstream valued added} \\ \text{by country (c=1,2,...,m)}}}.$$

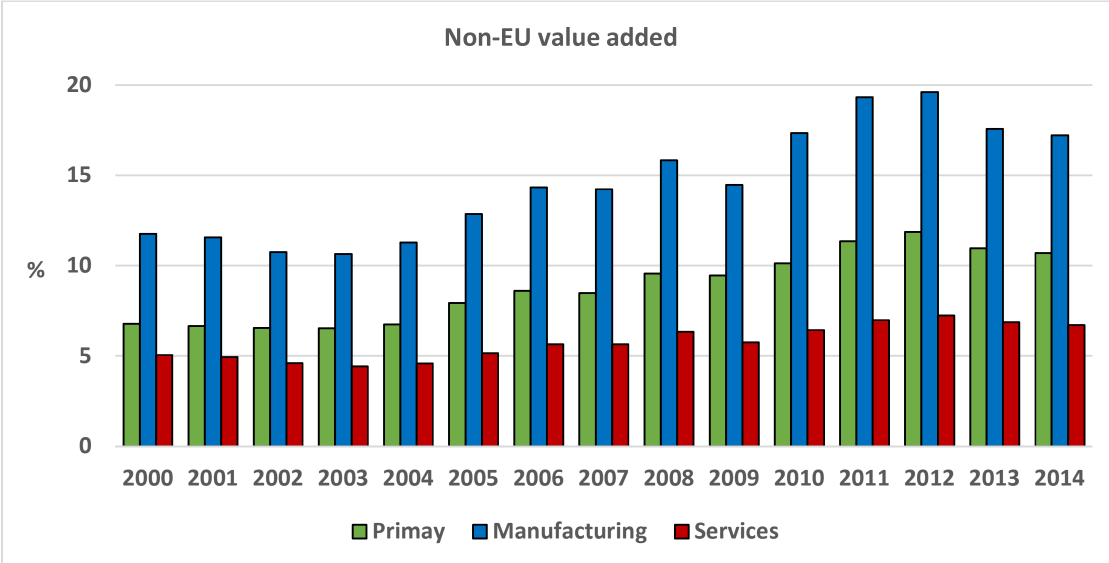
The $\boldsymbol{V}$-matrix provides a full decomposition of the contribution of each country (*c = 1, 2, …, m*) per unit of output in all value chains defined by the database, where the domestic shares (divided between final assembly and upstream production) are recorded on the diagonal blocks and the foreign shares by country on the off-diagonal blocks. The decomposition can be done by country and sector by simply exchanging the block-diagonal matrix of $\boldsymbol{v}$ for a diagonal matrix, thereby expanding that dimension of $\boldsymbol{V}$ from (country × sector) × country to (country × sector) × (country × sector).

4.4 Slicing the value chain

How much of the value added in the output of the European Union can be attributed to domestic inputs of the member states (referred to as domestic value added); how much can be attributed to inputs produced in other member states (referred to as EU value added); and how much can be attributed to inputs produced outside the European Union (referred to as non-EU value added)? We are interested both in the differences between primary production, manufacturing and services (Table 1) and the evolution over time.

Figure 4. Foreign value added in primary production, manufacturing and services
Weighted averages of all member states.





Source: Own calculations based on the Novermber 2016 edition of WIOD.

As one may expect, manufacturing uses more imported inputs from EU and non-EU countries than the primary sector, which in turn uses more imported inputs than the services sector. The manufacturing sector is by this measure more integrated into regional and global value chains than the other sectors. The division between EU and non-EU inputs is roughly fifty-fifty in all sectors, measured in value added. The imported share of value added is increasing over time and somewhat faster for non-EU inputs than EU inputs. Thus, there is no evidence that the European Union is closing its gates towards the outside world.[8]

Now, since the shares of both EU and non-EU inputs have increased over time, the domestic value-added shares must have fallen, albeit from a high level. The domestic share in primary production has fallen from 85.9 percent in 2000 to 79.2 percent in 2014; in manufacturing from 73.6 percent to 64.8 percent; and in services from 89.6 percent to 86.9 percent. Is that bad news? Presumably, this has contributed to lower costs and/or increased quality.

4.5 Degrees of backward and forward integration

Are all member states equally integrated in the supply chains in the European Union? To answer this question, we need metrics of integration. It may be helpful to recall Figure 1 at this point, which maps the flows of intermediate inputs between the member states. Arrows that point to a country indicate purchases of inputs and arrows that point from a country indicate sales of inputs. We refer to the former as backward and the latter as forward integration. The backward integration is calculated by summing the upstream value added over all member states in equation (10), apart from the domestic blocks on the diagonal. The forward integration can also be calculated in a roundabout way using equation (10). For example, to calculate the forward integration of Sweden, we could use equation (10) to calculate how much value added from Sweden that the other member

[8] The European Union has concluded bilateral free trade agreements with some 25 countries since 2000: Albania, Algeria, Bosnia and Herzegovina, Cameroon, Chile, Colombia and Peru, Côte d'Ivoire, Egypt, Macedonia, Georgia, Ghana, Israel, Jordan, Korea, Lebanon, Mexico, Montenegro, Morocco, Papua New Guinea and Fiji, Moldova, San Marino, Serbia and South Africa. (Source: WTO Regional Trade Agreement database).

states use in their production. However, we will derive a direct metric by following the supply chains forward through the input-output system to the final demand vector and measure how much value added that is routed from each member state through each of the other member states. This metric will also be used in section 5 to identify hubs in the input-output system.

We first ask how much value added that is exported via each individual member state *j = {1,2, …, 28}* and then sum the results. To isolate the production stages in country *j* we use an ancillary matrix with zero coefficients in all positions of $\boldsymbol{A}$ but for the columns of *j*, denoted $\boldsymbol{A_j}$. The value added exported through country *j* to the world market (as inputs in country *j*´s export of final products) is given by the following formula,

$$(11) \quad \boldsymbol{vax\_through_j} = v \cdot \{\boldsymbol{A_j} f + \boldsymbol{A}\boldsymbol{A_j} f + \boldsymbol{A}^2\boldsymbol{A_j} f + \boldsymbol{A}^3\boldsymbol{A_j} f + \cdots\} = v \cdot \{[\boldsymbol{I} - \boldsymbol{A}]^{-1}\boldsymbol{A_j} f\},$$

where v is the value added vector and where the operator · denotes the Hadamard product (element-by-element multiplication). Note that (11) accounts for all paths in the global input-output system that passes through country *j* either directly or indirectly after processing in other countries, including countries outside the EU. Summing over all member states except for the exporting country we get a measure of the forward integration within the European Union, normalized with the GDP (total value added) of the exporting country. Since the forward integration index measures the share of the national value added that is embodied as inputs in the output vector of the other member states, it is the mirror image of the backward integration index that measures the value added of the other member states embodied in the national output vector.

Figure 5 plots the backward and forward integration of the member states in 2000 and 2014 against the size of each economy measured by the logarithm of its GDP. The old member states (EU15) are indicated by blue circles and the new member states by orange circles. The correlation is negative in both directions. That is, smaller member states both buy and sell proportionally more inputs than larger member states as a share of GDP and are in this sense more integrated in the supply chains of the European Union, but with large differences between member states.

Figure 5. Integration into EU value chains

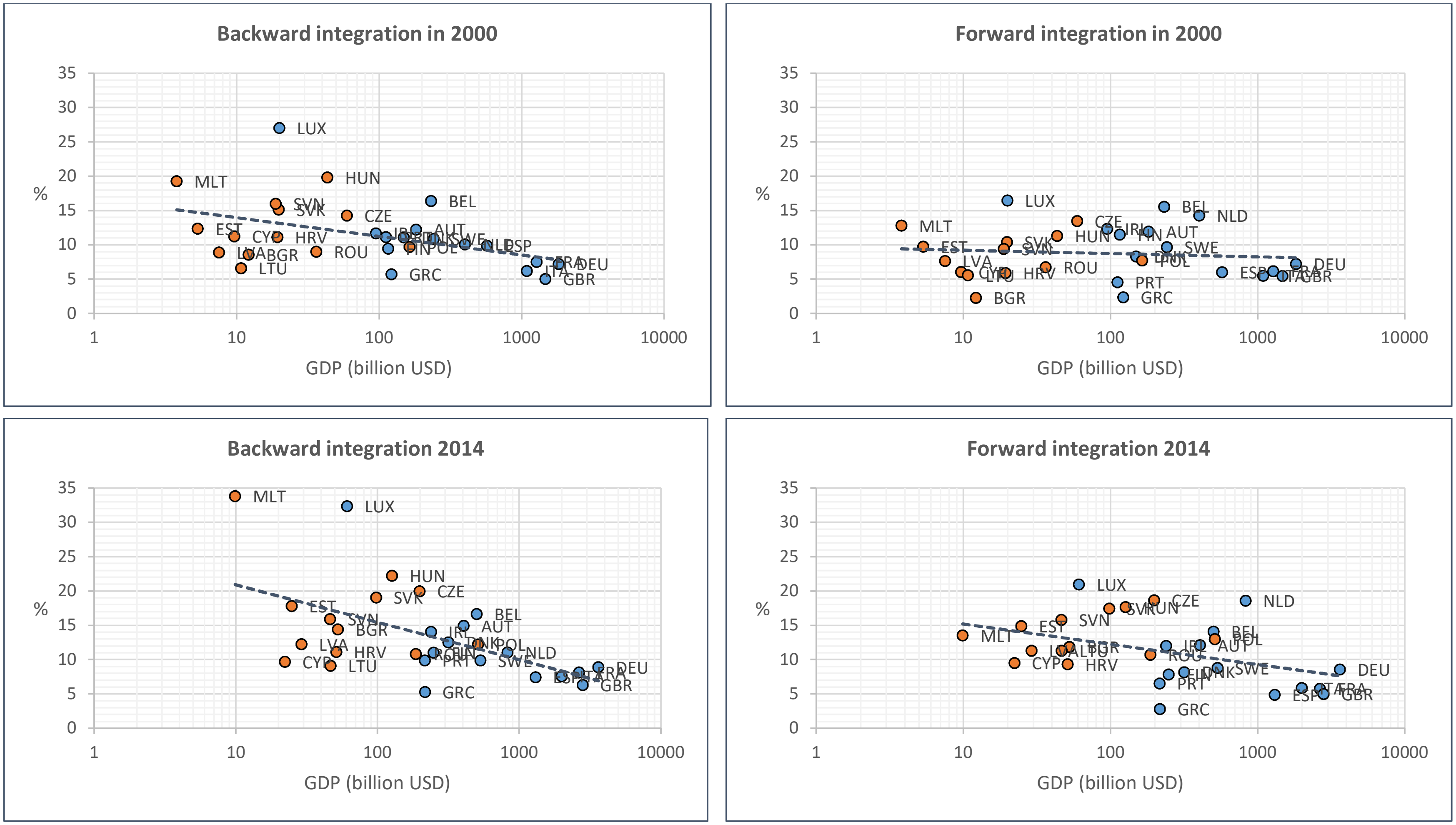


Figure 6. Integration into non-EU value chains

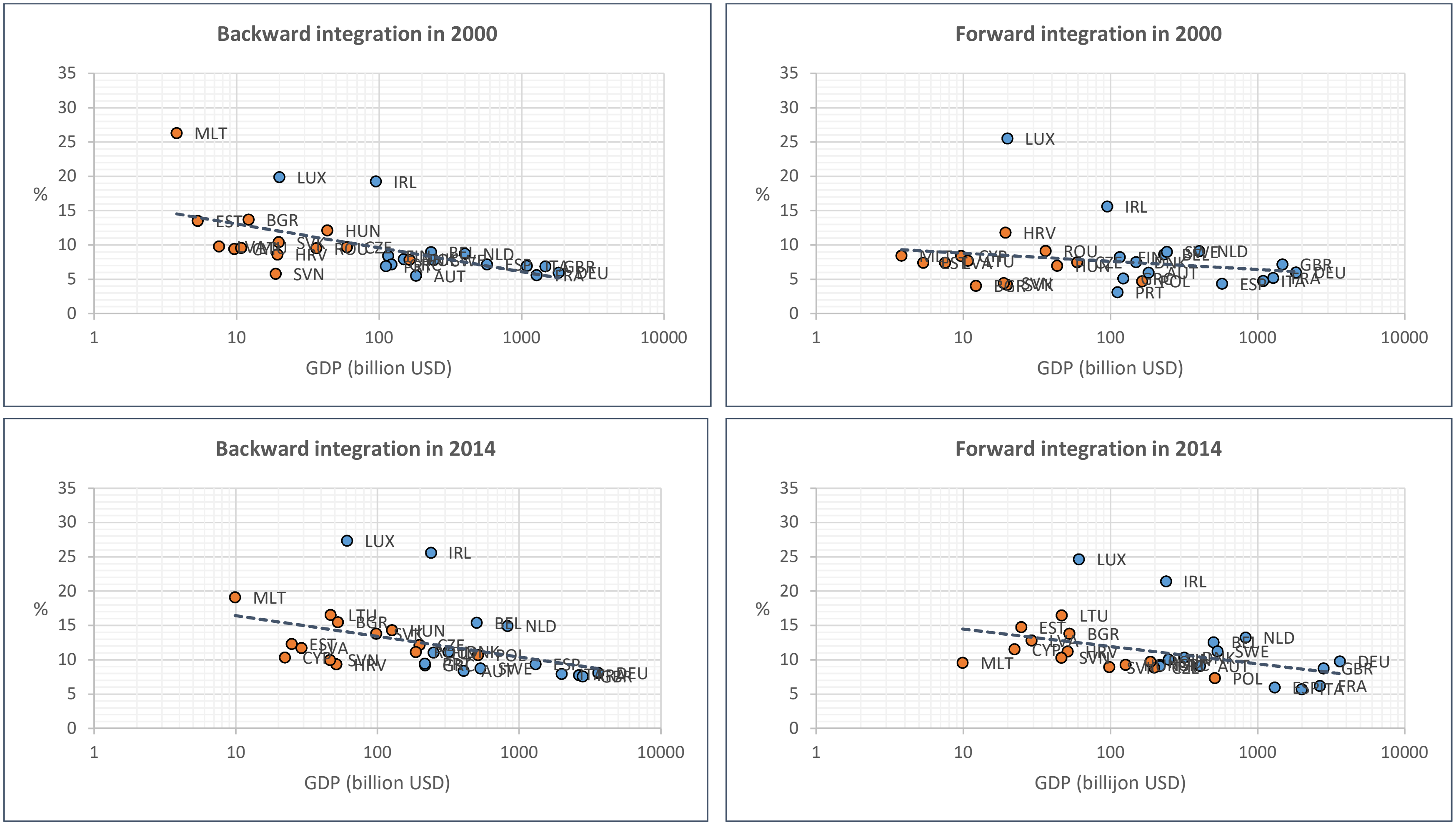


Figure 6 plots the backward and forward integration with the rest of the world. The correlation with the size of the economy is also in this case negative backwards and forwards in the supply chains. The general conclusion is that small economies tend to be more integrated as a share of GDP into both EU and non-EU value chains compared to large economies. This is natural since small countries cannot produce as many inputs as large countries without forgoing economies of scale in production. Furthermore, supply-chain trade may be particularly advantageous for small economies since it offers an opportunity to trade indirectly with the world through centrally located hubs (see Section 5).

Table 4. Determinants of the backward and forward integration of the member states into EU and non-EU value chains

	Backward EU	Forward EU	Backward non-EU	Forward non-EU
Ln(GDP)	-3.37***	-1.92***	-2.43***	-1.96***
	(0.20)	(0.16)	(0.13)	(0.12)
EU member (1/0)	3.28***	3.33***	0.06	1.30***
	(0.84)	(0.67)	(0.56)	(0.50)
EU member years	0.15***	0.08***	0.13***	0.14***
	(0.02)	(0.01)	(0.01)	(0.01)
Obs	420	420	420	420
R^2	0.43	0.30	0.51	0.49

Note: The regressions only include the member states of the EU and cover the period 2000-2014. Yearly fixed effects are included to control for business cycle and trends in the data.
*, **, *** indicate the significance level of the estimated countries (10%, 5% and 1%).

Apart from economic size, integration in the European Union also depends on how long a country has been a member. This is shown in Table 4. The integration impact of becoming a member of the EU is measured by a dummy variable that is zero in the years before accession and one after the accession plus the number years a country has been a member, a continuous variable. The estimated coefficients show that backward and forward integration is on average 3.28 and 3.33 percentage points higher respectively for European Union members than for the candidate member countries in any given year, and that backward and forward integration into the supply chains increases by 0.15 and 0.08 percentage points annually after accession to the European Union.

For completeness, we also run regressions on the integration into non-EU value chains. We are particularly interested in whether accession to the European Union reduces integration into non-EU value chains. As shown in the last two columns of Table 4, there is no evidence of a substitution effect. On the contrary, the relationship seems to be complementary. That is, acceding countries do not only increase their integration in EU value chains over time but also in non-EU value chains. This somewhat surprising result can be explained by the benefits offered by access to the European Union´s network of free trade agreements, productivity improvements (see section 6), and indirect exports of inputs to the world market through well-connected hubs in the EU (see section 5).

4.6 Division of labour in the European Union

We close this section by analysing the division of labour in the European Union. For reasons of space limitation, we divide the 56 sectors in WIOD into 8 groups of inputs defined in Table 2: Primary products; Resource-based manufactured inputs; Computer and electronic equipment; Machinery, vehicles, transport equipment and other manufactured inputs; Transportation services; Finance and insurance; Business services; and Other services. The specialization pattern is evaluated by comparing supply shares of each member state with weighted averages of all member states (marked by the zero lines in Figure 7).

Figure 7. Division of labour in the European Union

Deviations from weighted averages measured in percentage points

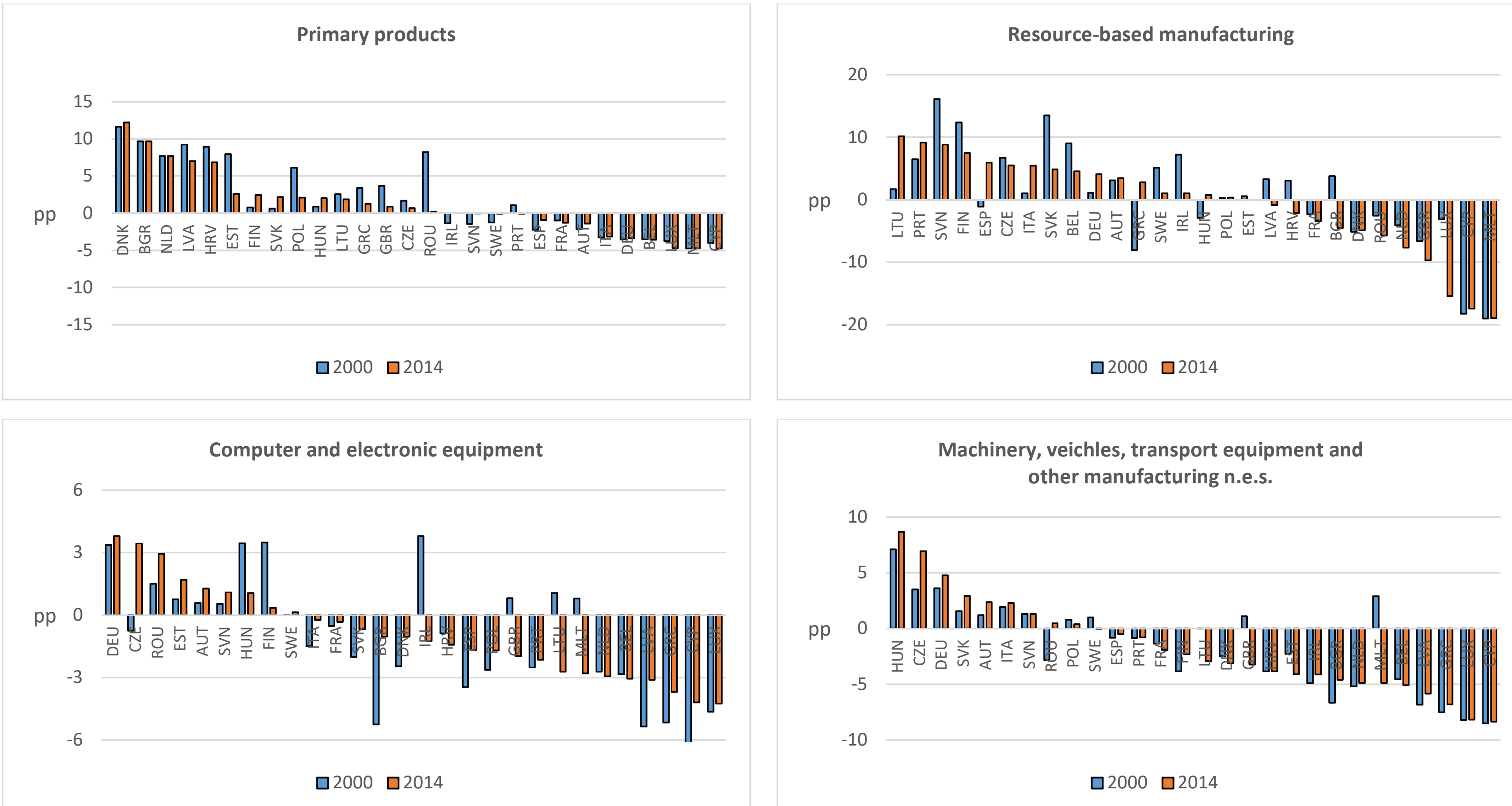
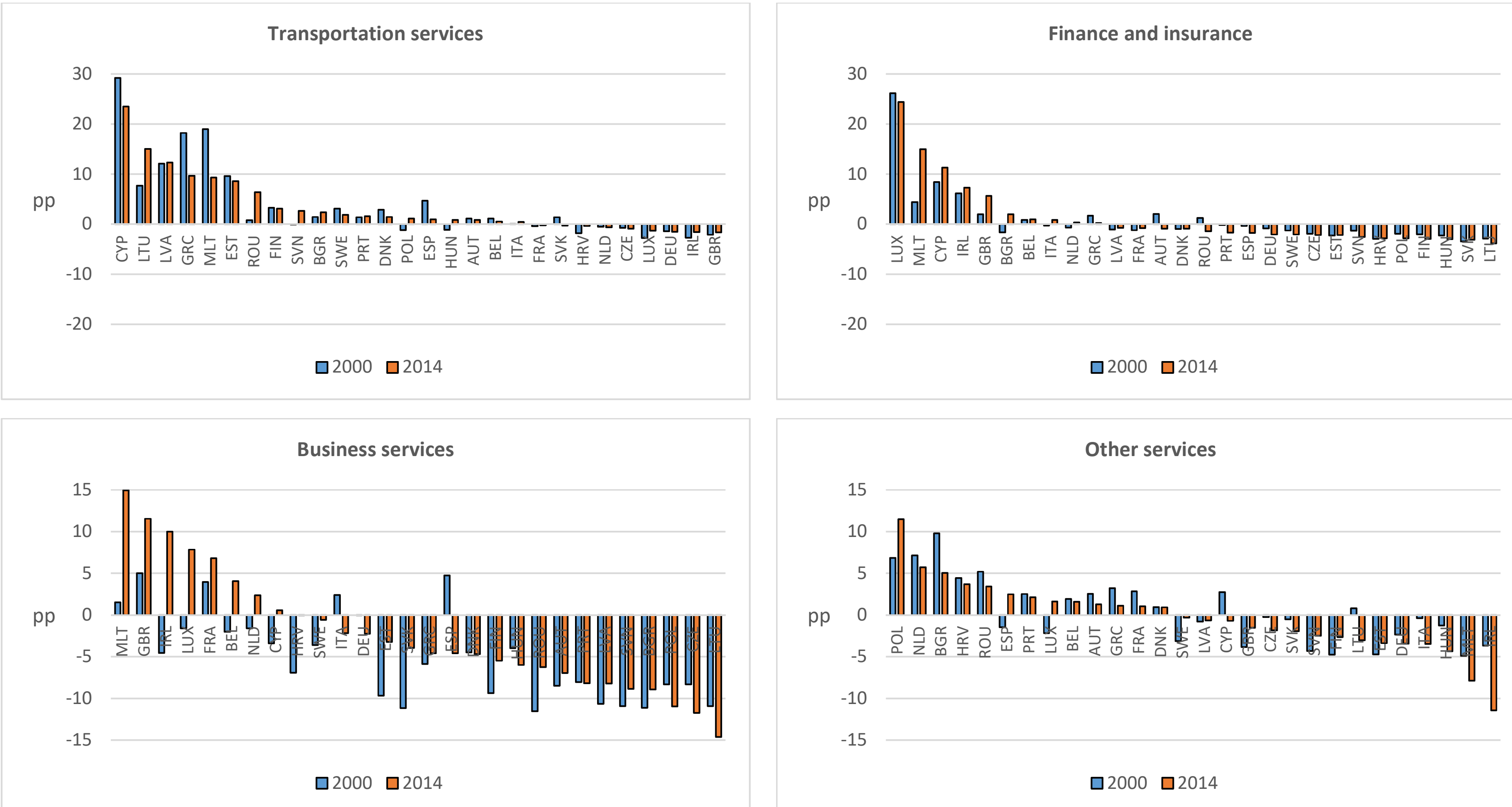


Figure 7. Division of labour in European Union D

Deviations from the weighted averages measured in percentage points



The first plot in Figure 7 shows that Denmark, Bulgaria, Netherlands, Latvia and Croatia are relatively large suppliers of primary inputs in relative – not absolute – terms. The second plot shows that Lithuania, Portugal, Slovenia and Finland are relatively large suppliers of resourced-based manufactured inputs; the third plot that Germany, Czech Republic, Romania, Estonia and Austria are relatively large suppliers of computers and electronic equipment; and the forth plot shows that Hungary, Czech Republic, Germany, Slovakia, Austria and Italy are relatively large suppliers of machinery, vehicles, transport equipment and other manufactured inputs. In services, Cyprus, Lithuania, Latvia, Greece, Malta and Estonia are relatively strong in transportation services; Luxembourg, Malta, Cyprus, Ireland and United Kingdom in financial and insurance services; Malta, United Kingdom, Ireland, Luxembourg and France in business services; and Poland, Netherlands, Bulgaria, Croatia and Romania in Other services, which includes utilities, construction, wholesale and retail and public services. The latter services are exported indirectly as inputs in the export vector of other intermediate products. Countries that are not mentioned above have supply patterns that are close to the averages.

Finally, if we compare old and new member states, old member states specialize more in services and new member states in primary products and manufactures, with the exception of Cyprus and Malta that are services economies (Table 5). It is noteworthy that services – business services in particular – is the fastest growing category of inputs.[9]

Table 5. Average composition of inputs of old and new member states to all member states
Per cent.

	2000		2014	
Category of inputs	**Old**	**New**	**Old**	**New**
Primary products	**5.1**	**9.0**	**5.0**	**7.1**
Manufactures	**44.1**	**47.3**	**36.4**	**40.5**
Resource based manufacturing	28.4	30.8	23.0	24.4
Computer and electronic equipment	6.5	5.6	4.7	4.9
Machinery, vehicles, transport equipment and other manufacturing	9.2	10.9	8.7	11.2
Services	**50.9**	**43.8**	**58.7**	**52.3**
Transportation services	6.9	7.5	7.2	9.8
Finance and insurance	4.3	2.6	5.3	2.8
Business services	21.4	12.8	25.8	15.7
Other services	18.3	20.9	20.4	24.0

Note: The shares do not sum to 100 because of rounding errors.

[9] On this point, see further National Board of Trade (2016).

5. The geography of the European Union production network

Network analysis – so-called graph theory in mathematics – is used in many academic disciplines to visualize and analyse systems composed of individual parts that are linked together in some way.[10] When the object is a social network – such as a Facebook group or an academic network – the adjective social is used to indicate both the nature of the network and the tools that are used, many of which were developed in sociology. Central in social network analysis is the "position" and "centrality" of individual members (countries in our case) and the advantage or disadvantage of a given position.

First, we are interested in the existence of hubs in the production network. To identify hubs we construct an index by calculating how much value added that is exported through country j from each member state, using formula (11), and dividing the result by the country´s total exports of intermediate inputs multiplied by 100. The pass-through or hub index ranges from 0 to 100 percent, where the upper limit indicates that all exports of intermediate inputs are inputs that pass through the hubs with no direct trade in intermediate inputs between the countries concerned. The maximum index value that we observe in the data is 27.6 percent (from the Czech Republic through Germany). The pass-through index is related to the so-called betweenness centrality index used in the network literature, which measures the importance of individual nodes as so-called bridges to other nodes in the system.[11] Our hub index is similar to the hub index derived independently by Lejour et.al. (2017).

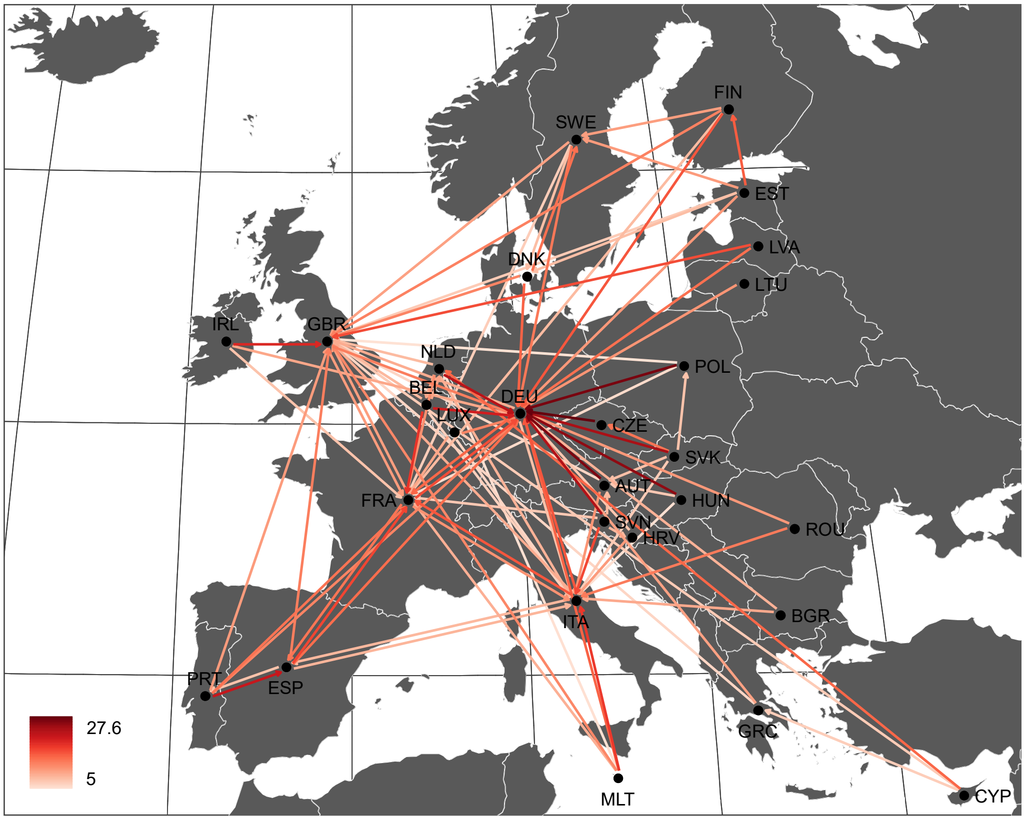
The threshold for being a hub is a matter of judgment. It depends both on the index value and on the absolute value of traded inputs. For the latter criterion to be fulfilled, a relatively large number of significant trade flows from other countries must pass through the country that is a hub. Figure 8 maps all intermediate bilateral sectoral trade flows that make up at least 5 percent of the intermediate exports of a member state. Somewhat arbitrarily, we define hubs as those countries that receive many incoming and outgoing arrows.

It is clear from the map that Germany is the central hub, especially for the new member states in Central and Eastern Europe. Up to one quarter of the exports of intermediate inputs of Poland, the Czech Republic, Slovakia and Hungary pass through Germany. The other three major economies in the European Union – France, United Kingdom and Italy – are also important hubs, but for a smaller number of countries. Even mid-size countries such as Sweden, Netherlands and Belgium are hubs for some neighbouring countries. For example, the largest hub for Estonia is not Germany but Sweden and Finland, suggesting a local cluster of supply links in the north-east corner of the European Union.

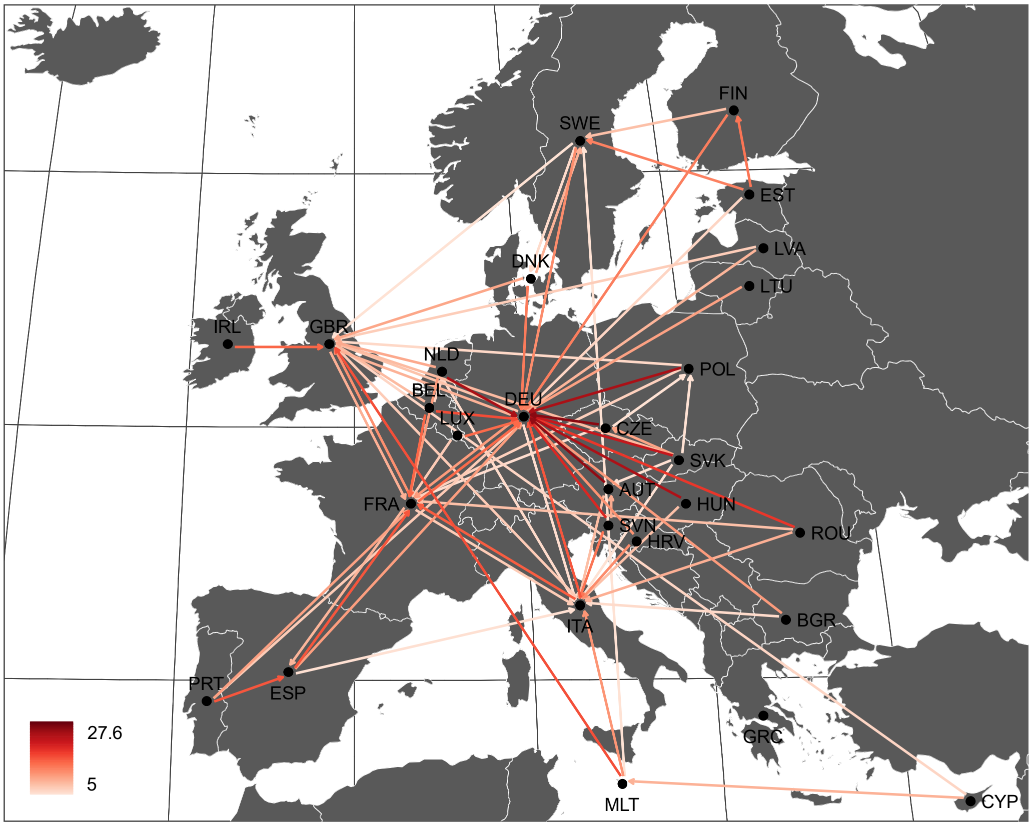
[10] For a general introduction to network analysis, see Newman (2010). For applications to trade networks, see Snyder and Kick (1979), Smith and White (1992), Gereffi and Korzeniewicz (1994), De Benedictis and Tajoli (2011), De Benedictis et.al. (2013), Cerina et.al. (2015) and Lejour et.al. (2017).
[11] See Newman (2010) for the mathematical definition of betweenness centrality.

Figure 8. Geography of the European Union production network:

2000



2014



If we compare the maps for 2000 and 2014 it seems at first sight that Germany has strengthened its hub position in the network. But the map is somewhat misleading, since it only includes trade flows above the 5 percent threshold. All hubs have in fact lost some ground, including Germany, as is evident from Table 6. The losses have mainly been to countries outside the European Union and to China in particular. For example, the share of all intermediate value-added exports in the European Union passing through Germany (not counting domestic value added) has fallen from 10.3 percent in in 2000 to 9.4 percent in 2014, whereas it has increased for Poland from 1.4 to 1.9 per cent. For the European Union as a whole, the vale added that passes through all hubs has decreased from 53.0 percent in 2000 to 49.4 percent in 2014, with a corresponding increase for hubs outside. The most important hub outside the European Union is the United States with a share of 8.4 percent in 2014 that is decreasing. China is at the same time becoming a more important hub, up from 1.8 percent in 2000 to 5.4 percent in 2014.

Table 6. The top ten hubs in the European Union
Share of intermediate exports of value added through each hub, percent

	2000	2014
Total EU	**53.0**	**49.4**
Germany	10.3	9.4
France	7.9	6.6
United Kingdom	6.1	5.4
Italy	5.3	4.3
Spain	4.8	2.9
Netherlands	3.0	2.3
Belgium	2.9	2.5
Sweden	2.0	1.5
Austria	1.7	1.7
Poland	1.4	1.9
Denmark	1.3	1.3

Table 7 below lists the top three hubs for each member state. Germany is on the top three list of all member states except Cyprus and Malta in 2014, which once again is a strong indication that Germany is the central hub in the European production network. Germany is particularly important as a hub for Austria, Czech Republic, Hungary, Poland and Slovakia. France is on the top three list of 13 member states in 2000 and 14 in 2014; United Kingdom for 13 member states in 2000 and 15 in 2014; Italy for 11 member states in 2000 and 12 in 2014; and Spain for 3 member states in 2000 and 2 in 2014. A handful other member states are also on the top three list for a neighbouring country, such as the Czech Republic for Slovakia and Finland and Sweden for Estonia.

Table 7. Top three hubs of each member state

Share of intermediate exports of value added through each hub, percent

	2000			2014		
	1st	2nd	3rd	1st	2nd	3rd
Austria	DEU (25.2)	ITA (8.2)	GBR (5.5)	DEU (23.2)	ITA (6.4)	FRA (4.6)
Belgium	DEU (16.5)	FRA (13.9)	NLD (7.4)	DEU (12.2)	FRA (10.7)	GBR (6.6)
Bulgaria	ITA (7.3)	DEU (6.9)	FRA (3.4)	DEU (7.9)	ITA (5.3)	FRA (4.0)
Croatia	ITA (7.8)	DEU (6.1)	SVN (4.3)	ITA (8.5)	DEU (8.3)	AUT (4.3)
Cyprus	NLD (10.7)	GBR (5.9)	GRC (5.8)	MLT (6.9)	GBR (5.5)	ITA (3.7)
Czech Republic	DEU (27.5)	AUT (4.9)	POL (4.5)	DEU (24.0)	FRA (5.2)	POL (5.1)
Denmark	DEU (10.9)	SWE (10.2)	GBR (9.0)	DEU (9.4)	GBR (7.4)	SWE (6.9)
Estonia	FIN (11.2)	DEU (7.9)	SWE (7.8)	FIN (9.9)	SWE (9.1)	DEU (5.5)
Finland	DEU (11.7)	GBR (9.2)	SWE (7.7)	DEU (9.3)	SWE (6.3)	GBR (4.9)
France	DEU (12.2)	ESP (9.9)	ITA (8.3)	DEU (10.5)	GBR (8.4)	ESP (6.8)
Germany	FRA (10.6)	GBR (7.2)	ITA (6.3)	FRA (7.8)	GBR (6.2)	ITA (5.2)
Greece	DEU (7.6)	GBR (5.5)	ITA (4.1)	ITA (3.8)	DEU (3.7)	GBR (3.2)
Hungary	DEU (23.6)	AUT (5.9)	ITA (5.1)	DEU (20.4)	ITA (6.3)	AUT (4.7)
Ireland	GBR (15.2)	DEU (7.3)	FRA (6.2)	GBR (10.7)	DEU (5.0)	ITA (3.4)
Italy	FRA (11.7)	DEU (11.6)	GBR (7.1)	DEU (11.7)	FRA (11.2)	GBR (5.9)
Latvia	GBR (12.2)	DEU (10.1)	SWE (4.5)	DEU (6.7)	GBR (5.8)	SWE (4.5)
Lithuania	DEU (8.2)	POL (4.4)	FRA (4.1)	DEU (7.5)	POL (4.0)	FRA (3.5)
Luxembourg	DEU (9.1)	FRA (7.3)	ITA (5.5)	DEU (10.6)	FRA (5.9)	BEL (4.5)
Malta	ITA (13.6)	DEU (10.9)	GBR (8.9)	GBR (12.0)	ITA (8.1)	SWE (5.0)
Netherlands	DEU (19.0)	FRA (8.4)	BEL (7.4)	DEU (20.9)	FRA (7.8)	GBR (7.2)
Poland	DEU (25.3)	FRA (5.3)	GBR (5.0)	DEU (21.0)	FRA (5.7)	GBR (5.4)
Portugal	ESP (17.7)	FRA (10,0)	DEU (9.1)	ESP (11.5)	FRA (7.6)	DEU (5.9)
Romania	ITA (9.5)	DEU (7.9)	FRA (3.9)	DEU (13.7)	ITA (6.9)	FRA (6.3)
Slovak Republic	DEU (20.8)	CZE (9.8)	AUT (6.3)	DEU (17.6)	CZE (7.5)	GBR (6.6)
Slovenia	DEU (19.8)	ITA (12.6)	HRV (6.7)	DEU (15.3)	ITA (9.9)	AUT (7.1)
Spain	FRA (12.7)	DEU (10.4)	GBR (9.3)	FRA (11.7)	DEU (7.7)	ITA (5.1)
Sweden	DEU (9.7)	GBR (7.5)	DNK (6.4)	DEU (8.5)	DNK (5.3)	GBR (5.1)
United Kingdom	DEU (9.4)	FRA (7.8)	ESP (4.6)	FRA (7.0)	DEU (6.9)	IRL (3.7)

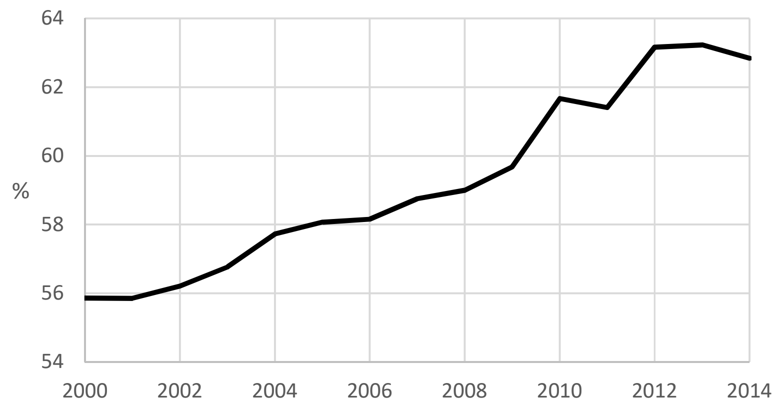
The next feature of the European production network that we are interested in is whether it has become "denser" over time. The literature defines density as the fraction of potential links that are present in a network.[12] Adapted to the input-output context, we define density as the share of intermediate exports of value added that is supplied directly to the ultimate user,

$$(12) \quad \boldsymbol{vax\_direct\_share_j} = \left[v \cdot \{\boldsymbol{A_j} f\}\right] \cdot / \left[v \cdot \{[\boldsymbol{I} - \boldsymbol{A}]^{-1} \boldsymbol{A_j} f\}\right],$$

weighted over all member states. (The other part is supplied through the hubs in the global input-output system). Results are plotted in Figure 9, which shows that density has increased from 55.9 to 62.8 percent between 2000 and 2014. In other words, the direct supply of inputs between the member states has, on average, increased from 55.9 to 62.8 percent over this period, whereas the indirect supply through hubs (including outside hubs) has decreased from 44.1 to 37.2 percent. The production network has in this sense become denser between 2000 and 2014, with more direct supply links between the member states.

[12] See Newman (2010), chapter 6.

Figure 9. Density of the EU production network
Direct exports of inputs between member states, percent



Finally, we are interested in the location of the centre of the European production network. The centre is calculated by weighing the midway position of all supply links with the flows of intermediate inputs, measured in value added.[13] It turns out that the centre has moved between 2000 and 2014 from Münchwald in Germany, located 88 kilometres west of Frankfurt, to Maintal-Dörningheim, located 14 kilometres east of Frankfurt. This can be explained by the integration of the new member states in the production network.

[13] The midway position should preferably be calculated on the basis of the midway position of the supply links between the countries´ economic centres, but a lack of data forces us to use the links between the capitals instead.

6. Wage convergence between member states

In the final section of the paper we will test whether wages are converging at the sector level, and whether the rate of convergence increases with backward and forward integration of the member states into the European production network (as well as into global value chains). Our hypothesis is that trade in inputs facilitates the diffusion of technology, allowing lagging countries to catch up with leading countries. This idea is central in the GVC literature. Humphrey and Schmitz (2000) argue, based on empirical research, that local producers learn a great deal from outside buyers about how to improve the production processes, attain consistent and high quality, and increase the speed of response to changes in demand conditions. Piermartini and Rubínová (2014) argue that supply-chain trade is particularly conducive to knowledge diffusion compared to trade in final products since buyers of inputs need to ensure the quality and compatibility of all parts and components. An example is provided by Baldwin and Lopez-Gonzalez (2015): "When Toyota makes car parts in Thailand, they do not rely on local know-how; they bring Toyota technology, Toyota management, Toyota logistics and any other bits of know-how needed since the Thai-made parts have to fit seamlessly into the company's production network".

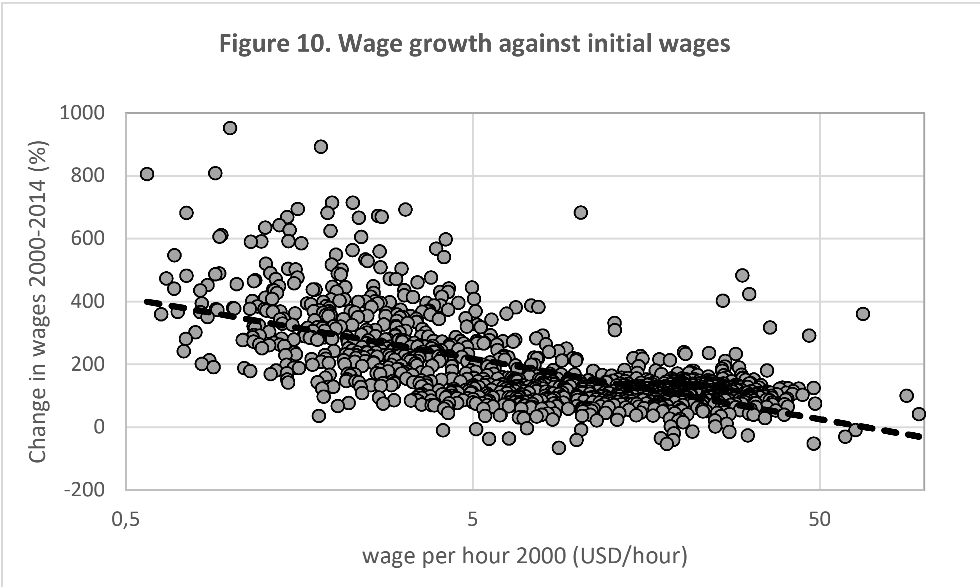
The wage rate is calculated from the Social Economic Accounts annexed to WIOD,[14] which include data on the total labour compensation and hours of work for each sector and country in the database. We adopt the β-convergence model of Baumol (1986), Barro and Sala-i-Martin (1992), Mankiw et.al. (1992) and, with applications to international trade, Ben-David (1993). The model is based on the transition dynamics of the neoclassical growth model of Solow (1956), which predicts convergence in per capita income among countries that share the same basic conditions for growth. Countries that are very different from each other may not converge because of persistent differences in the returns to investment (in favour of the country with better institutions and policies for growth). The Solow model is an aggregate model, but the same kind of transition dynamics can be expected at the sector level in an economic union where capital, labour and technology can flow freely.

Let us first plot the data to see if we can detect any β-convergence. All sectors in WIOD are included except for public, local and household services (heading O to U of ISIC, Rev 4).[15] The latter are dropped since they are either non-market activities or are oriented to the local market. We use a scatter plot with the initial hourly wage rates in 2000 on the horizontal axis, using a logarithmic scale as in the theoretical model, and the percentage change between 2000 and 2014 on the vertical axis. The result is plotted in Figure 10. Fifteen outliers with more than 1 000 percent change in the wage rate (from extremely low initial wages of less than 0.5 USD per hour) have been excluded.

The scatter plot suggests that wages are indeed converging as countries with lower initial wages tend to have higher wage increases. The dotted line in the plot shows the log-linear trend, but the actual relationship seems to be non-linear (which is the actual shape of the transition path in the Solow model) with proportionally faster wage growth for countries with relatively low initial wages.

[14] Gouma et.al. (2018).

[15] The excluded sectors are: (O84) Public administration and defence; compulsory social security, (P85) Education; (Q) Human health and social work activities; (R-S) Other service activities; (T) Activities of households as employers; and (U) Activities of extraterritorial organizations and bodies.



Let us next test if what we see can be confirmed by regressions. We specify the regression model in the classical way pioneered by Baumol (1986), Barro and Sala-i-Martin (1992) and Mankiw, Romer and Weil (1992),

$$(13) \quad \ln\left(\frac{w_{i,t}}{w_{i,t-1}}\right) = \alpha + \beta \, ln\left(w_{i,t-1}\right) + \omega X_{i,t} + \varepsilon_{it} \, ,$$

where $ln\left(w_{i,t}/w_{i,t-1}\right)$ is the wage increase between period *t-1* and *t*, $ln\left(w_{i,t-1}\right)$ is the logarithm of the wage rate in period *t-1*, $X_{i,t}$ a vector of control variables, and ε_{it} an error term (assumed to be independent and identically distributed). The control vector $X_{i,t}$ includes the forward and backward integration indices derived in Section 4 plus the size of the economy measured by $\ln(GDP_{it})$. The latter is included to control for the negative correlation observed between the size of the economy and the integration into regional and global value chains. All sectors are included in the regressions except public, local and household services in section O-U of ISIC Rev 4. To control for systematic differences across sectors, we adopt a fixed effect model by sector-and-year, with a total of 700 panels (50 sectors times 14 years). The regression results are presented in Table 8.

Table 8. Wage convergence

	(1)	(2)	(3)	(4)	(5)
ln[lagged wage rate]	-0.038***	-0.046***	-0.045***	-0.048***	-0.047***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
Backward integration EU		0.082***		0.078***	
		(0.023)		(0.025)	
Forward integration EU		0.045***		0.029	
		(0.017)		(0.018)	
ln[GDP]		0.007***	0.006***	0.008***	0.008***
		(0.001)	(0.001)	(0.001)	(0.001)
Backward integration non-EU			0.058*	0.026	
			(0.030)	(0.033)	
Forward integration non-EU			0.087***	0.076***	
			(0.020)	(0.021)	
Backward integration World					0.050***
					(0.015)
Forward integration World					0.051***
					(0.012)
Observations	19 530	19 530	19 530	19 530	19 530
Panels (sector-year)	700	700	700	700	700
R^2, within	0.04	0.05	0.05	0.05	0.05

*, **, *** indicate the significance levels of 10, 5 and 1 percent respectively.

The negative sign on the β-coefficient (the coefficient on the logarithm of the lagged wage rate) suggests that wages at the sector level are converging over time in the sense that member states with lower initial wages tend to enjoy faster wage growth rates. The forward and backward integration indices introduced in specification (2) to (5) are positive, but not always individually significant. The EU integration indices are both significant when they are entered alone in specification (2); as are the non-EU indices when they are entered alone in specification (3). However, when both EU and non-EU indices are included in specification (4), Backward EU and Forward non-EU are significant but not Forward EU and Backward non-EU. And when the indices are aggregated into a Backward World and Forward World in specification (5), both indices are significant and also of the same size.

We can therefore conclude that backward and forward integration into global and regional value chains is associated with larger wage increases for countries with low initial wages, but it is not always possible to distinguish the exact contribution of each of the four dimensions of integration (forward EU, backward EU, forward non-EU and backward non-EU). It should be noted that this does not necessarily mean that wages are converging overall in the European Union. That will depend on whether integration is general or concentrated to a group of countries. There is a possibility that integration is stronger among high-wage than low–wage countries. If so, wages may not converge but instead diverge. Furthermore, equation (13) is a conditional wage convergence model – conditional on the backward and forward integration of the member states relative to the size of the economy. The regression results suggest that wages will converge over time if all member states achieve the same level of integration over time for their respective size of the economy. However, if that is not the case wages may not converge fully.

7. Summary

Both the creation of the Single Market and the monetary union were designed to enhance integration and thereby promote more efficient use of resources and economic welfare, but their effects on integration has received relatively little attention by empirical research. Our paper uses tools from the global value chain, social network and wage convergence literatures to study integration of production in the European Union and how it has evolved over time. It makes both methodological and substantive contributions to the literature on European integration.

We find that integration of a member state is positively related to the size of the economy and the number of years it has been a member of the European Union. Although integration between member states increased substantially between 2000 and 2014 in terms of trade in intermediate inputs, this did not come at the expense of integration with non-members. On the contrary, integration with the rest of world increased more than integration between member states.

We also study the division of labour in the European Union. The new member states are suppliers of primary and manufactured inputs, except for Cyprus and Malta, which are exporters of services. The old member states increasingly export services instead of manufacturing inputs.

The geographical structure of the European production network can be described as consisting of hubs and spokes. Germany is the central and most important hub, while France, Italy and United Kingdom play less important roles as hubs. The centre of gravity of the production network has moved eastwards between 2000 and 2014, as could be expected following the accession of several Central and East European countries.

As a test of increasing integration, we analyse wage convergence across member states by regressing wage increases on measures of forward and backward production linkages both with other member states and with non-members. We find that wages increase faster for countries with low initial wages, which suggests that wages converge more rapidly as a result of integration.

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