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Global value chain participation and its impact on industrial upgrading

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Abstract

Participation in global value chains (GVCs) has become a central topic in trade and development policy. It has opened new ways to achieve industrial upgrading. However, some theoretical models suggest that not all countries will upgrade through participation in GVCs. Using panel data from the World Input-Output Database, we examine the effects of backward and forward GVC participation on three dimensions of industrial upgrading (process, product and skill upgrading). We find that backward GVC participation provides more upgrading opportunities for developing countries as it enables a less developed country to import sophisticated inputs. This activates learning through embodied knowledge. In contrast, forward participation has higher level of upgrading effect on developed countries.

KEYWORDS

global value chain participation, industrial upgrading, world input-output tables

1 | INTRODUCTION

The nature of production and international trade has changed in an important way during the last decades. Whereas countries (or firms) used to perform almost all tasks of the overall production process before exporting the product to other countries for consumption, advances in transport and telecommunication technology make it nowadays possible for a country to unbundle its tasks. That is, to minimise total production costs, firms perform one or few specific tasks themselves and then offshore other tasks to foreign countries for the next layer of production. Baldwin and Robert-Nicoud (2014) refer to the traditional trade pattern as ‘trade in goods’ and call the

new phenomenon ‘trade in tasks’. The set of all value-adding tasks that are needed in production is called a value chain. In the ‘trade in goods’ era, most value chains took place within a single country. Nowadays, value chains have become ‘global’ and the production is fragmented into smaller tasks that are carried out in multiple countries. With the enormous expansion of global value chains (GVCs), the relevance of GVCs has been set out in the academic literature and new data sets on ‘value-added’ trade (that remove the biased picture of trade benefits in traditionally measured ‘gross’ trade) emerged.

Countries (or firms) that perform one or some tasks in the production phase of globally produced products are called GVC participants. In this paper, we examine the effects of GVC participation on a country’s degree of industrial upgrading. Industrial upgrading is a term that frequently pops up in governmental reports, in economic policy documents and in mass media. However, industrial upgrading is a concept with many definitions as different users seem to differ in the interpretation of the concept (Tian et al., 2019). Irrespective of *the* definition, industrial upgrading has the aim to improve a country’s competitive advantage and enlarge the benefits of participation in production tasks. An unresolved debate is whether and to what extent GVC participation (or integration) benefits industrial upgrading in developed and in developing countries.

Two dominant views can be distinguished. The first view states that GVCs mainly benefit developed countries’ upgrading and that the opportunities for developing countries are limited. There are studies that emphasise that the rise of GVCs enables developed countries to offshore parts of low value-added tasks and specialise in high value-added tasks (e.g. Baldwin & Robert-Nicoud, 2014; Bhagwati et al., 2004; Mankiw & Swagel, 2006). This specialisation decreases production costs and increases resource allocation to more sophisticated tasks (and products), both of which are good for industrial upgrading in developed countries. However, with this specialisation, a concern for developing countries is that GVCs will leave them little scope for upgrading if the country’s GVC participation is locked mostly in exploiting natural resources, unskilled and low-cost labour, or simple tasks (Gereffi et al., 2005; UNCTAD, 2013).

The second view states that GVC participation provides more opportunities for developing countries to upgrade (Navas-Alemán, 2011). Hira and Hira (2008), Li and Liu (2014) and Samuelson (2004); for example, stress that GVCs facilitate technological transfers from developed to developing countries and, hence, shift competitive advantage from the former to the latter. Also, GVCs offer developing countries good opportunities to integrate into global production networks without having to master all relevant knowledge and without the need to possess all resources of the overall production process of a product (Amendolagine et al., 2019). It enables developing countries to enter into more modern manufacturing by initially performing simple tasks, which evolve through learning into more sophisticated tasks (see, e.g. Lin, 2011; Lin & Wang, 2012; Pietrobelli & Rabelotti, 2011).

Each of these viewpoints highlights one or more important aspects of the relationship between GVCs and industrial upgrading. This suggests that GVCs have uncertain effects on industrial upgrading which raises the following two questions. What concerns about GVCs are justified and for which countries will GVC participation lead to better industrial development? To answer these questions, we examine these issues empirically as there has been to date, to the best of our knowledge, no such study.

The purpose of this study is twofold. The first aim is to empirically analyse the effect of GVC participation on industrial upgrading. In our analysis, we measure GVC participation from two perspectives: backward and forward. The backward links reflect the use of foreign intermediate inputs to produce the final products of a GVC (Los et al., 2015). The forward links reflect the value-added in the exported intermediate inputs. We distinguish between backward and forward

GVC participation, because different studies (e.g. Havranek & Irsova, 2011) suggest that backward and forward links have different effects on productivity improvement.

Since different studies suggest that industrial upgrading is a multidimensional phenomenon (see Humphrey & Schmitz, 2002; Tian et al., 2019), we use three quantitative dimensions of industrial upgrading as our dependent variables as proposed by Tian et al. (2019). These measures capture process upgrading, product upgrading and skill upgrading.

Using the world multi-regional input–output tables from the World Input-Output Database (Dietzenbacher et al., 2013), we calculate the GVC participation of 1360 country industries (40 countries with 34 industries) for the period 1995–2011. We combine this with available data from the WIOD Socio Economic Accounts to calculate the three measures of industrial upgrading for the period of 1995–2009. We use the data to estimate a panel data regression model and find that an increase in GVC participation (no matter whether backward or forward) increases industrial upgrading in product and skill upgrading. However, we also find that backward and forward GVC participation show different effects on process upgrading.

The second aim of this paper is to test whether a country's development stage matters for the effects of GVC participation on industrial upgrading. We do this by distinguishing between developing countries and developed countries, and we test whether backward or forward GVC participation has stronger or weaker effects on industrial upgrading in developing countries or developed countries. Our results show that backward participation has stronger effects on industrial upgrading in developing countries, while forward participation provides higher level of upgrading effect on developed countries. Specifically, the process upgrading (productivity improvement) of developing countries relies more on backward GVC links than forward links. Comprehensively considering the effects of backward and forward GVC participation on the three dimensions of industrial upgrading, we do find that GVC integration benefits industrial upgrading for both developed and developing countries. Our results suggest that theoretical concerns that GVC integration have negative effects are not supported by the data. A nation that seeks to ban the international reorganisation of production may find that such reluctance will hinder industrial upgrading. Attempts to resist GVC participation while other nations embrace it may be futile or even counterproductive.

The remainder of the paper is organised as follows. Section 2 discusses the theoretical channels through which GVC participation affects industrial upgrading in developed and developing countries. Section 3 first presents the indicators of GVC participation and the three dimensions of industrial upgrading and continues with the empirical specification. In Section 4 and Section 5, we introduce data and present econometric results. Finally, Section 6 concludes.

2 | LITERATURE REVIEW: HOW GVC PARTICIPATION AFFECTS INDUSTRIAL UPGRADING

Trade can benefit its participants through a myriad of channels including economies of scale, deepening specialisation and efficient reallocation of resources. As to trade in final goods, the traditional *gains-from-trade* theorem based on the Heckscher-Ohlin-Vanek framework states that trade entails gains for all parties involved, and some trade is better than none. However, recent theoretical research shows that GVCs have changed the way trade is conducted, which has led to discussion about the impact of GVC participation on industrial upgrading. This literature examines typical GVCs that link low-wage countries, the *South*, to technologically advanced nations with high wages, the *North*. The difference between the two country groups generates incentives

to trade tasks, which in turn create a set of benefits and costs depending on the assumptions of the models.

Industrial upgrading is not very well defined due to its multidimensional features. Considering its multidimensionality, Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002) identify four distinct types of upgrading, namely process upgrading, product upgrading, functional upgrading and intersectoral upgrading. Tian et al. (2019) provide quantitative measures for process upgrading, product upgrading and skill upgrading. They argue that their measures also capture intersectoral upgrading at country level but not at industry level.

There has been much discussion about the consequences of increased production fragmentation and offshoring on the North's and the South's industrial upgrading. From this discussion, two popular viewpoints can be clearly distinguished. The first states that it is the *North* that mainly benefits from GVC participation, while the opportunities for the *South* are limited. This view emphasises both the static (cheaper intermediate inputs) and dynamic (reallocation of factors towards more efficient tasks) positive effects of GVC participation on the *North*. For example, Baldwin and Robert-Nicoud (2014) show how the rise of GVCs causes productivity and welfare improvement for the *North*. In their framework, in which trade in goods and trade in tasks both arise, both the *North* and the *South* compete for the production of either a good or a task. Since the *North* has lower unit labour requirements but higher wages, the rise of GVCs enables the *North* to combine its superior technology with low wages in the *South* through offshoring some of its tasks. The *North* can specialise in tasks which require better technology and generate higher value-added. This specialisation decreases average production costs for the *North* and leads to an increased allocation of resources to more sophisticated tasks, causing a rise in Northern output and wages. In other words, participating in GVCs enables the *North* to have cheaper intermediate inputs and reallocate more domestic resources towards higher value-added tasks, both of which have positive effects on industrial upgrading. On the other hand, the *South* is concerned that GVCs will force the *South* to specialise in simple and low value-added tasks for Northern final goods production with little scope for industrial upgrading in the long run (UNCTAD, 2013).

In contrast, a different theory states that it is the *South* that will upgrade most when it participates in GVCs. In Li and Liu (2014)'s dynamic model, a final good is produced using a continuum of tasks under the assumption that for each task Northern unit labour requirements are equal or below the ones of the *South*. The rise of GVCs allows the *North* and the *South* to specialise in tasks according to their skills and comparative advantage. Over time, participation in GVCs enables the *South* to lower its unit labour requirements, improve its productivity and make more sophisticated products through a learning-by-doing process, which leads the *North* to offshore more tasks to the *South* in the next period. This process will repeat itself until it reaches an 'integrated equilibrium', in which wages and technology are equalised. Throughout the process the *South* upgrades, but the *North* encounters downgrade pressure because its competitive advantage deteriorates when the *South* becomes more productive in tasks that had been performed in the *North* before. Rodríguez-Clare (2010) has a similar view. He shows that increases in offshoring benefit the *South* but harm the *North* in the short run.

However, Rodríguez-Clare (2010) also shows that the *North* can also upgrade in the long run. He points out that technology levels are determined by research efforts and research productivity. The rise of GVCs makes it possible that the resources released by offshoring in the *North* lead to an increased allocation of resources to research. According to his dynamic model, the overall effects of GVC participation should be positive for the *North* as long as the reallocation between production and research is not too sluggish. In other words, enabled by the shift of resources towards research, the *North* can upgrade by doing more sophisticated tasks or creating

new technologies. Baldwin and Robert-Nicoud (2014) also show that for both the *North* and the *South*, upgrading is possible when there is technology diffusion. Recent empirical findings suggest that this is very likely. For instance, Piermartini and Rubínová (2014) provide evidence that GVCs are a much stronger facilitator of knowledge spillovers than final goods trade. And Benz et al. (2015) present firm-level evidence on spillovers induced by offshoring.

To summarise, the discussed works suggest different channels through which GVC participation affects industrial upgrading of its participants. The main transmission channels include increased availability and quality of inputs, technology spillovers from multinationals, learning-by-doing, gains from specialisation as well as resources reallocation and pro-competitive effects of global competition (Crisuolo & Timmis, 2017). Gereffi et al. (2005) and Gereffi and Sturgeon (2013) also stress the importance of national governance and industrial policy for industrial development in a GVC era. However, the above claims are purely theoretical and the materialisation of these theoretical effects is uncertain. Therefore, empirical research is necessary for testing the theoretical predictions.

A few recent studies attempt to quantify the effects of GVC participation on economic upgrading. Kummritz et al. (2017) use the level of domestic value-added generated in a sector as the measure of economic upgrading, and quantify the effects of both backward (measured by the amount of foreign value-added embodied in exports) and forward (measured by the amount of domestic value-added re-exported by third countries) GVC participation on sectoral value-added growth. They find that GVC integration generally increases an industry's value-added, and they also highlight the importance of country-specific characteristics and policy for benefitting from trade integration. Constantinescu et al. (2019) also use the foreign value-added embodied in a country's gross exports as the measure of backward GVC linkage to investigate whether it increases productivity. They find that backward participation in GVCs is a significant driver of labour productivity in a set of 40 countries since 1995 (using WIOD 2016 release). Pahl and Timmer (2020) confirm the findings of Constantinescu et al. (2019), using a wider set of countries and including more lower-income countries for a longer time period. Yet, these studies only focus on value-added gains or labour productivity, that is one aspect of economic upgrading. Instead, the aim of this paper is to fully consider the multidimensionality of industrial upgrading. Moreover, we employ improved indicators of backward and forward GVC participation, as we will present in the next section.

3 | METHODOLOGY

3.1 | GVC participation indicators

Global value chain participation indicators measure to what extent countries/industries/firms are involved in vertically fragmented production. We use indicators based on backward linkages and on forward linkages, reflecting the two different ways in which a country can participate in GVCs. The backward linkage focuses on a country's GVC participation to the extent that they import intermediates to produce its products, while the forward linkage reflects that a country's GVC participation insofar they supply intermediate inputs to other countries for further production. The backward linkage is also referred to as a user's perspective, and the forward linkage is referred to as a provider's perspective.

We adopt the decomposition framework of Wang et al. (2017) and construct forward and backward GVC participation indices by decomposing value-added and final goods in an inter-country

TABLE 1 The world multi-regional input–output table^a

| | Intermediate use | | | Final use | | | Gross | | |
|--------------|------------------|--------------|----------|--------------|----------|--------------|--------------|--------------|---------|
| | in 1 | ... in r | in n | ... in n | in 1 | ... in r | in n | ... in n | outputs |
| Country 1 | Z^{11} | ... Z^{1r} | Z^{1n} | ... Z^{1n} | f^{11} | ... f^{1r} | ... f^{1n} | ... f^{1n} | y^1 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| Country r | Z^{r1} | ... Z^{rr} | Z^{rn} | ... Z^{rn} | f^{r1} | ... f^{rr} | ... f^{rn} | ... f^{rn} | y^r |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| Country n | Z^{n1} | ... Z^{nr} | Z^{nn} | ... Z^{nn} | f^{n1} | ... f^{nr} | ... f^{nn} | ... f^{nn} | y^n |
| Value-added | $(w^1)'$ | ... $(w^r)'$ | $(w^n)'$ | ... $(w^n)'$ | | | | | |
| Total inputs | $(y^1)'$ | ... $(y^r)'$ | $(y^n)'$ | ... $(y^n)'$ | | | | | |

Note: Bold indicates matrices or vectors.

input–output (IO) model. Our starting point is the standard world multi-regional IO accounting framework (see Miller & Blair, 2009) in Table 1 with n countries and m sectors (or industries) in each country. Output in each country sector is produced using domestic production factors and (domestic or foreign) intermediate inputs. In the meantime, output is used as an intermediate input in production or used to satisfy final demand, at home or abroad. When markets clear, the value of a product produced in a particular country sector must equal the value of this product used domestically and abroad. Let the value of the output by sector i in country s be y_i^s , the typical element of the vector \mathbf{y}^s . Then, the product market clearing condition (or accounting identity) can be written as

$$y_i^s = \sum_j \sum_r z_{ij}^{sr} + \sum_r f_i^{sr}, \tag{1}$$

where z_{ij}^{sr} (the typical element of the $m \times m$ matrix \mathbf{Z}^{sr}) gives the value of products shipped from sector i in country s for intermediate use by sector j in country r , and f_i^{sr} (the typical element of the vector \mathbf{f}^{sr}) the value of products shipped from sector i in country s to country r for final use (household consumption, private investments and government expenditures).

If we use $\mathbf{1}$ to indicate the m -element summation vector consisting entirely of ones, then the accounting identities can be written in matrix form as

$$\begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} = \begin{bmatrix} \mathbf{Z}^{11} & \dots & \mathbf{Z}^{1r} & \dots & \mathbf{Z}^{1n} \\ \vdots & \ddots & \vdots & \dots & \vdots \\ \mathbf{Z}^{r1} & \dots & \mathbf{Z}^{rr} & \dots & \mathbf{Z}^{rn} \\ \vdots & \dots & \vdots & \ddots & \vdots \\ \mathbf{Z}^{n1} & \dots & \mathbf{Z}^{nr} & \dots & \mathbf{Z}^{nn} \end{bmatrix} \begin{pmatrix} \mathbf{1} \\ \vdots \\ \mathbf{1} \\ \vdots \\ \mathbf{1} \end{pmatrix} + \begin{pmatrix} \sum_u \mathbf{f}^{1u} \\ \vdots \\ \sum_u \mathbf{f}^{ru} \\ \vdots \\ \sum_u \mathbf{f}^{nu} \end{pmatrix}. \tag{2}$$

We further define the input–output matrix $\mathbf{A}^{sr} = \mathbf{Z}^{sr} (\hat{\mathbf{y}}^r)^{-1}$ of dimension $(m \times m)$ with element $a_{ij}^{sr} = z_{ij}^{sr} / y_j^r$, which gives the inputs from sector i in country s for intermediate use by sector j in country r . This yields

$$\begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \dots & \mathbf{A}^{1r} & \dots & \mathbf{A}^{1n} \\ \vdots & \ddots & \vdots & \dots & \vdots \\ \mathbf{A}^{r1} & \dots & \mathbf{A}^{rr} & \dots & \mathbf{A}^{rn} \\ \vdots & \dots & \vdots & \ddots & \vdots \\ \mathbf{A}^{n1} & \dots & \mathbf{A}^{nr} & \dots & \mathbf{A}^{nn} \end{bmatrix} \begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} + \begin{pmatrix} \sum_u \mathbf{f}^{1u} \\ \vdots \\ \sum_u \mathbf{f}^{ru} \\ \vdots \\ \sum_u \mathbf{f}^{nu} \end{pmatrix}. \tag{3}$$

In compact form, this system can be rewritten as $\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f}$ and the solution is given by

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{f} = \mathbf{B}\mathbf{f}, \tag{4}$$

where \mathbf{y} is a $nm \times 1$ vector that gives all country sectors' gross outputs (inputs), \mathbf{A} the $nm \times nm$ global input-output matrix, and \mathbf{f} a $nm \times 1$ vector of final demand. \mathbf{I} is an $(nm \times nm)$ identity matrix with ones on the diagonal and zeros elsewhere. $\mathbf{B} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse.

We decompose both the intermediate input matrix and final demand vector into two parts and rewrite $\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f}$ as

$$\mathbf{y} = \mathbf{A}\mathbf{y} + \mathbf{f} = \mathbf{A}^D\mathbf{y} + \mathbf{f}^D + \mathbf{A}^F\mathbf{y} + \mathbf{f}^F, \tag{5}$$

where $\mathbf{A}^D = \begin{bmatrix} \mathbf{A}^{11} & \dots & \mathbf{O} & \dots & \mathbf{O} \\ \vdots & \ddots & \vdots & \dots & \vdots \\ \mathbf{O} & \dots & \mathbf{A}^{rr} & \dots & \mathbf{O} \\ \vdots & \dots & \vdots & \ddots & \vdots \\ \mathbf{O} & \dots & \mathbf{O} & \dots & \mathbf{A}^{nn} \end{bmatrix}$ is a $nm \times nm$ diagonal block matrix of domestic input coefficients with \mathbf{O} standing for a matrix of $m \times m$ dimension filled with zeros. \mathbf{A}^F is a $nm \times nm$ off-

diagonal block matrix of imported input coefficients, and $\mathbf{A}^F = \mathbf{A} - \mathbf{A}^D$. $\mathbf{f}^D = \begin{pmatrix} \mathbf{f}^{11} \\ \vdots \\ \mathbf{f}^{rr} \\ \vdots \\ \mathbf{f}^{nn} \end{pmatrix}$ is a $nm \times 1$

vector of final demand for domestic final products, and $\mathbf{f}^F = \mathbf{f} - \mathbf{f}^D$ is a $nm \times 1$ vector of final demand for foreign final products, that is final product exports. Rearranging equation (5) yields

$$\mathbf{y} = (\mathbf{I} - \mathbf{A}^D)^{-1} \mathbf{f}^D + (\mathbf{I} - \mathbf{A}^D)^{-1} (\mathbf{A}^F\mathbf{y} + \mathbf{f}^F) = \mathbf{L}\mathbf{f}^D + \mathbf{L}\mathbf{f}^F + \mathbf{L}\mathbf{A}^F\mathbf{B}\mathbf{f}, \tag{6}$$

where $\mathbf{L} = (\mathbf{I} - \mathbf{A}^D)^{-1}$ is a $nm \times nm$ diagonal block that denotes the domestic Leontief inverse.

Let $(\mathbf{v}^s)' = (\mathbf{w}^s)'(\hat{\mathbf{y}}^s)^{-1}$ be the m -element row vector which gives the value-added coefficients in country s . Its typical element $v_j^s = w_j^s/y_j^s$ gives the value-added generated in sector j in country s per dollar of output in this sector. Combining this with equation (6), we can decompose country s ' sectoral value-added as

$$\mathbf{w}^s = \hat{\mathbf{v}}^s \mathbf{y}^s = \hat{\mathbf{v}}^s \mathbf{L}^{ss} \mathbf{f}^{ss} + \hat{\mathbf{v}}^s \mathbf{L}^{ss} \sum_{r \neq s} \mathbf{f}^{sr} + \hat{\mathbf{v}}^s \mathbf{L}^{ss} \sum_{r \neq s} \mathbf{A}^{sr} \mathbf{y}^r. \tag{7}$$

This decomposition equation gives the distribution of value-added created in one country sector that is absorbed by final products in all country sectors.¹ It has three terms. The first term is domestic value-added (DVA) in production of final products for domestic demand without border-crossing production activities. The second term is DVA in production of final products exports, which does not involve any border-crossing production activities either. This part of DVA crosses national borders once, but only for final consumption. The third term is DVA in production of intermediate exports. It is DVA that relates to production activities outside the source country, and it denotes the source country's contribution to global production.

¹Note that we can write $\mathbf{y}^r = \sum_u^n \mathbf{B}^{ru} (\sum_g^n \mathbf{f}^{ug})$ which implies that each country sector is included as location of absorption.

Decomposition equation (7) shows how a country sector's value-added is used as primary input to produce goods and services, and to which country it is sold (i.e. 'where does the value-added go to'). This is a so-called provider's perspective. From this perspective, the forward GVC participation index (**fgvc**) is the DVA embodied in the exports of intermediate products as a share of the country sector's total value-added, namely

$$\mathbf{fgvc} = (\hat{\mathbf{w}}^s)^{-1} \hat{\mathbf{v}}^s \mathbf{L}^{ss} \sum_{r \neq s}^n \mathbf{A}^{sr} \mathbf{y}^r, \quad (8)$$

where the numerator is the third term in equation (7). Note that by combining (7) and (8), we can also write

$$\mathbf{fgvc} = \mathbf{I} - (\hat{\mathbf{w}}^s)^{-1} \hat{\mathbf{v}}^s \mathbf{L}^{ss} \left(\mathbf{f}^s + \sum_{r \neq s}^n \mathbf{f}^r \right) = \mathbf{I} - (\hat{\mathbf{w}}^s)^{-1} \hat{\mathbf{v}}^s \mathbf{L}^{ss} \mathbf{f}^s, \quad (9)$$

with $\mathbf{f}^s = \sum_u^n \mathbf{f}^{su}$.

The backward GVC participation indicator is constructed from the decomposition of final products. The value of a final product is equal to the summation of value-added contributions by all country sectors. The traditional way (see, e.g. Los et al., 2015) of decomposing country s 's final products ($\mathbf{f}^s = \sum_u^n \mathbf{f}^{su}$) is to decompose them into two parts: value-added contributed by country itself and value-added sourced from all foreign countries. That is $(\mathbf{f}^s)' = (\mathbf{v}^s)' \mathbf{B}^{ss} \sum_u^n \hat{\mathbf{f}}^{su} + \sum_{r \neq s}^n (\mathbf{v}^r)' \mathbf{B}^{rs} \sum_u^n \hat{\mathbf{f}}^{su}$. The backward GVC participation can now be defined as the share of foreign value-added (the second part) in the total value of this final product. That is, $\left[\sum_{r \neq s}^n (\mathbf{v}^r)' \mathbf{B}^{rs} \hat{\mathbf{f}}^s \right] (\hat{\mathbf{f}}^s)^{-1} = \sum_{r \neq s}^n (\mathbf{v}^r)' \mathbf{B}^{rs}$. However, this is not what we propose. The reason is that this measure of backward GVC participation would not include the following phenomenon. Consider a German car that is assembled in a German factory. It contains accessories that are made by workers in the Slovak Republic (and thus Slovak value-added). The production of these accessories uses steel imported from Germany and thus German value-added. In our opinion, the German value-added that is in the steel should be part of Germany's GVC participation. The traditional measure, however, excludes it because it is embodied in German final products (namely cars).

We suggest that cases like the German value-added in steel production belong to GVC participation since they involve border-crossing GVC production activities. Therefore, we decompose country s 's final products as.²

$$(\mathbf{f}^s)' = (\mathbf{v}^s)' \mathbf{L}^{ss} \hat{\mathbf{f}}^{ss} + (\mathbf{v}^s)' \mathbf{L}^{ss} \sum_{r \neq s}^n \hat{\mathbf{f}}^{sr} + \mathit{border_crossing}. \quad (10)$$

This decomposition gives the contribution of value-added from all source country sectors that are embodied in country s 's sectoral final products. The first term represents final products that are produced with only domestic value-added and that are consumed domestically. It does not involve any border-crossing trade or foreign production activities. The second term refers to final products that are produced with only domestic value-added but that are consumed directly by the importing country r . This is traditional final product trade, and it does not involve any foreign production activities either. The third term refers to all value-added

²It can be shown that the row vector $\mathit{border_crossing} = \sum_r (\mathbf{v}^r)' \mathbf{L}^{rr} \sum_{u \neq r}^n \mathbf{A}^{ur} \mathbf{B}^{rs} \sum_g^n \hat{\mathbf{f}}^{sg}$.

that is embodied in country s 's final products and that includes border-crossing production activities. These are the foreign value-added in the imported inputs but also the domestic value-added that is in exported intermediate products (e.g. German steel) which return in a next stage when they are embodied in imports (Slovak accessories).

Decomposition equation (10) shows where a country sector's final products come from and where the value is created. This is the so-called user's perspective. From here, the backward GVC participation index (**bgvc**) can be calculated as the share of a country sector's final products produced with value-added that is involved in GVC activities, namely $\mathbf{bgvc} = (\mathit{border_crossing}) \left(\hat{\mathbf{f}}^s \right)^{-1}$. Using (10) it follows that.

$$\mathbf{bgvc} = \mathbf{1}' - (\mathbf{v}^s)' \mathbf{L}^{ss} \left(\hat{\mathbf{f}}^{ss} + \sum_{r \neq s}^n \hat{\mathbf{f}}^{sr} \right) \left(\hat{\mathbf{f}}^s \right)^{-1} = \mathbf{1}' - (\mathbf{v}^s)' \mathbf{L}^{ss}. \quad (11)$$

Note that the structure of equation (11) is exactly the same as the structure of equation (9).

A different (more traditional) measure of GVC participation dates back to Hummels et al. (2001), who propose vertical specialisation. It refers to the imported foreign content (both direct and indirect foreign value-added) in a country's exports. In our robustness analysis, we use this measure and refer to it as VS. A second measure (to which we will refer as VS1) is also proposed by Hummels et al. (2001) and looks at vertical specialisation from the export side. It is calculated as the value of a country's intermediate exports that are used as inputs into another country's production of export goods. Hummels et al. (2001) provide a mathematical definition for VS using national input–output model, but do not provide mathematical terms for VS1. Koopman et al. (2014) have provided mathematical terms for both VS and VS1 based on their decomposition of gross exports. However, Wang et al. (2017) point out that the shares in the VS and VS1 measures use gross exports as the denominator, which may cause double counting problems and bias for some industries. Therefore, in this paper we adopt the measures defined above in (9) and (11) for the baseline analysis, and we use the VS and VS1 share to examine the robustness of our results.

3.2 | Measures of industrial upgrading

The measures we use for industrial upgrading build upon previous work. Different studies distinguish between different dimensions of industrial upgrading. Tian et al. (2019) propose three quantitative dimensions of upgrading in a GVC framework. Based on various studies that have proposed conceptual measures for industrial upgrading, they analyse the commonality of eight indicators of industrial upgrading (see Appendix A) that are widely used in the literature. Using an Exploratory Factor Analysis (EFA), they construct measures for (1) process upgrading, (2) product upgrading and (3) skill upgrading. More specifically, process upgrading is viewed as efficiency gains and productivity improvements. Product upgrading refers to gaining more value from GVC production, which is related to the effects of making better and more sophisticated products. Skill upgrading refers to increasing skill intensity of employment and exports, which capture partially functional upgrading (Timmer et al., 2019). The three dimensions capture well the previous conceptual categories of industrial upgrading and provide a quantitative basis for our empirical analysis. In this paper, we thus employ these three quantitative dimensions of upgrading as the dependent variables in the next section.

3.3 | Empirical specification

To capture the effects of GVC participation on industrial upgrading, we estimate a panel fixed effects model for industry i of country r at time t :

$$upg_{i,r,t} = \alpha + \beta_1 gvc_{i,r,t} + \alpha_{i,r} + \alpha_{i,t} + \alpha_{r,t} + \varepsilon_{i,r,t}. \quad (12)$$

As the dependent variable, we use (one of) the measures of industrial upgrading ($upg_{i,r,t}$). GVC participation ($gvc_{i,r,t}$) is proxied by either forward GVC participation ($fgvc_{i,r,t}$) or backward participation ($bgvc_{i,r,t}$), which were both defined in Section 3.1. In the benchmark regressions, the independent variables are lagged by one period. A set of industry-country fixed effects ($\alpha_{i,r}$), industry-year fixed effects ($\alpha_{i,t}$) and country-year fixed effects ($\alpha_{r,t}$) are included. Note that we have accounted for possible country, industry and time unobserved heterogeneity by using such fixed effects, and we thus argue that omitted variables bias is not a (big) concern. The model controls for country-specific effects, for instance, due to country-size differences: larger countries tend to have lower GVC participation because more intermediates are domestically available (see, e.g., Baldwin & Lopez-Gonzalez, 2015). It also captures effects due to country industry-specific differences. For example, Russian mining and petroleum industries have higher (forward) GVC participation than other countries because of its abundant natural resources. We are also aware of that some alternative variables such as the role of national states and state capacity could be potential explanations for upgrading. However, we stress that the main goal of this paper is to examine the relation between GVC participation and upgrading, instead of to come up with an exhaustive list of all variables that affect upgrading. We thus leave some other variables captured by fixed effects.

To examine whether the stage of development matters for the contribution of GVC participation to industrial upgrading, we also estimate models that include an interaction between the stage of development (d_r) and our GVC participation indicators to equation (12):

$$upg_{i,r,t} = \alpha + \beta_1 gvc_{i,r,t} + \beta_2 gvc_{i,r,t} * d_r + \alpha_{i,r} + \alpha_{i,t} + \alpha_{r,t} + \varepsilon_{i,r,t}. \quad (13)$$

We include a dummy variable d_r to distinguish between countries that are developed ($d_r = 1$) and countries that are developing ($d_r = 0$). To categorise countries, we use the classification of the World Bank based on gross national income (GNI) per capita for year 1995 (i.e. the start of the sample period). Developed countries refer to as high-income economies, and developing countries refer to as low- and middle-income economies. It should be noted that we have not included d_r independently in the regression specification. This is because this variable is fully captured by the country fixed effects, which ensures that our model is properly specified. In the empirical analysis, we also run regressions on developed and developing countries separately by splitting the sample. It turns out that sample splitting is identical to a fully interacted model. The estimated coefficients based on the split samples tell the same story as our interaction model. We thus present the results using our interaction setting.

We would further like to stress that our results mainly show associations between GVC participation and industrial upgrading, rather than causal effects. In particular, the regression model is potentially plagued by reverse causality. High level of upgrading (e.g. high productivity improvement), for example, may be the pre-requisite for integration into GVCs. We make efforts to deal with this issue in the following empirical analysis by using lagged independent variables and an instrumental variable to do robustness tests. However, this may be

insufficient to eradicate the reverse causality concern. For this reason, we refrain from stating any causal relationships.

4 | DATA SOURCE AND DESCRIPTIVE ANALYSIS

4.1 | Data source

We use the WIOD (2013 release) as our primary data source. WIOD covers 35 sectors for 40 countries (see Appendix B for an overview of the countries and sectors) in the world including most of the developed countries as well as major emerging economies such as Eastern European countries and the ‘BRIC’ (Brazil, Russia, India and China), which are of interest for industrial upgrading research. Estimates of the economic structure concerning the ‘Rest-of-World’ are also provided, to ensure that the production structure of the whole world is documented. It provides multi-regional input–output tables annually from 1995 to 2011. The IO tables contain information on international trade in both intermediate inputs and final products, and the primary inputs (value-added) in the production of each country industry, which allow us to implement the decomposition as outlined in Section 3.1.

The supplementary Socio Economics Account (SEA) dataset in WIOD provides information on capital compensation, capital stocks and the data on the skill structure of employment from 1995 to 2009 using the same sector classification. Labour is split into three types: low-, medium- and high-skilled labour, according to educational attainment. This supplement data set allows us to further calculate the measures of industrial upgrading as outlined in Section 3.2. The time-series nature of WIOD makes it possible for us to trace the actual dynamics in industrial upgrading and GVC participation in the 15-year time period for these 40 countries, through which we can investigate the relationship between GVC participation and industrial upgrading for both developed and developing economies.

We are also aware of other alternative data sources that are currently available, like the OECD-WTO Trade in Value Added (TiVA) database, the Eora database and the Global Trade Analysis Project. These data sets include more countries and more detailed industrial classifications than WIOD. However, they do not have a coupled supplementary data set that allows for all measures of industrial upgrading. Therefore, we prefer to use WIOD as our data source. In the following analysis, GVC participation indicators cover the period 1995–2011, while industrial upgrading indicators only cover the period 1996–2009 since the upgrading indicators are calculated as growth rates and data for employment by skill type are not available for 2010 and 2011. Furthermore, no labour data are available for sector 35 (private households with employed persons). All input–output calculations include 35 sectors, but only the indicators for the first 34 sectors are used in our factor analysis and empirical estimation.

4.2 | Forward and backward GVC participation

Figure 1 shows the relationship between the measures of forward and backward GVC participation. It shows 160 (=40 regions \times 4 aggregated sectors) observations at the country sector level for the year of 2007 in subplot (a) and of 2720 (=160 \times 17 years) pairs for all years 1995–2011 in subplot (b). The first observation is that forward and backward participation is positively correlated. The corresponding correlation coefficients for each year are in between

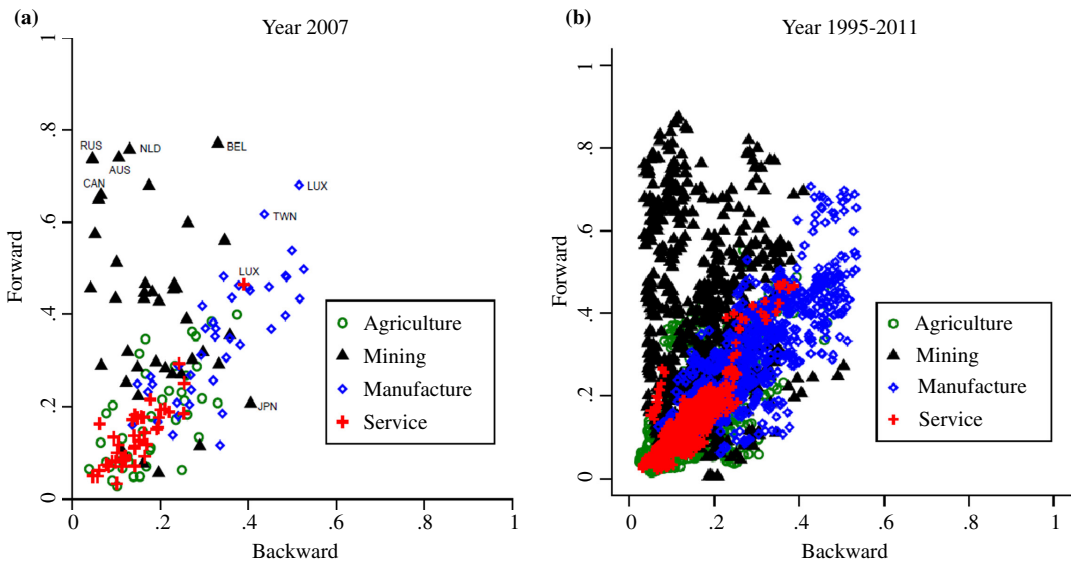


FIGURE 1 Scatterplots of the forward and backward GVC participation. *Notes:* Sectors' abbreviations 'Agriculture', 'Mining', 'Manufacture' and 'Service' stand, respectively, for industry 'c1', 'c2 and c8', 'c3-c7 and c9-c16' and 'c17-c35'. We could have presented a scatterplot for 35 industries from 40 regions over the period from 1995 to 2011. However, it turns out to be much less visualisable with too many scatters for 35 sectors (it is still available upon request). For ease of visualisation and interpretation, we present the scatterplot for these four aggregated categories.

Source: Authors' elaboration based on WIOD database. [Colour figure can be viewed at wileyonlinelibrary.com]

0.37 and 0.69, while the overall correlation coefficient for all 2720 pairwise observations is 0.45, with all coefficients being highly statistically significant. In the scatterplots for backward and forward GVC participation of [Figure 1](#), we also distinguish between four broadly defined sector categories, that is Agriculture, Service, Mining and Manufacturing. It can be seen that 'Agriculture' and 'Service' have significant lower GVC participation levels than 'Mining' and 'Manufacturing'. It confirms the widely held view that manufactured goods (when compared to services and agricultural products) are more globally fragmented with higher levels of international dependence.

Subplot (a) in [Figure 2](#) presents both forward and backward participation measures for each sector. Three sector groups can be distinguished. For the first group, both the forward and backward participation ratios are greater than the average level, which indicates their active participation in GVCs as both providers and users of intermediates. These sectors include most manufacturing sectors such as Electrical and optical equipment (c14) and Chemicals and chemical products (c9). Some case studies (e.g. Apple's iPod, Dedrick et al., 2010; the Nokia smartphone, Ali-Yrkkö et al., 2011) confirm the increased international fragmentation of such electrical products. For the second group, both the forward and backward participation ratios are low, indicating a low degree of GVC participation. These sectors include Agriculture (c1) and most Service sectors (e.g. c21, c22 and c29). The forward participation ratio of the third group is significantly greater than its backward participation. Mining and quarrying (c2) is the only sector in this group, which confirms that the Mining sector participates in GVCs by supplying intermediates rather than consuming intermediates. This is consistent with its upstream position in the global production network.

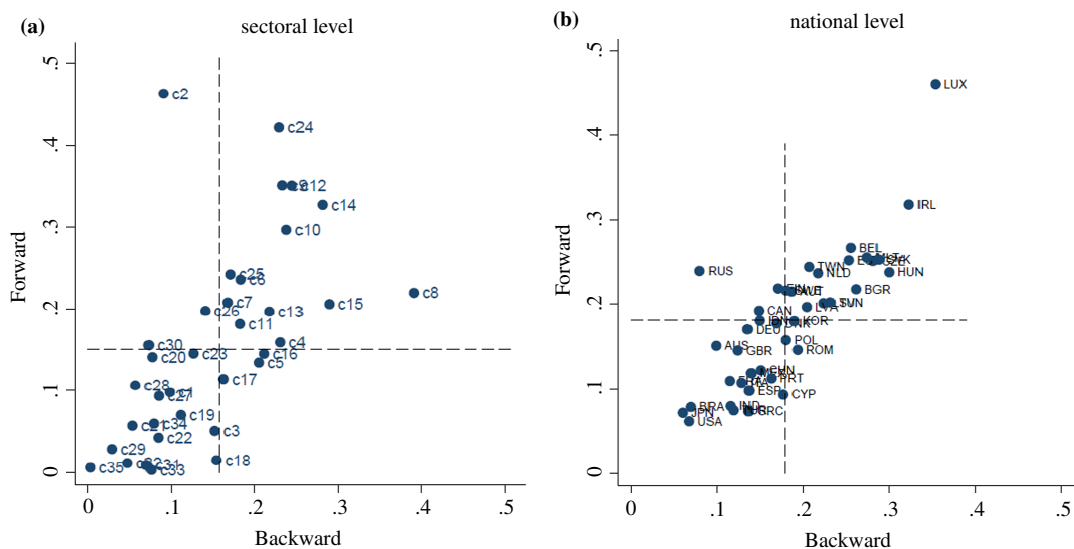


FIGURE 2 GVC participation measures at sectoral and national level. Notes: Both the forward and backward participation ratios presented in this figure are calculated as the arithmetic means of the corresponding ratios over the period 1995–2011. The dashed lines indicate the average forward and backward participation ratios at sectoral (subplot a) and national (subplot b) levels.

Source: Authors' elaboration based on WIOD database. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 GVC forward and backward participation at sectoral level (%)

| Sector | Forward Participation | | | Backward Participation | | |
|---------------|-----------------------|------|--------|------------------------|------|--------|
| | 1995 | 2011 | change | 1995 | 2011 | change |
| Agriculture | 9.3 | 10.8 | 1.6 | 8.8 | 10.0 | 1.2 |
| Mining | 39.3 | 47.9 | 8.6 | 8.8 | 8.9 | 0.1 |
| Manufacturing | 19.5 | 25.7 | 6.1 | 18.8 | 26.3 | 7.5 |
| Service | 6.0 | 8.3 | 2.2 | 6.7 | 10.0 | 3.3 |

Notes: The four categories' correspondence with the WIOD 35-industry classification is given in the note to Figure 1.

Apart from a significant decline in 2009 due to the global financial crisis, both the sectoral forward and backward participation ratios have been steadily increasing over the period 1995–2011. This GVC expansion is shown in Table 2. The Mining sector's forward participation is the highest, and it has increased from 39.3% in 1995 to 47.9% in 2011, while its backward ratio is very low and has hardly changed. The Manufacturing sector's forward and backward participation ratios are both high, and they have increased rapidly. The Service sector has a low participation ratio, but its ratio has increased relatively faster than Agriculture. Business services play a relative large role in explaining the rising GVC participation of the Service sector. On the one hand, this is related to the increased domestic offshoring of business service activities in developed countries to emerging and developing countries. On the other hand, the rising GVC participation of manufactured goods industries also enhances services' participation as services are not only directly involved in GVCs but also embodied in manufacturing trade.

Subplot (b) in Figure 2 presents both forward and backward participation measures for each country (region) in the sample. Similar to the sectoral analysis, these countries can be classified into three groups. For the first group, both the forward and backward participation ratios are

TABLE 3 GVC participation measures at country sector level (%), year 2007

| | Forward participation | | | Backward participation | | |
|---------------|-----------------------|-------------|-------------|------------------------|-------------|------|
| | c2 | c8 | c14 | c2 | c8 | c14 |
| Australia | 73.9 | 29.1 | 22.1 | 10.6 | 32.6 | 20.6 |
| Canada | 65.9 | 30.5 | 41.9 | 6.6 | 30.6 | 33.2 |
| China | 22.2 | 23.2 | 30.3 | 15.0 | 37.8 | 36.4 |
| Germany | 26.9 | 36.3 | 45.7 | 22.7 | 55.9 | 28.7 |
| Japan | 20.6 | 15.4 | 37.4 | 40.5 | 54.9 | 15.5 |
| India | 28.9 | 13.7 | 13.6 | 5.2 | 13.9 | 26.5 |
| Mexico | 45.6 | 11.2 | 45.3 | 4.2 | 7.2 | 57.8 |
| Russia | 73.7 | 31.8 | 14.6 | 4.6 | 5.2 | 13.5 |
| United States | 10.5 | 11.0 | 27.0 | 11.3 | 39.8 | 16.8 |

Notes: Sectors' abbreviations 'c2', 'c8' and 'c14' stand, respectively, for industry 'Mining and quarrying', 'Coke, refined petroleum and nuclear fuel' and 'Electrical and optical equipment'.

greater than the average level. Luxembourg and Ireland are examples. For the second group, both the forward and backward participation ratios are lower than the average level. The United States and Japan fall into this group and have much lower degree of GVC participation. These results are in line with the literature (see, e.g. Baldwin & Lopez-Gonzalez, 2015) that states that larger countries tend to have lower GVC participation because more intermediates are domestically available. Russia belongs to the third group, with its forward participation ratio being significantly greater than its backward participation. This is mostly because of its large exports of natural resources such as petroleum products and mineral ores. Countries such as Germany, South Korea and Canada are around the average level. Similar to the sectoral results, most countries' forward and backward participation ratios have increased over the period 1995–2011 and encountered a significant decline in 2009 (see Appendix C).

We observe that the participation ratio of the same industry in different countries is likely to be heterogeneous due to different country characteristics. Table 3 presents some examples. For Mining and quarrying (c2), countries, such as Australia, Canada and Russia, have a very large forward participation ratio but a very small backward ratio, reflecting that these countries are major exporters of natural resources because of their large endowments. Russia also shows a similar pattern in Coke and refined petroleum (c8), which reveals that Russia is also well endowed with energy resources. However, countries such as Germany, Japan and the United States follow a reverse pattern regarding refined petroleum, with their backward participation ratio being very large and significantly larger than their forward ratio. They rely more on imported energy as consumers than they can provide to the world as suppliers. In Electrical and optical equipment (c14), Germany comes out as the main global supplier, with its highest forward participation ratio. Another observation is that in sector c14, advanced countries such as Germany, Japan and United States tend to have a larger forward than backward participation ratio. For developing countries such as China, India and Mexico, the opposite holds.

4.3 | GVC participation and industrial upgrading

Before presenting the econometric results in the next section, we rank the country industries by their average level of (forward and backward) GVC participation over the period 1995–2009. We

TABLE 4 Differences in two groups: average upgrading level over 1996–2009

| | Forward Participation | | Backward Participation | |
|----------------------|-----------------------|-------|------------------------|-------|
| | Low | High | Low | High |
| All countries | | | | |
| Process upgrading | 0.037 | 0.044 | 0.035 | 0.056 |
| Product upgrading | 0.052 | 0.085 | 0.061 | 0.102 |
| Skill upgrading | 0.023 | 0.039 | 0.028 | 0.050 |
| Developing countries | | | | |
| Process upgrading | 0.030 | 0.039 | 0.037 | 0.064 |
| Product upgrading | 0.064 | 0.092 | 0.071 | 0.118 |
| Skill upgrading | 0.027 | 0.039 | 0.033 | 0.053 |

Notes: 'High GVC participation' are all observations in the top quartile of the respective distribution of the GVC participation index. 'Low GVC participation' is all observations in the bottom quartile of the distribution.

define the top quartile of these observations as the group with 'high GVC participation' and the bottom quartile as the group with 'low GVC participation'. In Table 4, we present the differences in the average upgrading level between the two groups. The group with 'high GVC participation' appears to have a higher level of industrial upgrading. For process upgrading, the mean is 0.037 (0.035) for observations with low forward (backward) GVC participation and 0.044 (0.056) for observations with high forward (backward) GVC participation in the full set of countries. In the subset of developing countries, it is 0.030 (0.037) and 0.039 (0.064), respectively. For product and skill upgrading, we observe similar results. These descriptive results suggest higher GVC participation might contribute positively to industrial upgrading.

5 | ECONOMETRIC RESULTS

5.1 | Does GVC participation enhance industrial upgrading?

Table 5 presents the results for the effects of both forward and backward GVC participation on the three dimensions of industrial upgrading. Focusing on the results for product upgrading and skill upgrading (section I of Table 5), we find a strong positive and significant relationship between GVC participation and industrial upgrading. Results based on the full sample show that a one per cent increase in backward participation is associated with 0.093 and 0.045 percentage point higher level in product and skill upgrading, respectively. Likewise, a one per cent increase in forward participation leads to similar increase in product upgrading and skill upgrading. However, for process upgrading, we find that backward participation has a significant and positive effect, while the effect of forward participation is negative and not statistically significant.

The results suggest that expanding and strengthening a country's GVC participation has positive effects on industrial upgrading, but forward participation has no effect on process upgrading. Instead of producing all inputs domestically, a country has access to better, cheaper and a wider variety of inputs through backward GVC participation, which reduces the production costs and thus improves the profits of firms that incorporate these inputs into their products. This process helps countries/firms to make better products and to make these products more efficiently, that is improving process and product upgrading. Forward GVC participation

TABLE 5 GVC participation and industrial upgrading

| Variables | Process | Product | Skill | Process | Product | Skill | |
|-------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|------------------------------------|------------------------------------|-----------------------------------|
| | (I) Full sample | | | (II) Full sample | | | |
| backward (−1) | 0.0581 ^{***} (0.0088) | 0.0934 ^{***} (0.0112) | 0.0450 ^{***} (0.0096) | 0.0593 ^{***} (0.0110) | 0.1042 ^{***} (0.0136) | 0.0478 ^{***} (0.0116) | |
| backward (−1)* <i>d_t</i> | | | | −0.0128 [*] (0.0187) | −0.0125 ^{**} (0.0235) | −0.0056 (0.0199) | |
| Adjusted <i>R</i> ² | .2816 | .3968 | .3670 | .2875 | .3976 | .3695 | |
| forward (−1) | −0.0380 (0.0046) | 0.0967 ^{***} (0.0057) | 0.0553 ^{***} (0.0051) | −0.0436 (0.0058) | 0.0775 ^{***} (0.0075) | 0.0476 ^{***} (0.0066) | |
| forward (−1)* <i>d_t</i> | | | | 0.0562 ^{**} (0.0099) | 0.0240 ^{**} (0.0125) | 0.0223 [*] (0.0108) | |
| Adjusted <i>R</i> ² | .2818 | .4035 | .3712 | .2820 | .4036 | .3696 | |
| Observations | 16,420 | 16,420 | 16,420 | 16,420 | 16,420 | 16,420 | |
| | | (III) Manufacturing sectors | | | (IV) Technology-intensive sectors | | |
| Backward (−1) | | 0.0626 ^{***} (0.0261) | 0.1089 ^{***} (0.0298) | 0.0513 ^{***} (0.0181) | 0.0715 ^{***} (0.0312) | 0.1162 ^{***} (0.0356) | 0.0627 ^{***} (0.0254) |
| Backward (−1)* <i>d_t</i> | | −0.0145 ^{**} (0.0436) | −0.0132 ^{**} (0.0498) | −0.0068 [*] (0.0305) | −0.0264 ^{***} (0.0515) | −0.0346 ^{***} (0.0685) | −0.0145 ^{**} (0.0532) |
| Adjusted <i>R</i> ² | | .3685 | .4830 | .6612 | .4058 | .5025 | .6832 |
| Forward (−1) | | −0.0330 (0.0098) | 0.0845 ^{***} (0.0113) | 0.0506 ^{***} (0.0068) | −0.0245 (0.0083) | 0.0926 ^{***} (0.0257) | 0.0568 ^{***} (0.0086) |
| Forward (−1)* <i>d_t</i> | | 0.0585 ^{***} (0.0158) | 0.0342 ^{***} (0.0179) | 0.0194 [*] (0.0112) | 0.0615 ^{***} (0.0226) | 0.0385 ^{***} (0.0247) | 0.0218 ^{**} (0.0196) |
| Adjusted <i>R</i> ² | | .3682 | .4935 | .6645 | .4035 | .5126 | .6921 |
| Observations | | 6520 | 6520 | 6520 | 2240 | 2240 | 2240 |
| Country- Industry fixed effects | | Yes | Yes | Yes | Yes | Yes | Yes |
| Country-Year fixed effects | | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry-Year fixed effects | | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Cluster standard errors are reported in parentheses. Variables of GVC participation and upgrading levels are in natural logarithms. The independent variables are lagged by one period. The full sample covers 34 sectors for 40 countries over 14 years (1996–2009), while manufacturing sectors cover 13 industries (c3-c7, c9-c16) for the same country group over the same period. Technology-intensive sectors cover 4 industries (c13-c16). It should be noted that there are 35 sectors in input–output tables from WIOD, but many upgrading indicators for sector 35 have null values because of the unavailability of underlying data. We thus exclude sector 35 in our panel estimation. Except for that, there are more null values in our empirical test. For example, there are no capital stock data for some European countries in year 2008 and 2009. When running the regression, those observations with null values are excluded automatically. Therefore, the number of observations in full sample is less than 19040 (= 40 countries × 34 sectors × 14 years). *d_t* denotes development stage. Developed countries refer to as high-income economies, and developing countries refer to as low- and middle-income economies, which are classified according to World Bank's income classification in 1995.

****p* < .01, ***p* < .05, **p* < .1.

is to provide intermediate inputs to global buyers, which enables a country to gain more value from these products (hence product upgrading). As to skill upgrading, GVC participation makes it possible for skill-abundant countries to relocate the unskilled-intensive tasks of the production process to the relatively unskilled-abundant countries, which increases the relative demand for skilled labour in the skill-abundant country and hence enhances skill upgrading. GVCs also provide possibilities for unskilled-abundant countries to increase their skill intensity through learning by doing. For example, multinational firms (MNEs) are key players in the materialisation of GVC production. The unskilled workers employed by MNEs in unskilled-abundant countries can be improved by training and on-the-job-learning, because MNEs typically provide more training and upgrading of human capital in order to achieve better outcomes.

We further investigate several avenues to explore heterogeneities of the impacts of two types of GVC participation on industrial upgrading. We explore heterogeneities across country groups and industries. In Table 5, we report in section II the conditioning effect of the stage of development on the relation between GVC participation and industrial upgrading. The point estimates of backward d_r for process and product upgrading are negative and statistically different from zero (90% confidence level for process upgrading and 95% for product upgrading). This suggests that developing countries benefit more from backward GVC participation than developed countries. We repeat the exercise by focusing on the manufacturing sectors³ (section III of Table 5) and technology-intensive industries⁴ (section IV of Table 5). The results largely confirm the results of the full sample, and the point estimates of backward d_r become larger than those in section II. This finding points to that manufacturing sectors in developing countries are particularly benefiting from backward GVC participation. This is consistent with Rodrik's (2013) convergence theory that lagging countries can catch up with the world productivity leader in manufacturing.

An important motivation that we conduct separate analysis on manufacturing sectors is that GVC participation as measured in this study may be potentially more relevant in manufacturing. As shown in Section 4.2, in contrast to agriculture and the service sectors, manufacturing value chains are more fragmented, in which we thus expect stronger spillovers. To this end, we attempt to classify sectors by sophistication of used intermediates and repeat the exercise for technology-intensive sectors separately. Comparing the point estimates in sections II, III and IV of Table 5, we indeed find a stronger upgrading effect for the technology-intensive industries than for the general manufacturing, and the effect for manufacturing is further larger than that for all the sectors. This suggests that, if a country imports sophisticated materials and components for the next layer of local production, this may activate learning, for example, through embodied technology. In contrast, assembly of simple inputs or raw materials

³We also exclude sector c8, 'Coke, refined petroleum and nuclear fuel'. There are some reasons to do so. Firstly, like another natural resource-intensive sector c2-'Mining and quarrying', the value chain of c8 provides little useful information about upgrading for countries with small endowments of natural resources. A very high forward GVC participation of this sector simply suggests that this country is well endowed with natural resources and exports a lot. A high backward GVC participation of sector c8 suggests that this country needs to import oil or other resources because they are not available domestically and this will not change. Secondly, trading raw oil is unlikely to have similar productivity dynamics as when trading intermediates in other manufacturing value chains. The economic relationship that we intend to study may thus not hold in this value chain.

⁴We classify industries of machinery (c13), electrical and optical equipment (c14), transport equipment (c15) and manufacturing, nec (c16) as technology-intensive sectors.

may generate much less learning and the upgrading potential might arise from cooperation with global buyers rather than from importing. That is why GVC participation offer less upgrading scope for the remaining industries with less sophisticated intermediate use, which are split between light manufacturing (e.g. food, textiles and wood) and resource-intensive industries (e.g. chemicals, rubber and metals).

The above analyses point to the conclusion that backward GVC participation provides more upgrading opportunities for developing countries as it enables a less developed country to import sophisticated inputs, which stimulate knowledge spillovers. In contrast, we find that forward GVC participation has higher level of upgrading effect on developed countries. The effect of forward participation on the three dimensions of industrial upgrading is significantly larger in developed countries than in developing countries, with the three coefficients of forward* d_r (in sections II, III and IV of [Table 5](#)) being positive and significant. More specifically, forward participation has a positive impact on product upgrading and skill upgrading for both developed and developing countries. However, its positive impact on process upgrading is observed only for developed countries, not for developing countries. A possible explanation for the different results among developed and developing countries could be their difference in forward GVC participation. For developed countries, forward integration into GVCs normally means that they can offshore parts of low value-added tasks and specialise in high value-added tasks. This process helps to lower labour costs, which has a positive effect on productivity improvement. However, for developing countries, forward participation in GVCs tends to be supplying raw materials and (cheap) labour and specialising in low value-added tasks. This process may generate employment and value-added, but does not necessarily provide learning opportunities to improve the productivity in developing countries.

5.2 | Robustness tests

The aforementioned findings suggest that GVC participation plays a role in boosting industrial upgrading. However, there are possible concerns that the results may depend on the choice of GVC participation indicator(s), and reverse causality and any omitted variables may lead to a biased estimate of coefficient. For example, a possible reverse causality concern is that a country sector where productivity growth is high tends to have high GVC participation and economies with a comparative advantage in high-skilled labour may be more willing to participate in GVCs. We attempt to address such concerns in a series of robustness tests. As mentioned above, manufacturing sectors are the major GVC participants, we thus focus on the sample of manufacturing in the following robustness tests.

The first robustness check deals with the alternative measures of GVC participation. We rerun the regressions by replacing the present indicators with two other GVC participation measures (VS and VS1 share, introduced in Section 3.1). The results are shown in section I of [Table 6](#). The results lead to similar conclusions to those presented above. Second, as stated in the literature review, the effects of GVC participation on industrial upgrading may materialise over a longer time period, and the effects in the short run may differ from those in the long run. Therefore, we use longer-period lagged values (i.e. a 5-year lag) to allow for a delayed response and to minimise reverse causality concerns. The results in section II of [Table 6](#) show that most coefficients for lagged values are statistically significant and slightly larger than the corresponding benchmark estimates in [Table 6](#). The estimates based on lagged values are largely consistent with the benchmark, but suggest larger positive effects of GVC participation on upgrading.

TABLE 6 Robustness tests

| Variables | Process | Product | Skill |
|---|---|------------------------------------|-----------------------------------|
| | (I) alternative measures of GVC participation | | |
| VS | 0.0563 ^{***} (0.0116) | 0.1568 ^{***} (0.0213) | 0.0484 ^{***} (0.0253) |
| VS * d_r | -0.0148 ^{**} (0.0089) | -0.0457 ^{**} (0.0327) | -0.0135 (0.0092) |
| Adjusted R^2 | .4026 | .6235 | .6587 |
| VS1 | 0.0021 (0.0013) | 0.0733 ^{***} (0.0108) | 0.0216 ^{***} (0.0058) |
| VS1 * d_r | 0.0358 ^{***} (0.0126) | 0.0205 ^{**} (0.0067) | 0.0124 [*] (0.0053) |
| Adjusted R^2 | .3655 | .5256 | .6339 |
| Observations | 6520 | 6520 | 6520 |
| Fixed effects | Country-Industry, Country-Year, Industry-Year | | |
| (II) independent variables lagged by five years | | | |
| backward (-5) | 0.0918 ^{***} (0.0365) | 0.1434 ^{***} (0.0387) | 0.0657 ^{***} (0.0203) |
| backward (-5) * d_r | -0.0272 ^{***} (0.0312) | -0.0413 ^{***} (0.0139) | -0.0126 ^{**} (0.0089) |
| R^2 | .3982 | .5226 | .6687 |
| forward (-5) | 0.0083 (0.0026) | 0.1126 ^{***} (0.0193) | 0.0584 ^{***} (0.0073) |
| forward (-5) * d_r | 0.0617 ^{***} (0.0132) | 0.0481 ^{***} (0.0171) | 0.0212 ^{**} (0.0092) |
| Adjusted R^2 | .3525 | .5125 | .6829 |
| Observations | 4280 | 4280 | 4280 |
| Fixed effects | Country-Industry, Country-Year, Industry-Year | | |
| (III) IV estimate | | | |
| backward (-1) | 0.0782 ^{***} (0.0261) | 0.0912 ^{***} (0.0254) | 0.0548 ^{***} (0.0145) |
| Adjusted R^2 | .3778 | .4982 | .6712 |
| Observations | 6520 | 6520 | 6520 |
| Fixed effects | Country-Industry, Country-Year, Industry-Year | | |

Notes: Cluster standard errors are reported in parentheses. The robustness tests are conducted on the sample of manufacturing sectors.

*** $p < .01$, ** $p < .05$, * $p < .1$.

Third, we use an instrumental variable technique to address the possibility that reserve causality and any omitted variables are leading to a biased result. Here, we focus only on the backward participation as we failed to find a good instrument for forward participation. We adopt the instrument for backward participation from Constantinescu et al. (2019). The idea is based on the

work of Baldwin and Lopez-Gonzalez (2015) who argue the existence of a technological asymmetry in the international production network whereby there are ‘headquarter economies’ and ‘factory economies’. Firms in the headquarter economies arrange the production networks, and they are the main providers of intermediates essential to exporting. Factory economies provide the labour. Specifically, Baldwin and Lopez-Gonzalez (2015) find that the headquarter-versus-factory-economy distinction exists clearly in backward specialisation, which they refer to as ‘import to export’. For industry i of country r at year t , we compute the instrument as the average value-added from the United States, Germany and Japan (headquarter economies) embodied in exports of industry i of three countries in the sample that are closest in income to country r . The underlying assumption is that the information and communication technology developments in these three economies and declining trade costs globally were the main drivers of GVC expansion. The instrument is positively and significantly correlated with the backward participation indicator that we proposed in Section 3.1. The results in section III of Table 6 point to a significant positive effect of backward participation on process, product and skill upgrading, which confirms our previous findings.

The fourth robustness check is to deal with the potential endogeneity (simultaneity) problem between GVC participation and product upgrading. As said, the three dimensions of industrial upgrading are a weighted linear combination of eight indicators. Particularly, the dimension ‘product upgrading’ has high weights on three of the indicators: growth of value-added exports, growth of the share in value-added exports and growth of the unit value-added exports. These three indicators are based on value-added exports, which may overlap with GVC participation measures. To address this concern, we exclude the dimension ‘product upgrading’ and focus on the other two dimensions (‘process upgrading’ and ‘skill upgrading’). Although process upgrading and skill upgrading have relatively low weights on the three indicators, we set the values of these three indicators to zero when calculating the dimensions ‘process upgrading’ and ‘skill upgrading’. We do this to cancel the influence of these three indicators. We find that the new coefficients for process and skill upgrading are in line with the benchmark estimates (results are available upon request).

Finally, classifying countries into income categories is arbitrary. Alternatively, we use a different classification based on GDP per capita. We rerun the relevant regressions using the alternative country classification based on GDP per capita. The results are similar to the ones reported above (results are available upon request). Overall these exercises confirm the benchmark results, and it suggests that the findings are not largely dependent on the chosen classification strategy.

6 | CONCLUSION

This paper is one of the first attempts to empirically assess the effects of GVC participation on industrial upgrading to provide objective evidence for some theoretical debates and inform policymaking. We find a positive effect of GVC participation on product and skill upgrading. This finding holds for both forward and backward GVC participation and across developed and developing countries. For process upgrading, the effects of forward integration and backward integration present different results. We find that the effect of backward GVC participation on industrial upgrading in developing countries is larger than that in developed countries. For forward participation, the contrary is the case. The results reveal that developed countries upgrade more through forward linkages, while developing countries (especially process upgrading) rely more on backward links than forward links. Comprehensively considering the effects of both types of

GVC participation on the three dimensions of industrial upgrading, we can conclude that GVC integration benefits industrial upgrading for both developed and developing countries.

This shows that potential concerns about the negative effects of GVC integration in some countries (either developed countries or developing countries) are not supported by the data. Countries that participate in GVC production are likely to upgrade and develop new competitive advantages because of the different endowments and technologies of developed and less developed countries. We stress that industrial upgrading through GVC participation is possible, but far from automatic. As Gereffi and Sturgeon (2013) argued, the successful developments of China and Thailand through GVC participation depend on their new and GVC-supportive industrial policies. On the contrary, a nation that seeks to ban GVC participation may find that such resistance will hinder industrial upgrading.

While these findings provide convincing evidence on the beneficial effects of GVCs, further research is necessary to improve our understanding of their functioning. Optimally, we would like to analyse firm-level data to see how firms respond to new competition through GVCs and how firms within GVC networks benefit each other. Our empirical results did not provide very solid evidence for developing countries that forward GVC participation benefits their upgrading. However, one might argue that forward integration triggers international competition among suppliers leading to productivity improvements. Future firm-level analysis may capture such influence channels that our industry-level data failed to capture.

Furthermore, it is essential for theoretical research to shed further light on how GVCs affect industrial upgrading. It is central to understand which effects dominate under which conditions and which policies could help to overcome barriers to gains from GVCs. Moreover, dynamic models could explore ways to move into higher value-added tasks within global value chains, a key interest of policymakers. Such models could then again provide testable hypotheses for future empirical work.

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CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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