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IMPULSES

This section appears at irregular intervals to present papers about conceptual debates and future developments in the field. For instance, this could be in the form of a new conceptualization, a discussion or re-development of a concept in the field, or an informed review and reflection about the field. The contributions relate to ongoing debates in the Journal of Economic Geography and speak to geography, economics and related fields in novel ways. The Editors invite scholars to participate in this discussion by submitting full-length academic papers for review.

Functional specialisation in trade

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Abstract

Production processes are fragmenting across borders with countries trading tasks rather than products. Export statistics based on value added reveal a process of vertical specialisation. Yet, what do countries do when exporting? In this article, we provide novel evidence on functional specialisation (FS) in trade. We find surprisingly large and pervasive heterogeneity in specialisation across countries. A positive (negative) correlation between GDP per capita and specialisation in R&D (fabrication) functions is documented. Specialisation in management and marketing functions is unrelated to income. We show how our approach can be easily extended to study FS in trade at the sub-national level. We argue that this is needed to better understand the potential for regional development under global integration.

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1. Introduction

International fragmentation of production has become pronounced, with firms carrying out specialised activities at specific geographical locations. In a simultaneous process of integration, local suppliers interact through cross-border flows of goods and services, technology and information. These global production networks are the topic of an expanding literature at the crossroads of geography, economics and business. It includes a rich body of work that analyses the coordination of activities within and across firms, the associated trade and knowledge flows and their interaction with regional development. The main aim of this article is to argue the need for a new generation of statistics that tracks what we refer to as *functional specialisation* (FS) in trade. These statistics capture trade flows of value added in particular activities such as R&D and fabrication, rather than trade in products. Based on a new dataset of occupations, we will provide for the first time a macroeconomic overview of specialisation patterns in the global economy. This contributes to a better understanding of the interplay of comparative advantages across regions, speaking to theories of multinational production and international trade (Markusen, 2002), urban development (Duranton and Puga, 2005) and global production systems (Gereffi et al., 2005; Coe et al., 2008).

The traditional approach to measure specialisation in trade is based on the product composition of countries' gross export flows. The shortcomings of this approach became increasingly apparent as international production fragmentation progressed. Based on gross exports numbers, one could, for example, find that the Philippines and China had a strong comparative advantage in high-tech products, such as electronics, at the end of the 1990s, while Japan and the USA did not (Lall, 2000). Yet, a country that appears to be a dominant exporter in a particular product may in fact contribute little value when production is fragmented. In an already classic case study, Dedrick et al. (2010) found that the Chinese contribution to its exports of electronics, such as Apple's iPod, was only minor. It mainly performed assembly activities on imported high-tech components while relying on software, supply chain orchestration and branding from East Asian and US companies.

In response, new trade statistics were developed based on the concept of value added in trade (Hummels et al., 2001; Johnson and Noguera, 2012). Countries were seen as to export a bundle of activities, some of which are carried out locally and others imported as in the trade-in-tasks concept popularised by Grossman and Rossi-Hansberg (2008). The key novelty was to include information from input–output tables such that one could measure the value that is added by domestic industries. These 'second generation' trade statistics have become part of the standard tool kit for trade analysts, available, for example, through the OECD/WTO trade-in-value-added initiative.

Table 1 provides an illustrative example of exports of electronic goods, which are produced in intricate networks crisscrossing many borders. It reports Balassa (1965) specialisation indices (also known as revealed comparative advantage indicators) for a select group of countries for the year 2011. Indices above one reflect specialisation and are shown in bold. China, Hungary, Mexico and Japan appear to be specialised in electronics based on gross exports (first column). Yet, a comparison with the second column, which is based on the value added in exports, reveals that Hungary and Mexico actually do not have comparative advantage in production of electronics for exports, while the USA does. This is because the latter country relies much less on imported intermediates to produce exports than the former countries, such that the share of domestic value added in its exports is much higher. The second-generation trade statistics thus provide a better assessment of where value added is created in global production networks.

Yet, value added trade statistics only capture part of the new reality of global production as they are silent on the nature of the activities that are performed in trade. With cross-border production sharing, countries can specialise in various stages of the production process. To this end we develop in this article a new, third, generation of trade statistics that not only traces value added but also characterises the activity a country performs in its exports. We refer to this as a *function* which is conceived of as a set of tasks carried out by a particular occupational class of workers. We will

Table 1. Specialisation indices for exports of electronic goods, 2011

Exporting country	Based on gross export value	Based on value added	Based on value added in functions			
			Fabrication	R&D	Management	Marketing
China	**2.56**	**2.57**	**4.02**	0.85	0.80	**2.19**
Hungary	**1.60**	0.97	**1.20**	0.83	0.70	0.97
Mexico	**1.54**	0.86	**1.83**	0.90	0.78	**1.12**
Japan	**1.38**	**1.57**	**2.06**	**1.49**	0.35	**1.91**
USA	0.90	**1.05**	0.59	**1.50**	**2.36**	**1.23**
Austria	0.66	0.72	0.50	**1.03**	0.82	0.68

Notes: Balassa indices based on comparing shares of electronics in exports of a particular country to similar share for all countries in the world, see Section 3. Exports of value added include value added by any industry in the export of goods from the electronics industry (ISIC rev. 3 industries 30 to 33). Indices bigger than one are in bold.
Source: Authors' calculations based on World Input–Output Database (November 2013 release) and Occupations database.

distinguish between four possible functions: fabrication, R&D, marketing and management (see Section 3 for further discussion). These functions differ in their demand for factor inputs as well as in their propensity to be relocated. For example, agglomeration forces are likely to induce spatial inertia in research and development activities, yet are much less relevant for assembly, testing or packaging activities (Mudambi et al., 2018). These activities are also likely to differ in their potential for productivity growth and in the generation of knowledge and other spillovers. Tracking FS is therefore crucial to better understand the position of a region in production networks and its potential for development under global integration as discussed in theories of the global production network (Henderson et al., 2002; Coe et al., 2008; Coe and Yeung, 2015) and global value chains (GVCs; Gereffi et al., 2001, 2005).

Using the FS approach reveals new and surprising patterns in trade, previewed in Table 1. Columns 3–7 show that Mexico and Hungary do have a comparative advantage in electronics production after all, but mostly in fabrication activities, and not in R&D or management activities. Similarly, comparative advantage of China is exclusively in fabrication and marketing activities. On the other hand, the USA and Japan are specialised in R&D, management and marketing activities associated with local multinational firms orchestrating and governing global networks of production. Interestingly, Austria appears to have a comparative advantage in R&D activities although neither gross exports, nor value added based indices revealed a comparative advantage. This example illustrates that the FS approach is not only conceptually appealing, but can also be fruitfully applied in empirical work and is able to uncover new patterns of specialisation. This is our main point, elaborated upon in the remainder of this article.

We proceed as follows. Section 2 briefly reviews the main findings from the first and second generation trade statistics on product and vertical specialisation in exporting. Based on a discussion of their limitations, we plea for shifting attention to FS. In Section 3, we lay out our methodology to trace FS in exports, and how to bring it to the data. We collected administrative data on occupational employment and wages, primarily from labour force surveys, for 35 industries in 40 countries. The new dataset is made public such that subsequent work is encouraged. This information is harmonised with information on inter-industry and inter-country flows of goods and services as recorded in the World Input–Output Database (the WIOD, see Timmer et al., 2015). Section 4 provides a discussion of empirical results on FS in the global economy, based on a variant of the Balassa (1965) specialisation index. We find a strongly positive correlation between GDP per capita and export specialisation in R&D functions, and a strongly negative correlation for fabrication functions. This reveals deepening of FS in the world economy. For management and marketing functions, correlations with GDP per capita are weak, however. Moreover, heterogeneity in specialisation patterns is large across countries at similar levels of income, suggestive of idiosyncratic factors that determine the local development of functions. These findings appear to be robust in additional bilateral analysis. Given abundant evidence for clustering of activities within countries, one would expect more extreme FS dynamics in (subnational) regions. Our approach has a natural extension to investigate regional specialisation in GVCs. Using new data for China, we report in Section 5 on FS of provinces in overall Chinese exports. This analysis is not only of interest by itself, but also serves to illustrate the rich potential of the method to help in better understanding the potential for regional development under global integration. Large-scale cross-regional analysis awaits further data development, however, as the availability of regional input–output tables and matching occupation statistics is still poor. Section 6 concludes, calling for further study of FS patterns in the world economy.

2. From product to functional specialisation in trade

2.1. Product specialisation in trade

The traditional approach to measure specialisation in international trade is based on analysis of countries' gross export flows. A country is said to specialise in a particular product when the product's share in its overall exports is higher than the corresponding share in exports of other countries (Balassa, 1965). This product specialisation index is often referred to as the RCA (revealed comparative advantage) index. RCA indices are widely used to test theories of trade, location, industrial structure and foreign investment. To this end, products are typically classified according to the factor input intensities of the parenting industries such as primary products which are intensive in natural resources and land, and manufactured products which are intensive in (un)skilled labour or capital. Endowment differences across countries seem to explain existing patterns of product specialisation in trade, in particular between poor and rich regions, as shown, for example, in early work by Leamer (1984). Romalis (2004) provides further evidence, showing that countries captured larger shares of trade in commodities that more intensively used their abundant factors. In addition, countries that rapidly accumulated a factor saw their export structures systematically shift towards industries that intensively used that factor.

Various authors highlighted hyper-specialisation in trade. Hanson (2012) documented that exports of low- and middle-income countries are typically concentrated in a limited number of products, based on trade data for narrowly defined product categories (6-digit HS code). Hausmann and Rodrik (2003) provide a model explaining hyper-specialisation based on externalities in export production through non-pecuniary knowledge spillovers or through externalities associated with making inputs available at a lower cost. Based on detailed import data for the USA, Schott (2004) finds that specialisation is even more fine-grained. He provides strong evidence of endowment-driven specialisation when manufacturing goods are distinguished by their 'quality' as revealed by differences in unit-values within very narrowly defined product categories (10-digit). The implication of Schott's findings is that developed countries seemed to specialise in higher quality goods while developing countries specialised in lower quality goods in the period studied (1972–1994).

Yet while trade economists have been reasonably successful in explaining the structure of trade at any point in time, they have been much less successful in understanding how the determinants of trade patterns change over time. This is particularly true since the dramatic entry of China, India and other emerging economies in the global economy and the formation of global production networks (Baldwin, 1989; Hanson, 2012). Lall (2000) was one of the first to point out that international production fragmentation posed a major threat to a clean interpretation of trade statistics as it '…does not indicate the *process* involved in making the same product in different locations. Thus, a high technology product like semiconductors can involve genuinely high-tech processes in the USA and relatively simple assembly in Malaysia. In our data both would appear equally technologically advanced. … we cannot deal with this in any consistent manner'. (Lall, 2000, 340). Fortunately, this statement turned out to be too pessimistic.

2.2. Vertical specialisation in trade

In an influential contribution, Hummels et al. (2001) proposed a new measure of 'vertical specialisation in trade' that captures the degree of international production fragmentation. It is measured as the share of domestic value added in gross exports.[1] This share is one when all activities needed to produce exports are performed within the exporting country. The share is declining in the amount of intermediates imported. A country with a low share is thus said to be vertically specialised in trade, carrying out a limited number of production stages for its exports. To measure this, product export statistics needed to be complemented by information on value added. Importantly, this is the value added by the exporting industry (in the last stage of production), but also by other domestic industries in upstream stages of production.

Hummels et al. (2001) relied on a procedure that was originally developed by Leontief (1953).[2] Using input–output tables for 14 countries compiled by the OECD, they found that vertical specialisation increased in all countries (except Japan), suggesting a widespread process of production fragmentation in the world economy between 1970 and 1990. It was pointed out that increased interdependence of countries had major implications for trade policy, for example, through cascading effects of import tariffs and other types of trade protection (Yi, 2003) as well as regulatory policy such as labour standards (Feenstra, 1998). Johnson and Noguera (2012, 2017) provided broader

1 To be precise, Hummels et al. (2001) defined a measure which they called the 'import content of exports'. Koopman et al. (2012) defined 'domestic value added in exports, and showed that it is equal to gross exports minus the 'import content of exports'. We follow the 'domestic value-added' terminology as it can be clearly contrasted with other trade measures in a unified framework as shown in Los et al. (2016) and Los and Timmer (2018).

2 Less well known, Chenery et al. (1986) provide similar analyses that foreshadow this work.

evidence, documenting vertical specialisation in 36 out of 37 countries.[3] They also showed that the global ratio of value added to gross exports declined by about 10 percentage points over the four decades from 1970 to 2008. Fragmentation accelerated over time as the ratio was falling roughly three times as fast during 1990–2008 compared to 1970–1990.

The rise of China as a prime location for assembly activities was boosted by its accession to the WTO in 2001. It relied heavily on processing trade as firms imported the major parts and components, typically with tariff exemptions and other tax preferences, and, after assembling, export the finished products. Koopman et al. (2012) found that in 2002, the share of domestic value added in Chinese exports of electronic computers was only 19.3%. For all manufacturing exports, the share was 50% in 1997 and 2002, increasing to 60% in 2007. This suggested that China gained the capabilities to substitute imported intermediates by domestic products, taking over more advanced production activities. Kee and Tang (2016) provide further firm-level evidence for this process of upgrading. The study of Koopman et al. (2012) led to a general recognition of the importance to account for heterogeneity in import use across different types of firms, in particular those located in export processing zones that typically use more imported inputs.[4]

Studies of vertical specialisation in trade also exposed the increasing irrelevance of a product or industry classification of trade flows. Value added originates not only from the sector that is exporting but also includes value added generated in other domestic industries in upstream stages of production. For the world as a whole, manufacturing goods account for nearly 70% of gross exports, and services account for 20% (in 2008). In contrast, manufacturing and services industries both account for about 40% of total value-added exports (Johnson, 2014, Figure 1). Most of the value added by services sectors is through delivering intermediates to manufacturing production whose output is subsequently exported. For example, Koopman et al. (2014, Figure 2) showed that based on gross exports Japan is not specialised in business services, while India is (in 2004). In terms of sectoral value added, the situation is reversed, however, as Japan exported many services indirectly through exports of manufacturing goods. Taking account of upstream stages of production is thus crucial in measuring value added in trade flows.

Trade in value added (TiVA) measurement has quickly expanded and broadened into a wider set of so-called GVC measures. This was made possible by various initiatives that generated the multi-country input–output data needed to calculate the measures. They are published on a regular basis by the OECD/WTO TiVA initiative (available at *oe.cd/tiva*).[5]

3 Johnson and Noguera (2012) introduced the concept of 'value added exports'. It is defined as the value added generated in a country that is consumed (absorbed) abroad and has been developed as a measure of exports that fits international trade models that are written in value added terms (Johnson, 2014). Its measurement requires international input–output tables that track origin and destination of trade flows. Empirically the measure is close to 'domestic value added in exports' as long as overall exports of a country are analysed. This is not true for bilateral trade flows however, see Los and Timmer (2018) for a comprehensive discussion.

4 Using detailed data on imports and exports of Mexican firms, de Gortari (2017) finds that import intensities of output can also vary across destination markets.

5 Johnson (2017) provide useful overviews. See Dietzenbacher and Tukker (2013) for an in depth review of available data.

2.3. Towards functional specialisation in trade

With cross-border production sharing, countries can specialise in various stages of the production process. And while measures of vertical specialisation are informative of a country's value-added contribution to its exports, they are silent about the characteristics of the tasks carried out. Yet, this is crucial to understand the position of a region in global production networks and its potential for development. A low value added to gross export ratio may reflect specialisation in different activities that vary highly in skill and technology content. For example, a country's value added in exports is typically low when it concentrates on the final stage of production (before delivering to the consumer). Yet the activity in this stage can be low-tech (such as assembling a laptop out of imported complex components) or high-tech (such as manufacturing an engine and putting it in an imported car body). Moreover, a country can specialise in trade without importing. Suppose that a country (the USA) initially produces cars at home, carrying out all stages of production. Then it starts to export car parts to Mexico, where these are assembled into final products and subsequently exported. In this case, the USA is specialising in a particular upstream stage of production, yet the share of value added in its exports is unchanged (namely unity). Value added in exports is thus an incomplete measure of specialisation in trade. Information on the type of activity, or function, carried out needs to be added.

One way to characterise activities is through tracking the industry in which value is added, as in Koopman et al. (2014) and Johnson and Noguera (2012, 2017). Value added from manufacturing industries could be equated with fabrication activities and value added from services industries with supporting (headquarter) activities. But functions are different from industries and there is no simple one-to-one mapping, as emphasised in earlier literature on urban development, such as Duranton and Puga (2005) and Barbour and Markusen (2007). Administrative data is organised through classifying establishments (or firms) by their primary activity, which is the activity that makes the largest contribution to value added. In practice establishments perform various activities and combine these in-house (Bernard et al., 2017). Importantly, this mix is changing over time, known as 'servicification of manufacturing'. Crozet and Millet (2017) find that, in 2007, 40% of French firms classified as manufacturing sold more services than goods. Kelle (2013) found a large shift in German manufacturing firms toward services exports, for example, in installing and maintaining machinery. Bernard and Fort (2015) document the rise of factory-less goods producers in the USA. These firms design the goods they sell and coordinate production networks, yet are not actually engaged in fabrication activities. They might be classified as wholesalers or as manufacturers in the current US industrial statistical system. Fontagné and Harrison (2017) provide wider evidence for this phenomenon. This indicates that we cannot rely on a mere statistical classification of industries to understand FS in trade.

There is another problem with the second-generation trade statistics that distorts a territorial interpretation. They track the value that is added by factor inputs in a particular geographical area, which is not necessarily related to the income that is earned by local workers and entrepreneurs. Value added consists of compensation for workers and a gross operating surplus that accrues as income to the owners of capital assets (tangible physical assets as well as intangibles). The emergence of global production chains involved sizeable flows of cross-border investment, and part of the generated value-added will accrue as capital income to multinational firms. The residence of the ultimate recipients of this income is notoriously hard to track, not least because of the notional relocation of profits for tax accounting purposes (Lipsey, 2010; Guvenen et al., 2017). This obscures a territorial interpretation of value added trade statistics as capital income shares in value added are large, especially in poorer countries (Timmer et al., 2014). We will present a measure of FS that is not prone to this problem as it is exclusively based on labour income. In contrast to capital income, labour income is much more likely to remain in the region as workers typically reside close to the production location.

3. Measuring functional specialisation in trade

In this section, we outline our framework to measure functional specialisation (FS) in international trade. In short, the contribution of a particular function to a country's exports is measured by the income of domestic workers that carry out this function. We start with a formal description of our new measure of FS in trade and provide some caveats for proper interpretation. Next, we discuss data and measurement methods.

3.1. An index of functional specialisation

The standard tool to analyse specialisation patterns is by means of the Balassa index, after Balassa (1965), which originally referred to the relative trade performance of countries. It compares a country's share in world exports of a particular product group to its share in overall exports. Variants of this approach relate this to shares in specific markets or trade partners. As discussed above, a country that looks like a dominant exporter in a particular product may in fact contribute little value to those exports. Koopman et al. (2014) argue therefore that specialisation indices should be calculated on the basis of value added instead.[6] We continue this line of reasoning and introduce specialisation indices based on labour income in functions.

Let subscript i be a country, and define f_i^k the income from function k in country i's exports. We then define the FS index for function k in country i as

$$\mathrm{FS}_i^k = \frac{(\mathrm{f}_i^k / \sum_k \mathrm{f}_i^k)}{\sum_i \mathrm{f}_i^k / \sum_i \sum_k \mathrm{f}_i^k} \tag{1}$$

The numerator measures the share of function k in overall income in country i's exports. The denominator calculates the income share of this function for all countries in their exports. If the index is above one, the country is said to be specialised in that function. Note that throughout this section, we take the country as the unit of observation. Yet nothing in the method precludes application to sub-national regions, as shown in Section 5.

Balassa type indices have the benefit of being simple and intuitive, and variants have been utilised in countless studies. Yet, how should it be interpreted? It is often referred to as an index of revealed comparative advantage. French (2017) shows that in a world with frictionless trade, the standard Balassa index (based on gross exports) would indeed be a theoretically-consistent indicator of comparative advantage. Yet, bilateral trade costs and market conditions interact with the forces of comparative advantage in determining a country's exports. These may differ across destinations. French (2017)

6 See Ceglowski (2017) for a recent application.

argues therefore that relative *bilateral* trade flows better reflect countries' fundamental patterns of comparative advantage. In that case, the effects of comparative advantage can be isolated from other bilateral and market-specific effects of trade distortions. We therefore also define a bilateral FS index for country i exporting to country j as follows:

$$\mathrm{BFS}_{i,j}^{k} = \frac{(\mathrm{f}_{i,j}^{k}/\sum_k \mathrm{f}_{i,j}^{k})}{\sum_i \mathrm{f}_{i,j}^{k}/\sum_i \sum_k \mathrm{f}_{i,j}^{k}} \tag{2}$$

The numerator in the bilateral index is the share of function k in overall exports from country i to market j. It is expressed relative to a 'bundle' of exporters to the same market. As a result, it can be interpreted as a measure of country i's ability to deliver function k to market j, relative to all countries that export to j.

Three remarks are in order at this point. Firstly, the FS index has intuitive appeal as a measure of specialisation, but should not be straightforwardly interpreted as a measure of (revealed) comparative advantage. If, according to Ricardian trade theory, differences in relative productivity determine the pattern of trade, then the (observable) pattern of trade can be used to infer (unobservable) differences in relative productivity. French (2017) shows how the Balassa index straightforwardly maps into variables of a commonly used class of quantitative trade models. These models feature trade in final goods and await further development of models that feature trade in tasks as well (Baldwin and Robert-Nicoud, 2014; Antràs and de Gortari, 2017).

Secondly, it might be noted that the FS index is related to concentration indices traditionally used in economic geography, for example, a Herfindahl index based on the distribution of employment (or value added) across industries in a region. Yet, the FS index is fundamentally different as it is based on a comparison of shares, not distributions. More importantly, it is only based on a subset of activities in a region, namely those that are (directly and indirectly) related to exporting. As such, it provides a natural delineation between traded and non-traded activities which cannot be made using only employment or industry statistics (Kemeny and Storper, 2015).

Finally, it should be noted the labour incomes are nominal values, stated in a common currency (US$) which reflects that countries compete in an international market for carrying out these functions.[7] It might also be insightful to realise that functional income is the product of the number of workers carrying out the function, their productivity in doing so (value added per worker) and the labour income share in value added. Changes in any of these subcomponents may affect the FS index, but only when they differentially affect the functions. For example, an increase in the productivity of all workers in a country will, ceteris paribus, not have an impact on its FS indices, but an increase in productivity that only affects say fabrication workers might. Pursuing this decomposition is an interesting avenue for future research, relating FS to technological change and income distributions in global production.

3.2. Measurement framework

Our measurement proceeds in two main stages. We first trace domestic value added in exports. Importantly, this contains value added that is contributed by the industry that is

7 This also means that incomes can be aggregated across countries in the denominator. It is easy to show that the shares are invariant to the choice of another numeraire currency.

exporting and the value-added contributions of other domestic industries that contribute indirectly through the delivery of intermediate inputs. To account for these indirect contributions, one needs to use information from input–output tables. In a second step we extend this approach by tracing what type of workers (characterised by occupation) were involved in production. This procedure is often used in studies of the factor content of trade, and harks back to the seminal work by Leontief (1953). For example, Wolff (2003) analysed the changing occupation content of US exports. Labour content is typically stated in quantities such as number of workers. We differ as we want to track the value added of workers as measured by their labour income. Moreover, our approach is more general and can also be used in a multi-country setting, tracking domestic as well as foreign contributions, as outlined in Section 5.

Let $\mathbf{e}$ be a vector of exports (of dimension G $\times$ 1) with G the number of goods in the economy.[8] Let $\mathbf{A}^D$ be the G $\times$ G domestic coefficient matrix with typical element a_{st} indicating the amount of domestic product s used in production of one unit of t (all in nominal terms).We can then derive a vector $\mathbf{y}$ (G $\times$ 1) which represents the total gross output needed in each industry to produce exports as:

$$\mathbf{y} = (\mathbf{I} - \mathbf{A}^D)^{-1}\mathbf{e}, \tag{3}$$

where $\mathbf{I}$ is a G $\times$ G identity matrix with ones on the diagonal and zeros elsewhere. $(\mathbf{I} - \mathbf{A}^D)^{-1}$ is the well-known Leontief inverse matrix which ensures that all domestic output related to exports, direct and indirect, are taken into account. It should be noted that this type of analysis does not depend, nor presumes, that the production process is linear, although it is often illustrated through simple examples based on a chain-like sequence of activities resulting in a finished product. Yet, the method is equally valid in more complex constellations, in fact in any network of production that can be described by individual stages of production that are linked through trade.[9]

Let vector $\mathbf{d}$ (G $\times$ 1) be the amount of domestic value added needed for a country's exports. It can be derived by pre-multiplying $\mathbf{y}$ as given in Equation (3):

$$\mathbf{d} = \mathbf{V}\mathbf{y}, \tag{4}$$

where $\mathbf{V}$ is the matrix (G $\times$ G) with diagonal element v_{gg} representing the value added to gross output ratio for industry g and zeroes otherwise. Note that vector $\mathbf{d}$ contains value added generated in industries that export as well as in non-exporting industries through the delivery of intermediate inputs.

For the purpose of this article, we extend this approach as follows. Let $\mathbf{B}$ be a matrix of dimension K $\times$ G, where K is the number of different functions. A typical element of this matrix (b_{kg}) denotes the income of all workers performing function k in industry g, expressed as a share of value added in g. Then

$$\mathbf{f} = \mathbf{B}\mathbf{d}, \tag{5}$$

where vector $\mathbf{f}$ of dimensions ($K \times 1$) with typical element f^k representing value added by function k in a country's exports.

8 Each product is associated with an industry, so G is also the number of industries.

9 It does rely on the assumption that the same technology is used in an industry, irrespective of the production stage in which it operates. When richer firm-level information becomes available, this decomposition framework can be readily adapted.

Substituting (4) and (3) in (5), we derive

$$\mathbf{f} = \mathbf{BV}(\mathbf{I} - \mathbf{A}^{D})^{-1}\mathbf{e} \quad (6)$$

This is our key equation to measure the domestic value added by function in a country's exports. When vector **e** includes all exports made by country *i*, then the calculated vector **f** will contain elements f_i^k, the domestic value added from function *k* in country *i*'s exports. These elements are needed to calculate the FS index in Equation (1). By appropriately modifying vector **e**, such that it only includes exports to *j*, one can derive the $\mathrm{f}_{i,j}^k$ needed for the bilateral measure in Equation (2). Alternatively, **e** can be chosen such that only exports of say electronics are analysed, as reported on in Table 1.

It should be noted that the value added by a function is measured by the income of workers that carry it out. The sum across all functions (all elements of **f**) is thus equal to the overall wage bill in gross exports. Capital income, which is the remainder when wages are subtracted from domestic value-added exports is not further analysed.[10] Capital assets cannot be straightforwardly allocated to functions, in contrast to workers. For example, a computer can be utilised in many tasks and we have no information on its particular use. In addition, the ownership of capital income is hard to assess as discussed above.

3.3. Data sources

An important quandary in understanding specialisation is how to define a set of activities that 'go together' and conversely, where to draw the boundaries between activities that are 'different' (Kemeny and Storper, 2015). Moreover, these boundaries will change over time as the 'glue' that binds activities together might dissolve due to technological advances (Baldwin, 2016). This is a complicated matter, both in concept and empirically. Here, we take a pragmatic solution, that is, inspired by studies of offshoring behaviour of multinationals and allows for quantification across a large set of countries with available data sources. A well-known distinction is between fabrication and headquarter activities, typical associated with unskilled (blue collar) and skilled (white collar) labour. Fröbel et al. (1977) was one of the first studies to document the 'new' international division of labour in which advanced countries (West-Germany in their case) off-shore fabrication to low-wage regions, while retaining headquarter activities at home. We start from that distinction and map our list of occupations to four so-called business functions: fabrication, R&D and technology development (abbreviated R&D), sales and distribution activities (Marketing), and other support activities (Management). These groups constitute a relevant level of analysis as multinational firms typically organise their activities around these functions due to internal economies of scale (Porter, 1985).[11]

10 Timmer et al. (2014) show that capital income makes up around 35% of the value of manufactured goods, with an increasing trend over 1995–2011.

11 Online appendix Table A2 shows the business functions that we distinguish, their descriptions as well as exemplary occupational categories. The full mapping of occupations to business functions is also provided online. It further provides additional data for US manufacturing firms that externally validate our approach. Ideally, we would like to distinguish more functions, but we had to strike a balance between the level of detail and maintaining comparability across countries and over time. One possibility is to use the industry in which the worker is employed as an additional characteristic beyond the occupational status. For example, it might be argued that a fabrication activity in mining is 'different'

Recent research confirms that business functions define the boundaries of activities that are co-located in particular locations, and are the relevant unit in firms' decision to offshore (Sturgeon and Gereffi, 2009; Nielsen, 2018). Using the categorisation suggested by Blinder (2009), we find that about 83% of the jobs that we relate to the R&D function is considered to be 'highly offshorable' or 'offshorable' (for the US goods industries in 2004). This rate is 65% for fabrication activities, 64% for management activities and the lowest for marketing activities (43%). Yet, offshorability of individual jobs does not take into account benefits of co-location and tacit knowledge flows that can bind jobs together in particular locations. For that reason, science-based activities might be less likely to be relocated than, for example, assembly activities (Baldwin and Evenett, 2012; Lanz et al., 2013; Mudambi et al., 2018). The strength of these spillovers are likely to be positively related to the educational requirements for each activity. Based on cross-classified data (occupation by educational attainment level) from the *American Community Survey* 2007 we find that the share of college educated workers varies from a low 0.07 in fabrication activities, 0.27 in marketing, 0.54 in management and up to 0.67 in R&D activities carried out in the USA. Further research into the mapping of factor inputs into functions is needed to relate FS to countries' factor endowments and remuneration.

We built up a new Occupations Database from detailed survey and census data for forty countries, including all EU 27 countries (as of January 2011), Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Korea, Taiwan, Turkey and the USA. For each country, data is collected for 35 industries (this provides information for our matrix **B**). These include agriculture, mining, construction, utilities, fourteen manufacturing industries, telecom, finance, business services, personal services, eight trade and transport services industries and three public services industries. For each country-industry, we have collected time series information on occupations of workers and their wages. For the USA, we use the same data sources as in Autor (2015), namely the *2000 Current Population Census* and the annual *American Community Surveys*. Data for European countries are from the harmonised individual level European Union *Labour Force Surveys*. For the remaining countries we obtain the required data from national statistical offices. For example, for China we obtain occupations data from the population censuses. We find large variation in the occupational distribution of workers in the same industry across different countries. For example, in 2011 the income share of R&D workers in the electronics industry in the USA was 29%, while only 9% in China. Conversely, the income shares are respectively 15% and 69% for fabrication workers. In the Online Appendix, we list the main sources of data for each country. We also provide the business functions data file and programs for replication. Information can be found in the additional Online Material to this article at the journal's website.

A major challenge is the creation of consistent time series. We harmonise the data by mapping national industry classifications to the *International Standardised Industrial Classification* (ISIC) revision 3.1. Furthermore, the national occupation classifications are mapped into a single classification of occupational groupings based on the International Standard Classification of Occupations 1988 (ISCO). Constructing a common occupational classification is difficult, because national classifications need

from a fabrication activity in textiles or in retailing, if only because of higher impediments for relocation given the complementarity with mining sites. This requires a more explicit discussion about what makes particular activities 'stick' to a location, a fruitful avenue for further work.

not be based on similar guiding principles. For example, some statistical offices categorise workers by level of skill and others by area of expertise. We use crosswalks provided by statistical offices to guide our mapping. A second challenge is information on wages. The EU *Labour Force Surveys* do not provide information on wage incomes, and we complement this with information from the EU *Structure of Earnings Surveys*. For China, we obtain wage data from the IZA *Wage indicator surveys*. Other countries provide wage and employment information in the same data source.

To apply our methodology we need further information on exports (**e**), industry output and value added (**V**) and domestic intermediate requirements ($\mathbf{A^D}$) for each country.[12] Annual data for these variables is taken from the 2013 release of the WIOD which has a similar industry classification as the occupations database. The WIOD is constructed using the conceptual framework of the System of National Accounts and on the basis of published national accounts and international trade statistics, as discussed in Dietzenbacher et al. (2013) and Timmer et al. (2015). As such it takes into account reported nominal flows of goods and services between plants within and across countries. This includes arm's length transactions through the market (inter-firm trade), as well as transactions between affiliated plants (intra-firm trade). The value of intra-firm trade might differ from market valuation due to transfer pricing practices in particular involving intellectual property. Tracing the size of these distortions is notoriously difficult and an important area of research (Neubig and Wunsch-Vincent, 2017; Guvenen et al., 2017).

4. Functional specialisation in trade: main trends

This section presents and discusses trends in FS in trade for the period from 1999 to 2011. The length of the period studied is dictated mainly by the scarce availability of data on occupations. While relatively short, this period is characterised by a rapid process of international production fragmentation with increased foreign direct investment flows and associated trade in intermediate goods and services, boosted in particular by the accession of China to the WTO.[13] We have three main findings.

Finding 1: FS in the global economy deepens

Since the 1970s, the world economy has been characterised by a (then) 'new' international division of labour where firms in advanced countries off-shore manual production activities to low-wage regions, while retaining headquarter activities at home. This was first documented extensively in a study of West-German firms by Fröbel et al. (1977). Dicken (1992) provides a broader view highlighting the declining share of advanced nations in global manufacturing employment and exports. With advances in information and communication technology, a similar offshoring process could be observed for particular business services. A theoretical underpinning based on differences in factor endowments is provided in classic work on multinational production by

12 It should be noted that the FS index only requires information on intermediates sourced from other domestic industries. Put otherwise, it requires information on the imports of a country, but not on the origin of the imports. As such, a national input–output table provides sufficient information and there is no need to use a global input-output table (Los et al., 2015, 2016).

13 Timmer et al. (2016) show increasing international fragmentation of production in the period up to the global financial crisis in 2008. Afterwards the fragmentation process lost pace, but did not reverse.

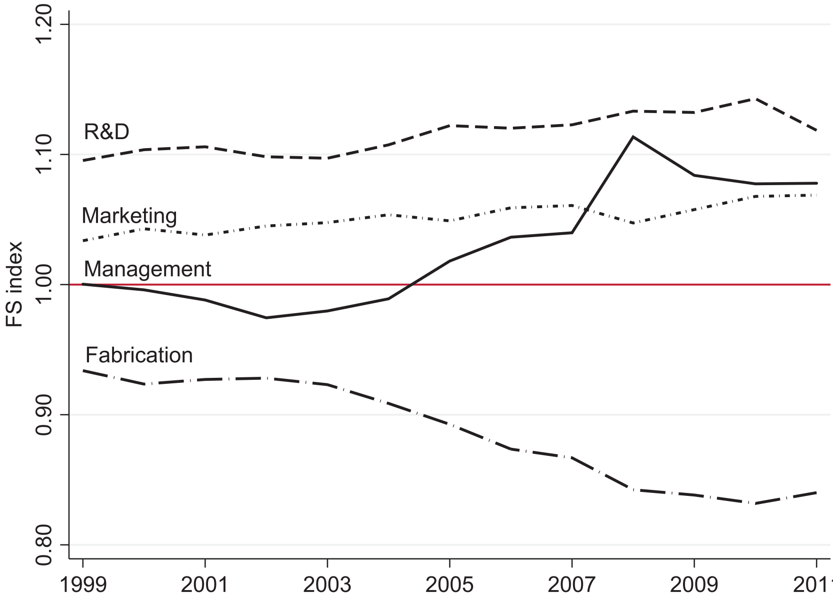


Figure 1. Functional specialisation of advanced countries in exports.
Notes: Observations above the horizontal line indicate specialisation in a function ($FS \geq 1$). Advanced countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Luxembourg, The Netherlands, Portugal, South-Korea, Spain, Sweden, Taiwan, UK and the USA. Calculated according to Equation (1), comparing functional income shares in exports of all goods and services by all advanced countries to the same shares for all countries in the world.
Source: Authors' calculations based on World Input–Output Database (November 2013 release) and Occupations database.

Markusen (2002), see also Feenstra (2010). The interaction of declining communication and coordination costs and the opening up of labour-abundant economies such as India and China played a decisive role in accelerating this process (Baldwin, 2016).

Our results show that the global division of labour even deepened in the 2000s as advanced countries continued to de-specialise in fabrication activities. Figure 1 shows the evolution of the FS index for the period 1999–2011 based on aggregated exports from a set of 21 advanced countries in the world.[14] The FS index in this figure is calculated according to Equation (1). We find that advanced economies continued to specialise in head quarter activities, while de-specialising in fabrication activities. Throughout this period, the FS indices for R&D and for marketing were well above unity, and gradually increased. In contrast, the importance of fabrication activities was already low in 1999 and continued to decline further in the 2000s. The strongest swing is found for management activities whose importance quickly picked up, such that by 2011 a pattern of deep specialisation in the world economy is established with headquarter activities mainly in Europe, the USA and East Asia, and fabrication activities in other parts of the world.

Since the mid-1990s, China has been a major offshoring and production location and it quickly became the world's largest exporter of goods at the end of the 2000s. Its FS index

14 These are the 15 countries that joined the European Union before 2004 plus Australia, Canada, the USA, Japan, South Korea and Taiwan.

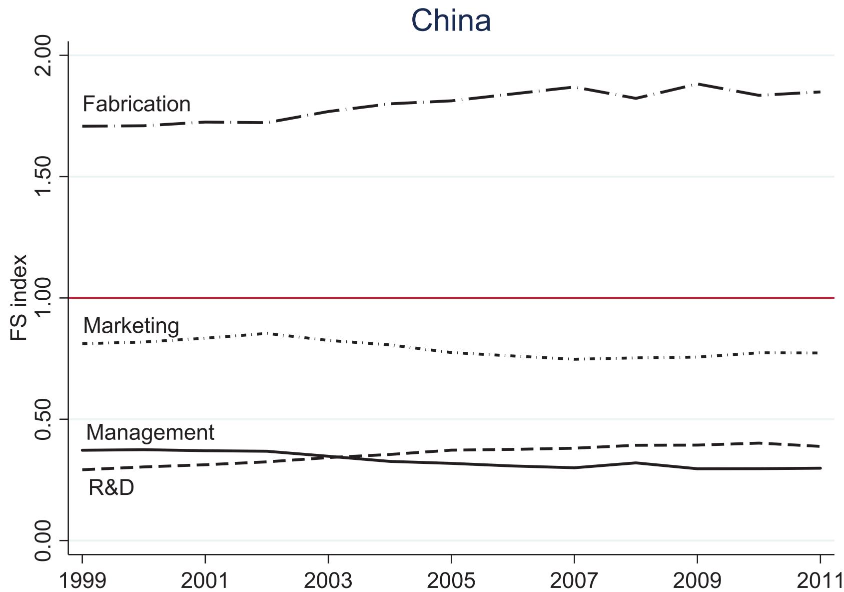


Figure 2. Functional specialisation of China in own exports.
Notes: Observations above the horizontal line indicate specialisation in a function (FS ≥ 1). Calculated according to Equation (1), comparing functional income shares in exports of all goods and services by China to the same shares for all countries in the world.
Source: Authors' calculations based on World Input–Output Database (November 2013 release) and Occupations database.

for fabrication was already high in 1999, increased even somewhat further after 2001 when it joined the WTO, and levelled off after 2007 (Figure 2). The income share in exports from fabrication activities in China is estimated to be about 63.4% in 2011, with an FS index of 1.85 by far the highest in our set of countries. Headquarter activities are relatively unimportant: R&D, management and marketing have FS indices of, respectively, 0.39, 0.30 and 0.77 in 2011. At first sight, these results might run counter other findings that suggest industrial upgrading in Chinese manufacturing in the second half of the 2000s, substituting imports of sophisticated parts and components by local goods whose production arguably requires more R&D and other headquarter activities (Kee and Tang, 2016). And indeed, we find that, in absolute terms, the income generated in headquarter activities has rapidly increased. Yet our findings also suggest that fabrication activities were growing even faster, such that the FS index of R&D, which is stated relative to other functions, remains low. This does not exclude the possibility that more profound changes took place in production of goods that are mainly sold domestically, for example, under local brand names. Such type of upgrading would not be captured in the FS index which is based on analysis of production for export only.[15]

15 In addition, it should be pointed out that we do not have data that distinguishes between processing and non-processing firms (Koopman et al., 2012). This is becoming less of a problem as export processing zones decline in (relative) importance.

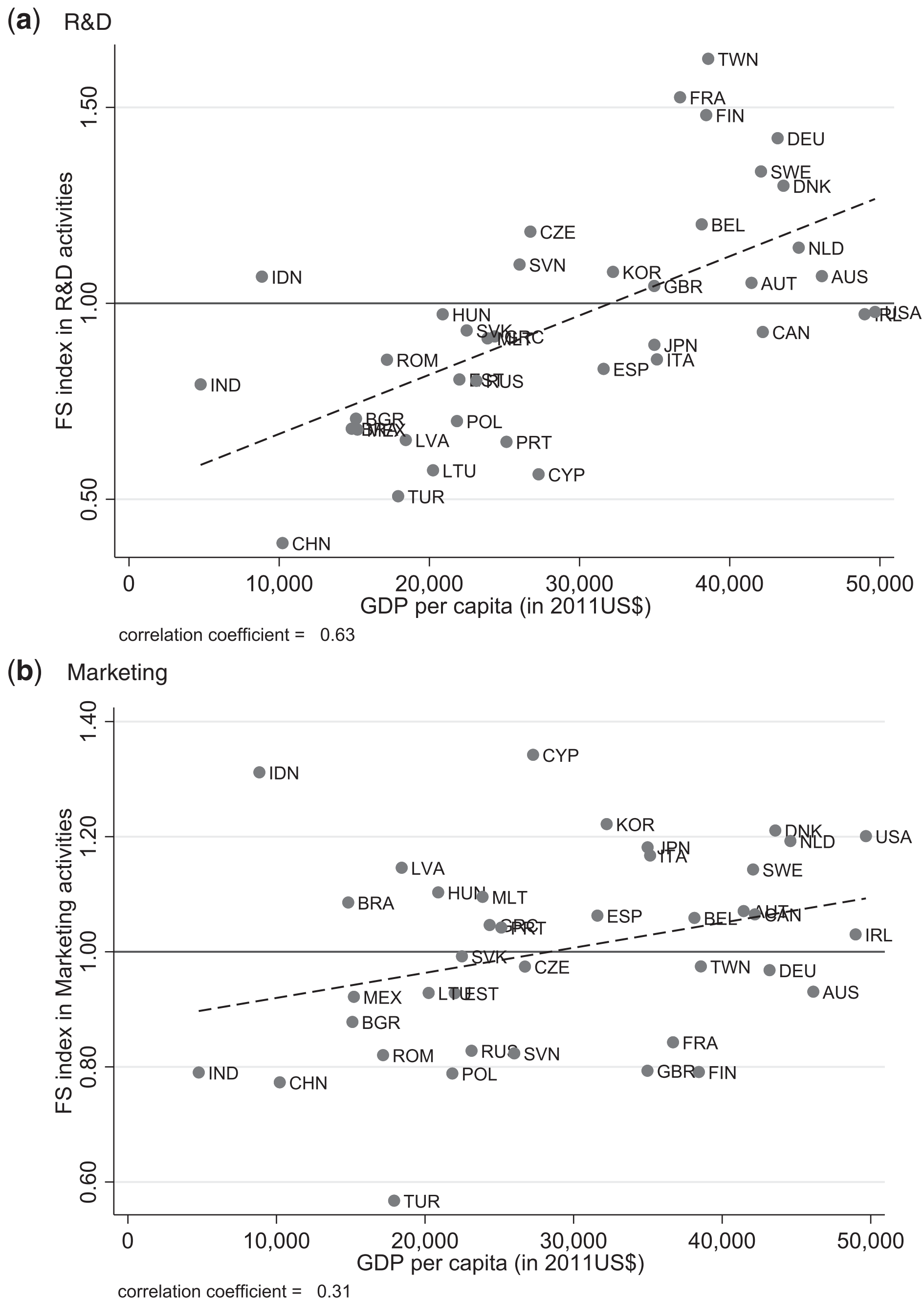
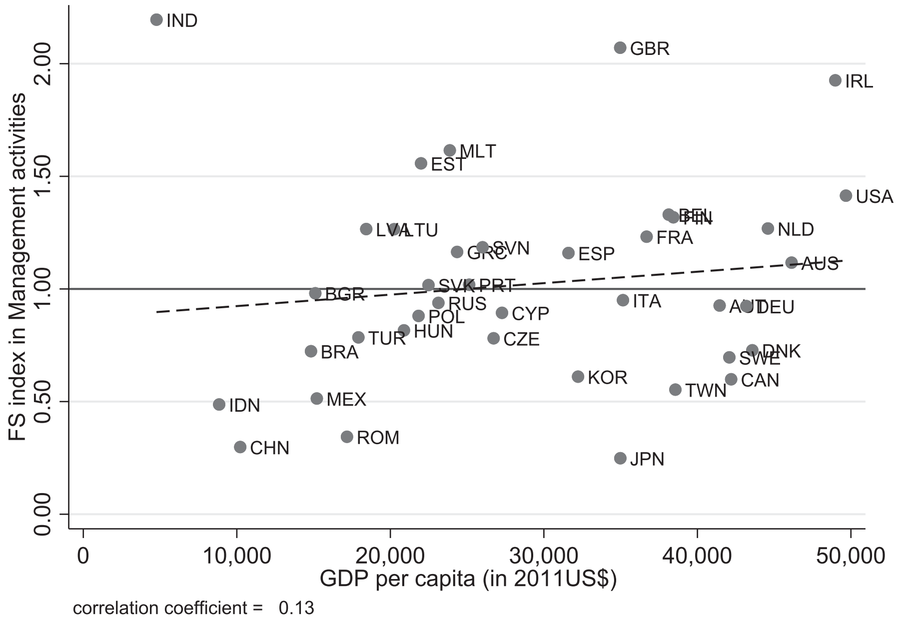


Figure 3. FS in own exports (by country), 2011.
Notes: Countries above the horizontal line indicate specialisation in a function (FS ≥ 1).
Source: Authors' calculations based on World Input–Output Database (November 2013 release) and Occupations database. GDP per capita from Feenstra et al. (2015).

(c) Management



(d) Fabrication

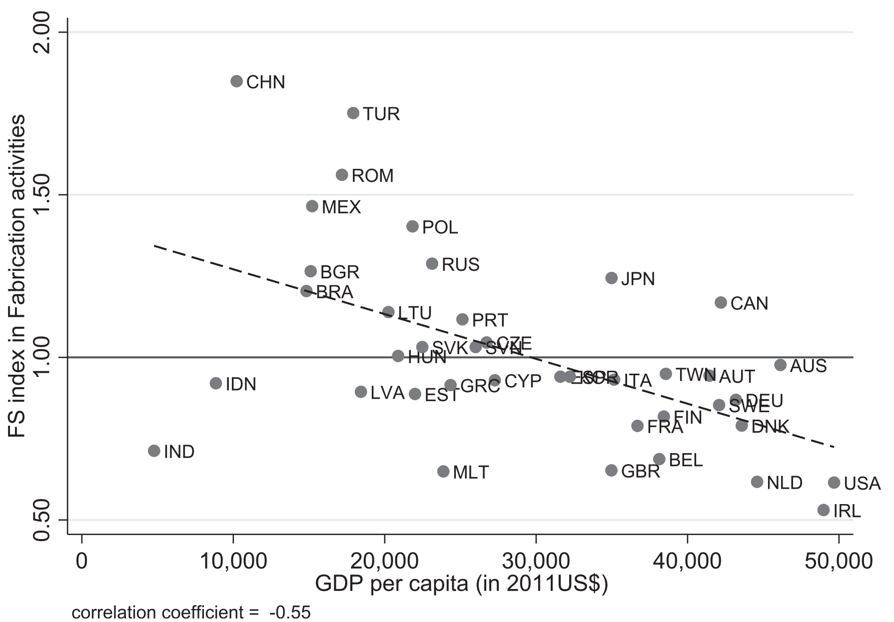


Figure 3. Continued.

Finding 2: High degree of heterogeneity in FS across countries

Our detailed data on functions allow for a sharper focus on the type of activities countries carry out in the global economy. Perhaps surprisingly, we find that advanced countries at similar levels of income can have rather different specialisation patterns. This is clear from Figure 3, which plots GDP per capita against the FS index for our set of forty countries (in 2011). This helps to uncover broad relations between levels of economic development and FS. A plot graph is given for each of the four functions. The horizontal lines separate country observations with FS indices below and above one. (For reference, the values for the FS indices for each country are given in Appendix Table A1). The first panel in Figure 3 shows a clear correlation between GDP per capita and FS in R&D activities (Pearson correlation of 0.63). In 2011 most advanced economies have a clear comparative advantage in R&D activities, in particular Taiwan, France, Finland and Germany. In Italy and Japan, the FS indices are well below one, although they increased over the period from 1999 to 2011, converging to the R&D specialisation of most other advanced nations (see Appendix Table A1). One can conclude that specialisation in R&D is a widespread phenomenon for advanced economies.

This pattern is much less clear for the other headquarter activities though. The second and third panels in Figure 3 show FS indices in marketing and management activities, respectively. Correlation with GDP per capita is positive, but much less strong: 0.13 for marketing and 0.30 for management. One group of countries, including Belgium, Ireland, the Netherlands, Spain and the USA, has a comparative advantage in both activities. Austria, Canada, Denmark, Japan, Italy, South Korea and Sweden are specialised in marketing activities, but not in management. In contrast Finland, France and the UK are specialised in management activities, but not in marketing. To understand the reasons for this variety, more detailed case study is required. But as a first step one can relate this to the type of goods and services that an economy exports. For example, UK's strong comparative advantage in management is related to its exceptional high export share of financial services, as this industry is generally characterised by a high share of management workers relative to other industries (in the UK, but also in other countries). Similarly, the Canadian specialisation in fabrication activities in 2011 is related to its unusual large export share of natural resources compared to most other advanced countries. Mining and manufacturing of primary products such as steel have a high share of fabrication activities, that is, well above the economy-wide average. Yet, there might be other determinants of specialisation. For example, consumer demand in Japan is well known to have a strong preference for local brands and quality, which might drive an unusual large share of fabrication activities to still take place locally. South Korea is specialised in marketing partly related to the large share of electronics and automotive exports. These industries have an exceptional high share of marketing activities in South Korea compared to other countries, which opens up avenues for further inquiry into the particular setup of production networks of South Korean multinationals in the region and beyond.

Heterogeneity is also found among less advanced countries. Specialisation in fabrication activities is negatively related with income per capita (correlation of −0.55). Yet also for this function, strong heterogeneity can be observed, as shown in panel *d* of Figure 3. India has much smaller shares of fabrication activities in their exports. The Indian economy is well known for its stunted industrial development, characterised by a high share of small-sized firms (Ahsan and Mitra, 2017). Firm owners are classified as managers, who will drive up the FS index for management. Another reason is related to the large share of IT services in Indian exports. Lower level IT workers are not likely to be classified as fabrication workers in the occupation statistics, yet from our perspective, this would be desirable as their jobs share many characteristics with the typical fabrication job in manufacturing, such as the high degree of routineness (Autor, 2015).

Finding 3: FS patterns are pervasive

The findings so far suggest that there are many idiosyncratic determinants of a country's specialisation pattern. All advanced countries have well-functioning legal systems, high-quality infrastructure and in general high levels of human capital. Differences in specialisation must be driven by other characteristics such as the size of the country, attractiveness for multinational headquarter location, geographical characteristics, as well as historical built up of capabilities and networks. These characteristics are likely to develop (and dwindle) only slowly. In Table 2, we provide a transition table for FS that confirms this hypothesis. Each country is allocated to a group according to the function for which it had the highest FS index for a given year. This maximum can only be for one function such that the groups are mutually exclusive. So, for example, Denmark is found to be specialised in R&D in 1999 as its highest FS index is for this function. This was still true in 2011, so it is placed in the top left cell of the transition table. Additionally, we separated the group with the highest FS in fabrication into two sub groups. The 'fabrication only' group contains countries for which the FS indices for all other functions were smaller than one, so they can be said to specialise exclusively in fabrication.

Tellingly, the diagonal cells in the matrix contain most of the countries: 31 out of 40. This indicates that specialisation patterns only evolved slowly over the period 1999–2011, in particular for countries that are more advanced. Arguably, this period is rather short, and it is left for future research to establish this stability over longer periods. Some fast-growing countries developed new specialisation patterns even within a decade, as shown by the non-diagonal entries. This includes various Central and Eastern European countries such as the Czech Republic, Hungary, Latvia and Slovenia, which graduated from being specialised in fabrication towards headquarter activities. Greece and Spain moved from being specialised exclusively in fabrication toward being specialised in management, which might partly relate to the dwindling of local manufacturing fabrication activities. This finding serves to remind us that the FS index is a relative measure: it is based on a comparison of value added of various activities within a country and is silent on the overall level of activity in a country. It has therefore to be interpreted in conjunction with other information on volumes of trade.

A key question that remains to be answered is what can explain these patterns of specialisation. Heckscher–Ohlin differences in endowments are likely to play a major role in driving specialisation in fabrication activities that are intensive in low skilled labour, and specialisation in R&D activities that are skill-intensive. Yet management and marketing activities do not map easily into particular sets of factor requirements. Moreover, FS is likely to depend also on particular externalities within and across functions.[16] For example, Defever (2006, 2012) emphasises the impact of complementarities between R&D and fabrication activities that are carried out in one location, and discusses other motives for co-location of activities. Belderbos et al. (2016) provides a

16 Grossman and Rossi-Hansberg (2012) provide a general equilibrium model with countries that have similar relative factor endowments but vary in size, and hence in associated local spillovers of production. This determines patterns of task specialization in their model.

Table 2. Transition matrix of countries based on their FS in exports

1999 2011	R&D	Management	Marketing	Fabrication	Fabrication (only)
R&D	Denmark; Finland; France; Germany; Sweden; Taiwan			Czech republic	
Management	Australia	Belgium; Estonia; India; Ireland; Lithuania; Malta; Netherlands; UK; USA		Latvia; Slovenia	Greece; Spain
Marketing			Cyprus; Indonesia; Italy; Luxembourg; South Korea	Austria; Hungary	
Fabrication				Brazil; Canada; Japan; Portugal; Slovakia	Bulgaria
Fabrication (only)					China; Mexico; Poland; Russia; Romania; Turkey

Notes: Allocation of countries to a particular group is based on highest functional specialisation index of the country in 1999 (columns) and 2011 (rows). For source, see Appendix Table A1.

related study in a global production network context. Ascani et al. (2016) emphasise the importance of protection of intellectual property rights for firms' decisions to (re)locate R&D facilities. Defever (2012) finds that market access motives are an important driver for the location of sales and marketing activities close to end-consumers. Coe and Hess (2005) discuss the important role of transnational retailers in creating new supply network structures, suggesting intricate links between location of marketing, management and fabrication functions across regions. Gereffi (1999) shows how large retailers manage global production systems of textiles and govern the distribution of value along the chain. The role of the distribution sector is generally ignored in empirical trade-in-value-added studies which focus exclusively on production stages. Novel work is needed on value added in the distribution stage.[17] All in all, it is the interaction of factor

17 Chen et al. (2018) provide a first quantification at the macro-level and find the income share for intangible capital such as brand names, dedicated software, logistic systems, marketing and technological know-how, to be much larger than for tangible capital, and increasing over time.

endowments with economic and social institutions as well as locational factors and positioning in global networks that ultimately determine comparative advantage (Coe and Yeung, 2015; Baldwin and Evenett, 2012).

How sensitive are these findings on FS? A potential concern relates to the aggregate nature of our analysis. Differences in bilateral trade costs and trade distortions that are destination market-specific might obscure the identification of a country's specialisation pattern in a unilateral analysis (French, 2017). We therefore also calculated bilateral FS indices based on Equation (2) for each country towards each destination market. In general, we find that strong specialisation patterns based on aggregate exports are also observed in exports towards specific markets. This suggests that differences in bilateral trade costs are not large enough to undo a country's inherent advantage in a particular function. We illustrate this by showing in Table A2 the results for German and Chinese exports in 2011. Germany's specialisation in R&D is clearly visible toward all destination markets. Similarly, in the aggregate analysis Germany was not found to be specialised in fabrication activities. This holds also toward 34 out of the 39 markets. Exceptions are found in exports toward small Western European countries like Denmark, Sweden and the Netherlands. Compared to other exporters, Germany is specialised in fabrication activities in its export to these specific markets. The aggregate findings on Chinese specialisation are also robust: the bilateral results toward all possible destination markets confirm the aggregate specialisation pattern.[18]

We find it useful to also report on another investigation into the robustness of the aggregate results. The approach put forth in this article is conceptually attractive as it considers all stages of production. Yet, it relies heavily on additional information on input–output linkages, potentially increasing the scope for measurement error. To test for robustness of the results, we also calculated FS indices based on information on the last stage of production only, that is, based on the functional income distribution in the industries that export. We simplify Equation (6) and measure **f** in this case as **BVIe**. It is important to note that in this way a lot of information are ignored. On average, the last stage industry in a country contributes only about halve of the domestic value added in its exports (51% in 2011, weighted average across all countries) and can be as low as 32% (e.g., average across industries in China). We find that the correlations of GDP per capita with last-stage based FS indices are quantitatively comparable to those reported in Figure 3. Yet, for more detailed export flows (at country and product level) major differences can appear. For example, South Korea is not specialised in R&D based on the last stage information, but it clearly is when considering all stages in the chains. This is because manufacturing industries have been particularly active in outsourcing R&D activities to domestic business services. Taiwan is more marketing oriented than appears from last-stage only, as its exports include a particular large share of marketing activities in logistics and transport services that are indirectly exported through manufacturing goods. More generally, most countries, with the notable exception of China, have higher shares of fabrication activities when ignoring other stages of production in the calculation of FS. We conclude that consideration of activities deeper

18 Results for other countries can be generated using the program and data provided in the online appendix material. The bilateral findings should be qualified due to the nature of the data at hand. Input–output information generally does not vary across export partners, that is, the production technology of the exporting industry is not destination specific. The variation in results across bilateral partners hence comes from variation in the export product mix towards various destinations.

down the chain is needed for a better understanding of a country's position in global production networks.

5. Functional specialisation of regions: the case of Chinese exports

So far, we analysed the specialisation of countries in trade based on functional incomes related to their exports. With suitable data at hand, similar analyses could be carried out for sub-national regions. Large scale cross-country analysis awaits further data development, however, as the availability of regional input–output tables and matching occupation statistics (cross-classified by industry and region) is still poor. Fortunately, progress is being made and more is to be expected in the near future.[19] Using novel data, we report in this section on an analysis of FS of Chinese provinces in overall exports by China.

China's integration into the global economy started out from selected coastal locations assigned as export processing zones. Gradually, backward linkages to other regions started to develop, a process that accelerated in the 2000s. Industrial capabilities spread out to inland regions that initiated production for local demand as well as international exports, using increasing amounts of foreign inputs. By now most regions have been deeply involved in domestic production networks and these have been getting increasingly complex (Meng et al., 2017; Luck, 2017). Do Chinese regions differ in their FS patterns? To answer this question, we use detailed information collected by Chen et al. (2018) on the occupations of workers in 42 industries in 31 provinces of China from the population census in 2012. This is combined with information on inter-industry and inter-provincial flows of intermediate inputs build up from value-added tax invoice data. We use this data to measure FS of provinces in the production for overall Chinese exports.[20]

Provinces can contribute to Chinese exports through exporting internationally themselves, or through delivering intermediates to other provinces that subsequently export internationally. The FS indices are calculated according to a modified version of Equation (1). The numerator now measures the share of function k in the overall income in province i that is related to Chinese exports. The denominator is the same share for all provinces together. If the index is above one, the province is said to be specialised in that function in the domestic production network of Chinese exports.

The first column in Table 3 shows the provincial shares in domestic value added in Chinese exports for the year 2012. The other columns show the FS indices. We report on the top seven provinces. The largest contributor is Guangdong, a coastal province in the South of China. This region hosted the first special economic zones, established in the 1980s in the proximity to Hong Kong. It has been the major production and assembly region in China for a long time. This legacy is reflected in its specialisation pattern in 2012 as the FS index for fabrication is still above one. Yet, it has also developed new capabilities and is now also a major host to management activities, including organisation of production in other provinces. Innovative activities are

19 See for example Meng et al. (2017) for a Chinese interregional table, Los et al. (2017) for analyses using sub-national input–output tables for Europe and Boero et al. (2018) for the US.

20 Functional income is derived as in (6) with $\mathbf{A^D}$ now extended to contain input requirements classified by industry and province. The export vector contains values for international exports by each province.

Table 3. Functional specialisation of Chinese provinces participating in exports from China, 2012

Participating province	Labour income share (%)	FS index for			
		R&D	Management	Marketing	Fabrication
Guangdong	22.8	0.71	**1.17**	0.88	**1.09**
Jiangsu	12.7	**1.28**	0.90	0.93	0.98
Zhejiang	7.8	**1.19**	**1.44**	**1.14**	0.88
Shanghai	6.7	**1.23**	0.98	**1.52**	0.76
Beijing	6.5	**2.21**	**1.17**	**2.11**	0.33
Shandong	6.3	0.71	0.80	0.81	**1.14**
Fujian	5.0	**1.03**	0.89	0.94	**1.02**
Other provinces	32.1	0.81	0.33	0.79	**1.17**

Notes: FS indices calculated according to Equation (1), adapted to measure domestic value added of provinces in Chinese exports as discussed in main text. Indices bigger than one are indicated in bold. Results for top seven contributing provinces and aggregate of the other 24 provinces.
Source: Calculations based on data from Chen et al. (2018).

geographically concentrated within the province, such as in the electronics hardware cluster in the Shenzhen area. Identification of these hubs requires more granular study of sub-provincial specialisation patterns. Large urban regions like Beijing and Shanghai are heavily specialised in headquarter activities with Beijing focusing more on R&D and Shanghai most specialised in marketing. Most of the other regions, like Shandong, are specialised in fabrication activities. We find this to be true for 23 out of the 31 Chinese provinces. The FS indices are suggestive of a regional division of labour within China with coastal regions orchestrating production networks that reach deep into the inland regions, mirroring the global division of labour documented in the previous section.

6. Concluding remarks

In this article, we argued the need for analysing FS of regions in global production networks, and demonstrated the potential for its measurement. We proposed a novel index based on comparing occupational labour incomes. This index is grounded in the new reality that countries and regions are competing in tasks rather than products. Countries export a bundle of activities, some of which are carried out locally and others imported. This insight has been around for some time, and patterns of vertical specialisation in trade have been documented using trade-in-value-added statistics. Yet, until now we lacked data on the type of activities that were carried out. We collected new rich data on the occupational structure of the labour force to characterise domestic activities that add value in exports. We used it to provide for the first time an overview of FS in the global economy for the period 1999–2011.

We found a continuing FS process as rich countries specialised further in headquarter activities, while de-specialising in fabrication. China greatly expanded activities in exporting over this period, most of which were fabrication activities, still accounting for more than 60% of its domestic value added in exports in 2011. We also found a high degree of heterogeneity in specialisation patterns across countries at similar levels of income. Almost all advanced countries are specialised in R&D activities (in particular countries such as France, Germany, Sweden and Taiwan). Some are most specialised in marketing activities (like South Korea and Italy), while others are most specialised in management activities (like Belgium, Estonia, the UK and the USA). Thirdly, we found that countries' specialisation patterns are pervasive and change only slowly over time. Nevertheless, some smaller countries in Eastern Europe such as the Czech Republic, Latvia and Slovenia have managed to shift comparative advantage away from fabrication activities.

Taken together these findings are suggestive of the importance of many factors in determining comparative advantage, including standard Heckscher–Ohlin differences in factor endowments, as well as local externalities through linkages and associated spillovers. Obviously, these externalities go beyond traded input–output relationships, as they typically involve non-recorded knowledge flows that are tacit and intangible. Yet, it seems reasonable to assume that they are positively related to trade flows and GVC participation. Our FS approach is therefore a useful place to start a quantitative analysis. It offers a macroeconomic background, charting patterns and trends that ground more detailed case studies of networks with specific information on technologies and products, production capabilities as well as location characteristics and full institutional and historical detail. The importance of local conditions is stressed in the theory on global production network articulated by Dicken et al. (2001), Henderson et al. (2002) and further developed in Coe et al. (2008) and Coe and Yeung (2015). Special attention is also needed for the way in which lead firms coordinate cross-border activities in the network (intra- and inter-firm). Governance is central in the GVC theory developed in Gereffi (1994, 1999) and Gereffi et al. (2001, 2005). Sturgeon et al. (2008) provide a good example in their study of changes in global automotive production networks. More generally, we fully agree with Storper (2018) that the use of a broader structural and developmental macro framework in combination with microeconomic analysis will help in better understanding the current regional economic divergence around the world.

Our new data is made public (see Online Material) to encourage follow up research and the development of complementary data sets. Can we expect the proposed new generation of FS measures to become a standard tool in due time? There is hope: ongoing efforts in the international statistical community aim to improve and harmonise data sources underlying the second generation TiVA statistics and to institutionalise their production in regular statistical programs. In the short run this involves mixing existing firm-level data and firm characteristics (such as firm size, ownership and export status). In the longer term this would entail the development of common business registers across countries, increased data reconciliation and new data collections on value-chains beyond counterparty transactions (Landefeld, 2015). The measurement of trade in (and use of) intangibles, in particular intellectual property such as brand names, databases and designs is a particular area in need of further research. Promising is the development of new firm-level surveys that track the type of business functions that are carried out domestically and those that are offshored by a multinational firm within GVCs. These surveys are in a testing phase and may become part of a regular statistical program (Nielsen, 2018). Yet, we expect that in the near future researchers need to continue their reliance on the traditional product trade statistics that have a high level of granularity, together with the novel composite measures of functional value added presented in this article. All in all, we hope to have shown that the FS approach to trade is helpful in better understanding regional development under global integration.

Supplementary material

Supplementary data for this paper are available at *Journal of Economic Geography* online.

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Appendix

Table A1. Functional specialisation in trade, 1999 and 2011

	RD 2011	MGT 2011	MAR 2011	FAB 2011	RD 1999	MGT 1999	MAR 1999	FAB 1999
Specialised in R&D								
Czech republic	**1.18**	0.78	0.97	**1.05**	**1.13**	0.68	0.91	**1.17**
Denmark	**1.30**	0.73	**1.21**	0.79	**1.17**	**1.08**	0.92	0.97
Finland	**1.48**	**1.32**	0.79	0.82	**1.40**	**1.18**	0.74	0.99
France	**1.53**	**1.23**	0.84	0.79	**1.65**	**1.00**	0.85	0.88
Germany	**1.42**	0.92	0.97	0.87	**1.49**	0.85	0.91	0.95
Sweden	**1.34**	0.70	**1.14**	0.85	**1.51**	0.57	**1.07**	0.93
Taiwan	**1.63**	0.55	0.95	0.97	**1.18**	0.64	**1.02**	**1.07**
Australia	**1.07**	**1.12**	0.93	0.98	**1.13**	0.89	**1.01**	0.99
Belgium	**1.20**	**1.33**	**1.06**	0.69	**1.16**	**1.26**	0.93	0.89
Estonia	0.81	**1.56**	0.93	0.89	0.79	**1.45**	0.73	**1.12**
Greece	0.92	**1.16**	**1.05**	0.91	0.94	0.91	0.88	**1.16**
India	0.79	**2.20**	0.79	0.71	0.53	**2.34**	0.66	0.89
Ireland	0.97	**1.93**	**1.03**	0.53	0.89	**1.99**	0.94	0.67
Latvia	0.65	**1.27**	**1.15**	0.89	0.71	**1.03**	0.89	**1.19**
Lithuania	0.57	**1.27**	0.93	**1.14**	0.63	**1.46**	0.65	**1.25**
Malta	0.91	**1.62**	**1.10**	0.65	**1.02**	**1.21**	**1.00**	0.91
Netherlands	**1.14**	**1.27**	**1.19**	0.62	**1.23**	**1.34**	**1.04**	0.73
Slovenia	**1.10**	**1.19**	0.82	**1.03**	**1.12**	0.70	0.79	**1.26**
Spain	0.83	**1.16**	**1.06**	0.94	0.86	0.89	0.92	**1.17**
UK	**1.04**	**2.07**	0.79	0.65	**1.15**	**1.74**	0.83	0.77
US	0.98	**1.41**	**1.20**	0.62	**1.00**	**1.31**	**1.18**	0.71
Specialised in marketing								
Austria	**1.05**	0.93	**1.07**	0.94	0.91	**1.00**	0.96	**1.06**
Cyprus	0.56	0.89	**1.34**	0.93	0.56	0.38	**1.29**	**1.18**
Hungary	0.97	0.82	**1.10**	**1.00**	**1.02**	0.84	0.94	**1.12**
Indonesia	**1.07**	0.49	**1.31**	0.92	0.47	0.95	**1.31**	0.95
Italy	0.86	0.95	**1.17**	0.93	0.68	0.70	**1.26**	**1.02**
Luxembourg	0.91	0.80	**1.81**	0.36	0.87	0.68	**1.75**	0.54
South Korea	**1.08**	0.61	**1.22**	0.94	**1.05**	0.69	**1.26**	0.89
Specialised in fabrication								
Brazil	0.68	0.72	**1.09**	**1.20**	0.49	0.39	**1.05**	**1.41**
Canada	0.93	0.60	**1.06**	**1.17**	0.87	0.69	**1.03**	**1.16**
Japan	0.89	0.25	**1.19**	**1.24**	0.64	0.34	**1.07**	**1.36**
Portugal	0.65	**1.02**	**1.04**	**1.12**	0.76	0.91	**1.00**	**1.12**
Slovakia	0.93	**1.02**	0.99	**1.03**	**1.12**	0.68	0.88	**1.20**
Only specialised in fabrication								
Bulgaria	0.71	0.98	0.88	**1.27**	**1.10**	0.63	0.68	**1.40**
China	0.39	0.30	0.77	**1.85**	0.29	0.37	0.81	**1.71**
Mexico	0.68	0.51	0.92	**1.47**	0.36	0.95	0.94	**1.32**
Poland	0.70	0.88	0.79	**1.40**	0.56	0.61	0.65	**1.64**
Romania	0.86	0.34	0.82	**1.56**	0.96	0.40	0.59	**1.64**
Russia	0.80	0.94	0.83	**1.29**	0.91	0.58	0.91	**1.30**
Turkey	0.51	0.79	0.57	**1.75**	0.50	0.79	0.56	**1.67**

Notes: RD refers to R&D; MGT to management; MAR to marketing and FAB to fabrication. Allocation of countries to a particular group is based on highest functional specialisation index of the country in 2011. Entries bigger than one in bold.

Source: Authors' calculations according to Equation (1) based on World Input–Output Database (November 2013 release) and Occupations database.

Table A2. Bilateral functional specialisation of China and Germany in 40 destination markets, 2011

	Germany				China			
	RD	MGT	MAR	FAB	RD	MGT	MAR	FAB
Australia	**1.51**	0.95	0.96	0.82	0.50	0.31	0.89	**1.66**
Austria	**1.17**	0.95	0.95	0.98	0.34	0.30	0.82	**1.90**
Belgium	**1.22**	0.86	0.97	1.00	0.36	0.28	0.89	**1.93**
Bulgaria	**1.42**	0.96	**1.07**	0.80	0.41	0.32	0.89	**1.58**
Brazil	**1.42**	0.96	**1.03**	0.77	0.40	0.28	0.71	**2.08**
Canada	**1.59**	0.76	0.91	0.96	0.38	0.23	0.73	**2.14**
China	**1.45**	0.96	0.93	0.84	–	–	–	–
Cyprus	**1.43**	0.81	**1.04**	0.89	0.42	0.25	0.75	**1.88**
Czech Republic	**1.27**	0.95	0.93	0.94	0.38	0.31	0.81	**1.85**
Germany	–	–	–	–	0.41	0.28	0.82	**1.80**
Denmark	**1.21**	0.86	0.90	**1.08**	0.36	0.29	0.86	**1.91**
Spain	**1.33**	0.84	**1.01**	0.90	0.29	0.24	0.62	**2.20**
Estonia	**1.30**	0.89	**1.04**	0.89	0.36	0.26	0.76	**1.84**
Finland	**1.25**	0.92	0.88	**1.03**	0.34	0.31	0.93	**1.86**
France	**1.35**	0.86	0.94	0.95	0.36	0.28	0.80	**1.89**
UK	**1.35**	0.84	0.93	0.98	0.36	0.26	0.72	**2.10**
Greece	**1.39**	0.93	1.00	0.86	0.37	0.29	0.82	**1.80**
Hungary	**1.27**	0.91	0.89	0.99	0.39	0.34	0.90	**1.80**
Indonesia	**1.84**	**1.06**	0.90	0.77	0.40	0.30	0.70	**1.71**
India	**1.69**	0.87	**1.06**	0.79	0.42	0.28	0.80	**1.65**
Ireland	**1.38**	0.64	0.95	**1.23**	0.33	0.28	**1.03**	**2.48**
Italy	**1.34**	0.88	0.99	0.90	0.33	0.29	0.87	**1.77**
Japan	**1.68**	**1.01**	**1.02**	0.73	0.41	0.31	0.79	**1.64**
South Korea	**1.51**	**1.00**	**1.01**	0.77	0.42	0.38	0.94	**1.55**
Lithuania	**1.45**	0.88	**1.12**	0.81	0.39	0.28	0.89	**1.60**
Luxembourg	**1.35**	0.55	0.91	**1.86**	0.30	0.22	0.89	**4.04**
Latvia	**1.35**	0.83	**1.04**	0.90	0.37	0.26	0.73	**1.90**
Mexico	**1.56**	0.81	0.94	0.90	0.45	0.28	0.79	**1.86**
Malta	**1.31**	0.84	**1.02**	0.93	0.40	0.24	0.80	**2.05**
Netherlands	**1.19**	0.82	0.92	**1.10**	0.39	0.27	0.90	**1.94**
Poland	**1.24**	0.93	0.98	0.93	0.35	0.28	0.75	**1.88**
Portugal	**1.48**	0.81	0.92	0.96	0.39	0.26	0.78	**1.99**
Romania	**1.36**	0.91	0.96	0.91	0.39	0.28	0.75	**1.89**
Russia	**1.69**	**1.08**	**1.08**	0.71	0.31	0.28	0.68	**1.64**
Slovakia	**1.35**	0.97	0.91	0.93	0.37	0.30	0.73	**1.89**
Slovenia	**1.32**	0.93	0.95	0.93	0.36	0.30	0.78	**1.85**
Sweden	**1.21**	0.84	0.88	**1.10**	0.40	0.30	0.90	**1.94**
Turkey	**1.68**	0.89	**1.08**	0.79	0.32	0.23	0.62	**1.77**
Taiwan	**1.56**	**1.14**	0.91	0.78	0.44	0.37	0.73	**1.75**
US	**1.57**	**1.04**	**1.09**	0.68	0.45	0.36	0.83	**1.61**
Other countries	**1.46**	0.97	0.94	0.87	0.40	0.31	0.71	**1.95**
All	**1.42**	0.92	0.97	0.87	0.39	0.30	0.77	**1.85**

Notes: RD refers to R&D; MGT to management; MAR to marketing and FAB to fabrication. Entries bigger than one in bold. The indices in the final row correspond with the unilateral indices in Table A1.
Source: Authors' calculations according to Equation (2) based on World Input–Output Database (November 2013 release) and Occupations database.