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Global Value Chains and Structural Upgrading

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Abstract

Global value chains (GVCs) are increasingly seen as a part of the industrial policy toolkit as they facilitate the entry into global markets and MNEs have greater incentives to share knowledge within their production network. Making use of international input-output data for 53 countries, this paper investigates econometrically how countries' participation in GVCs affects structural upgrading. A sizeable structural change bonus arising from increasing GVC trade is identified for emerging and transition economies. However, this bonus is not stronger for GVC trade than for trade in general. Therefore, the role of GVCs as an industrial policy tool should not be overestimated.

Keywords: structural upgrading, global value chains, cross-country production sharing, industrial policy, emerging and transition economies

JEL classification: F12, F60, O14, O25

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1. Introduction

International production networks and global value chains (GVCs) are a defining feature of '21st century trade' (Baldwin, 2011). Geographically-dispersed production, also referred to as the 'second unbundling' (Baldwin, 2013), was rendered possible by technological developments, in particular by the ICT revolution which drastically reduced communication costs and thus the co-ordination costs of offshoring. The existence of large differences in wage costs between countries made the internationally fragmented production profitable (see Arndt and Kierzkowski, 2001). The new opportunities arising from cross-border production sharing gave rise to high expectations with regards to the development potential for emerging economies. This is due to at least two reasons. Firstly, in the presence of GVCs, countries can link into manufacturing production more easily as it suffices to master a segment of the production process instead of having to acquire the entire range of capabilities needed for the production of a product (Collier and Venables, 2007). Secondly, foreign multinational firms managing international production networks have an incentive to share knowledge and technologies with production partners that are part of this network (Baldwin, 2016) For this reason researcher (e.g. Gereffi and Sturgeon, 2013; Naudé, 2010) and policy-makers (European Commission, 2014) have started to consider participation in GVCs as a part of the industrial policy toolkit with a high potential to facilitate structural upgrading.

Structural change is an integral component of numerous models of economic development such as the dual economy model by Lewis (1954). A salient feature of this literature is that a shift of resources from a sector with relatively low productivity to a sector with relatively higher productivity contributes to aggregate productivity growth. In other words, such a type of resource shifts, for example from a 'traditional' sector to a 'modern' sector entails a 'structural change bonus' (Timmer and Szirmai, 2000). According to McMillan and Rodrik (2011) this type of growth-enhancing structural change – or structural upgrading – is essential to achieve high and sustained aggregate productivity[1] growth. The extent of structural upgrading in this view also explains the differences in the growth performance of South East Asian countries on the one hand and Latin American and Sub-Saharan African countries on the other hand.

Using the measure of McMillan and Rodrik (2011) for structural upgrading this paper links the structural change hypothesis to GVCs and subjects it to an empirical investigation. More precisely, it analyses econometrically how countries' participation in GVCs, proxied by an input-output based measure for GVC integration labelled re-exported domestic value added *(DVAre)*, affects structural upgrading. The *DVAre* is equal to the forward production part of 'deep cross-country production sharing' in Wang et al. (2017) and is also similar to the more widely used VS1 measure, initially conceptualised by Hummels et al. (2001). We undertake separate econometric analyses for the global sample and emerging and transition economies only. These countries, which we think of as the South, constitute mainly offshoring destinations and we assume that these countries are characterised by a dual economy (Lewis, 1954). Emerging and transition economies are of particular interest because structural upgrading plays a more

[1] Peneder (2013) emphasises that structural change and economic development affect each other in various ways without a clear direction of causality.

pronounced role for them and we may also expect that the impact of GVC integration on structural change is greater.

While keeping the focus on the GVC–structural upgrading nexus, this paper also investigates the relationship between structural upgrading and an overall measure for trade for which we use the concept of value added exports (VAX) introduced by Johnson and Noguera (2012a). This allows for a comparison of the impacts of GVC-related trade and overall trade respectively on structural upgrading. The main insight from this type of comparison is an assessment of how large the additional impetus for structural upgrading stemming from GVCs that goes beyond that of standard trade really is.

The paper's contribution to the literature is therefore twofold. Firstly, it examines the relationship between structural upgrading and GVC-related trade for a large number of countries, including both advanced economies and emerging and transition countries. While the impact of GVC integration on labour productivity has been investigated in the literature (see Kummritz, 2016) and there is some work on GVCs and structural change related to manufacturing activity (Stöllinger, 2016), to the best of our knowledge the issue of economy-wide structural upgrading has not been tackled quantitatively yet. Secondly, the structural effects of GVC-related trade are put in perspective by comparing them with the structural impact of trade in general. This type of comparison is generally neglected in the GVC literature but we feel it is important given that after all integration in GVCs manifests itself in trade activities which may be of a different nature, e.g. more granular and more often accompanied by investments. An interesting question is therefore whether GVC-related trade has differentiated structural impacts with the expectation that there is a positive 'additionality' of this particular type of trade.

The remainder of this paper is structured as follows. Section 2 discusses some of the related literature and the guiding conceptual framework, Section 3 explains the main indicators as well as some descriptive evidence. Section 4 describes the econometric model and provides information on the data sources, followed by the results presented in Section 5. Section 6 concludes.

2. Related literature

Two strands of the literature are central to the research question at hand: the literature on structural change, including the dual economy concept (Lewis, 1954), and the comparatively newer and mushrooming literature on global value chains and offshoring.

The importance of shifts in the economic structure for economic growth has long been recognised in the literature on economic development. Baumol (1967) described a ‘growth disease’ scenario resulting from differences in productivity growth across sectors because, under certain circumstances, resources will continuously shift towards the ‘non-progressive’ sector acting as a drag on productivity (Nordhaus, 2008)[2]. In a more optimistic view, researchers also argued for the possibility of a ‘structural change bonus’ as opposed to a ‘structural change burden’ implied by Baumol’s growth disease (Timmer and Szirmai, 2000; Peneder, 2003). Syrquin (1988) provided empirical evidence that resource reallocations contribute to total factor productivity (TFP) growth, especially in developing countries. Since then a large body of literature has been accumulated emphasising the importance of manufacturing – which is typically considered to be the primary ‘progressive sector’ and hence the ‘engine of growth’ in the entire economy (e.g. Rodrik, 2008; Szirmai, 2012; Rodrik, 2013; Szirmai and Verspagen, 2015; Haraguchi et al., 2017) – for the growth process. Spurred by the catching-up processes in South East Asian countries, more empirical research on this topic based on industry level data, employing shift and share analysis, was undertaken (e.g. Fagerberg, 2000; Timmer and Szirmai, 2000; Peneder, 2003) which arrived at mixed results regarding the relevance of structural change for economic growth. Despite this mixed evidence, McMillan and Rodrik (2011) argue forcefully that positive structural change is the main factor explaining the superior growth performance of South East Asia compared to other emerging regions such as Latin America or Sub-Saharan Africa during the period 1995-2005. Their claim is that *‘[H]igh growth countries are typically those that have experienced substantial growth-enhancing structural change’* (McMillan and Rodrik, 2011, p. 49).

The phenomenon of structural upgrading is also the essential feature in dual economy models (Lewis, 1954). These are two-sector models of the economy in which the two sectors differ with respect to the incentives and possibilities to accumulate capital and hence their productivity prospects. The fundamental distinction is between a ‘traditional sector’ with low labour productivity, commonly associated with agriculture and a ‘modern sector’, associated mainly with manufacturing and more recently also with business related services, where the incentives to accumulated capital lead to higher labour productivity. In such a constellation, new employment opportunities (which may come from new domestic entrepreneurs, state activism or foreign capital) in the modern sector induces structural upgrading by shifting resources to more productive activities. Dual economies model thereby assume some sort of market imperfections which impede the purely-market driven transition from labour (and

[2] Assuming productivity increases in the ‘progressive’ sector while considering the ‘non-progressive’ sector to be stagnant implies a relative increase in the unit cost in the latter, provided that wages progress informely across the two sectors. If price elasticity of demand is highly inelastic or the income elasticity of demand is highly elastic so that the two sectors capture fixed shares of expenditure, the ‘non-progressive’ sector will command an ever increasing share of factor inputs.

other resources) into the modern sector until the marginal value product of labour is equated in both sectors.

In open economies, international trade must be considered as an important factor influencing economic structures. According to standard trade models comparative advantages, based on resource endowments or technology, drive specialisation and an economy's sector composition. A shortcoming in the empirical literature in this context is that the measure of structural upgrading is derived from changes in real labour productivity. This choice is due to data limitations because data on total factor productivity at the sectoral level is hardly available for developing and emerging economies.

Despite this shortcoming, some mechanism highlighted in models of offshoring (e.g. Feenstra and Hanson, 1996; Grossman and Rossi-Hansberg, 2008) can shed light on the relationship between GVC trade and structural upgrading. Offshoring models capture trade relations that result from the international fragmentation of production and are typically extensions and modifications of the Heckscher-Ohlin model (Feenstra, 2008). For example, in Feenstra and Hanson (1996) – one of the first offshoring models – there is a continuum of intermediate inputs[3] to be performed along the firm's value chain to produce a final good[4]. Firms in the 'North', which is the skilled labour- and capital-intensive country, have the possibility to perform some of these activities in the unskilled labour-abundant 'South'. They will do so by offshoring the more labour-intensive tasks which results in a specialisation according to comparative advantages within the industry: the North will specialise in the production of the skill-intensive inputs while the South will specialise in the labour-intensive inputs. The extent of offshoring of intermediate inputs is determined by the cost-minimising behaviour of the firm which will produce at home as long as production costs of the intermediate input is cheaper there. New offshoring opportunities will arise if capital is transferred from the North to the South. In this case, the rental rate of capital in the South decreases which will induce further offshoring. Retaining the cost-minimising behaviour of the Northern firms but assuming a dual economy in the South, the Feenstra and Hanson model predicts structural upgrading in the South as long as offshoring (and the associated capital investment) takes place in 'modern' high productivity sector. In contrast, the Feenstra and Hanson model entails no clear prediction for structural change in the North, given that it is essentially a one sector model. If offshoring takes place in capital-intensive industries where labour productivity is high, the cost-savings resulting from offshoring should lead to an expansion of the sector[5]. This way, also the North could – for completely different reasons – also experience structural upgrading (as measured by shifts in labour resources). However, this need not be the case, given that the sector is offshoring unskilled labour-intensive inputs so that the overall change in the demand for labour (skilled and unskilled) is undetermined.

An alternative model of offshoring is developed by Grossman and Rossi-Hansberg (2008) in which there are two sectors each of them producing a final good by combining a continuum of 'tasks'. These tasks in turn require either skilled or unskilled labour inputs. The North can again offshore the performance of tasks to a lower cost location. The extent of offshoring in this set-up is determined by the trade-off between offshoring costs associated with the individual tasks on the one hand and the wage differential between the offshoring country ('headquarter economy') and the offshoring destination ('factory

[3] Later contributions in the literature typically refer to these intermediate inputs as 'tasks'.

[4] This assumption is a modification of the Heckscher-Ohlin model with a continuum of goods (Dornbusch et al., 1980).

[5] The *industry*-level labour productivity in the industry where firms start (or intensify) offshoring certainly increases.

economy') on the other hand. In the Grossman and Rossi-Hansberg model offshoring entails productivity gains which stem from the reduction in offshoring costs. This increase in productivity in the North is isomorphic to labour-augmenting technological progress. Improved offshoring opportunities of labour-intensive tasks[6] also entail structural change in the North which takes the form of an expansion of the sector that is unskilled labour-intensive, provided that offshoring costs are symmetric across industries. If offshoring costs are lower in the skill-intensive industry, it may also enjoy greater productivity gains and therefore expand[7]. In the offshoring destination, i.e. the South, labour productivity will also increase because tasks are performed with Northern technology. Maintaining the assumption that offshoring of tasks to the South occurs mainly in the modern sector, the country will experience structural upgrading as it was the case in the Feenstra and Hanson model.

In addition to formal models of offshoring there is also a large GVC literature based on case studies. These studies fully recognise the new opportunities for technological learning and skill acquisition entailed by offshoring and GVCs (see for example Sturgeon and Memedovic, 2011). However, despite the various opportunities brought about by GVCs, detailed analyses of the experiences of particular countries or industries do not lead to a uniformly positive assessment of the impacts of GVCs – especially on the side of the offshoring destinations. On the one hand, the potential of GVCs to bring about 'compressed development' (Whittaker et al., 2010) is acknowledged. On the other hand, there are also voices pointing out that *'GVCs are not necessarily a panacea for development'* (Sturgeon and Memedovic, 2011, p. 3). In particular, GVC integration entails the risk of creating barriers to learning and of uneven development (Kaplinsky, 2005) as well as lock-ins in low valued added activities (Kaplinsky and Farooki, 2010)[8]. The impediments to successful GVC-driven development may undermine the huge development potential of GVCs which derives from the fact that countries can link into manufacturing production more easily. The latter stems from the fact that in the presence of GVCs it suffices to master a small segment of the production process without a need to acquire all the capabilities needed for the entire production of a product (Collier and Venables, 2007).

In light of the huge development potential of GVCs as well as the aforementioned impediments, the ultimate consequences for countries participating in GVCs on productivity and structural change depend on a variety of factors including the type of value chain (Gereffi et al., 2005)[9], the extent of rent sharing between firms forming the value chain (e.g. Chesbrough and Kusunoki, 2001) and the support provided by the lead firm and resulting knowledge transfers (Pietrobelli and Rabellotti, 2011).

Given that the measure of structural upgrading used in the empirical part of this paper constitutes a part of aggregate labour productivity growth, this paper is also related to the literature on GVCs and productivity. Recent contributions in this strand of the literature use indicators for countries' involvement in GVCs derived from international Input-Output tables (e.g. Hummels et al., 2001; Stehrer, 2012;

6 The model by Grossman and Rossi-Hansberg (2008) is flexible enough to also analyse offshoring of skill-intensive tasks. Here the more relevant case of offshoring of unsklilled-labour intensive tasks is described.

7 This is the outcome in the small-country case. The results in the case of endogenous goods prices differ greatly with respect to factor rewards but not with regards to structural shifts between sectors which anyway depend mainly on the assumed offshoring costs across sectors.

8 Obviously, this assessment is quite distinct from the expectation that multinational firms are willing to share knowledge and technologies with the partner firms in their supply chain as described in Baldwin (2016).

9 The literature on GVCs distinguishes between various types of GVCs which differ with regard to the complexity of the activities involved, the capabilities required by the participating partners and also the expected knowledge flows (see Gereffi et al., 2005).

Stehrer, 2013; Johnson and Noguera, 2012a; Koopman et al., 2014; Wang et al., 2013) which is also the approach taken in this paper. Kummritz (2016) investigates the relationship between GVC participation and both domestic value added and labour productivity. Using a new and innovative instrumental variable, he finds that increases in both backward and forward GVC participation leads to higher domestic value added and to higher productivity with larger effects found for forward production integration. Kiyota et al. (2016) apply the approach by Timmer et al. (2013) to calculate the shares in world manufacturing GVC income for six Asian countries. Using this indicator as a measure of competitiveness, they find that the competitiveness of most Asian countries increased. Moreover, the growing manufacturing GVC income in Asia also coincides with increasing real income per worker, a result that contrasts with that in Timmer et al. (2013) for European countries.

Kummritz (2016) and Kiyota et al. (2016) both use the levels of the respective GVC measure which are, after all, a measure of a particular type of trade flows. Another approach is taken by Stöllinger (2016) who investigates the impacts of GVC integration on manufacturing structural change – proxied by changes in the value added share of manufacturing – for EU Member States. In this contribution the GVC measures are set in relation to gross exports so that the explanatory variables reflect the *intensity* GVC trade rather than the *level* of GVC trade. The key result in Stöllinger (2016) is that GVC integration has differentiated effects on EU Member States. For a subset of these Member States, coined the Central European Manufacturing Core, a positive impact of GVC integration on the manufacturing share is found while the opposite is true for the remaining EU members outside this group of core countries.

3. Indicators and descriptive evidence

Productivity decompositions have a long tradition going back to Fabricant (1942) and since then have been used intensively in the analysis of structural change (e.g. Fagerberg, 2000; Timmer and Szirmai, 2000; Peneder, 2003) in various contexts and levels of disaggregation. The measure for structural upgrading and the decomposition method in this paper follows McMillan and Rodrik (2011, p. 63). In this decomposition changes in overall real labour productivity between period *t* and *t-1* (ΔLP_t) are split into a 'within-industry' labour productivity component and a 'structural change' component. Formally, the change in real labour productivity at the country level can be written as:

$$\Delta LP_t = \sum_i emp_{i,t-1} \cdot \Delta lp_{i,t} + \sum_i lp_{i,t} \cdot \Delta emp_{i,t}$$

where *i* denotes sectors so that $emp_{i,t}$ is the share of sector *i* in total employment in period *t* and $\Delta emp_{i,t}$ are changes thereof between period *t* and *t-1*. Likewise $lp_{i,t}$ is sector-level labour productivity in period *t* and $\Delta lp_{i,t}$ are changes thereof between period *t* and *t-1*. The first term in this equation is the 'within-sector' labour productivity component and the second term is the 'structural change' component. This structural change effect, if positive, signals structural upgrading indicating that the economy shifts labour resources towards more productive sectors and it signals structural downgrading if this effect is negative. The sector classification for this purpose follows the classification used in the GGDC 10-Sector Database (Timmer et al., 2014)[10].

The results of this decomposition of labour productivity, expressed as annualised growth rates, are shown in Table 1 for the period 1995-2010. In line with the findings in the literature, the structural upgrading does not account for the lion share of labour productivity growth (e.g. Fagerberg, 2000; Peneder, 2003; Foster-McGregor and Verspagen, 2016). In the majority of countries, the structural upgrading contributed only modestly to labour productivity growth.

Nevertheless, in the South East Asian (SEA) emerging economies (with the exception of Malaysia), structural upgrading contributed positively to labour productivity growth and hence to the catching-up process of these countries. Structural upgrading was also recorded for a number of other emerging economies as well as the Central and Eastern European (CEE) EU Member States which we also refer to as transition economies. In contrast, structural upgrading hardly contributed to labour productivity growth in the average Latin American country (see also McMillan and Rodrik, 2011), though this regional view hides considerable heterogeneity across countries. For example, while Argentina suffered from a structural 'downgrading', a mild structural upgrading is detectable for Brazil and Mexico.

In developed countries, the contributions of structural change are in most cases negligible and in more than half of the cases negative. The pattern that structural change is relatively more important in developing than in developed countries is also in line with the findings in Foster-McGregor and Verspagen (2016). We therefore conclude that the structural upgrading part of labour productivity growth

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[10] Fort he list of sectors included see Appendix 2.

is quantitatively small but it may nevertheless be essential for a country's growth and transformation process as is often argued in the literature (Peneder, 2003; McMilland and Rodrik, 2011; Foster-McGregor and Verspagen, 2016). We use the structural upgrading measure in Table 1 as the performance measure in the baseline specifications.

Table 1 / Decomposition of real labour productivity growth, 1995-2010

	Emerging and transition economies				**Developed economies**				
	country	labour productivity growth	within-industry	structural upgrading	country	labour productivity growth	within-industry	structural upgrading	
South East Asia	CHN	9.09%	7.52p.p.	1.57p.p.	HKG	3.19%	2.50p.p.	0.69p.p.	South East Asia
	IDN	1.41%	0.87p.p.	0.53p.p.	JPN	1.34%	1.46p.p.	-0.12p.p.	
	MYS	2.16%	2.32p.p.	-0.16p.p.	KOR	2.97%	3.29p.p.	-0.31p.p.	
	PHL	2.16%	1.73p.p.	0.42p.p.	SGP	0.48%	0.78p.p.	-0.29p.p.	
	THA	1.68%	1.10p.p.	0.58p.p.	TWN	2.68%	2.34p.p.	0.34p.p.	
	average	**3.30%**	**2.71p.p.**	**0.59p.p.**	**average**	**2.13%**	**2.07p.p.**	**0.06p.p.**	
Latim America	ARG	0.73%	1.27p.p.	-0.54p.p.					Latim America
	BRA	0.82%	0.53p.p.	0.29p.p.					
	CHL	2.13%	2.24p.p.	-0.11p.p.					
	COL	0.39%	0.19p.p.	0.20p.p.					
	CRI	1.24%	1.15p.p.	0.09p.p.					
	MEX	-0.08%	-0.25p.p.	0.17p.p.					
	average	**0.87%**	**0.85p.p.**	**0.02p.p.**					
Europe (CEE EU members)					AUT	1.15%	1.00p.p.	0.16p.p.	Europe
					BEL	0.93%	0.94p.p.	-0.01p.p.	
					DEU	0.83%	0.67p.p.	0.15p.p.	
					DNK	0.84%	1.25p.p.	-0.41p.p.	
					ESP	0.63%	0.92p.p.	-0.29p.p.	
					FIN	1.29%	1.31p.p.	-0.02p.p.	
	CZE	2.48%	2.38p.p.	0.10p.p.	FRA	0.80%	1.13p.p.	-0.33p.p.	
	EST	5.02%	4.85p.p.	0.17p.p.	GBR	1.22%	1.27p.p.	-0.05p.p.	
	HUN	2.13%	1.66p.p.	0.47p.p.	GRC	1.34%	0.93p.p.	0.41p.p.	
	LTU	5.58%	5.01p.p.	0.57p.p.	ITA	-0.45%	0.06p.p.	-0.51p.p.	
	LVA	4.92%	3.95p.p.	0.97p.p.	LUX	0.57%	-0.10p.p.	0.67p.p.	
	POL	2.85%	3.23p.p.	-0.38p.p.	NLD	0.99%	1.41p.p.	-0.42p.p.	
	ROU	2.36%	2.74p.p.	-0.38p.p.	NOR	0.75%	1.78p.p.	-1.03p.p.	
	SVK	4.84%	3.51p.p.	1.33p.p.	PRT	1.15%	0.26p.p.	0.90p.p.	
	SVN	3.00%	2.87p.p.	0.13p.p.	SWE	2.54%	2.90p.p.	-0.36p.p.	
	average	**3.69%**	**3.36p.p.**	**0.33p.p.**	**average**	**0.97%**	**1.05p.p.**	**-0.08p.p.**	
Other	CYP	1.40%	1.13p.p.	0.27p.p.	AUS	1.33%	1.29%	0.04%	Other
	IND	5.45%	4.38p.p.	1.07p.p.	CAN	0.77%	0.93%	-0.16%	
	RUS	3.08%	2.63p.p.	0.46p.p.	ISR	1.26%	1.06%	0.20%	
	ZAF	2.36%	2.78p.p.	-0.42p.p.	USA	1.38%	1.49%	-0.11%	
	average	**3.07%**	**2.73p.p.**	**0.34p.p.**	**average**	**1.19%**	**1.19%**	**-0.01%**	

Note: Unweighted average for regions. Labour productivity growth calculated as the compound annual growth rate. CEE = Central and Eastern European.
Source: GGDC 10-Sector Database, Eurostat, United Nations Statistics Division National Accounts Database; author's calculations.

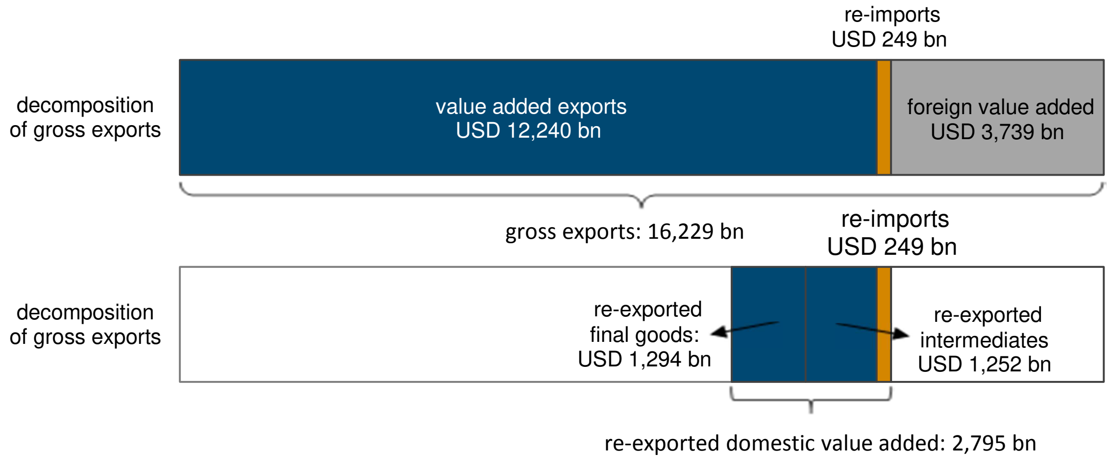
Linking structural upgrading with the emergence of GVCs requires a measure of countries' involvement in cross-border production activities. For this purpose we rely on international input-output data to calculate the GVC-related component of value added exports (Johnson and Nouguera, 2012). Following

Wang et al. (2017) we consider GVC-related trade to be that part of trade which crosses borders at least twice[11].

The indicator, which we label re-exported domestic value added (*DVAre*), is a forward production integration measure which means that the domestic value added of the reporting country is 'traced forward' along the value chain. Importantly, forward looking measures take only domestic value added into account – in contrast to backward production integration measures (such as the foreign value added in exports) which are based on foreign value added (embodied in domestic exports) and for this reason harder to interpret[12]. Hence, the forward looking measures rely on the 'active' part of production integration, that is, the domestic value added embodied in such GVC-related trade.

Due to the criterion that the domestic value added has to cross borders at least twice, the DVAre corresponds to the forward measure of 'deep' production integration in Wang et al. (2017). Re-exported domestic value added consists of three sub-components which are *(i)* value added exported in the form of intermediates to a partner country which is further exported to a third country in the form of final goods; *(ii)* value added exported in the form of intermediates to a partner country which is further exported to a third country in the form of intermediates; and *(iii)* value added exported in the form of intermediates to a partner country which return home to the initial exporting country in the form of either final or intermediate goods[13].

Figure 1 / Decomposition of gross exports and re-exported domestic value added: World in 2010



Note: World includes 61 countries for which data is available plus rest of the world.
Source: OECD ICIO, wiiw calculations.

11 Wang et al. (2017) refer to this type of trade as 'deep cross-country production sharing'.

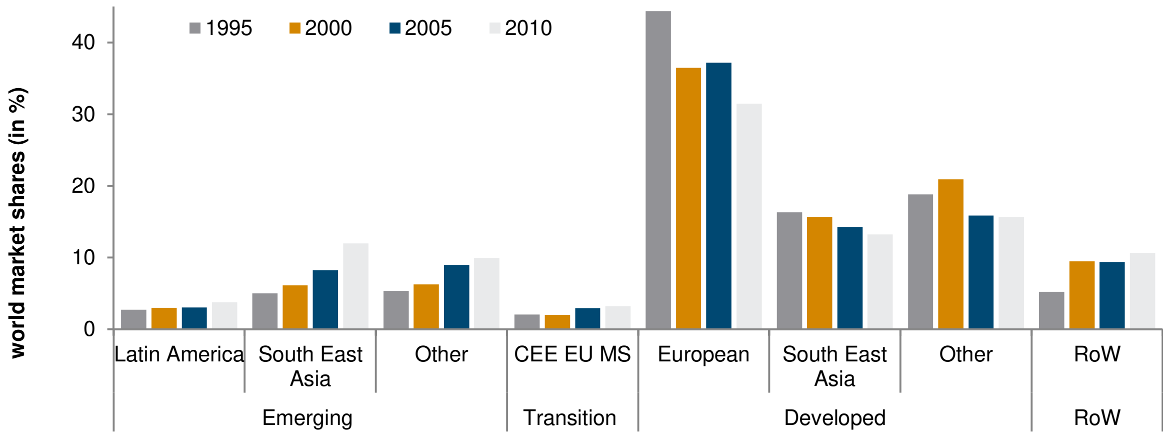
12 The interpretation of backward production integration measures is difficult because a high value of the indicator, e.g. of foreign value added in exports, is typically interpreted as evidence for a strong involvement into international production networks. At the same time, a high share of foreign value added in exports, per definition, implies a relatively lower share of domestic value added. While a strong integration in GVCs is considered to be advantageous for an economy or even a sign of competitiveness, countries are typically interested in capturing a high value added share which would imply, ceteris paribus, a lower share of foreign value added in exports. This does not imply that backward production integration does not affect structural upgrading but it is not the focus of this paper.

13 The technical details for calculating VAX and DVAre are found in Appendix 5. For an alternative exposition see Wang et al. (2013).

The upper panel in Figure 1 illustrates the basic decomposition of total gross exports for worldwide exports in 2010. This decomposition distinguishes three parts: the value added exports (VAX) introduced by Johnson and Noguera (2012a), which intuitively is the domestic value added absorbed by foreign countries; the re-imports, which constitute also domestic value added that is involved in international trade but finally absorbed domestically; and finally the foreign value added in exports. The VAX is the 'active' participation of a country in trade. This will serve as an indicator for a countries overall involvement in international trade. The lower panel in Figure 1 focuses on the DVAre which for the world as a whole amounted to USD 2,795 billion in 2010. This represents some 17% of gross exports. The DVAre are a sub-component of the value added exports plus the re-imported domestic value added. The latter, however, is a minor item representing about 1.5% of gross exports.

Figure 2 gives an overview of the development of re-exported domestic value added of different groups of countries, expressed as world market shares in global DVAre, which is also going to be the indicator used in the econometric investigation.

Figure 2 / Development of world market shares in re-exported domestic value added (DVAre), 1995-2010



Note: CEE EU MS = Central and Eastern European Member States. RoW = Rest of the World.
Source: OECD ICIO, wiiw calculations.

The general picture that emerges is similar to that of the development of world market shares in overall trade: emerging and developing economies have made significant inroads into international trade and production which is reflected in steadily increasing world markets shares in GVC-related trade, i.e. shares in global DVAre. As was observable in the case of structural upgrading, the emerging economies of South East Asia appear to have been most successful in getting actively involved in GVC. The relationship between these two developments will be explored econometrically.

4. Econometric model and hypothesis

The empirical model we develop attempts to identify the relationship between GVC trade, on the one hand, and structural upgrading, on the other hand, taking into account the theoretical considerations discussed in section 2. The concept of structural upgrading used in this context is based uniquely on shifts of labour resources across broadly defined sectors. More precisely it reflects the extent to which labour resources are moved towards sectors with higher labour productivity. This concept obviously has important limitations because neither does it take into account broader resources shifts derived from total factor productivity developments nor can it capture structural upgrading within sectors. Given existing data constraints when working with a relatively large country sample, however, there is little we can do about this[14]. A sufficiently large country sample that includes also emerging economies is absolutely necessary since – as was shown in Section 3 – structural upgrading is of particular relevance for emerging markets and transition economies. Therefore our analysis relies on data for 53 countries, 26 of which are emerging and transition economies[15]. The main data source for obtaining data on structural upgrading is the Groningen Growth and Development Centre (GGDC) 10-Sector Database[16]. This database provides information on employment and real value added at the sectoral level for a large number of countries, including developing countries. Information on value added for additional countries has been supplemented with real value added data from Eurostat and the UN National Accounts database where such data was available. Likewise, to supplement employment data information from Eurostat and the International Labour Organisation (ILOSTAT Database) has been collected.

A second limitation in terms of data concerns the sample period. This is due to the fact that the international input-output data needed to calculate the DVAre (as well as the VAX) is available only for the period 1995-2011. The data comes from OECD's Inter-Country Input-Output (ICIO) Database[17]. The ICIO Database provides information on global inter-industry linkages along with final demand structures for 61 countries and the rest of the world for the years 1995, 2000, 2005 and 2008-2011[18]. With regard to the industry structure, the database comprises 34 industries based on the ISIC Rev. 3 classification of industries[19]. For the calculation of the VAX and the DVAre, the three separate entities of China (domestic economy, non-processing export economy and processing economy) as well as the two entities of Mexico (global manufacturing, non-global manufacturing) have been aggregated to one economy.

Combining the information on structural upgrading and DVAre results in a slightly unbalanced panel dataset including 53 countries. For the estimations we use 5-year intervals so that we end up with three time periods (1995-2000; 2000-2005, 2005-2010). Hence, in the regression models the contribution of

14 To the extent that structural change in these other factors do not vary over time, parts may be captured by the country fixed effects.

15 For the list of countries see Appendix 1.

16 Publicly available at http://www.rug.nl/research/ggdc/data/10-sector-database. For details see also: Timmer et al., 2014.

17 Publicly available at: http://www.oecd.org/sti/ind/input-outputtablesedition2015accesstodata.htm

18 In the latest update in 2017 the missing years were added but this does not help to extend the sample period.

19 See Appendix for details.

structural upgrading to real labour productivity growth over 5 year intervals serves as the dependent variable[20]. The structural upgrading indicator has the advantage that it encompasses the entire economy. Therefore it is a comprehensive measure for structural upgrading which we deem preferable compared to the changes in the value added share of sectors which are considered to be of particular importance such as manufacturing (see Stöllinger, 2016). The model is estimated alternatively for the full sample and emerging and transition economies only.

The objective of the econometric model is to identify whether, and in the affirmative to what extent, structural upgrading is explained by GVC trade where we use world market shares in DVAre ($wmsDVAre$) as the key explanatory variables. In line with the offshoring model of Feenstra and Hanson (1996) we also include inward FDI in the model to capture the potential structural effect of foreign investors creating new employment opportunities in the offshoring sector of the offshoring destination. Hence, the amount of inward FDI in country *c*, expressed in per cent of gross fixed capital formation, is expected to have a positive impact on structural upgrading – at least in emerging and transition economies – as it goes hand in hand with GVC integration. This is also in line with Baldwin's notion of the trade-FDI-services nexus (Baldwin, 2011) which characterises international trade relationships in the 21st century. To control for observable country characteristics a number of control variables is included as well. Hence, the basic specification to be estimated is

(1) $$\Delta STRUP_{c,t} = \alpha + \beta_1 \cdot wmsDVAre_{c,t-1} + \beta_2 \cdot FDI_{c,t-1} + X_{c,t} \cdot \varphi + \delta_t + \mu_c + \varepsilon_{c,t}$$

where $\Delta STRUP_{c,t}$ is the structural component of log growth rate of the labour productivity of country *c* between period *t* and *t-1*. The $wmsDVAre_{c,t-1}$ is the world market share of country *c* in GVC trade at the beginning of the respective period (i.e. *t-1*) and $FDI_{c,t-1}$ is the 5-year average of inward foreign direct investment in per cent of gross fixed capital formation of country *c* in the 5-year period preceding period *t*. Note that the DVAre measure comprises domestic value added originating from all industries in the economy. The matrix $X_{c,t}$ contains a set of control variables that are further discussed below.

The regression also includes time fixed effects, δ_t, and, depending on the specification, also country fixed effects, μ_c. $\varepsilon_{c,t}$ denotes the error term.

The presence of a dual economy in emerging economies (and to some extent also still in European transition economies) leads to the expectation that structural upgrading and active participation in GVCs (as measured by *DVAre*) are positively related. This will be the case as long as offshoring leads to new employment opportunities in modern sectors of the economy with relatively high labour productivity. The above mentioned argument that GVCs facilitate the move into new activities because it suffices to acquire the capabilities required for a particular task in the value chain as opposed to all tasks along the value chain (Collier and Venables, 2007) also points in the same direction. Finally, there is a third argument in favour of a positive association between GVC trade and structural upgrading which is that lead firms of international production networks have an intrinsic interest to share their technology with partner firms within the network (Baldwin, 2016)[21].

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[20] In contrast to Table 1 in Section 3, the econometric model uses 5-year growth rates of real labour productivity instead of annualised growth rates within each 5 year period.

[21] As pointed out in the literature section, this preparedness of lead firms to share knowledge as well as the potential for technology spillovers may not be universal and depends to a large extent on the type of value chain.

Taken together these arguments lead to the first hypothesis to be tested in the econometric model:

Hypothesis 1: Larger active participation in GVC as measured by higher world market shares of GVC trade fosters structural upgrading

Hypothesis 1 implies that the coefficient of $wmsDVAre_{c,t-1}$, β_1, is expected to be positive.

Note that the arguments above in favour of the GVC participation – structural upgrading nexus are relevant for emerging markets and European transition economies in their role as offshoring destinations. In contrast, the structural implications – especially in terms of labour reallocation – for advanced economies are less straightforward. While labour productivity is bound to increase because of cost savings on the side of offshoring firms, the economic structure may shift either towards more labour or more capital intensive sectors, depending on the structure of offshoring costs. Hence, labour resources are bound to be reallocated towards sectors with lower average labour productivity (labour-intensive) industries when offshoring costs are lower in the capital-intensive sector. In that case employment is likely to decline in the capital intensive industry because the production of some of the intermediate inputs (or tasks) is shifted abroad. This leads to a second hypothesis.

Hypothesis 2: The structural implications of GVC trade are stronger in emerging and transition economies than in advanced economies.

Another interesting question in this context is whether the relationship between GVC trade and structural upgrading – be it globally or in emerging and transition economies – is indeed stronger than the one between general trade and structural upgrading. To this end a variant of equation (1) is estimated in which the trade measure, DVAre, is replaced by the VAX:

(1') $$\Delta STRUP_{c,t} = \alpha + \tilde{\beta}_1 \cdot wmsVAX_{c,t-1} + \tilde{\beta}_2 \cdot FDI_{c,t-1} + \tilde{X}_{c,t} \cdot \varphi + \delta_t + \mu_c + \varepsilon_{c,t}$$

where $wmsVAX_{c,t}$ is the world market share of country *c* in global value added exports at the beginning of the respective period (i.e. *t-1*). If it is true that participation in GVCs facilitates structural upgrading, the coefficient of $wmsVAX$ in equation (1'), $\tilde{\beta}_1$, should be smaller than β_1 estimated in the regression model using the DVAre as the trade integration measure (equation 1). This is a third hypothesis to be tested.

Hypothesis 3: The impact of GVC trade on structural upgrading is stronger than the corresponding impact of value added exports (VAX) on structural upgrading.

Hypothesis 3 therefore postulates that there is an additionality of GVC trade with regards to structural upgrading compared to general trade.

Next to GVC trade and inward FDI, the regression also includes several control variables which are explained in the following.

Real GDP. Among the fastest growing economies during the last one and a half decades were a number of large economies, including above all China but also India and Brazil. Therefore real GDP is included as a control for economic size. The variable enters the regression in log form. The value is that from the beginning of the period *(t-1)*. This control is particularly important in the specifications without country fixed effects.

Population. This is an alternative control for country size which is included for the same reason as real GDP. Population equally is included in log form using beginning of the period values *(t-1)*.

Real GDP per capita. The beginning of the period value of real GDP per capita is intended to control for a country's stage of development. As mentioned earlier, structural upgrading is expected to be stronger in more backward countries, i.e. countries with lower GDP per capita. Therefore the inclusion of GDP per capita, which is also in log form, captures a convergence effect and a negative coefficient for the GDP per capita is expected.

Total factor productivity. Real total factor productivity (TFP) is an alternative indicator for capturing the convergence effect. The TFP measure is expressed relative to that of the US (in purchasing power parity terms).

Natural resource rents. This variable takes into account the possibility of a 'resource course'. According to the 'resource course' hypothesis countries which are rich in natural resources find it harder to achieve structural change due to the windfall gains from natural resources and Dutch disease effects which drive up wages and other factor prices. The natural resource rents are expressed in per cent of GDP. A negative sign for the coefficient of rents is expected.

Exchange rate overvaluation. Another essential control variable is the real exchange rate. The potential impact of the real exchange rate on structural change arises from the fact that relatively higher domestic prices, i.e. a higher real exchange rate, should hamper the move into tradable sectors (see Rodrik, 2008). The indicator used is the measure of undervaluation or overvaluation of the exchange rate suggested by Dollar (1992). The measure is based on the price level of consumption and exploits the empirical regularity that the price level is generally higher in countries with higher per capita income. We follow the approach by Rodrik (2008) in estimating the expected real effective exchange rate (or relative price level) by regressing the log of the price level of consumption on the log of GDP per capita controlling for time fixed effects. The difference between the actual price level and the predicted price level obtained from the regression is the degree to which the real exchange rate is overvalued. A value greater than 0 indicates that a country's real exchange rate is overvalued, values smaller than 0 indicate an undervalued real exchange rate. Given the hypothesis that an overvalued real exchange rate hampers structural change, a negative coefficient of the overvaluation measure is expected.

The data for real GDP, GDP per capita, population and natural resource rents are taken from the World Bank's World Development Indicators (WDI), except for GDP data for Taiwan which come from TradingEconomics. Data for the real exchange rate comes from the Penn World Tables (version 8.1) which provides relative price levels of consumption vis-à-vis the US. The same data source is used for the total factor productivity measure. Finally, FDI data is taken from UNCTAD's FDI database.

5. Results

This section comprises the econometric results for the models in equation (1) and (1'). The models are estimated with three types of panel estimators. The first one is a 'pooled' model, the second is a fixed effects model and the third type is the Hausman-Taylor estimator. Since the fixed effects model does not deliver a lot of insights, the results are placed in the Appendix. The main reason for the disappointing performance of the fixed effects model is that most of the variation in the world market shares in DVAre and VAX stem is in the between-country dimension. To some extent this is due to the fact that with only three 5-year periods, the time dimension of the sample is very short which tends to reduce the within-variation. Therefore the values obtained for the F-tests throughout the specifications are also very low too. These problems associated with the fixed effects estimator are also the reason why we resort to the Hausman-Taylor estimation procedure which partially remedies these problems.

The specifications without country fixed effects include dummy variables for the CEE transition economies and emerging economies respectively which is intended to control for particularities of the two country groups (relative to that of advanced economies) apart from the stage of development which should be captured by the GDP per capita and the TFP level respectively.

5.1. POOLED PANEL RESULTS

Table 2 presents a first set of results for the panel regression models in equation 1 and equation 1' for both the global sample and the subsample of emerging and transition economies. We refer to this model as 'pooled' model because it does not include country fixed effects. The model features time fixed effects though. The specifications in Table 2 (A-C) differ with respect to the control variables included.

More specifically, the stage of development is alternatively captured by real GDP per capita (DVAre A.1 and DVAre C.1) and total factor productivity (DVAre B.1); while real GDP (DVAre A.1 and DVAre B.1) and population (DVAre C.1.) serve as alternative measures for country size.

Starting with the control variables in the global model, the results suggest that structural upgrading is, on average, stronger in countries with lower income, as indicated by the negative coefficient of real GDP per capita. This result, which is a type of convergence effect, is in line with the descriptive evidence. The coefficient is statistically highly significant in specifications DVAre A.1 and DVAre C.1 but not in specification DVAre B.1 which uses TFP instead of GDP per capita as measure for the stage of development.

Next, the coefficient for the exchange rate overvaluation turns out to be negative which is in line with the result in Rodrik (2008). This implies that an overvalued real exchange rate makes structural upgrading more difficult. It reflects the fact that relatively higher domestic prices make a structural shift towards tradable sectors, which regularly coincide with the more productive sectors, more difficult (at least where firms compete mainly on prices).

Table 2 / GVC trade, value added exports and structural upgrading, pooled panel results

Dependent variable: Structural upgrading (STRUP)

Sample:	Global						Emerging and transition economies					
Specification:	(A.1)	(B.1)	(C.1)	(A.1')	(B.1')	(C.1')	(A.1)	(B.1)	(C.1)	(A.1')	(B.1')	(C.1')
trade integration indicator:	DVAre			VAX			DVAre			VAX		
wms DVAre	0.0403	0.0269	0.0418				0.3441**	0.3216**	0.3514**			
	(0.0251)	(0.0247)	(0.0254)				(0.1471)	(0.1505)	(0.1368)			
wms VAX				0.0546*	0.0393	0.0560*				0.2856**	0.2780**	0.2880***
				(0.0319)	(0.0316)	(0.0322)				(0.1084)	(0.1090)	(0.0992)
FDI (% of GFCF)	0.0040	0.0030	0.0041	0.0041	0.0031	0.0043	0.0130	0.0108	0.0127	0.0125	0.0105	0.0122
	(0.0031)	(0.0033)	(0.0029)	(0.0031)	(0.0033)	(0.0029)	(0.0144)	(0.0143)	(0.0140)	(0.0146)	(0.0145)	(0.0141)
real GDPcap	-0.0038***		-0.0048***	-0.0038***		-0.0051***	-0.0019		-0.0029	-0.0017		-0.0028
	(0.0014)		(0.0017)	(0.0014)		(0.0018)	(0.0019)		(0.0025)	(0.0018)		(0.0024)
real TFP		-0.0057			-0.0058			0.0009			0.0012	
		(0.0049)			(0.0050)			(0.0083)			(0.0083)	
real GDP	-0.0007	-0.0005		-0.0009	-0.0006		-0.0006	-0.0004		-0.0007	-0.0006	
	(0.0006)	(0.0006)		(0.0006)	(0.0006)		(0.0011)	(0.0011)		(0.0011)	(0.0011)	
population			-0.0008			-0.0009			-0.0007			-0.0008
			(0.0006)			(0.0006)			(0.0009)			(0.0010)
REER overvaluation	-0.0045*	-0.0061**	-0.0047*	-0.0043*	-0.0060**	-0.0046*	-0.0059	-0.0082*	-0.0060	-0.0059	-0.0080*	-0.0061
	(0.0026)	(0.0026)	(0.0026)	(0.0025)	(0.0025)	(0.0025)	(0.0045)	(0.0044)	(0.0043)	(0.0044)	(0.0045)	(0.0043)
resource rents	-0.0111	-0.0196	-0.0104	-0.0096	-0.0186	-0.0087	-0.0269	-0.0316*	-0.0261	-0.0158	-0.0204	-0.0147
	(0.0137)	(0.0128)	(0.0137)	(0.0138)	(0.0129)	(0.0138)	(0.0183)	(0.0170)	(0.0184)	(0.0174)	(0.0157)	(0.0175)
emerging	-0.0032	-0.0009	-0.0031	-0.0033	-0.0009	-0.0031	-0.0008	0.0005	-0.0007	-0.0011	-0.0000	-0.0010
	(0.0025)	(0.0026)	(0.0025)	(0.0026)	(0.0026)	(0.0025)	(0.0025)	(0.0021)	(0.0025)	(0.0025)	(0.0021)	(0.0024)
transition	-0.0021	-0.0018	-0.0021	-0.0022	-0.0019	-0.0022						
	(0.0027)	(0.0030)	(0.0025)	(0.0027)	(0.0030)	(0.0025)						
country fixed effects	no	No	no	no	No	no	no	no	no	no	no	no
time fixed effects	yes	Yes	yes	yes	Yes	yes	yes	yes	yes	yes	yes	yes
Observations	149	149	149	149	149	149	75	75	75	75	75	75
F-test	3.667	2.802	3.159	3.611	2.787	3.126	2.520	2.272	2.509	3.247	3.084	3.125
R^2-adj.	0.155	0.135	0.156	0.159	0.138	0.160	0.145	0.135	0.147	0.151	0.143	0.152

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significant at the 1%, 5% and 10% level respectively. All regressions include a constant.

The main result in Table 2, however, is that at the global level the positive association between the world market share in DVAre and structural upgrading is not statistically significant (specifications DVAre A.1 – VAre C.1). Nor is there a significant relationship between inward FDI and structural upgrading. It should be mentioned though that a marginally statistically significant coefficient (at the 10% level) is obtained for the coefficient of DVAre when the FDI variable is excluded from the regression model. These results are reported in Appendix 3.

As such this is a sobering outcome for those who put high hopes into global value chains as a development tool. In addition, looking at the specifications VAX A.1' – VAX C.1' it becomes obvious that the relationship between overall trade and structural upgrading is stronger and statistically significant at the 10% level in at least two of the three specifications (VAX A.1' and VAX C.1'). This is in contradiction with hypothesis 3, i.e. that GVCs provide additional opportunity for countries to upgrade their production structure, which was derived from the argument that the influx of foreign capital and the fact that only parts of the supply chain needs to be mastered in order to start new activities. A possible explanation for this result is that GVC trade is causing structural 'downgrading' in offshoring countries, i.e. advanced economies. As explained in the literature section this could arise if offshoring sectors have higher average labour productivity than the rest of the economy and overall employment declines in these sectors. Certainly, it could also be due to experiences of emerging and transition economies but the right hand side of Table 2, which contains the results for emerging and transition economies only, suggests otherwise. For these two groups of countries the positive and statistically significant coefficient of DVAre indicates that integration in GVCs does foster structural upgrading. In terms of magnitude, the result suggests that a 1 percentage point increase in the world market share of GVC strengthens structural upgrading by 0.32-0.35 percentage points, depending on the specification. This finding confirms hypothesis 2 that the effect of GVC trade on structural upgrading is greater for emerging and transition economies than for advanced countries. Also, the coefficients in the specifications using DVAre as the trade indicator variable are slightly larger than for those in the VAX specifications. This would be in line with hypothesis 3 but the F-test for equality of coefficients between DVAre and VAX is not rejected at conventional levels of significance[22]. Therefore the pooled model provides partial evidence in favour of hypothesis 1 in the sense that a positive GVC–structural upgrading nexus was identified for the subgroup of emerging and transition economies but not in the global sample. Implicitly this also confirms hypothesis 2 while hypothesis 3 finds no empirical support.

5.2. HAUSMAN-TAYLOR RESULTS

The Hausman-Taylor estimator (Hausman and Taylor, 1981) is essentially a random-effects model which distinguishes among the explanatory variables between those that are exogenous and those that are endogenous. In principle, the Hausman-Taylor estimator is a random-effects model for panel data which takes into account that some of the covariates may be correlated with the unobserved individual-level random effects. The Hausman-Taylor estimator then takes the correlation between the unobserved individual effect (in this case the country effect) and the endogenous variables into account. For determining which of the control variables are endogenous we follow Szirmai and Verspagen (2015) and run bivariate regressions with structural upgrading, i.e. the dependent variable, and each of the control variables (see also Baltagi et al., 2003).

[22] In none of the F-tests performed is the p-value lower than 0.15.

In each case a fixed effects and a random effects model is estimated and a Hausman test is employed to decide whether the random effects model is appropriate. If this is the case, i.e. if the null-hypothesis that the random effects model is efficient and consistent is not rejected the respective variable is treated as exogenous, whereas if the Hausman test decides in favour of a fixed effects model, the variable is treated as endogenous. The country group dummies, emerging and developing, are treated as exogenous without any testing[23]. This procedure leads to the treatment of the world market shares of DVAre and VAX[24] as well as the resource rents as endogenous variables, while inward FDI, the real GDP per capita, real TFP, real GDP, population and the exchange rate overvaluation enter the model as exogenous variables.

For the global sample of the Hausman-Taylor estimations (left hand panel in Table 3) the switch to the Hausman-Taylor estimator does not alter the result obtained for the GVC trade variable. The coefficient of DVAre is now estimated to be larger but it again not statistically significant throughout the three specifications (DVAre A.1 – DVAre C.1). However, the VAX-specifications perform better and yield positive and statistically significant coefficients in specification VAX A.1 and VAX A.2. In terms of magnitude the coefficient of VAX is about four times larger than in the pooled model and they exceed those of the fixed effects model by about a third. As such, this result contradicts hypothesis 3 which suggested that the structural effect of GVC trade is stronger than that of overall trade.

The right hand panel of Table 3 contains the results from the Hausman-Taylor estimations for the emerging and transition economies. In this subsample, the coefficient of DVAre is statistically significant and estimated to be in the range of 0.53 to 0.62. This suggests that a 1 percentage point increase in the world market share of DVAre is strengthening structural upgrading by slightly more than half a percentage point. Given the overall size of structural upgrading, this is a sizeable effect even if one takes into account that a 1 percentage point increase in the world market share is a very large increase. This result fully confirms hypothesis 2 that GVC trade impacts structural upgrading positively above all in emerging and transition economies. Hypothesis 3, however, still finds no support. An interesting finding for the subsample of emerging and transition economies is that the coefficient of the FDI variable is positive and highly statistically significant. This is in line with the notion that GVC trade is often accompanied by FDI flows which together tend to strengthen structural upgrading in offshoring destinations.

In summary, the Hausman-Taylor estimations provide empirical support for hypothesis 1 only for the emerging and transition economies, which implies a confirmation of hypothesis 2 that integration in GVCs matters predominantly for emerging and transition economies where it has an economically significant impact on structural upgrading. In contrast, even in the case of emerging and transition economies, the structural impact of GVC trade is no greater than that of overall trade, which is in contradiction to hypothesis 3.

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[23] For the Hausman-Taylor estimation at least one such time-invariant explanatory variable is needed for the instrumentalisation.

[24] We use 0.05 as the critical value for the F-test as the general decision rule for rejecting the null hypothesis of the Hausman test. However, we also consider the DVAre variable as endogenous (i.e. we consider the test to be rejected) because with 0.068 the p-value obtained is close to the critical value. This approach has the advantage that we can compare the results for the regressions using DVAre and VAX respectively as the trade measure because the p-value of VAX variable is 0.023 and the null-hypothesis in this case is clearly rejected.

Table 3 / GVC trade, value added exports and structural upgrading, Hausman-Taylor estimations

Dependent variable: Structural upgrading (STRUP)

Sample:	Global						Emerging and transition economies					
Specification:	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)
trade integration indicator:	DVAre			VAX			DVAre			VAX		
wms DVAre	0.1142	0.1311	0.1011				0.5697**	0.6154**	0.5250*			
	(0.1055)	(0.1053)	(0.1048)				(0.2791)	(0.2665)	(0.2884)			
wms VAX				0.2322*	0.2448**	0.2119*				0.6159***	0.6423***	0.5989**
				(0.1214)	(0.1211)	(0.1207)				(0.2278)	(0.2240)	(0.2385)
FDI (% of GFCF)	0.0064	0.0062	0.0065	0.0064	0.0060	0.0065	0.0362***	0.0373***	0.0380***	0.0355***	0.0384***	0.0396***
	(0.0050)	(0.0049)	(0.0050)	(0.0050)	(0.0048)	(0.0050)	(0.0137)	(0.0136)	(0.0137)	(0.0133)	(0.0134)	(0.0135)
real GDPcap	0.0019		0.0047	0.0003		0.0014	0.0028		0.0093	0.0003		0.0056
	(0.0054)		(0.0065)	(0.0051)		(0.0065)	(0.0075)		(0.0107)	(0.0058)		(0.0100)
real TFP		-0.0014			-0.0022			-0.0135			-0.0114	
		(0.0063)			(0.0062)			(0.0140)			(0.0135)	
real GDP	0.0003	-0.0011		-0.0019	-0.0030		0.0008	0.0013		-0.0011	-0.0005	
	(0.0034)	(0.0024)		(0.0032)	(0.0024)		(0.0045)	(0.0049)		(0.0032)	(0.0042)	
population			0.0024			0.0001			0.0046			0.0016
			(0.0044)			(0.0042)			(0.0078)			(0.0064)
REER overevaluation	-0.0003	-0.0003	-0.0002	-0.0010	-0.0011	-0.0010	-0.0065	-0.0044	-0.0069	-0.0054	-0.0042	-0.0068
	(0.0030)	(0.0029)	(0.0030)	(0.0030)	(0.0029)	(0.0030)	(0.0052)	(0.0052)	(0.0053)	(0.0051)	(0.0051)	(0.0051)
resource rents	0.0510***	0.0510**	0.0527***	0.0475**	0.0485**	0.0496***	0.0243	0.0212	0.0305	0.0298	0.0306	0.0366
	(0.0197)	(0.0200)	(0.0196)	(0.0193)	(0.0198)	(0.0192)	(0.0287)	(0.0287)	(0.0291)	(0.0267)	(0.0270)	(0.0267)
emerging	0.0055	0.0015	0.0054	0.0032	0.0010	0.0055	-0.0026	-0.0050	-0.0084	-0.0026	-0.0037	-0.0051
	(0.0112)	(0.0061)	(0.0154)	(0.0101)	(0.0055)	(0.0141)	(0.0132)	(0.0140)	(0.0276)	(0.0088)	(0.0115)	(0.0219)
transition	0.0096	0.0044	0.0131	0.0055	0.0019	0.0105						
	(0.0131)	(0.0082)	(0.0171)	(0.0117)	(0.0074)	(0.0156)						
time fixed effects	Yes	yes	yes	yes	Yes	yes	yes	yes	yes	yes	yes	yes
Observations	149	149	149	149	149	149	75	75	75	75	75	75
F-test	1.975	1.963	2.069	2.220	2.239	2.290	2.755	2.925	2.974	2.964	3.263	3.343

Note: Endogenous variables: world market shares of DVAre and VAX respectively; resource rents. Robust standard errors in parentheses. ***, **, and * indicate statistical significant at the 1%, 5% and 10% level respectively. All regressions include a constant.

6. Conclusions

This paper empirically investigated the link between structural upgrading and countries' involvement in global value chains. The nexus between the two phenomena is interesting per se but it is also of utmost policy relevance as policy-makers, especially in developing countries, put high hopes in global value chains as an effective industrial policy tool. The results obtained from this empirical exercise, however, only provide limited support for such optimism. While an enhancing effect of increasing GVC trade on structural upgrading could be identified for emerging and transition economies, this effect is undistinguishable from the corresponding structural effect of trade in general. Hence, once emerging and transition countries manage to capture additional world market share in trade, on average, this goes hand in hand with accelerated structural upgrading Importantly, it is irrelevant whether this trade integration is taking place via GVC trade or other forms in trade.

These results should be considered as a first piece of evidence on the issue of GVCs and structural upgrading and there are a number of caveats. The two most import ones are that both the number of countries and the time period that could be covered in this analysis are strongly limited by data availability. At the moment the only possibility to overcome these limitations would be to rely on alternative – though less precise – indicators for participation in GVCs such as trade in parts and components trade or to use estimated values for GVC indicators (see Johnson and Noguera, 2012b). Another caveat is that by relying on intermediate trade flows from inter-country input-output data for defining the degree of GVC integration, other aspects of GVC integration such as international investment flows are disregarded. In the empirical work we tried to compensate for this by including FDI inflows as a separate variable. Also related to the DVAre as the measure for GVC integration is the fact that this indicator assumes a sequential value chain in which each production step has a natural upstream and downstream activity, also termed 'snakes' by Baldwin and Venables (2013) in contrast to 'spiders'. Spider-like organisation of production means that several inputs are sent simultaneously to a central location which is typically the assembling unit where a final good is produced. Some of the trade flows related to such spiders are not captured by the DVAre measure which is an obvious shortcoming.

At this stage there are many aspects of GVC integration that were not integrated into the analysis. Nevertheless we believe that this is a promising first step for the analysis of the global implications and the potential of GVC integration for structural change in open economies which continues to be the central objective of industrial policy. The routes for future research in this area include the inclusion of some of these missing aspects of GVC integration such as the functional specialisation of countries along the value chain of (manufacturing) firms such as R&D, production or related business.

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Appendix

APPENDIX 1: LIST OF COUNTRIES

Code	Country	Geographic group	Country group
ARG	Argentina	Latin America	Emerging economy
AUS	Australia	Other advanced	Advanced economy
AUT	Austria	Europe advanced	Advanced economy
BEL	Belgium	Europe advanced	Advanced economy
BGR	Bulgaria	Europe transition	Transition economy (CE European EU members)
BRA	Brazil	Latin America	Emerging economy
CAN	Canada	Other advanced	Advanced economy
CHE	Switzerland	Europe advanced	Advanced economy
CHL	Chile	Latin America	Emerging economy
CHN	China	South East Asia emerging	Emerging economy
COL	Colombia	Latin America	Emerging economy
CRI	Costa Rica	Latin America	Emerging economy
CYP	Cyprus	Other emerging	Emerging economy
CZE	Czech Republic	Europe transition	Transition economy (CE European EU members)
DEU	Germany	Europe advanced	Advanced economy
DNK	Denmark	Europe advanced	Advanced economy
ESP	Spain	Europe advanced	Advanced economy
EST	Estonia	Europe transition	Transition economy (CE European EU members)
FIN	Finland	Europe advanced	Advanced economy
FRA	France	Europe advanced	Advanced economy
GBR	United Kingdom	Europe advanced	Advanced economy
GRC	Greece	Europe advanced	Advanced economy
HKG	Hong Kong	South East Asia advanced	Advanced economy
HUN	Hungary	Europe transition	Transition economy (CE European EU members)
IDN	Indonesia	South East Asia emerging	Emerging economy
IND	India	Other emerging	Emerging economy
IRL	Ireland	Europe advanced	Advanced economy
ISR	Israel	Other advanced	Advanced economy
ITA	Italy	Europe advanced	Advanced economy
JPN	Japan	South East Asia advanced	Advanced economy
KOR	South Korea	South East Asia advanced	Advanced economy
LTU	Lithuania	Europe transition	Transition economy (CE European EU members)
LUX	Luxembourg	Europe advanced	Advanced economy
LVA	Latvia	Europe transition	Transition economy (CE European EU members)
MEX	Mexico	Latin America	Emerging economy
MYS	Malaysia	South East Asia emerging	Emerging economy
NLD	Netherlands	Europe advanced	Advanced economy
NOR	Norway	Europe advanced	Advanced economy
NZL	New Zealand	Other advanced	Advanced economy
PHL	Philippines	South East Asia emerging	Emerging economy
POL	Poland	Europe transition	Transition economy (CE European EU members)
PRT	Portugal	Europe advanced	Advanced economy
ROU	Romania	Europe transition	Transition economy (CE European EU members)
RUS	Russia	Other emerging	Emerging economy
SGP	Singpore	South East Asia advanced	Advanced economy
SVK	Slovakia	Europe transition	Transition economy (CE European EU members)
SVN	Slovenia	Europe transition	Transition economy (CE European EU members)
SWE	Sweden	Europe advanced	Advanced economy
THA	Thailand	South East Asia emerging	Emerging economy
TUR	Turkey	Other emerging	Emerging economy
TWN	Taiwan	South East Asia advanced	Advanced economy
USA	United States	Other advanced	Advanced economy
ZAF	South Africa	Other emerging	Emerging economy

APPENDIX 2: LIST OF SECTORS FOR THE DECOMPOSITION OF LABOUR PRODUCTIVITY

Sector	Number
Agriculture	1
Mining	2
Manufacturing	3
Utilities	4
Construction	5
Trade, restaurants and hotels	6
Transport, storage and communication	7
Finance, insurance, real estate and business services	8
Government services	9
Community, social and personal services	10

Note: The classification follows the GGDC 10-Sector Database (Timmer et al., 2014).

APPENDIX 3: ADDITIONAL REGRESSION RESULTS FOR THE STRUCTURAL UPGRADING MODEL

Pooled model results without inward FDI as control variable

Appendix Table A3.1 presents the results for the regression models in equation (1) and (1') for the pooled model but omitting the FDI variable. As can be seen from the table the coefficient of re-exported domestic value added (DVAre) is statistically significant at the 10% level. In terms of magnitudes, the result suggest, that 1 one percentage point increase in the world market share of VC trade strengthens structural upgrading by 0.04 percentage points. Still, the effect for the all countries is much smaller than the estimated effect for emerging and transition economies. In the latter case, the result is very similar to the results in the main text which includes the FDI variable both in terms of magnitude and statistical significance.

Table A3.1 / GVC trade and structural upgrading, pooled model without FDI

Dependent variable: Structural upgrading

Sample	Global			Emerging and transition economies		
Specification	(DVAre A.1)	(DVAre B.1)	(DVAre C.1)	(DVAre A.1)	(DVAre B.1)	(DVAre C.1)
trade integration indicator		DVAre			DVAre	
wms DVAre	0.0428*	0.0320	0.0424*	0.3353**	0.3222**	0.3380**
	(0.0250)	(0.0245)	(0.0251)	(0.1454)	(0.1454)	(0.1335)
real GDPcap	-0.0028**		-0.0043**	-0.0012		-0.0027
	(0.0014)		(0.0017)	(0.0020)		(0.0025)
real TFP		-0.0044			0.0023	
		(0.0044)			(0.0079)	
real GDP	-0.0011*	-0.0009		-0.0010	-0.0008	
	(0.0006)	(0.0006)		(0.0009)	(0.0009)	
population			-0.0011**			-0.0010
			(0.0006)			(0.0008)
REER overvaluation	-0.0053**	-0.0065**	-0.0058**	-0.0067	-0.0086*	-0.0070
	(0.0026)	(0.0026)	(0.0026)	(0.0049)	(0.0045)	(0.0048)
resource rents	-0.0121	-0.0183	-0.0112	-0.0290	-0.0315*	-0.0276
	(0.0138)	(0.0129)	(0.0137)	(0.0182)	(0.0164)	(0.0182)
emerging	-0.0032	-0.0013	-0.0029	-0.0004	0.0004	-0.0003
	(0.0025)	(0.0026)	(0.0025)	(0.0024)	(0.0021)	(0.0023)
transition	-0.0030	-0.0026	-0.0029			
	(0.0025)	(0.0029)	(0.0024)			
country fixed effects	no	no	no	no	no	no
time fixed effects	yes	yes	yes	yes	yes	yes
Observations	151	151	151	76	76	76
F-test	3.789	2.946	3.213	2.962	2.582	2.923
R^2-adj.	0.133	0.121	0.133	0.136	0.133	0.138

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significant at the 1%, 5% and 10% level respectively. All regressions include a constant.

Fixed effects results

Since the pooled model results presented in Table A3.1 of the main text does not control for unobserved heterogeneity across countries, also a fixed effects estimator was tested. However, as can be seen in Table A3.2 the results from the fixed effects model provide little insights as none of the key variables are statistically significant. The coefficients for the world market shares in GVC trade remain positive and are similar in magnitude as those in the pooled model but are far from being statistically significant at conventional levels of confidence across the three specifications (DVAre A.1- DVAre C.1) in the global model (left-hand side of Table A3.2). The same is true for the coefficient of VAX (specifications VAX A.1' – VAX C.1') in the subsample of emerging and transition economies. Importantly, in the fixed effects model also the estimations for the subsample of the emerging and developing countries do not deliver any significant results for the main variables. In general, the fixed-effects model performs rather poorly with the coefficient of natural resource rents being the only significant result and this also only in the global sample. Surprisingly, the sign of the coefficient would suggest that resource rich economies find it easier to diversify and move into high-productivity activities.

Table A3.2 / GVC trade, value added exports and structural upgrading, fixed effects model

Dependent variable: Structural upgrading (STRUP)

Sample:	Global						Emerging and transition economies					
Specification:	(A.1)	(B.1)	(C.1)	(A.1')	(B.1')	(C.1')	(A.1)	(B.1)	(C.1)	(A.1')	(B.1')	(C.1')
trade integration indicator:	DVAre			VAX			DVAre			VAX		
wms DVAre	0.0680	0.0756	0.0443				0.4276	0.3701	0.3710			
	(0.1242)	(0.1208)	(0.1118)				(0.5265)	(0.4802)	(0.4747)			
wms VAX				0.1674	0.1795	0.1351				0.5347	0.4690	0.4577
				(0.1850)	(0.1747)	(0.1776)				(0.3607)	(0.3402)	(0.3233)
FDI (% of GFCF)	0.0056	0.0056	0.0058	0.0058	0.0057	0.0058	0.0376	0.0394	0.0370	0.0396	0.0408	0.0388
	(0.0127)	(0.0131)	(0.0125)	(0.0127)	(0.0131)	(0.0125)	(0.0474)	(0.0465)	(0.0484)	(0.0467)	(0.0460)	(0.0479)
real GDPcap	-0.0125		0.0126	-0.0111		0.0096	-0.0053		0.0224	-0.0013		0.0177
	(0.0185)		(0.0113)	(0.0183)		(0.0094)	(0.0261)		(0.0165)	(0.0261)		(0.0161)
real TFP		-0.0043			-0.0040			-0.0255			-0.0231	
		(0.0117)			(0.0113)			(0.0241)			(0.0232)	
real GDP	0.0237	0.0127		0.0189	0.0090		0.0229	0.0251		0.0132	0.0194	
	(0.0232)	(0.0141)		(0.0219)	(0.0119)		(0.0331)	(0.0209)		(0.0323)	(0.0203)	
population			0.0345			0.0298			0.0440			0.0341
			(0.0211)			(0.0197)			(0.0385)			(0.0382)
REER overvaluation	0.0002	-0.0006	0.0014	-0.0005	-0.0012	0.0007	-0.0067	-0.0048	-0.0032	-0.0068	-0.0048	-0.0040
	(0.0038)	(0.0035)	(0.0034)	(0.0037)	(0.0035)	(0.0033)	(0.0075)	(0.0070)	(0.0079)	(0.0074)	(0.0070)	(0.0082)
resource rents	0.0563***	0.0565**	0.0560***	0.0531***	0.0532**	0.0530***	0.0393	0.0387	0.0468*	0.0422	0.0417	0.0489
	(0.0198)	(0.0230)	(0.0171)	(0.0190)	(0.0218)	(0.0166)	(0.0281)	(0.0299)	(0.0267)	(0.0301)	(0.0307)	(0.0295)
country fixed effects	yes	yes	yes	yes	yes	Yes	yes	yes	yes	yes	yes	yes
time fixed effects	yes	yes	yes	yes	yes	Yes	yes	yes	yes	yes	yes	yes
Observations	149	149	149	149	149	149	75	75	75	75	75	75
F-test	2.018	1.472	2.543	2.109	1.701	2.610	1.793	1.875	2.452	2.211	2.572	2.431
R^2-adj.	0.286	0.282	0.298	0.293	0.291	0.303	0.218	0.250	0.239	0.242	0.269	0.257

Note: Robust standard errors in parentheses. ***, **, and * indicate statistical significant at the 1%, 5% and 10% level respectively. All regressions include a constant.

APPENDIX 4: GVC TRADE, VALUE ADDED EXPORTS AND LABOUR PRODUCTIVITY

Structural upgrading is the key performance indicator investigated in this paper and we emphasised the importance of structural upgrading for the catch-up process in line with the view of several scholars (e.g. McMillan and Rodrik, 2011; Diao, 2017). However, overall labour productivity growth is doubtlessly a central element for growth and development too. For this reason we use labour productivity as a second performance measure and investigate the relationship between labour productivity and integration in GVCs. In addition this exercise is interesting because structural upgrading is part of labour productivity growth and also because we can compare our results with existing results in the literature (see Kummritz, 2016) to rule out the possibility that our findings are influenced by the particular choice of our measure for GVC integration – an approach for which there are already results in the literature.

The same framework as in the structural upgrading model is used to investigate the relationship between the GVC-related trade and labour productivity growth. This leads to the following regression model:

(2) $$LPgrowth_{c,t} = \alpha + \tilde{\beta}_1 \cdot wmsDVAre_{c,t-1} + \tilde{\beta}_2 \cdot FDI_{c,t-1} + \tilde{X}_{c,t} \cdot \varphi + \delta_t + \mu_c + \varepsilon_{c,t}$$

where $LPgrowth_{c,t}$ is the growth of real labour productivity in country *c* between period *t* and *t-1*. Guided by the almost universal prediction of (static) trade theories that trade increases productivity and the existing results in the literature we also expect a positive coefficient of $\tilde{\beta}_1$ in equation (2). As in the structural model, we run the labour productivity regression also for overall trade using again the VAX as general trade indicator which leads to the following second labour productivity model:

(2') $$LPgrowth_{c,t} = \alpha + \tilde{\beta}_1 \cdot wmsVAX_{c,t-1} + \tilde{\beta}_2 \cdot FDI_{c,t-1} + \tilde{X}_{c,t} \cdot \varphi + \delta_t + \mu_c + \varepsilon_{c,t}$$

We focus her on the results from the Hausman-Taylor estimations of the real labour productivity model in equations (2) and (2')[25].

As expected, the models deliver a positive effect of world market shares in GVC trade on labour productivity growth (Table A4.1) which confirms the finding in Kummritz (2016). This result holds true for both the global sample and for the subsample of emerging and developing economies. For the global sample, the estimated coefficient is statistically significant at the 1% level in specifications DVAre A.2 and at the 5% level in specifications DVAre B.2 and DVAre C.2 for the global sample. When considering only emerging and transition economies, all estimated coefficients are statistically significant at the 1% level. Hence, these results are much stronger in terms of statistical significance than are those of the structural models in the main text. Also, in terms of magnitude the coefficients obtained are quite large and much larger than in the structural model. This implies that the nexus between growing world market shares in trade and labour productivity growth is stronger than that between growing world market shares in trade and structural upgrading.

25 Pooled model results and results from fixed effects regressions are obtainable upon request.

Table A4.1 / Regression results for real labour productivity growth, Hausman-Taylor estimations

Dependent variable: Real labour productivity growth

Sample:	Global						Emerging and transition economies					
Specification:	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)	(A.2)	(B.2)	(C.2)
trade integration indicator:	DVAre			VAX			DVAre			VAX		
wms DVAre	0.7018***	0.6660**	0.6308**				2.2610***	1.9358***	2.2625***			
	(0.2621)	(0.2752)	(0.2958)				(0.6261)	(0.6121)	(0.6236)			
wms VAX				0.9501***	0.9009***	0.9095***				1.9442***	1.7157***	1.9395***
				(0.2939)	(0.2993)	(0.3121)				(0.5389)	(0.5300)	(0.5347)
FDI (% of GFCF)	0.0011	-0.0021	0.0064	0.0012	-0.0020	0.0037	0.0114	0.0128	0.0116	0.0169	0.0169	0.0173
	(0.0118)	(0.0116)	(0.0109)	(0.0119)	(0.0116)	(0.0115)	(0.0294)	(0.0301)	(0.0294)	(0.0295)	(0.0300)	(0.0295)
real GDPcap	-0.0234**		-0.0388***	-0.0233**		-0.0416***	-0.0344		-0.0739***	-0.0250		-0.0759***
	(0.0096)		(0.0105)	(0.0111)		(0.0117)	(0.0224)		(0.0243)	(0.0236)		(0.0247)
real TFP		-0.0309**			-0.0350**			0.0117			0.0169	
		(0.0143)			(0.0146)			(0.0321)			(0.0321)	
real GDP	-0.0108**	-0.0101**		-0.0144**	-0.0135**		-0.0382*	-0.0451**		-0.0497**	-0.0506***	
	(0.0054)	(0.0049)		(0.0066)	(0.0054)		(0.0209)	(0.0186)		(0.0243)	(0.0196)	
population			-0.0099**			-0.0133**			-0.0460*			-0.0620**
			(0.0048)			(0.0053)			(0.0254)			(0.0299)
REER overevaluation	-0.0078	-0.0120	-0.0085	-0.0091	-0.0125*	-0.0093	-0.0256**	-0.0321***	-0.0286**	-0.0240**	-0.0303***	-0.0281**
	(0.0072)	(0.0073)	(0.0078)	(0.0071)	(0.0071)	(0.0074)	(0.0112)	(0.0115)	(0.0114)	(0.0112)	(0.0113)	(0.0115)
resource rents	0.0946*	0.1081**	0.0998*	0.0974**	0.1073**	0.0979**	-0.0104	0.0109	-0.0139	0.0317	0.0467	0.0272
	(0.0483)	(0.0522)	(0.0525)	(0.0466)	(0.0490)	(0.0482)	(0.0625)	(0.0634)	(0.0627)	(0.0588)	(0.0597)	(0.0590)
emerging	-0.0231	-0.0072	-0.0227**	-0.0243	-0.0094	-0.0189	0.0223	0.0510	0.0489	0.0413	0.0562	0.0809
	(0.0164)	(0.0103)	(0.0099)	(0.0204)	(0.0117)	(0.0130)	(0.0694)	(0.0599)	(0.0971)	(0.0826)	(0.0633)	(0.1172)
transition	-0.0087	-0.0023	-0.0074	-0.0124	-0.0067	-0.0067						
	(0.0182)	(0.0140)	(0.0108)	(0.0232)	(0.0158)	(0.0137)						
time fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	149	149	149	149	149	149	75	75	75	75	75	75
F-test	3.342	3.799	5.096	3.413	3.950	4.008	4.115	3.621	4.150	4.122	3.705	4.170

Note: Endogenous variables: world market shares of DVAre and VAX respectively; resource rents. Robust standard errors in parentheses. ***, **, and * indicate statistical significant at the 1%, 5% and 10% level respectively. All regressions include a constant.

We also take some comfort from the fact that the coefficient of DVAre in the global sample throughout the specifications is rather close to the result in Kummritz (2016) which means that the results are not very sensitive to the exact definition of the GVC trade indicator[26]. As was the case in the structural model, also for the labour productivity growth model, the coefficients obtained for both the DVAre and the VAX variable are much larger for the subsample of emerging and transition economies. A noticeable difference is that in this subsample, the productivity growth model delivers slightly larger coefficients for the DVAre than for the VAX which was not the case in the structural model. The main conclusion to draw from these results is that GVC trade and trade in general seems to affect labour productivity growth more strongly than structural upgrading. Put differently, initiating structural upgrading with international trade seems to be more difficult than fostering labour productivity growth.

APPENDIX 5: CALCULATION OF VALUE ADDED EXPORTS (VAX) AND RE-EXPORTED DOMESTIC VALUE ADDED (DVARE)

Calculation of value added exports

The concept of value added exports (VAX) was initially suggested by Johnson and Noguera (2012a), though the expositions here follow more closely the discussion in Stehrer (2012) and Stehrer (2013).

Three components are required to calculate the value added exports. For any reporting country *r*, these components are the (industry-specific) value added requirements per unit of gross output, v_i^r, where *i* denotes the industry dimension (with $i \in I$); the Leontief inverse of the global input-output matrix, $\boldsymbol{L}$; and the global final demand vector, f_i^C, where the subscript *C* indicates that the vector comprises the final demand of all countries $c \in C$.

Country *r*'s (industry-specific) value added coefficients are defined as $v_i^r = \frac{value\ added_i^r}{gross\ output_i^r}$. The value added coefficients are arranged in a diagonal matrix of dimension *C·I* x *C·I*[27]. This matrix contains the value added coefficients of reporting country *r* for all industries along the diagonals. The remaining entries of the matrix are zero.

The second element is the Leontief inverse of the global input-output matrix, $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$ where $\boldsymbol{A}$ denotes the matrix of coefficients containing the typical element $a_{i,j}^{r,c}$ – the technical coefficients – which indicates the value of the sales of country *r*'s industry *i* to country *c*'s industry *j* per unit of production of *c*'s industry *j*. The technical coefficients describing the domestic production process in country *r* are found along the diagonal elements while the off-diagonal elements constitute country *r's* imports (from a column perspective). The dimension of the matrix of coefficients and the Leontief matrix is also *C·I* x *C·I.*

The final building block is the (industry-specific) global final demand vector f_i^C, which has the dimension *C·I* × 1. This final demand is split into separate blocks indicating the origin of the demand for the final goods. This split of final demand by demanding country, however, appears *within* the elements in the

[26] The forward production integration indicator in Kummritz (2016) is slightly larger than the indicators used here which eliminate some double counting of trade flows in the GVC trade measure.

[27] In the OECD-ICIO there are 62 countries (including the rest of the world) and 34 industries so that the dimension of the matrix is 2108 x 2108.

column vector. As usual, each row is associated with the source of the production that is the subject of the final demand.

In the 3-country-2-sector case, which includes the reporting country *r* and partner countries 2 and 3 and assumes a manufacturing sector (*m*) and a services sector (*s*), the full final demand vector, f_i^C, has the form

$$f_i^C = \begin{pmatrix} f_m^{r,r} + f_m^{r,2} + f_m^{r,3} \\ f_s^{r,r} + f_s^{r,2} + f_s^{r,3} \\ f_m^{2,r} + f_m^{2,2} + f_m^{2,3} \\ f_s^{2,r} + f_s^{2,2} + f_s^{2,3} \\ f_m^{3,r} + f_m^{3,2} + f_m^{3,3} \\ f_s^{3,r} + f_s^{3,2} + f_s^{3,3} \end{pmatrix}$$

where the subscript *C* indicates that the vector comprises the final demand of all countries $c \in C$. The typical element of this vector contains the final demand from all possible sources. For example, the element $f_s^{r,3}$ captures the value of final goods that country 3 demands from the services sector in country *r*. The value added exports comprise only value added that is created in one country but absorbed in another. Therefore the final demand from reporting country *r* itself needs to be eliminated for the calculation of country *r*'s VAX. This is done by setting the demand from country *r* to zero, yielding an adjusted final demand vector, $f_i^{c \neq r}$. This vector has the form:

$$f_i^{c \neq r} = \begin{pmatrix} 0 + f_m^{r,2} + f_m^{r,3} \\ 0 + f_s^{r,2} + f_s^{r,3} \\ 0 + f_m^{2,2} + f_m^{2,3} \\ 0 + f_s^{2,2} + f_s^{2,3} \\ 0 + f_m^{3,2} + f_m^{3,3} \\ 0 + f_s^{3,2} + f_s^{3,3} \end{pmatrix}$$

Reporting country *r*'s value added exports can then be calculated as

(A1) $$VAX_i^{r,*} = \boldsymbol{v_i^r} \cdot \boldsymbol{L} \cdot f_i^{c \neq r}$$

where $VAX_i^{r,*}$ is a row vector of dimension *C*·*I* × 1 which contains the sector-specific value added exports of country *r* to all partner countries.

To further illustrate the calculation, the matrices in equation (A1) are shown in detail for the three countries (reporting country *r* and partner countries 2 and 3) – two sectors case (sectors *m* and *s*):

$$\begin{pmatrix} VAX_{m,*}^{r,*} \\ VAX_{s,*}^{r,*} \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} v_m^r & 0 & 0 & 0 & 0 & 0 \\ 0 & v_s^r & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} l_{m,m}^{r,r} & l_{m,s}^{r,r} & l_{m,m}^{r,2} & l_{m,s}^{r,2} & l_{m,m}^{r,3} & l_{m,s}^{r,3} \\ l_{s,m}^{r,r} & l_{s,s}^{r,r} & l_{s,m}^{r,2} & l_{s,s}^{r,2} & l_{s,m}^{r,3} & l_{s,s}^{r,3} \\ l_{m,m}^{2,r} & l_{m,s}^{2,r} & l_{m,m}^{2,2} & l_{m,s}^{2,2} & l_{m,m}^{2,3} & l_{m,s}^{2,3} \\ l_{s,m}^{2,r} & l_{s,s}^{2,r} & l_{s,m}^{2,2} & l_{s,s}^{2,2} & l_{s,m}^{2,3} & l_{s,s}^{2,3} \\ l_{m,m}^{3,r} & l_{m,s}^{3,r} & l_{m,m}^{3,2} & l_{m,s}^{3,2} & l_{m,m}^{3,3} & l_{m,s}^{3,3} \\ l_{s,m}^{3,r} & l_{s,s}^{3,r} & l_{s,m}^{3,2} & l_{s,s}^{3,2} & l_{s,m}^{3,3} & l_{s,s}^{r,3} \end{pmatrix} \cdot \begin{pmatrix} 0 + f_m^{r,2} + f_m^{r,3} \\ 0 + f_s^{r,2} + f_s^{r,3} \\ 0 + f_m^{2,2} + f_m^{2,3} \\ 0 + f_s^{2,2} + f_s^{2,3} \\ 0 + f_m^{3,2} + f_m^{3,3} \\ 0 + f_s^{3,2} + f_s^{3,3} \end{pmatrix}$$

The coefficients in the Leontief matrix represent the total direct and indirect input requirements of any country for producing one dollar worth of output for final demand. For example, the coefficient $l_{m,s}^{r,r}$ indicates the total input requirement of country *r*'s services sector from country *r*'s manufacturing sector for producing one unit of output of sector *s*. Likewise, the coefficient $l_{m,m}^{r,3}$ indicates the input requirement of the manufacturing sector in country 3 per unit of its output that is supplied by country *r*'s manufacturing sector.

The resulting elements, $VAX_{m,*}^{r,*}$ and $VAX_{s,*}^{r,*}$, are the total value added exports of country *r*'s manufacturing and services sector to all other sectors (indicated by the asterisk in the subscript) of all partner countries (indicated by the asterisk in the superscript).

Calculation of re-exported domestic value added

The starting point for the calculation of the re-exported domestic value added (*DVAre*) is the decomposition of gross exports following the approach in Wang et al. (2013). The DVAre measure is a sub-component of the better-known value added exports (VAX) plus the domestic value added exported but returning home which is not part of VAX. The components which define DVAre are all contained in the key equation (equation (37) on p. 30) in Wang et al. (2013). These elements are characterised by the fact that the value added crosses borders at least twice. They comprise:

(a) The intermediate exports of reporting economy *r* to a partner country which are ultimately shipped to the destination country in the form of final goods.
(b) The intermediate exports of reporting economy *r* to a partner country which are ultimately shipped to the destination country in the form of intermediate goods.
(c) The intermediate exports of reporting economy *r* to a partner country which are consequently re-imported by country *r* in the form of either final goods or intermediate goods.

Note that all these export flows are exports of intermediates in the first export, while the ultimate export may take the form of a final goods or an intermediate goods export.

While not done explicitly in Wang et al. (2013), the decomposition allows for the identification of four 'roles' that a country can take in trade flows that form part of DVAre. These roles are:

(i) *reporting economy, **r,** which is the source country of the value added exported*
(ii) *immediate production partner, **ipp**, which is the recipient country of the first export by the source country r. The immediate production partner necessarily ships the value added (originating from country r) to another country.*
(iii) *ultimate production partner, **upp**, which is the last country in the production chain, responsible for the last production step and sale. This last sale can be an export or a domestic sale.*
(iv) *destination country, **dest**, which is the country of final demand, i.e. the country of absorption.*

In this categorisation the first three roles are all 'producers' because they are involved in the production process. In contrast, the role 'destination' is not part of the producers since it is the country of absorption. Certainly, for a particular trade flow, a particular country can take several roles. A simple example is a re-import, in which case the reporting country is identical to the country of absorption.

In technical terms, there are three terms of interest in the decomposition by Wang et al. (2013). In all these terms the notation is slightly adjusted to fit the description of the roles above. In particular, the index r denotes the reporting country and so on. So for any export flow ϕ, the indication $\phi^{r,ipp}$ means an export from the reporting country to the immediate production partner. Wang et al. (2013) indicate their decomposition at the bilateral level between reporting economy *r* and the immediate production partner, *ipp*:

(a) *Exports of intermediates with the ultimate export being an intermediate goods export, which are labelled* $DVAreex_{inter}^{r,ipp}$

$$DVAreex_{inter}^{r,ipp} = (V^r L^{rr})^T \# (A^{r,ipp} \sum_{upp \neq r,ipp}^{C} L^{ipp,upp} \cdot F^{upp,upp})$$

where $'\#'$ denotes an elementwise multiplication, V^r is the value added coefficient and L^{rr} the domestic Leontief inverse. Furthermore, $A^{r,ipp}$ is the sub-matrix of the global direct input coefficient matrix containing the elements representing inter-industry sales from reporting economy *r* to the immediate production partner, *ipp*. $L^{ipp,upp}$ is the global Leontief matrix with the elements representing direct and indirect inter-industry sales from the immediate production partner to the ultimate production partner, *upp*. Finally, is $F^{upp,upp}$ is the final demand involving purchases by the ultimate production partner – which here is equal to the country of destination so that $F^{upp,upp} = F^{dest,dest}$ – from itself. Hence, in this case the final sale is a domestic transaction and not an export. In other words, the country where the last production step is undertaken and the country of absorption are identical.

(b) *Exports of intermediates with the ultimate export being a final goods export, which are labelled* $DVAreex_{final}^{r,ipp}$

There are two types of re-exports of intermediates. In the first cases the immediate production partner, *ipp*, sells on the final good directly to the destination country, *dest*:

$$DVAreex_{final(1)}^{r,ipp} = (V^r L^{rr})^T \# (A^{r,ipp} \cdot L^{ipp,ipp} \sum_{dest \neq r,ipp}^{C} F^{ipp,dest})$$

In the second case the immediate production partner, *ipp*, sells on an intermediate good to another production partner, *upp*, which ultimately sells the final good to the destination country, *dest:*

$$DVAreex_{final(2)}^{r,ipp} = (V^r L^{rr})^T \# (A^{r,ipp} \sum_{upp \neq r,ipp}^{C} L^{ipp,upp} \sum_{dest \neq r,upp}^{C} F^{upp,dest})$$

In this second case, there are (at least)[28] three border crossings.

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[28] There are 'at least' three border crossings as potentially there may be additional countries that the value added passes on its way from the reporting economy to the destination country. This may happen 'within' the $B^{ipp,upp}$ shipment which cannot be further tracked with this approach.

(d) Exports of intermediates which return home to the reporting economy

$$DVAreimp_{total}^{r,ipp} = (V^r L^{rr})^T \#(A^{r,ipp} \cdot L^{ipp,ipp} \cdot F^{ipp,r} + A^{r,ipp} \sum_{upp \neq r,ipp}^{C} L^{ipp,upp} \cdot F^{upp,r} + A^{r,ipp} \cdot L^{ipp,r} \cdot F^{r,r})$$

Note that within the re-imports there are actually also these three sub-types of imports, i.e. the value added that returns home to the reporting economy directly in the form of final goods, value added that returns home to the reporting economy via a first (*ipp*) and a second production partner (*upp*), and value added that is re-imported in the form of intermediate goods.

In contrast to the focus in Wang et al. (2013) on the bilateral flows between the reporting country and the immediate production partner, the approach in Chapter 4 of this report requires all 'roles' described above. Also, with regards to bilateral exports, the view is that the main interest should be with flows between the reporting economy and the destination country, i.e. $\phi^{r,dest}$ as usual in trade analysis even if this flow is indirect via other countries. Hence, the geographic split of exports will be according to destination countries. The information on the immediate and the ultimate production partner will be used to identify the regional versus global VC trade. Hence, in essence the same bilateral *DVAre* flows are used but they are aggregated differently.

The way the calculations are performed ensures that the *DVAre* originating from all source countries is covered and that all 'roles' remain identifiable. This poses some problems of dimensionality so that the usual matrix algebra used to calculate, for example, VAX needs to be adjusted.

The general approach is to calculate all possible combinations of trade flows between the quadruples (*r-ipp-upp-dest*) using matrix algebra and then single out the combinations necessary to single out the three types of *DVAre*.

Hence the matrix calculations will yield a 'magnified' DVAre measure, $\widehat{\boldsymbol{DVAre}}$, which contains all possible combinations of quadruples, some of which need to be dropped later on because they actually do not form part of *DVAre*.

The general approach to calculate these 'magnified DVAre', $\widehat{DVAre}$, is the following:

$$\widehat{\boldsymbol{DVAre}} = \boldsymbol{v}^r \cdot \boldsymbol{L}^{rr} \# (\boldsymbol{A}^r \cdot \boldsymbol{B} \cdot \boldsymbol{F}^{dest})$$

where '#' denotes again an elementwise multiplication. $\boldsymbol{L}^{rr}$ is the (blockdiagonal) domestic Leontief inverse. Post-multiplication of the value added coefficient matrix $\boldsymbol{v}^r$ with the domestic Leontief inverse ensures that only value added embodied in intermediate exports is considered. The result of $v^r \cdot \boldsymbol{L}^{rr}$ constitutes the first part in the calculation of *DVAre*.

The second part of the calculation entails the sub-matrix of the global direct input coefficient matrix ($\boldsymbol{A}^r$) for the reporter *r*, the global Leontief inverse, $\boldsymbol{B}$, and the final demand coming from each of the potential destination countries, represented by the final demand matrix $\boldsymbol{Y}^{dest}$. In the $A^{r,}$ matrix, the reporting country *r* is selling to the immediate production partner (*ipp*). In the case of the Leontief inverse the ultimate production partner (upp) is selling to the final destination country (*dest*). Y^{dest} is the (destination-specific) final demand matrix, which is also a block-diagonal matrix.

As for the first part of the calculation, $\boldsymbol{v^r} \cdot \boldsymbol{L^{rr}}$, the actual calculation is performed using the value added coefficient matrices with the full country industry dimension (*C x I*) and containing the value added coefficient of all reporters (i.e. no values are set to zero)**.** Because of the issue of dimensionality, the value added coefficient matrix for each reporting economy *r* is transformed into a row vector. These country-specific row vectors are combined to yield – for the 3-country-2-sector case, assuming a manufacturing sector (*m*) and a services sector (*s*) – a value added coefficient matrix of the form

$$\begin{pmatrix} v_m^r & v_s^r & 0 & 0 & 0 & 0 \\ 0 & 0 & v_m^2 & v_s^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & v_m^3 & v_s^3 \end{pmatrix}$$

Also, the domestic Leontief inverses are inserted as the diagonal blocks into a diagonal matrix of dimension *C x I* to yield the $\boldsymbol{L^{rr}}$ matrix. This matrix has the following form:

$$\begin{pmatrix} l_{m,m}^{r,r} & l_{m,s}^{r,r} & 0 & 0 & 0 & 0 \\ l_{s,m}^{r,r} & l_{s,s}^{r,r} & 0 & 0 & 0 & 0 \\ 0 & 0 & l_{m,m}^{2,2} & l_{m,s}^{2,2} & 0 & 0 \\ 0 & 0 & l_{s,m}^{2,2} & l_{s,s}^{2,2} & 0 & 0 \\ 0 & 0 & 0 & 0 & l_{m,m}^{3,3} & l_{m,s}^{3,3} \\ 0 & 0 & 0 & 0 & l_{s,m}^{3,3} & l_{s,s}^{r,3} \end{pmatrix}$$

The above-described value added coefficient matrix $\boldsymbol{v_i^r}$ is multiplied with the block-diagonal domestic Leontief inverse.

$$[\boldsymbol{v_i} \cdot \boldsymbol{L^{rr}}]$$

In the 3-country-2-sector example the following result is obtained:

$$\boldsymbol{vL^{rr}} = \begin{pmatrix} v_m^r & v_s^r & 0 & 0 & 0 & 0 \\ 0 & 0 & v_m^2 & v_s^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & v_m^3 & v_s^3 \end{pmatrix} \cdot \begin{pmatrix} l_{m,m}^{r,r} & l_{m,s}^{r,r} & 0 & 0 & 0 & 0 \\ l_{s,m}^{r,r} & l_{s,s}^{r,r} & 0 & 0 & 0 & 0 \\ 0 & 0 & l_{m,m}^{2,2} & l_{m,s}^{2,2} & 0 & 0 \\ 0 & 0 & l_{s,m}^{2,2} & l_{s,s}^{2,2} & 0 & 0 \\ 0 & 0 & 0 & 0 & l_{m,m}^{3,3} & l_{m,s}^{3,3} \\ 0 & 0 & 0 & 0 & l_{s,m}^{3,3} & l_{s,s}^{r,3} \end{pmatrix}$$

$$= \begin{pmatrix} v_m^r\, l_{m,m}^{r,r} + v_s^r\, l_{s,m}^{r,r} & v_m^r\, l_{m,s}^{r,r} + v_s^r\, l_{s,s}^{r,r} & 0 & 0 & 0 & 0 \\ 0 & 0 & v_m^2\, l_{m,m}^{2,2} + v_s^2\, l_{s,m}^{2,2} & v_m^2\, l_{m,s}^{2,2} + v_s^2\, l_{s,s}^{2,2} & 0 & 0 \\ 0 & 0 & 0 & 0 & v_m^3\, l_{m,m}^{3,3} + v_s^3\, l_{s,m}^{3,3} & v_m^3\, l_{m,s}^{3,3} + v_s^3 l_{s,s}^{3,3} \end{pmatrix}$$

The resulting matrix, $\boldsymbol{L^{rr}}$, is transposed blockwise and post-multiplied with a *C I x1* vector of ones to yield a *1 x C I* column vector of the form.

$$vL^{rr} = \begin{pmatrix} v_m^r\, l_{m,m}^{r,r} + v_s^r\, l_{s,m}^{r,r} \\ v_m^r\, l_{m,s}^{r,r} + v_s^r\, l_{s,s}^{r,r} \\ v_m^2\, l_{m,m}^{2,2} + v_s^2\, l_{s,m}^{2,2} \\ v_m^2\, l_{m,s}^{2,2} + v_s^2\, l_{s,s}^{2,2} \\ v_m^3\, l_{m,m}^{3,3} + v_s^3\, l_{s,m}^{3,3} \\ v_m^3\, l_{m,s}^{3,3} + v_s^3\, l_{s,s}^{3,3} \end{pmatrix}$$

The column vector v^{rr} is the first part of the operation.

The second part requires the matrix multiplication of $\boldsymbol{A^r}$ with the global Leontief inverse $\boldsymbol{L}$ and then with the appropriate (reporter-specific) block-diagonal final demand matrix,· $\boldsymbol{F^{dest}}$.

Using the roles as defined above for each reporting economy *r*, the reporting-country-specific rows of the direct input coefficient A are used to define $\boldsymbol{A^r}$ which has dimension *C·I x C·I*. In the 3-country-2-sector case this matrix has the form

$$\boldsymbol{A^r} = \begin{pmatrix} a_{m,m}^{r,r} & a_{m,s}^{r,r} & a_{m,m}^{r,2} & a_{m,s}^{r,2} & a_{m,m}^{r,3} & a_{m,s}^{r,3} \\ a_{s,m}^{r,r} & a_{s,s}^{r,r} & a_{s,m}^{r,2} & a_{s,s}^{r,2} & a_{s,m}^{r,3} & a_{s,s}^{r,3} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

The blockwise diagonalisation of this $\boldsymbol{A^r}$ matrix yields

$$\boldsymbol{diag}(\boldsymbol{A^r}) = \begin{pmatrix} a_{m,m}^{r,r} & a_{m,s}^{r,r} & 0 & 0 & 0 & 0 \\ a_{s,m}^{r,r} & a_{s,s}^{r,r} & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{m,m}^{r,2} & a_{m,s}^{r,2} & 0 & 0 \\ 0 & 0 & a_{s,m}^{r,2} & a_{s,s}^{r,2} & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{m,m}^{r,3} & a_{m,s}^{r,3} \\ 0 & 0 & 0 & 0 & a_{s,m}^{r,3} & a_{s,s}^{r,3} \end{pmatrix}$$

This matrix is post-multiplied with the global Leontief matrix L to yield:

$$diag(\,\boldsymbol{A^r}\,) \cdot \boldsymbol{L}\ \ )$$

The details of these matrices are as follows:

$$diag(A^r) \times L = \begin{pmatrix} a_{m,m}^{r,r} & a_{m,s}^{r,r} & 0 & 0 & 0 & 0 \\ a_{s,m}^{r,r} & a_{s,s}^{r,r} & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{m,m}^{r,2} & a_{m,s}^{r,2} & 0 & 0 \\ 0 & 0 & a_{s,m}^{r,2} & a_{s,s}^{r,2} & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{m,m}^{r,3} & a_{m,s}^{r,3} \\ 0 & 0 & 0 & 0 & a_{s,m}^{r,3} & a_{s,s}^{r,3} \end{pmatrix} \begin{pmatrix} l_{m,m}^{r,r} & l_{m,s}^{r,r} & l_{m,m}^{r,2} & l_{m,s}^{r,2} & l_{m,m}^{r,3} & l_{m,s}^{r,3} \\ l_{s,m}^{r,r} & l_{s,s}^{r,r} & l_{s,m}^{r,2} & l_{s,s}^{r,2} & l_{s,m}^{r,3} & l_{s,s}^{r,3} \\ l_{m,m}^{2,r} & l_{m,s}^{2,r} & l_{m,m}^{2,2} & l_{m,s}^{2,2} & l_{m,m}^{2,3} & l_{m,s}^{2,3} \\ l_{s,m}^{2,r} & l_{s,s}^{2,r} & l_{s,m}^{2,2} & l_{s,s}^{2,2} & l_{s,m}^{2,3} & l_{s,s}^{2,3} \\ l_{m,m}^{3,r} & l_{m,s}^{3,r} & l_{m,m}^{3,2} & l_{m,s}^{3,2} & l_{m,m}^{3,3} & l_{m,s}^{3,3} \\ l_{s,m}^{3,r} & l_{s,s}^{3,r} & l_{s,m}^{3,2} & l_{s,s}^{3,2} & l_{s,m}^{3,3} & l_{s,s}^{3,3} \end{pmatrix}$$

$$= \begin{pmatrix} a_{m,m}^{r,r} \cdot l_{m,m}^{r,r} + a_{m,s}^{r,r} \cdot l_{s,m}^{r,r} & a_{m,m}^{r,r} \cdot l_{m,s}^{r,r} + a_{m,s}^{r,r} \cdot l_{s,s}^{r,r} & a_{m,m}^{r,r} \cdot l_{m,m}^{r,2} + a_{m,s}^{r,r} \cdot l_{s,m}^{r,2} & a_{m,m}^{r,r} \cdot l_{m,s}^{r,2} + a_{m,s}^{r,r} \cdot l_{s,s}^{r,2} & a_{m,m}^{r,r} \cdot l_{m,m}^{r,3} + a_{m,s}^{r,r} \cdot l_{s,m}^{r,3} & a_{m,m}^{r,r} \cdot l_{m,s}^{r,3} + a_{m,s}^{r,r} \cdot l_{s,s}^{r,3} \\ a_{s,m}^{r,r} \cdot l_{m,m}^{r,r} + a_{s,s}^{r,r} \cdot l_{s,m}^{r,r} & a_{s,m}^{r,r} \cdot l_{m,s}^{r,r} + a_{s,s}^{r,r} \cdot l_{s,s}^{r,r} & a_{s,m}^{r,r} \cdot l_{m,m}^{r,2} + a_{s,s}^{r,r} \cdot l_{s,m}^{r,2} & a_{s,m}^{r,r} \cdot l_{m,s}^{r,2} + a_{s,s}^{r,r} \cdot l_{s,s}^{r,2} & a_{s,m}^{r,r} \cdot l_{m,m}^{r,3} + a_{s,s}^{r,r} \cdot l_{s,m}^{r,3} & a_{s,m}^{r,r} \cdot l_{m,s}^{r,3} + a_{s,s}^{r,r} \cdot l_{s,s}^{r,3} \\ a_{m,m}^{r,2} \cdot l_{m,m}^{2,r} + a_{m,s}^{r,2} \cdot l_{s,m}^{2,r} & a_{m,m}^{r,2} \cdot l_{m,s}^{r,r} + a_{m,s}^{r,2} \cdot l_{s,s}^{r,r} & a_{m,m}^{r,2} \cdot l_{m,m}^{2,2} + a_{m,s}^{r,2} \cdot l_{s,m}^{2,2} & a_{m,m}^{r,2} \cdot l_{m,s}^{r,r} + a_{m,s}^{r,2} \cdot l_{s,s}^{2,2} & a_{m,m}^{r,2} \cdot l_{m,m}^{2,3} + a_{m,s}^{r,2} \cdot l_{s,m}^{2,3} & a_{m,m}^{r,2} \cdot l_{m,s}^{2,3} + a_{m,s}^{r,2} \cdot l_{s,s}^{r2,3} \\ a_{s,m}^{r,2} \cdot l_{m,m}^{2,r} + a_{s,s}^{r,2} \cdot l_{s,m}^{2,r} & a_{s,m}^{r,2} \cdot l_{m,s}^{r,r} + a_{s,s}^{r,2} \cdot l_{s,s}^{r,r} & a_{s,m}^{r,2} \cdot l_{m,m}^{2,2} + a_{s,s}^{r,2} \cdot l_{s,m}^{2,2} & a_{s,m}^{r,2} \cdot l_{m,s}^{r,r} + a_{s,s}^{r,2} \cdot l_{s,s}^{2,2} & a_{s,m}^{r,2} \cdot l_{m,m}^{2,3} + a_{s,s}^{r,2} \cdot l_{s,m}^{2,3} & a_{s,m}^{r,2} \cdot l_{m,s}^{2,3} + a_{s,s}^{r,2} \cdot l_{s,s}^{2,3} \\ a_{m,m}^{r,3} \cdot l_{m,m}^{3,r} + a_{m,s}^{r,3} \cdot l_{s,m}^{3,r} & a_{m,m}^{r,3} \cdot l_{m,s}^{3,r} + a_{m,s}^{r,3} \cdot l_{s,s}^{3,r} & a_{m,m}^{r,3} \cdot l_{m,m}^{3,2} + a_{m,s}^{r,3} \cdot l_{s,m}^{3,2} & a_{m,m}^{r,3} \cdot l_{m,s}^{3,2} + a_{m,s}^{r,3} \cdot l_{s,s}^{3,2} & a_{m,m}^{r,3} \cdot l_{m,m}^{3,3} + a_{m,s}^{r,3} \cdot l_{s,m}^{r3,3} & a_{m,m}^{r,3} \cdot l_{m,s}^{3,3} + a_{m,s}^{r,3} \cdot l_{s,s}^{3,3} \\ a_{s,m}^{r,3} \cdot l_{m,m}^{3,r} + a_{s,s}^{r,3} \cdot l_{s,m}^{3,r} & a_{s,m}^{r,3} \cdot l_{m,s}^{3,r} + a_{s,s}^{r,3} \cdot l_{s,s}^{3,r} & a_{s,m}^{r,3} \cdot l_{m,m}^{3,2} + a_{s,s}^{r,3} \cdot l_{s,m}^{3,2} & a_{s,m}^{r,3} \cdot l_{m,s}^{3,2} + a_{s,s}^{r,3} \cdot l_{s,s}^{3,2} & a_{s,m}^{r,3} \cdot l_{m,m}^{3,3} + a_{s,s}^{r,3} \cdot l_{s,m}^{3,3} & a_{s,m}^{r,3} \cdot l_{m,s}^{3,3} + a_{s,s}^{r,3} \cdot l_{s,s}^{3,3} \end{pmatrix}$$

Define this matrix as AL^r

$$\boldsymbol{AL^r} = \begin{pmatrix} AL^{r,r}_{m,m} & AL^{r,r}_{m,s} & AL^{r,2}_{m,m} & AL^{r,2}_{m,s} & AL^{r,3}_{m,m} & AL^{r,3}_{m,s} \\ AL^{r,r}_{s,m} & AL^{r,r}_{s,s} & AL^{r,2}_{s,m} & AL^{r,2}_{s,s} & AL^{r,3}_{s,m} & AL^{r,3}_{s,s} \\ AL^{2,r}_{m,m} & AL^{2,r}_{m,s} & AL^{2,2}_{m,m} & AL^{2,2}_{m,s} & AL^{2,3}_{m,m} & AL^{2,3}_{m,s} \\ AL^{2,r}_{s,m} & AL^{2,r}_{s,s} & AL^{2,2}_{s,m} & AL^{2,2}_{s,s} & AL^{2,3}_{s,m} & AL^{2,3}_{s,s} \\ AL^{3,r}_{m,m} & AL^{3,r}_{m,s} & AL^{3,2}_{m,m} & AL^{3,2}_{m,s} & AL^{3,3}_{m,m} & AL^{3,3}_{m,s} \\ AL^{3,r}_{s,m} & AL^{3,r}_{s,s} & AL^{3,2}_{s,m} & AL^{3,2}_{s,s} & AL^{3,3}_{s,m} & AL^{3,3}_{s,s} \end{pmatrix}$$

This is a *CI x CI* matrix, of which there are *C* such matrices, one for each reporter. Note that in this matrix the indices of the elements are to be interpreted as follows: first index indicates the immediate production partner (*ipp*) and the index indicates the last country in the value chain, i.e. the ultimate production partner (*upp*).

In the next step this AL^r matrix is post-multiplied with the global final demand matrix for each of the countries.

The (industry-specific) global final demand vector f has the dimension *C·I* × 1. In the 3-country-2-sector case, it takes the form:

$$f = \begin{pmatrix} f^{r,r}_m + f^{r,2}_m + f^{r,3}_m \\ f^{r,r}_s + f^{r,2}_s + f^{r,3}_s \\ f^{2,r}_m + f^{2,2}_m + f^{2,3}_m \\ f^{2,r}_s + f^{2,2}_s + f^{2,3}_s \\ f^{3,r}_m + f^{3,2}_m + f^{3,3}_m \\ f^{3,r}_s + f^{3,2}_s + f^{3,3}_s \end{pmatrix}$$

This final demand is split into separate blocks indicating the origin of the demand for the final goods. From the OECD-ICIO data the information in this vector can also be used to form a *CI x CI* final demand matrix, F. For the 3-country-2-sector case:

$$\boldsymbol{F} = \begin{pmatrix} f^{r,r}_m & f^{r,2}_m & f^{r,3}_m \\ f^{r,r}_s & f^{r,2}_s & f^{r,3}_s \\ f^{2,r}_m & f^{2,2}_m & f^{2,3}_m \\ f^{2,r}_s & f^{2,2}_s & f^{2,3}_s \\ f^{3,r}_m & f^{3,2}_m & f^{3,3}_m \\ f^{3,r}_s & f^{3,2}_s & f^{3,3}_s \end{pmatrix}$$

As usual, each row is associated with the source of the production that is the subject of the final demand. For example, the element $f^{r,3}_s$ captures the value of final goods that country 3 demands from the services sector in country *r*.

This matrix is now split into column vectors for each individual country, f^r. This vector indicates the value added from all sources needed to satisfy final demand of a destination country *dest* and has dimension *CI x 1*:

$$f^{dest} = \begin{pmatrix} f_m^{r,dest} \\ f_s^{r,dest} \\ f_m^{2,dest} \\ f_s^{2,dest} \\ f_m^{3,dest} \\ f_s^{3,dest} \end{pmatrix}$$

Each of the destination-specific column vectors (there are *C* such vectors) are diagonalised and pre-multiplied with each of the AL^r matrices calculated above. Note that there is not only F but there are C such f^{dest} diagonal matrices. In this context f^{dest} is used to avoid confusion with country *r* as the source of the value added (although they can be identical, i.e. in the case of re-imports).

$$\boldsymbol{ALf^{r \to dest}} = \boldsymbol{AL^r} \cdot f^{dest}$$

This operation is done not only for the *AL* matrix of country *r* but for all of the *C* countries. The arrow in the superscript of the $\boldsymbol{ALf^{r \to dest}}$ matrix should indicate that the value added will travel from *r* to *dest* via other countries.

For country *r*, and defining country 3 as the destination country (*dest*), the 3-country-2-sector case can be written as follows:

$$AL^r f^{dest}$$
$$= \begin{pmatrix} AL_{m,m}^{r,r} & AL_{m,s}^{r,r} & AL_{m,m}^{r,2} & AL_{m,s}^{r,2} & AL_{m,m}^{r,dest} & AL_{m,s}^{r,dest} \\ AL_{s,m}^{r,r} & AL_{s,s}^{r,r} & AL_{s,m}^{r,2} & AL_{s,s}^{r,2} & AL_{s,m}^{r,dest} & AL_{s,s}^{r,dest} \\ AL_{m,m}^{2,r} & AL_{m,s}^{2,r} & AL_{m,m}^{2,2} & AL_{m,s}^{2,2} & AL_{m,m}^{2,dest} & AL_{m,s}^{2,dest} \\ AL_{s,m}^{2,r} & AL_{s,s}^{2,r} & AL_{s,m}^{2,2} & AL_{s,s}^{2,2} & AL_{s,m}^{2,dest} & AL_{s,s}^{2,dest} \\ AL_{m,m}^{dest,r} & AL_{m,s}^{dest,r} & AL_{m,m}^{dest,2} & AL_{m,s}^{dest,2} & AL_{m,m}^{dest,dest} & AL_{m,s}^{dest,dest} \\ AL_{s,m}^{dest,r} & AL_{s,s}^{dest,r} & AL_{s,m}^{dest,2} & AL_{s,s}^{dest,2} & AL_{s,m}^{dest,3} & AL_{s,s}^{dest,dest} \end{pmatrix} \cdot \begin{pmatrix} f_m^{r,dest} & 0 & 0 & 0 & 0 & 0 \\ 0 & f_s^{r,dest} & 0 & 0 & 0 & 0 \\ 0 & 0 & f_m^{2,dest} & 0 & 0 & 0 \\ 0 & 0 & 0 & f_s^{2,dest} & 0 & 0 \\ 0 & 0 & 0 & 0 & f_m^{dest,dest} & 0 \\ 0 & 0 & 0 & 0 & 0 & f_s^{dest,dest} \end{pmatrix}$$
$$= \begin{pmatrix} AL_{m,m}^{r,r} \cdot f_m^{r,dest} & AL_{m,s}^{r,r} \cdot f_s^{r,dest} & AL_{m,m}^{r,2} \cdot f_m^{2,dest} & AL_{m,s}^{r,2} \cdot f_s^{2,dest} & AL_{m,m}^{r,dest} \cdot f_m^{dest,dest} & AL_{m,s}^{r,dest} \cdot f_s^{dest,dest} \\ AL_{s,m}^{r,r} \cdot f_m^{r,dest} & AL_{s,s}^{r,r} \cdot f_s^{r,dest} & AL_{s,m}^{r,2} \cdot f_m^{2,dest} & AL_{s,s}^{r,2} \cdot f_m^{2,dest} & AL_{s,m}^{r,dest} \cdot f_m^{dest,dest} & AL_{s,s}^{r,dest} \cdot f_m^{dest,dest} \\ AL_{m,m}^{2,r} \cdot f_m^{r,dest} & AL_{m,s}^{2,r} \cdot f_s^{r,dest} & AL_{m,m}^{2,2} \cdot f_m^{2,dest} & AL_{m,s}^{2,2} \cdot f_m^{2,dest} & AL_{m,m}^{2,dest} \cdot f_m^{dest,dest} & AL_{m,s}^{2,dest} \cdot f_m^{dest,dest} \\ AL_{s,m}^{2,r} \cdot f_m^{r,dest} & AL_{s,s}^{2,r} \cdot f_s^{r,dest} & AL_{s,m}^{2,2} \cdot f_m^{2,dest} & AL_{s,s}^{2,2} \cdot f_m^{2,dest} & AL_{s,m}^{2,dest} \cdot f_m^{dest,dest} & AL_{s,s}^{2,dest} \cdot f_m^{dest,dest} \\ AL_{m,m}^{dest,r} \cdot f_m^{r,dest} & AL_{m,s}^{dest,r} \cdot f_s^{r,dest} & AL_{m,m}^{dest,2} \cdot f_m^{2,dest} & AL_{m,s}^{dest,2} \cdot f_m^{2,dest} & AL_{m,m}^{dest,dest} \cdot f_m^{dest,dest} & AL_{m,s}^{dest,dest} \cdot f_m^{dest,dest} \\ AL_{s,m}^{dest,r} \cdot f_m^{r,dest} & AL_{s,s}^{dest,r} \cdot f_s^{r,dest} & AL_{s,m}^{dest,2} \cdot f_m^{2,dest} & AL_{s,s}^{dest,2} \cdot f_m^{2,dest} & AL_{s,m}^{dest,dest} \cdot f_m^{dest,dest} & AL_{s,s}^{dest,dest} \cdot f_m^{dest,dest} \end{pmatrix}$$

There are C x C such matrixes for each reporter-destination combinations. The 'route' along which the value added travelled from the reporter to the destination can be read directly from the indices of the global Leontief matrix. Therefore, from this $AL^r f^{dest}$ matrix all three relevant items for the calculation of the *DVAre* can be identified. In the above example, all elements in the matrix have country *r* as reporter and country *dest* as the destination country. The element $AL_{s,s}^{2,dest} \cdot f_m^{dest,dest}$ then is value added originating from country *r* that is exported in the form of intermediates to country 2, which takes the role of the immediate production partner. Country 2 is processing and re-exporting the value added in the form of intermediates to the final destination country in the form of intermediates. The destination country (dest) is responsible for the final production step, so it also has the role of the ultimate production partner.

The final step is to multiply elementwise the first part, $\boldsymbol{vL^{rr}}$**,** with the second part:

$$\boldsymbol{vL^{rr}}\#\boldsymbol{AL^{r}} \cdot f^{dest}$$

This yields the magnified *DVAre*. To obtain the *DVAre* as defined above the required elements of the universe of combinations $\boldsymbol{vL^{rr}}\#\boldsymbol{AL^{r}} \cdot f^{dest}$ need to be singled out. More precisely, the components of *DVAre* defined above are obtained as follows

(a) *Exports of intermediates with the ultimate export being an intermediate goods export, which are labelled* $DVAreex_{inter}^{r,ipp}$

Contains all elements where $r \neq ipp \cap r \neq dest \cap [ipp \neq upp \cap upp = dest]$.

(b) *Exports of intermediates with the ultimate export being a final goods export (*$DVAreex_{final}^{r,ipp}$*)*

$$DVAreex_{final(1)}^{r,ipp}$$

Contains all elements where $r \neq ipp \cap r \neq dest \cap [ipp = upp \cap upp \neq dest]$.

$$DVAreex_{final(2)}^{r,ipp}$$

Contains all elements where $r \neq ipp \cap r \neq dest \cap [ipp \neq upp \cap upp \neq dest]$.

(c) *Exports of intermediates which return home to the reporting economy (*$DVAreimp_{total}^{r,ipp}$*)*

Contains all elements where $r = dest \cap r \neq ipp$.

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