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Measuring industrial upgrading: applying factor analysis in a global value chain framework

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ABSTRACT

A key question for promoting international competition is how to improve the position of countries and industries in global value chains (GVCs). The first step is to properly measure industrial upgrading in GVCs. This is not a trivial issue because upgrading has not been defined unambiguously. Several authors have used different (and sometimes related) measures, all of which indicate certain aspects of upgrading. Rather than trying to find the single, ultimate measure of upgrading, we propose a different approach. We examine the multidimensionality of industrial upgrading, using eight indicators in factor analysis. Four of the eight indicators adopt the GVC perspective and include, for example, the growth of the share in value-added exports. We provide three quantitative dimensions of industrial upgrading: process upgrading, product upgrading, and skill upgrading. With these dimensions, we compare and analyze the upgrading of different countries and industries using the World Input–Output Database.

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1. Introduction

Industrial upgrading, which is also often referred to as 'economic upgrading' or just 'upgrading', is a term that frequently pops up in governmental reports, in documents on economic policy and in mass media. It is not very well defined though, and different users seem to differ slightly in their interpretations of what 'upgrading' is. According to the Oxford English Dictionary, upgrading means to '[r]aise (something) to a higher standard, in particular improve (equipment or machinery) by adding or replacing components'.

A key challenge for workers, firms, industries, and even countries is thus to enlarge the benefits (irrespective of the definition) of participating in production activities. A product or service follows several stages of production from its conception to end-use (i.e. from design, through fabrication, marketing, and distribution, to support for the final consumer). This full range of activities is called a value chain. In the past, most value chains

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took place within a single country (or even region). Nowadays, value chains cross borders, and they have become 'global'. The activities are carried out in global networks of interconnected firms (Gereffi and Fernandez-Stark, 2016). It should be emphasized that there has been an enormous increase in international production fragmentation due to advances in information technology and telecommunications over the last two decades (Baldwin and Robert-Nicoud, 2014). That is, the production is sliced up (i.e. fragmented) in ever smaller pieces (or tasks) that are carried out by a foreign firm.

A proper discussion of the policy aspects of industrial upgrading requires its quantification. That is the aim of this paper, i.e. to measure upgrading at the industry and country level. As indicated above, there are two difficulties involved. On the one hand, there is no single definition of upgrading that is widely accepted as *the* definition. On the other hand, the measurement framework should take into account that production now occurs in global value chains (GVCs).

To address these challenges, we propose the following method. First, we (systematically) review the literature and identify eight indicators for upgrading. Four indicators are based on gross exports (such as export growth and the share of a country or industry in all exports). But we know that gross exports provide a biased picture of the benefits of trade when a large amount of international production fragmentation is present (Johnson and Noguera, 2012; Johnson, 2014; Koopman et al., 2014). Therefore, we argue in favor of the GVC perspective and replace the export-based indicators by similar, new indicators based on value-added exports.

Second, we employ exploratory factor analysis (EFA) on the set of indicators to investigate the multidimensionality of industrial upgrading.[1] This is because (as we shall show in the literature review) the indicators suggest that industrial upgrading is a multidimensional phenomenon that cannot be captured by a single measure. For example, Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002) identify four distinct types of upgrading: process, product, functional, and intersectoral upgrading, suggesting that several dimensions may be important. This typology has also been followed by Giuliani et al. (2005) who focus on 12 clusters in Latin America or by Evgeniev and Gereffi's (2008) study of the textiles and apparel sector in Turkey and Bulgaria. Both studies clearly suggest that upgrading has more dimensions. Using one indicator (or even several indicators) to measure upgrading would ignore certain aspects of industrial upgrading and perhaps duplicate others.

EFA is frequently used to extract information common to many indicators and reduce that information into a lower number of unobserved variables called 'factors'. Our indicators are calculated from the World Input–Output Database. Previewing the results from the EFA, we label the main factors as three quantitative dimensions of industrial upgrading: process upgrading, product upgrading, and skill upgrading. Each of these dimensions corresponds to a concept of upgrading identified by Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002). Using these dimensions, we compare and analyze the upgrading levels of different countries and industries. Results at both the country level and the country-industry level show that process, product, and skill upgrading moderately correlate, but they indeed reflect different dimensions of industrial upgrading. It confirms

[1] Factor analysis is a statistical technique and its applications distinguish two categories. An exploratory factor analysis (EFA) explores the data and reports 'what the data tell us'. A confirmatory factor analysis checks whether earlier findings or a theory can be confirmed. This paper only uses EFA, so that EFA and factor analysis will be used interchangeably.

the multidimensionality of industrial upgrading and our proposal that upgrading should be measured in a systematic way.

2. The measurement of upgrading

In this section, we introduce our framework for measuring industrial upgrading in a GVC perspective. Section 2.1 starts with a brief sketch of what has been done in the past on upgrading and indicates differences of them with our work (i.e. the GVC perspective and the split of labor use according to skill types). Section 2.2 is a more formal and mathematical exposition that leads to the upgrading indicators to be applied to the factor analysis in Section 3.

2.1. Background and overview of the literature

Upgrading was initially defined as the ability to make better products, to make them more efficiently, or to move more into skilled activities (Porter, 1990). It is important to understand the factors that facilitate improvements in products and processes. If these factors arise from the activities of a firm, the original concept of upgrading is helpful. But, as Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002) point out, this concept is restricted to the level of the firm and fails to capture upgrading processes across sectors. Also within sectors, upgrading processes that involve groups of interlinked firms in GVCs (due to the rise in international fragmentation) cannot be captured. Therefore, the interpretation of upgrading was widened by Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002) who identified four distinct types of upgrading. These were process upgrading, product upgrading, functional upgrading, and intersectoral upgrading. Gereffi (2005) and Gibbon and Ponte (2005) attempted to catch these four types of upgrading in a single, more generic concept of upgrading. Upgrading is a move: to higher value-added activities in production; to the use of improved technology, knowledge and skills; and to increased benefits from participation in GVCs.

The four types of upgrading proposed by Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002) were identified by them in a conceptual framework without quantitative measures. However, each of the four types of upgrading suggests its own indicators. Process upgrading refers to an increase in the efficiency of production processes. For example, the substitution of labor for capital (which happens when automation takes place) may yield a greater level of productivity. Indicators for process upgrading that have been proposed are labor productivity growth (see, e.g. Taglioni and Winkler, 2016), capital compensation growth (Milberg and Winkler, 2011), and capital intensity growth (Barrientos et al., 2011).

Product upgrading occurs where new products are introduced or when certain existing products are enhanced faster than are competing products. It entails moving into more sophisticated products within an existing value chain. Indicators that have been proposed for product upgrading are export growth and growth of the export share. Kaplinsky and Readman (2005) suggest the combination of the export share growth and the growth in the export unit value (reflecting the average price of the exported products). Higher prices for the exported products despite constant (or increasing) export shares suggest that products have upgraded (see also Amighini, 2006). Li and Song (2011) provide further motivation for the use of the export share and the export unit value by arguing that product quality is the linchpin. Differences in product quality are globally evaluated by consumers and reflected in their preferences (and the shares) and consequently product prices. High-quality products have higher prices than do low-quality products (Aiginger, 1997). A price increase thus reflects an upgrade of the quality of the product or service if the share is stable or rising.

Functional upgrading involves performing more sophisticated business functions or more skill-intensive activities. A typical example of functional upgrading is a move from simple assembly to full-package production to developing an own product design. This is reflected by increasing shares of skill-intensive activities and the use of high-skilled workers. Two proposed indicators for functional upgrading are the increase in the skill intensity of the sector's employment and the increase in the skill intensity of the exports (Barrientos et al., 2011; Milberg and Winkler, 2011).

The fourth type of upgrading is intersectoral upgrading. It is the shift to a more technologically advanced production chain. This involves disintegrating processes into other industries and/or other value chains. Intersectoral upgrading is related to changing the production mix toward producing goods and services with a higher value added. The production (and employment and exports) of a country gradually shifts across sectors, from agriculture and natural resource extraction to light industries like textile, and subsequently toward more modern manufacturing and the service sectors (see, e.g. Lewis, 1954, for a discussion of structural change). So far, there is no unambiguous indicator to measure intersectoral upgrading. But some researchers (e.g. Lin and Yu, 2012) use the sectoral composition of gross domestic product (GDP) and the sectoral composition of exports to study intersectoral upgrading at country level.[2]

In conclusion, we extract from the literature the following eight indicators of upgrading: labor productivity growth; capital compensation growth; capital intensity growth; export growth; export share growth; growth of export unit value; growth of the skill intensity of employment; and growth of high-skilled labor exports. A list of these indicators and their sources is provided in Appendix A of the Online Supplementary Material.

Four out of the eight indicators suggested in the literature are based on gross exports. Increased international production fragmentation has led to enormous growth in the trade in intermediate products and to countries specializing in small parts of value chains. This was made possible by rapidly falling communication and transport costs over the past two decades implying that various stages of production can be performed in other regions and countries. In the past, a country performed the whole production process of a product and exported the product to compete with other countries in the global market. The value that the exporting country received was the price of the exported product, and it reflected the gains or benefits for that country. Due to globalization, today's products and services are made in global production networks (GPNs) or GVCs, rather than in a specific country (Timmer et al., 2013, 2015). A country imports raw materials and intermediate goods,

[2] In the EFA, later in the paper, we do not include the sectoral composition of GDP or exports as an indicator though. We think a country's sectoral change is captured by other indicators that we do include. For example, a country's change in its sectoral composition of exports is reflected in its change in the unit value-added exports (i.e. value-added exports per dollar of gross exports). Because they add little or no additional information, we avoid using similar indicators for the sake of orthogonality, i.e., they would overweight a factor. Nevertheless, we do consider the effects of a change in the share of exports between natural resource and non-resource intensive sectors and run a robustness check of country-specific results in Section 4.3.

adds one or more layers of value, and sells the resulting product to a foreign producer who adds the next layer(s). This corresponds to Baldwin's (2006) 'second unbundling', where the location of the production of intermediate inputs differs from the location of making the final product. In today's situation, the price of an exported product is no longer the value that the exporting country receives for the product. Consequently, the value of gross exports (as recorded by customs data and reported in official trade statistics) goes to all the countries involved in the production stages and not only to the final exporter. To capture this new situation, we suggest new indicators of industrial upgrading. We suggest that they use the domestic value added of a country that is embodied in all foreign final demands (also known as value-added exports), rather than the value of gross exports.

Concerns about the gap between the value of gross exports and the value-added exports have been expressed. Case studies of the Apple iPad and iPhone (Kraemer et al., 2011) reveal that the value added generated in China (which exports the final Apple products) is only 1.8% of their export value for China. Because Apple continues to keep its pre- and post-fabrication activities (such as product design, software development, product management, and marketing) in the USA, the USA remains the main beneficiary in value-added terms. Other case studies of the iPod and laptops (Dedrick et al., 2010) and the Nokia smartphone (Ali-Yrkkö et al., 2011) confirm that these pre- and post-fabrication activities generate much value added (Baldwin and Evenett, 2012). China's benefits from participating in Apple's GVCs are thus much smaller than the huge gross export values from China suggest. This is because China is involved only in the assembly part of the GVCs, which generates little value added. Koopman et al. (2012) and Chen et al. (2018) focus on the role of assembly activities in producing export products. Their results show that the value added in exports related to assembly activities is much lower than the value added in other exports and is far lower than otherwise suggested by the gross export values (see Johnson and Noguera, 2012, for similar findings for a larger set of countries). This gap between the value of gross exports and the value-added exports is well recognized. The OECD and the World Trade Organization (WTO) have launched their 'Made in the World' initiative and proposed 'trade in value added'. This alternative approach for the measurement of world trade provides a better answer to certain questions (see OECD-WTO, 2012).

When measuring industrial upgrading, however, to our knowledge, only a few recent studies have adopted value added-based indicators from a GVC perspective.[3] In this paper, we adjust conventional indicators and replace the value of gross exports by the value-added exports (i.e. the value added created in one country to satisfy – directly and indirectly – final demand in another country, see Johnson and Noguera, 2012). For example, the growth of the export share is replaced by the growth of the share in value-added exports. In the same way are export growth and export unit value growth adjusted. With regard to the other four indicators that are not based on gross exports (i.e. labor productivity growth, capital compensation growth, capital intensity growth, and growth of the skill intensity of employment), we keep their conventional definitions. The detailed definitions for the eight indicators are provided in the following subsection (and in Appendix A of the Online Supplementary Material).

[3] A few recent studies started to adopt the GVC perspective when using the measure of economic upgrading. For instance, Taglioni and Winkler (2016) and Ahmad and Primi (2017) adopted the growth of domestic value added in gross exports as the measure of economic upgrading. Rather than using such a single measure, in this paper, we point out that industrial upgrading can be a multifaceted phenomenon that cannot be characterized well by a single measure.

Figure 1. The world multi-regional input–output table.

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

A second feature of our study is that we split labor according to skill types. High-, medium- and low-skilled labor are determined by the educational attainment of the workers. We focus, in particular, on high-skilled labor. The reason is that high-skilled workers are supposed to be more able than medium- and low-skilled workers to make better products and/or to make them more efficiently. High-skilled workers also often specialize in higher value-added activities such as R&D, design and marketing activities, whereas low-skilled workers are often production or service workers who create less value. A rising share of high-skilled labor thus indicates that an industry has experienced upgrading. The growth in the share of high-skilled labor is a proxy for the increased skill intensity of employment. For example, the growth of the skill intensity of exports is measured by the growth in the high-skilled labor embodied in foreign final demand.

2.2. Indicators of industrial upgrading

Our starting-point is the world multi-regional IO table in Figure 1 with n countries and m sectors (or industries) in each country.[4] The $m \times m$ matrix $\mathbf{Z}^{sr}$ gives intermediate deliveries from country s to country r. Its typical element z_{ij}^{sr} gives the value of goods and services shipped from sector i in country s for intermediate use by sector j in country r. The value of goods and services shipped from sector i in country s to country r for final use (household consumption, private investments, and government expenditures) is given by f_i^{sr}, the typical element of the vector $\mathbf{f}^{sr}$. The value of the output by sector i in country s is given by y_i^s, the typical element of the vector $\mathbf{y}^s$. The accounting identity (or product market clearing condition) is

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

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

[4] Bold-faced lower-case letters are used to indicate vectors, bold-faced capital letters indicate matrices, italic lower-case letters indicate scalars (including elements of a vector or matrix). Subscripts indicate industries and superscripts indicate countries. Vectors are columns by definition, row vectors are obtained by transposition, denoted by a prime (e.g. $\mathbf{x}'$). Diagonal matrices are denoted by a circumflex (e.g. $\hat{\mathbf{x}}$).

$$\begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} = \begin{bmatrix} \mathbf{Z}^{11} & \cdots & \mathbf{Z}^{1r} & \cdots & \mathbf{Z}^{1n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ \mathbf{Z}^{r1} & \cdots & \mathbf{Z}^{rr} & \cdots & \mathbf{Z}^{rn} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ \mathbf{Z}^{n1} & \cdots & \mathbf{Z}^{nr} & \cdots & \mathbf{Z}^{nn} \end{bmatrix} \begin{pmatrix} \mathbf{u} \\ \vdots \\ \mathbf{u} \\ \vdots \\ \mathbf{u} \end{pmatrix} + \begin{pmatrix} \sum_t \mathbf{f}^{1t} \\ \vdots \\ \sum_t \mathbf{f}^{rt} \\ \vdots \\ \sum_t \mathbf{f}^{nt} \end{pmatrix} \tag{2}$$

The $m \times m$ matrix $\mathbf{A}^{sr} = \mathbf{Z}^{sr}(\hat{\mathbf{y}}^r)^{-1}$ gives the input coefficients. Its typical element $a_{ij}^{sr} = z_{ij}^{sr}/y_j^r$ gives the dollars of input from sector i in country s for intermediate use by (and measured per dollar of output by) sector j in country r. This yields

$$\begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1r} & \cdots & \mathbf{A}^{1n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ \mathbf{A}^{r1} & \cdots & \mathbf{A}^{rr} & \cdots & \mathbf{A}^{rn} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ \mathbf{A}^{n1} & \cdots & \mathbf{A}^{nr} & \cdots & \mathbf{A}^{nn} \end{bmatrix} \begin{pmatrix} \mathbf{y}^1 \\ \vdots \\ \mathbf{y}^r \\ \vdots \\ \mathbf{y}^n \end{pmatrix} + \begin{pmatrix} \sum_t \mathbf{f}^{1t} \\ \vdots \\ \sum_t \mathbf{f}^{rt} \\ \vdots \\ \sum_t \mathbf{f}^{nt} \end{pmatrix} \tag{3}$$

Let the final demands vector be split into n vectors, one for each receiving country. That is, define

$$\mathbf{f} = \begin{pmatrix} \sum_t \mathbf{f}^{1t} \\ \vdots \\ \sum_t \mathbf{f}^{rt} \\ \vdots \\ \sum_t \mathbf{f}^{nt} \end{pmatrix} = \begin{pmatrix} \mathbf{f}^{11} \\ \vdots \\ \mathbf{f}^{r1} \\ \vdots \\ \mathbf{f}^{n1} \end{pmatrix} + \ldots + \begin{pmatrix} \mathbf{f}^{1n} \\ \vdots \\ \mathbf{f}^{rn} \\ \vdots \\ \mathbf{f}^{nn} \end{pmatrix} = \mathbf{f}^1 + \ldots + \mathbf{f}^n.$$

Equation 3 can be written as $\mathbf{y} = \mathbf{A}y + \mathbf{f} = \mathbf{A}y + (\mathbf{f}^1 + \ldots + \mathbf{f}^n)$ and the solution is given by $\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f}^1 + \ldots + \mathbf{f}^n) = \mathbf{L}(\mathbf{f}^1 + \ldots + \mathbf{f}^n)$, where $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. In its partitioned form this $nm \times nm$ matrix is given by

$$\mathbf{L} = \begin{bmatrix} \mathbf{L}^{11} & \cdots & \mathbf{L}^{1r} & \cdots & \mathbf{L}^{1n} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ \mathbf{L}^{r1} & \cdots & \mathbf{L}^{rr} & \cdots & \mathbf{L}^{rn} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ \mathbf{L}^{n1} & \cdots & \mathbf{L}^{nr} & \cdots & \mathbf{L}^{nn} \end{bmatrix}.$$

The outputs that are necessary for (or embodied in) the final demands of any country except country s are given by $\mathbf{L}\left(\sum_{t \neq s} \mathbf{f}^t\right)$. Note that for country s the nm-element vector $\sum_{t \neq s} \mathbf{f}^t$

gives *foreign* final demands. The domestic output embodied in the foreign final demands is, for country *s*, given by $\sum_k \mathbf{L}^{sk}\left(\sum_{t\neq s}\mathbf{f}^{kt}\right)$.

The m-element vector $(\mathbf{v}^r)' = (\mathbf{w}^r)'(\hat{\mathbf{y}}^r)^{-1}$ gives the value-added coefficients in country r. Its typical element $v_j^r = w_j^r/y_j^r$ gives the value added (in dollars) generated in sector j in country r per dollar of output in this sector. The value added generated in sector i in country s that is embodied in foreign final demands (i.e. final demand outside country s) is given by the ith element of the vector

$$\mathbf{vax}^s = \sum_k \sum_{t\neq s} \hat{\mathbf{v}}^s \mathbf{L}^{sk}\mathbf{f}^{kt}. \tag{4}$$

This is value added of country s that ultimately ends up in a foreign final demand bundle (e.g. consumption of households abroad). This is the export by country s of its domestic value added. The value-added exports of country s (vax^s) and the value-added exports of sector i in country s are given by: $vax^s = \mathbf{u}'\mathbf{vax}^s$ and vax_i^s (i.e. the ith element of $\mathbf{vax}^s$).

Instead of value added, we can also take any factor input such as capital or labor. For example, let the typical element h_j^r of the m-element vector $\mathbf{h}^r$ give the amount of high-skilled labor used in sector j in country r. Let the m-element vector $(\mathbf{l}^r)' = (\mathbf{h}^r)'(\hat{\mathbf{y}}^r)^{-1}$ give the input coefficients for high-skilled labor in country r. Its typical element $l_j^r = h_j^r/y_j^r$ gives the amount of high-skilled labor used in sector j in country r per dollar of output in this sector. The export by country s of high-skilled labor is defined as the high-skilled labor in country s that is embodied in final demands abroad (i.e. outside country s). Similar to (4), it is calculated as $\sum_k \sum_{t\neq s} \hat{\mathbf{l}}^s \mathbf{L}^{sk}\mathbf{f}^{kt}$. This sketches the GVC perspective on measuring the embodiment of factor inputs in foreign final demands.

We continue with presenting and defining the upgrading indicators that we will use in the factor analysis in the next section.

(1) *labpr*: labor productivity growth. Labor productivity is calculated as the ratio of value added to labor, i.e. the value added per unit of labor. Labor is defined as 'all persons engaged'. This includes, next to all paid employees, also the self-employed and informal workers. Note that this indicator (and all indicators hereafter) is a growth rate. That is, $labpr = (p_t - p_{t-1})/p_{t-1}$, where p_t denotes the labor productivity of a country in year t.
(2) *capcom*: capital compensation growth. Capital is one of the three primary factors of production (i.e. natural resources, labor, and capital), consisting of both tangible (like machinery and buildings) and intangible assets (like patents and copyrights). Capital compensation refers to the remuneration for the use of capital assets.
(3) *capint*: capital intensity growth. Capital intensity is calculated as the ratio of capital stock to labor. The capital stock is the value of the fixed capital that can be used as input in production of goods and services in an accounting interval. For many countries, capital stocks have been constructed on the basis of the Perpetual Inventory Method in which the capital stock in year t is estimated as the sum of the depreciated capital stock in year $t - 1$ plus real investment in year t.

(4) *vax*: growth of value-added exports. The value-added exports are calculated in equation (4).
(5) *vaxshare*: growth of the share of country s in all value-added exports. The share of country s is calculated as $vaxshare^s = vax^s / \sum_r vax^r$ at the country level and as $vaxshare_i^s = vax_i^s / \sum_r vax_i^r$ at the sector level.
(6) *vaxr*: growth of the unit value-added exports. The unit value-added exports are also known as the VAX-ratio (Johnson and Noguera, 2012). It is calculated as the value-added exports (of a country or industry) divided by the gross exports.
(7) *hsemp*: growth of the skill intensity of employment. The skill intensity of employment is obtained as the amount of high-skilled labor (measured in working hours) as a share of total employment. The labor force in each industry distinguishes low-skilled, medium-skilled, and high-skilled workers.
(8) *hse*: growth of high-skilled labor exports. It is calculated as the amount of high-skilled labor (also measured in working hours) that is directly and indirectly needed in the production for foreign final demand.

Note that among the above eight indicators we adjust the four indicators that are based on gross exports, while we keep the conventional definitions for the other four indicators. Intuitively, to make all indicators consistent with the GVC framework, we could have also adjusted the other measures (i.e. labor productivity growth *labpr*, capital compensation growth *capcom*, capital intensity growth *capint*, and growth of the skill intensity of employment *hsemp*) from the GVC perspective by connecting them to foreign final demands. However, we choose not to do this because this may cause some conceptual bias for GVC-driven upgrading. That is, if we would calculate labor productivity as the ratio of the value added embodied in foreign final demand and the amount of labor embodied in foreign final demand, then we would capture the part of labor productivity that is linked to GPNs. However, then we would neglect the isolated domestic part. We believe that even those sectors which are relatively isolated from GPNs can significantly contribute to the country's productivity. For example, China is a huge importer (rather than exporter) of natural resources. Its resource-extracting sectors (e.g. mining and quarrying) could have weak links to foreign final demands (not in the center of GPNs like electronic equipment), but may have strong links to domestic production. The development of excavation technology can also help a lot in search and exploration of latent natural resources, i.e. boosting productivity and upgrading. We should not neglect this kind of upgrading in our framework. Taking this remark into account, we decide to keep the conventional definitions for the indicators *labpr*, *capcom*, *capint*, and *hsemp*.

Implementing the GVC perspective outlined above and calculating the indicators at country and sector level requires a time series of global multi-regional input–output tables. The World Input–Output Database (WIOD 2013 Release, Dietzenbacher et al., 2013) contains these tables and it provides the necessary employment data for the three skill levels using the same sector classification. It also provides capital compensation and capital stock data at the same sectoral level. The data are for 40 countries and the rest of the world (RoW) using a 35-sector classification (see Appendix B of the Online Supplementary Material for a listing of the countries and sectors). Considering that price fluctuation might affect the results, we use world input–output tables in the prices of previous years and data on

Table 1. Correlation matrices of the upgrading indicators.

	labpr	*capcom*	*capint*	*vax*	*vaxs*	*vaxr*	*hsemp*	*hse*
labpr	1							
capcom	0.43	1						
capint	0.56	0.16	1					
vax	0.34	0.25	0.14	1				
vaxs	0.34	0.29	0.15	0.75	1			
vaxr	0.11	0.08	−0.07	0.11	0.23	1		
hsemp	0.16	0.12	0.12	0.14	0.17	−0.07	1	
hse	0.15	0.06	−0.09	0.21	0.18	−0.31	0.55	1
labpr	1							
capcom	0.34	1						
capint	0.45	0.12	1					
vax	0.25	0.36	0.05	1				
vaxs	0.23	0.35	0.04	0.72	1			
vaxr	0.09	0.14	−0.01	0.15	0.19	1		
hsemp	0.12	0.01	0.14	0.12	0.02	−0.01	1	
hse	0.19	0.05	−0.18	0.44	0.42	−0.06	0.59	1

Notes: The table shows pairwise correlation coefficients. The estimates are based on the data over the period of 1996–2009. The acronyms refer to: (*labpr*) labor productivity growth, (*capcom*) capital compensation growth, (*capint*) capital intensity growth, (*vax*) growth of value-added exports, (*vaxs*) growth of the share in value-added exports, (*vaxr*) growth of unit value-added exports, (*hsemp*) growth in the share of high-skilled labor in total employment, (*hse*) growth of high-skilled labor exports. The upper panel shows correlation coefficients for the sample of countries (40 countries × 14 years = 560 observations). The lower panel is for the sample of country-industries (40 countries × 34 industries × 14 years = 19,040 observations). We note that there are 35 sectors in input–output tables from WIOD; But many indicators for sector c35 have null values because of the unavailability of basic data. We thus exclude sector c35 in our analysis. Outside of that, there are more null values in our empirical test. For example, there are no capital stock data for some European countries for years 2008 and 2009. In this case, the indicator *capint* will have null values for these countries. In the EFA, these cases with missing values are deleted to prevent overestimation (Tabachnick and Fidell, 2007).

capital stock, gross output, and value added at constant prices to calculate corresponding indicators.

The factor analysis in the next section uses the eight upgrading indicators for the years 1996–2009. Although the published input–output data cover the period 1995–2011, data for employment by skill type are not available for 2010 and 2011. Also, no labor data are available for sector c35 (Private households with employed persons), and this sector exports little in any case. All input–output calculations include 35 sectors (with labor input coefficients for sector c35 set equal to zero), but only the indicators for the first 34 sectors are used in our factor analysis.

3. Latent variables and factor analysis

3.1. Factor analysis: theory and method

In Section 2, we have identified eight indicators that have been proposed in the literature to measure industrial upgrading. These indicators do not perfectly correlate (see correlation matrix in Table 1), and therefore, each indicator contains a different aspect of the (latent) concept of industrial upgrading. It may even be the case that industrial upgrading is a multifaceted phenomenon that cannot be characterized well by a single indicator. But we believe that there may exist a lower number of underlying variables that captures common information (about upgrading) that is contained in the eight identified indicators of upgrading. Therefore, we propose to examine the dimensionality of these indicators using EFA.

Factor analysis finds its origin in the measurement of human intelligence in psychometrics. Spearman (1904) observed that children's performance ratings, across seemingly unrelated school subjects, were positively correlated, and reasoned that these correlations reflected the influence of an underlying general mental ability that entered into performance on all kinds of mental tests. He suggested that all mental performance could be conceptualized in terms of a single general ability factor, which was termed human intelligence.

Similar to the measurement of human intelligence, we here use the eight different indicators that proxy different aspects of upgrading to measure the underlying latent variable 'upgrading'. However, (like later human intelligence measurement studies, see, e.g. Thomson, 1916; Carroll, 1993), we allow for the possibility that upgrading may be multi-dimensional. Previewing our results, we find that the latent variable 'industrial upgrading' consists of three separate latent sub-variables ('process upgrading', 'product upgrading', and 'skill upgrading').

Factor analysis describes the statistical variance common among observed, correlated variables (called indicators) in terms of a potentially lower number of unobserved (i.e. latent) sub-variables called factors. For present purposes, we employ EFA to identify the variance shared by the indicators to form a latent variable (industrial upgrading in our case). EFA creates the latent variable by assuming that the observed indicators are 'generated' by a linear combination of other latent variables (the factors) and an individual error term. Following Wansbeek and Meijer (2000), this linear model can be expressed as follows:

$$\mathbf{x} = \mathbf{B}\xi + \boldsymbol{\varepsilon}, \tag{5}$$

where $\mathbf{x}$ is a vector containing m observed indicators (in our case the eight indicators of industrial upgrading), and $\boldsymbol{\xi}$ is a vector of latent variables (*factors*) that the indicators are supposed to measure.$\mathbf{B}$ is the matrix of parameters (*factor loadings*) with dimension $(m \times k)$ (k is the number of factors and we will illustrate how to decide on the value for k in the following paragraph, $k \leq m$); the parameters are weights applied to the indicators that reveal the latent factors. As such, a (relatively) high (in absolute value) factor loading implies that the observed indicator contains a relatively high amount of information about the specific latent factor. $\boldsymbol{\varepsilon}$ is the random measurement error term, and its variance is called the *unique variance*. It is the part of the observed indicator that cannot be explained by the underlying factors. The predicted values of $\boldsymbol{\xi}$ are $\hat{\boldsymbol{\xi}}$, and are called *factor scores* (in our case upgrading scores).

In factor analysis it is critical to decide on the number of factors that will represent the indicators. Theoretically, we can get as many factors as we have indicators (m). But the point of factor analysis is to reduce the number of information sources—a small group of factors that capture the core information from the indicators. There are three ways to decide on the appropriate number of factors to retain. First is the Kaiser criterion, which recommends that all factors with eigenvalues greater than one should be included in the model. The second way is to 'eyeball' the scree plot of the eigenvalues for the factors and find a point where the plot suddenly gets relatively flat—the elbow of the scree plot (Cattell, 1966). Third, a likelihood ratio test can be performed to contrast the factor model against the alternative saturated model. Not surprisingly, the scree test has been criticized being too subjective, and the likelihood ratio test is sensitive to model overfitting. So we also consult information criteria such as Akaike information criterion and the Schwarz criterion.

It is possible that the resulting latent factors of the standardized outcome of the model are difficult to interpret (and hence to label). This happens when indicators load substantially on more than one factor. Fortunately, the matrix of factor loadings can be multiplied by any orthonormal matrix without affecting the distribution of the indicators. This multiplication, called a 'rotation', can make the factor loadings more readily interpreted when it simplifies the factor structure. We use the Oblimin rotation, which minimizes the correlation between columns of the factor loadings matrix. In doing so, every indicator resulted in a high loading on just one factor and substantially lower loadings on all other factors. Such a clear distribution of the factor loading matrix made it possible for us to attach an economic meaning to the estimated factors.

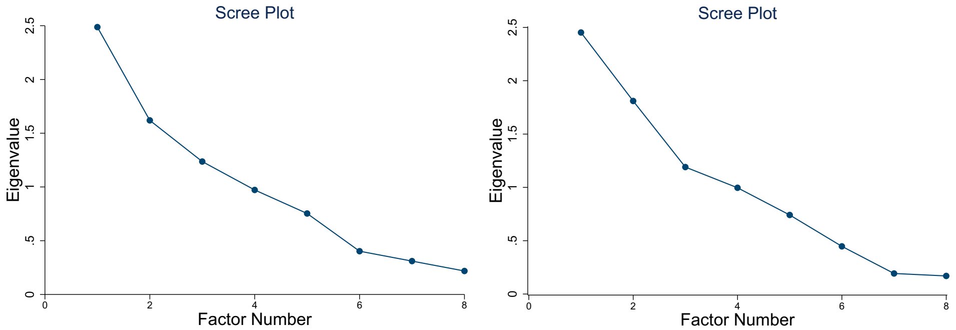
With the factor loadings set, it becomes possible for us to calculate factor scores. We use the Bartlett (1937) predictor, i.e. the best linear unbiased predictor of the factor scores. They are based on a linear combination of the estimated factor loadings and the observed indicators. The factor scores, in turn, serve as our measures of the dimensions of industrial upgrading. We thus call them upgrading scores hereafter. For a technical exposition on factor loading estimation and factor scores prediction, see Wansbeek and Meijer (2000).

3.2. Factor analysis: results

In this section, we employ EFA to examine the dimensionality of industrial upgrading and obtain upgrading scores. We provide estimation results for two samples as we aim to analyze the upgrading performance at both country level and country-industry level. The first analysis consists of 40 countries, and the other consists of 1360 (40 countries × 34 industries) country-industries. Both analyses are based on eight indicators for the period 1996–2009. The pairwise correlation matrices of the indicators are shown in Table 1. As can be seen from Table 1, the different indicators of upgrading are correlated, as they should, because they are intended to measure the same concept. However, the correlations between these indicators are not perfect (i.e. −1 or 1). As they all intend to measure the same concept, we conclude that (it is very likely that) each indicator is an imperfect measure of upgrading, and each of them may capture some aspects of upgrading.

To extract the appropriate number of factors to be included in the analysis, we use various statistical tests. First, we look at the scree plot. The left plot in Figure 2 shows the scree test for the sample of countries and the right is for the sample of country-industries. Following the 'elbow criterion', the left plot is not very decisive for determining the number of factors to retain. Both the third and the fourth data points show some kind of an 'elbow'. However, it can be seen from the right plot that three factors have a large eigenvalue relative to the other factors and explain a relatively large part of the variance contained in all indicators. Hence, it seems appropriate to opt for three factors. This is confirmed by the fact that in both samples three eigenvalues exceed one and by the Kaiser criterion. Next, we perform the LR test, which compares the three-factor model against a saturated model. In both samples the test rejects the null-hypothesis that the estimates of a saturated model are equal in favor of the (restricted) three-factor model. It suggests the three-factor model is appropriate. Finally, we also consider the value of Akaike information criterion and the

Figure 2. Cattell's scree test for the sample of countries and the sample of country-industries.



Notes: The left plot shows the scree test for the sample of countries and the right one for the sample of country-industries.

Table 2. Rotated factor loadings matrices and unique variance estimates.

	Factors				Factors			
Indicators	Product upgrading	Process upgrading	Skill upgrading	Unique variance	Product upgrading	Process upgrading	Skill upgrading	Unique variance
labpr	0.24	0.86	0.03	0.21	0.28	0.82	0.06	0.23
capcom	0.26	0.56	0.13	0.62	0.26	0.59	−0.13	0.55
capint	0.01	0.81	−0.08	0.34	0.16	0.84	0.01	0.26
vax	0.89	0.12	0.13	0.18	0.89	0.02	0.12	0.17
vaxs	0.92	0.13	0.03	0.13	0.90	0.01	0.10	0.16
vaxr	0.32	−0.11	−0.31	0.78	0.39	0.05	−0.20	0.75
hsemp	0.06	0.16	0.75	0.40	0.05	0.12	0.92	0.13
hse	0.19	−0.14	0.87	0.18	0.23	−0.26	0.78	0.28

Notes: Factor loadings are estimated using maximum likelihood method and the method of rotation is Oblimin. The left panel shows the estimates for the sample of countries and the right panel for the sample of country-industries. Factor loadings with absolute terms larger than 0.3 are in gray.

Schwarz criterion. For both criteria, we find the minimal test statistic in the case of a factor model with three factors. All these outcomes lead us to conclude that the three-factor model is the most appropriate option.

The estimation results of our factor analysis are shown in Table 2. The estimates in this table are best interpreted as correlation coefficients (factor loadings) between the factor and the indicators. Since the unrotated factor loadings are (as explained) not so informative, we show the results after Oblimin rotation. This leads to a pattern in which the first factor has a high loading on some indicators and the other factors on the other indicators, etc. In Table 2, it is clear that the same indicators have high loadings on the specific factor in both samples. For example, the indicator *labpr* has a high loading (0.86) on the second factor while it has much lower loadings on the first (0.24) and third (0.03) factors. The indicators with high loadings can be used to interpret the factors. The indicator *labpr*, therefore, can be used to interpret the second factor.

Recalling that we concluded in Section 2.1 that the eight (conventional) indicators were related to the four conceptual types of industrial upgrading proposed by Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002), we believe it is not difficult to label our three quantitative, albeit latent, dimensions of upgrading. In both samples, the first factor has high loadings for growth of value-added exports, growth of the share in value-added exports, and growth of the unit value-added exports. These three indicators all relate to gaining more value through GVCs, which is related to the effect of making better products, hence product upgrading. Better products lead to more use by producers located further downstream in the GVC. The second factor follows from the three indicators (labor productivity growth, capital compensation growth, and capital intensity growth) with high loadings. These three indicators are clearly related to improving the efficiency of production processes in terms of their factor use. We can say that this factor is the quantitative reflection of process upgrading. Therefore, instead of devising a new label, we follow previous work and label the second factor as 'process upgrading'. Finally, the third factor has high loadings for indicators that relate to the increase of skill intensity. This factor is thus labeled 'skill upgrading'.

It should be stressed that we label the third factor as 'skill upgrading' (which is also a commonly used term, see, e.g. Taglioni and Winkler, 2016) instead of sticking to 'functional upgrading'. That is because, although 'skill upgrading' provides information about functional upgrading, it focuses on the skill intensity of employment only and functional upgrading is broader in its coverage. As Timmer et al. (2019) recently suggested, once occupation data at the country-industry level are available, we can use them to distinguish the functions (fabrication, R&D, marketing and management, etc.) that are carried out by a particular occupational class of workers and, further, to measure functional upgrading.

Note that we do not include the fourth conceptual type of industrial upgrading (i.e. 'intersectoral upgrading') that was proposed by Kaplinsky and Readman (2001) and Humphrey and Schmitz (2002). This is because both 'skill upgrading' and 'product upgrading' capture elements of intersectoral upgrading. This is the case for 'skill upgrading' because the growth of high-skilled labor exports adopts the GVC perspective, which accounts for intersectoral linkages. This is also the case for our GVC-based 'product upgrading' because both domestic and international interdependencies between sectors are already well captured by the indicators based on value-added exports.

Apart from the factor loadings, Table 2 also reports the estimated measurement errors of the individual indicators. The variance of an indicator contains two parts: the common variance and the unique variance. The factors account for the common variance and the latter refers to the variance contained in the individual indicators that cannot be attributed to any of the factors. In other words, the indicators with a low unique variance contain relatively little variance that cannot be attributed to the multiple dimensions of upgrading.

The upgrading scores we obtained reflect different dimensions of upgrading. Table 3 shows the correlation matrices of the predicted upgrading scores. It can be seen that the factors moderately correlate, which implies that they indeed reflect different dimensions of upgrading. Our findings are summarized in Figure 3.

4. Empirical results

Since individual countries and sectors are heterogeneous with respect to their production structures, the upgrading scores of the dimensions are country- and sector- specific. For example, the upgrading level of the Chinese transport equipment industry may be different from that of the Chinese chemicals industry as well as from that of the German transport

Figure 3. A three-level hierarchy for industrial upgrading.

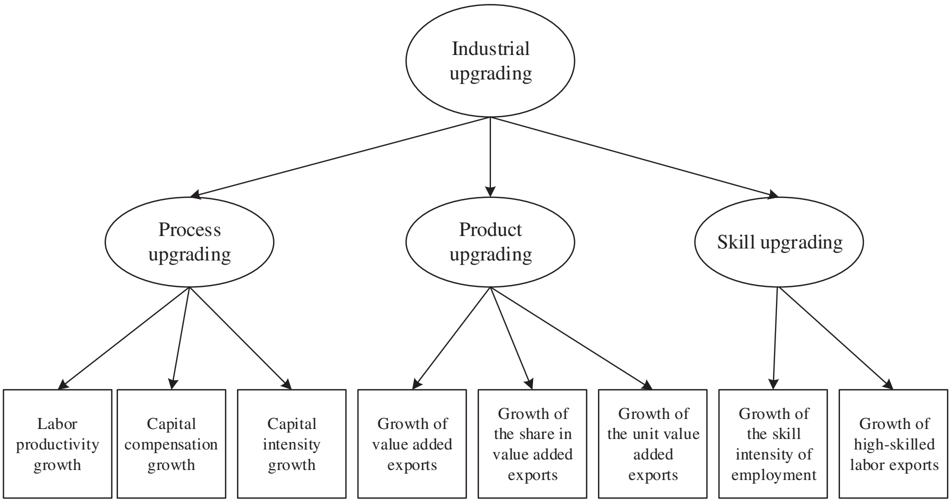


Table 3. Correlation matrices of the factor scores for the three identified dimensions of upgrading.

	Product	Process	Skill	Product	Process	Skill
Product	1.00			1.00		
Process	0.23	1.00		0.36	1.00	
Skill	0.15	0.09	1.00	0.22	0.12	1.00

Notes: The left panel shows the correlation coefficients between the three factors of upgrading for the sample of countries and the right panel does so for the sample of country-industries.

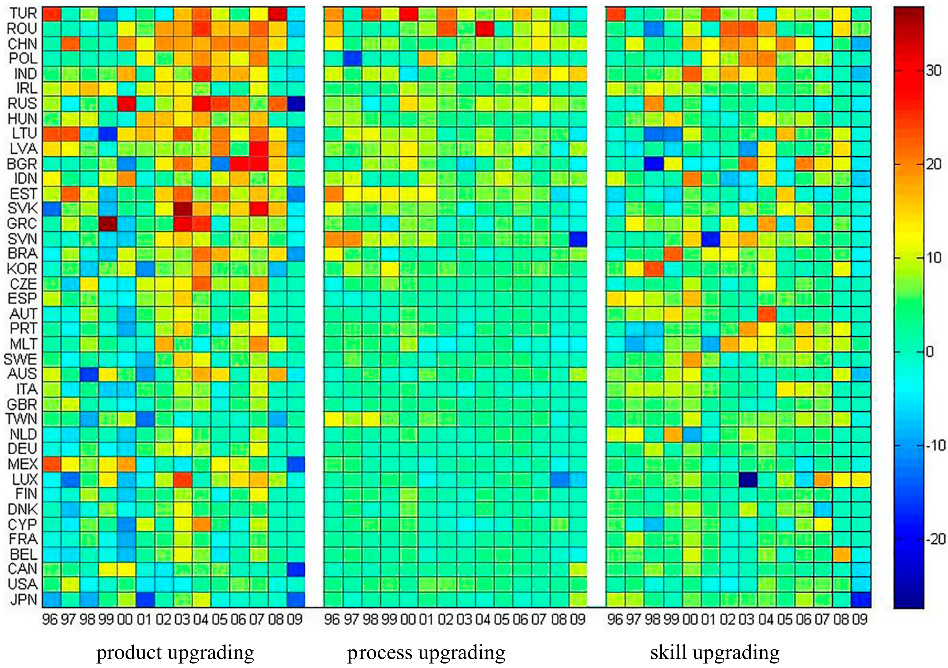
equipment industry. We first present the country-specific results, which are based on the national sample. Then we zoom in further to consider sector-specific upgrading levels in subsection 4.2.

4.1. Country-specific results

Figure 4 presents a color map of the country-specific upgrading scores from 1996 to 2009. Note countries are ordered by their average scores on level of product, process, and skill upgrading. The following observations can be made. First, the figure shows that the importance of the three dimensions of industrial upgrading varies across countries and within countries over time. Second, there are more red grids (reflecting high scores) for product upgrading than for process and skill upgrading. This implies that most countries performed better in product upgrading than in process and skill upgrading. Third, the upgrading scores largely decreased in 2009 since the color grids tend to be darker blue. The global financial crisis turns out to have a major effect upon upgrading scores.

We say a country has experienced upgrading (downgrading) when the factor score for this country is greater (lesser) than zero. The number of countries that have experienced upgrading or downgrading over the period of 1996–2009 is given in Table C-1 (in the

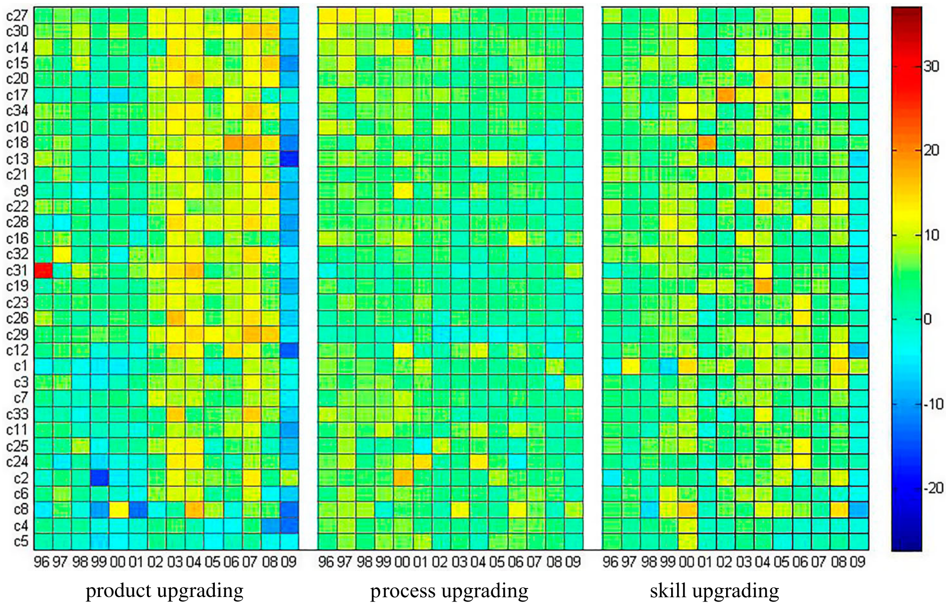
Figure 4. The colormap of the country-specific upgrading scores.



Online Supplementary Material). We see that most countries have experienced upgrading in this period. In almost all years before 2009, there are more upgrading countries than downgrading countries. But in 2009, when the global financial crisis started, the opposite is the case. Since 2002, most countries have performed ever better with respect to product upgrading. China is a typical beneficiary of the prosperous global economy. In Figure 4 we observe that the color grids of China's product upgrading are red and orange from 2002 to 2007. The underlying data show that China's product upgrading scores remained around 20% from 2002 to 2007. These results are consistent with other findings that suggest industrial upgrading in Chinese manufacturing in the 2000s (e.g. Kee and Tang, 2016). An explanation of this stable growth is China's accession to the WTO and its subsequent integration into GVCs.

According to overall average scores of the dimensions over the entire period, emerging countries, such as Turkey, China, and India, have experienced more upgrading than have developed countries such as the USA and Japan. This supports the convergence theory that developing countries have the potential to upgrade faster than developed countries. Figure 4 shows that Turkey, Romania, China, Poland, and India are the top five countries to experience upgrading. But the rankings in Table C-2 (see Online Supplementary Material) reflect that the top five most upgraded countries on one dimension are not necessarily among the top five on another dimension. For example, countries with the highest scores on the 'product upgrading' dimension are China, Poland, Romania, Lithuania, and Russia, while on the 'process upgrading' dimension they are Turkey, Romania, Estonia, Russia, and China. Again, this reinforces the view that these three dimensions moderately correlate, but indeed are different dimensions of industrial upgrading.

Figure 5. The colormap of the sector-specific upgrading scores.



4.2. Sector-specific results

Since sectors in different countries are heterogeneous with respect to their production structures, we now zoom in on sector-specific upgrading levels in this section. Figure 5 presents the color map of upgrading scores by sector over the period. They are average scores in a given year and are – by sector – derived as arithmetic means of sector scores for the 40 countries in a year. For example, the product upgrading score of Electrical and optical equipment (WIOD code: c14) in 1996 (see the first column and the third row in Figure 5) is 9.53%. It means that for the 40 sampled countries the average product-upgrading level for sector c14 is 9.53% in 1996. In Figure 5, industries are ordered by the rank of their average level of upgrading scores across the period. We find that in the GVCs the sector with most upgrading is Post and telecommunications (c27); it has an average score of 6.50%. Renting (c30) and Electrical and optical equipment (c14) are consistently (and respectively) the second and third highest in upgrading scores. In contrast, Textiles and textile products (c4) and Leather, leather, and footwear (c5) have the lowest.

To be more specific, we have the following findings.

- Similar to the country-specific results, the rankings based on the 'product upgrading' dimension differ from that based on 'process upgrading' and 'skill upgrading'.
- For all three dimensions, but especially for product upgrading, service sectors generally perform better than other sectors.
- In the manufacturing sectors, technology-intensive industries like Electrical and optical equipment (c14) and Transport equipment (c15) show higher levels of upgrading. They rank in the top end no matter whether the ranking is based on 'product upgrading' or any other dimensions.

- Resource- and labor-intensive industries have lower levels of upgrading. These industries are (in descending order of their rankings): Mining and quarrying (c2); Wood and products of wood and cork (c6); Coke, refined petroleum and nuclear fuel (c8); Textiles and textile products (c4) and Leather, leather and footwear (c5).
- Due to the global financial crisis, the extent of international trade in intermediates and final goods largely decreased in 2009. The crisis turns out to have a dramatic effect on industrial upgrading. The upgrading scores, especially for product upgrading, largely decreased in 2009.

As illustrated above, Electrical and optical equipment (c14) is the most upgraded manufacturing sector. We will compare whether this typical globalized sector has experienced more upgrading in one country than in others. If we rank the 40 countries by their arithmetic means of the three upgrading scores (depicted in Figure 6), over the 14 considered years, we find:

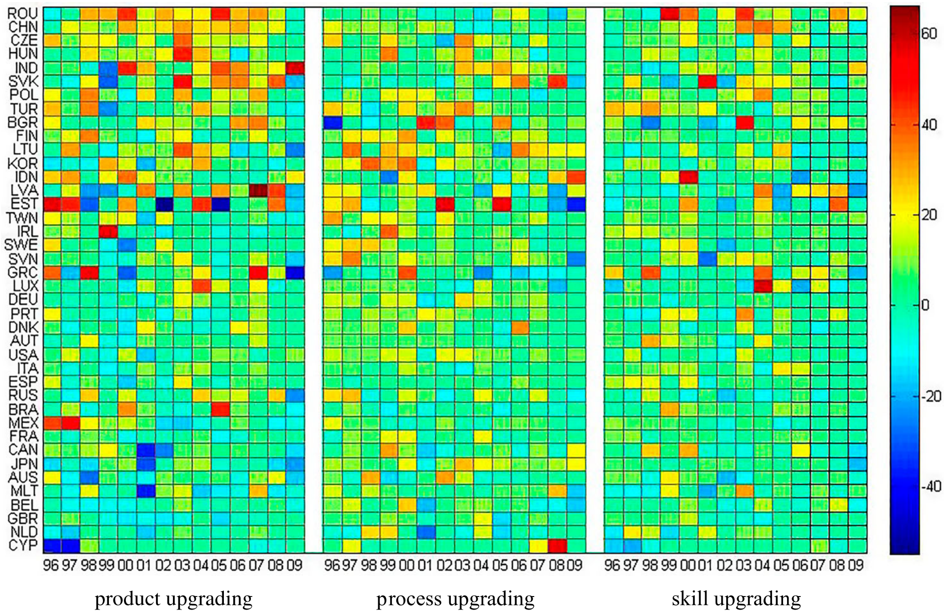
- The average score is positive for each of the 40 countries. This implies that all countries have experienced upgrading in this period. But their upgrading is different. According to the average scores, Romania and China are the top two upgraded countries in Electrical and optical equipment (c14).
- If we rank the countries by the average level of product, process and skill dimensions separately, we find that China and Romania do not perform well in process upgrading (see Table C-3 in the Online Supplementary Material). Countries like South Korea, Finland, Japan, USA, and Turkey perform best.
- The upgrading scores of Electrical and optical equipment (c14) have a much wider range than country- and sector-specific results. This implies that the scores of a particular sector for a specific country can fluctuate heavily.

Our results indicate that developing countries have generally upgraded more than developed countries in technology-intensive industries like Electrical and optical equipment and Transport equipment. Yet, it should be stressed that more upgrading does not imply higher absolute levels of competitiveness in GVCs. For example, China performed significantly better than USA, Japan, and European countries in upgrading, but its absolute values of labor productivity, high-skilled intensity of workers, and value-added exports ratio were much lower than those of these countries.

4.3. Robustness check of country-specific results

So far, our country-specific results in subsection 4.1 are based on a sample that includes all sectors, both natural resource and non-resource intensive sectors. However, one may argue that the growth in the domestic value-added exports at the country level does not necessarily indicate successful upgrading in GVCs. For example, the growth may be due to an increase in exports of natural resources (which typically have a large domestic value-added content). In this case, a country – in particular a country that is well endowed with natural resources – may experience some upgrading if, for example, a certain excavation technology is largely improved. This kind of upgrading in GVCs, however, plays no (or just a minor) role in countries with small endowments of natural resources. The literature

Figure 6. The colormap of upgrading scores for electrical and optical equipment.



on upgrading focuses on improvements that can be achieved through well-chosen policies, rather than on improvements that follow from pure technological changes (which are often considered as exogenous). So, for upgrading, we are particularly concerned with international success in relatively sophisticated sectors that use complex technologies and high-skilled human resources. To check the robustness of our country-specific results, we therefore redo the analysis, but exclude the resource-intensive sectors from the data. The excluded sectors are: Agriculture, hunting, forestry, and fishing (c1); Mining and quarrying (c2); Wood and products of wood and cork (c6); Coke, refined petroleum, and nuclear fuel (c8); Other non-metallic mineral (c11); Basic metals and fabricated metal (c12).

After the resource-intensive sectors have been dropped, we recalculated the indicators, repeated the factor analysis and got new upgrading scores for the countries. The comparison for the country-specific results before and after dropping six resource-intensive sectors is presented in Appendix D of the Online Supplementary Material. We observe that the upgrading scores and rankings for the countries change slightly, which suggests that the results are generally robust and consistent. The second observation is that after dropping the resource-intensive sectors, almost all countries' upgrading scores increase except for Brazil, Australia, Mexico, and Canada. This is consistent with the results in subsection 4.2 that the six resource-intensive sectors were among the least upgrading sectors. Hence, the average upgrading scores of the non-resource sectors become larger after dropping the least upgrading sectors.

Going into further details, we find that countries with a decreasing (increasing) share of their resource-intensive sectors in the exports climb up (descend) the ranking ladder. From Appendix D of the Online Supplementary Material we observe that Luxembourg climbs up the most (from rank 32 to17), and Australia falls (from 25 to 29). Looking further into the underlying data, we find that the aggregate value-added export share of these six sectors in the total value-added exports are very low of Luxembourg and it declines from 11.7% in 1995 to 4.9% in 2009. In contrast, the value-added export share of the six excluded sectors is much higher in Australia and it increases from 38.3% in 1995 to 49.3% in 2009. From this we draw the conclusion that the changes in the export structure matter when it comes to the upgrading level in GVCs.

5. Conclusion

The main purpose of this paper is to measure the industrial upgrading level of different countries and industries in GVCs. We point out that some conventional indicators (such as changes in trade volumes and changes in shares in world exports markets) are increasingly misleading in a world that increases the fragmentation of production along GVCs. Therefore, we adjust such indicators to the GVC perspective. Using eight indicators for upgrading in an EFA, we examine the multidimensionality of industrial upgrading. We wind up with three quantitative dimensions of industrial upgrading: process upgrading, product upgrading, and skill upgrading. With these dimensions, we compare and analyze the upgrading levels for countries and for sectors.

We find that process, product, and skill upgrading correlate somewhat, but, indeed, reflect different dimensions of industrial upgrading. Importantly, the upgrading scores of the dimensions can be derived for sectors and countries. Almost all countries appear to have experienced downgrading in 2009 due to the global financial crisis. The results also follow the convergence theory as developing countries such as Turkey, China, and India seem to have experienced more upgrading than did developed countries such as USA and Japan.

In terms of sectors, service sectors, and technology-intensive sectors such as Electrical and optical equipment and Transport equipment experienced higher levels of upgrading than did resource- or labor- intensive sectors. The upgrading levels of technology-intensive sectors in developing countries were generally higher than in developed countries. Of course, higher upgrading levels suggest only faster growth; they do not mean that developing countries are absolutely better off positionally than are developed countries in GVCs.

We stress that industrial upgrading should be measured systematically due to its multidimensionality. So we propose three quantitative dimensions of industrial upgrading from a GVC perspective. From a policy perspective, we obtain useful empirical insights from our measures. For instance, we observe that China's Electrical and optical equipment performed quite well in product upgrading during our studied timeframe, especially after China's accession to the WTO. That is to say, by integrating into GVCs, China not only exported more Electrical and optical equipment, but also gained more value by exporting better and more sophisticated electrical products. A good example is the success of China's mobile phone industry in moving from the production of low-end feature phones to high-end smartphones (e.g. Huawei, Xiaomi, Oppo, and Vivo). We also observe that China's Electrical and optical equipment industry performed less well in process (productivity) upgrading. This is likely because China integrated into the GVC of Electrical and optical equipment by performing simple and low value-added tasks (assembly type of activities) on a large scale. Such assembly activities are labor-intensive, and China has been able to engage in GVC via its low wages. As a consequence, China's performance is low after the growth of capital compensation and capital intensity are accounted. As its labor costs have effectively increased, China has become less interested in promoting such 'simple' activities. Instead, China has become engaged in policies that can help promote productivity and competitiveness in more technology-intensive activities.

Our results also provide a quantitative basis for future research. One possible direction is to empirically examine how integrating into GVCs affects industrial upgrading. There has been a wide-ranging set of conflicting discussion about whether and to what extent integration into GVCs benefits its participants (i.e. developed and developing countries). One position is that the rise of GVCs enables developed countries to offshore some low value-added tasks so they can focus upon specializing in high value-added tasks. This approach supports industrial upgrading. But this suggests that the ensuing technological transfer from developed to developing countries could shift some competitive advantages from the former to the latter. To understand the viability and degree of such concerns, we need more information, i.e. empirical evidence. The latter requires the use of quantitative measures of industrial upgrading such as the ones we have proposed in this paper.

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Disclosure statement

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