CHAPTER

18

Accounting for growth and productivity in global value chains

Marcel P. Timmer[1], *Xianjia Ye*[2]

[1]Faculty of Economics and Business, University of Groningen, Groningen, The Netherlands; [2]Utrecht School of Economics, Utrecht University, Utrecht, The Netherlands

18.1 Introduction

One of Dale Jorgenson's major contributions to the economics profession is the art of growth accounting. In a series of articles with numerous collaborators he outlined the theoretical and empirical foundation of measuring the contribution of factor input and productivity growth to output, culminating in an exhaustive analysis of US postwar growth (Jorgenson et al., 1987). This by now classic study set the gold-standard for the growth accounting technique which quickly became a powerful tool in the economists' tool box. With a lag, it also permeated into the confines of official statistics as the framework of the system of national accounts expanded with each revision, gradually incorporating the concepts of labor and capital services as well as multifactor productivity (MFP) (Jorgenson, 2018a). Progress was steady yet slow, not the least due to the high demands that productivity analysis puts on the data, in particular regarding proper investment and capital stock statistics. Nevertheless, Dale's tireless efforts over the decades bore fruit, influencing, energizing, and connecting researchers and statisticians all over the world, as shown, for example, by the progress being made in the EUKLEMS and World KLEMS projects (Jorgenson et al., 2016; Jorgenson, 2018b).

The growth accounting technique was originally developed for analyzing growth at the aggregate country or industry level. In this chapter we explore the usefulness of applying the growth accounting technique for analysis of a vertically integrated production process. There are both conceptual and empirical reasons for doing so. The main reason is the increasing occurrence of outsourcing and offshoring of production stages. This global fragmentation of production owes much to advances in information and communication technologies that bring down the costs of (cross-border) coordination of production across firms and countries (Baldwin, 2016). Other factors have also been important, notably market liberalization and economic restructuring in many countries, financial deregulation and the integration of global capital markets, and improved contract enforcement in many jurisdictions (Buckley and Strange, 2015). Offshoring has a long history going back to the

Measuring Economic Growth and Productivity
https://doi.org/10.1016/B978-0-12-817596-5.00018-4

1960s, taking great flight in the past two decades, to a significant extent propelled by the accession of China to the WTO in 2001 (Johnson and Noguera, 2012; Los et al., 2015). This led to an increasing cross-country interdependence of production, exemplified by intermediate goods and services as well as technologies crossing borders. As a result nowadays a production process of a good typically consists of many activities which are carried out in different places around the world. For example, an iPad is designed in California, the United States, but assembled in Shenzhen, China on the basis of more than 100 components which are in turn manufactured in many places around the world. This is referred to as global value chain (GVC) production.

This new phenomenon invites new questions: what is driving output growth in a GVC? Is it mainly driven by increased use of labor and capital inputs, or has there been also improvements in productivity through technological change? When offshoring is simply a process of relocating a particular production stage from one country to another without any change in the production technology, productivity growth is expected to be nil yet production costs may decline. On the other hand, it might also be the case that offshoring is just one manifestation of a much larger wave of technical innovations that improve the efficiency in the use of factor inputs throughout the chain. Alternatively, one might hypothesize that the availability of cheap factor inputs might lead to the buildup of slacks or other inefficiencies in the process, if only during the transition phase during which stages are relocated. In this chapter we will show that the traditional growth accounting method can be used to shed light on these issues. To do so, it needs to be applied in the framework of a production function in which all stages of production are vertically integrated. We outline how this can be done in theory as well as in practice.

The remainder of this chapter is organized as follows. In Section 18.2 we outline our general approach to growth accounting for GVCs, and discuss the data sources used. In Section 18.3 we provide an example of a GVC growth account and present results for 273 GVCs of manufacturing products that have been finalized in advanced countries. In Section 18.4 we highlight the importance, and plausibility, of the assumption of perfect global factor input markets for the measurement of multi factor productivity in GVCs. Section 18.5 concludes.

18.2 General approach and data

18.2.1 Prior contributions

The analysis of productivity in vertical integrated production processes has a long history, going back at least to Domar (1961). To fix ideas, assume that a local industry produces a final good (Y_1) using domestic labor (L_1) and capital (K_1) as well as intermediate inputs (M_2) according to a constant returns to scale production function $Y_1 = A_1F_1(L_1, K_1, M_2)$ with (Hicks neutral) technology A_1. Further suppose that the intermediates are produced abroad with labor in country 2 according to $M_2 = A_2F_2(L_2, K_2)$. Combining the two stages, one can write the vertically integrated production function for the final good as $Y_1 = A_VF_V(L_1, K_1, L_2, K_2)$ with technology A_V a combination of technologies A_1 and A_2. We refer to this as a GVC production function that relates total capital inputs and labor inputs to the production of a final product. Measures of MFP growth in vertically integrated production were proposed by Rymes (1972), Pasinetti (1977), and Hulten (1978). A well-known result, inspired by Domar (1961), is that MFP growth in the chain is the weighted sum of MFP growth in the two industries that comprise the integrated production sector, where the weights are the ratios of industry gross output to the value of output of final product (Hulten, 1978). Other variations of vertically integrated measurement frameworks include Wolff (1994), Durand (1996), and Aulin-Ahmavaara (1999). All these measures were developed for a closed economy setting.

More recently, Gu and Yan (2017) and Timmer and Ye (2018) provide frameworks that extend the vertical integration approach to an open economy setting. In their analyses they cover all inputs in production, domestic as well as abroad, taking advantage of the new availability of data on factor use in a large set of countries through the World Input–Output Database (WIOD, Timmer et al., 2015). Gu and Yan (2017) compare standard MFP growth in a country with what they call "effective" MFP growth. The latter includes also MFP growth in other countries that is embodied in upstream foreign industries delivering inputs that are imported. Effective MFP growth will surpass standard aggregate MFP growth in an open economy if productivity growth is higher in the foreign industries producing the imported intermediates than the aggregate domestic economy. This is a useful measure to track when there is a tight relationship between the price development of final goods and the rate of effective MFP, such that technical improvements in any stage of production (home and abroad) are reflected in a lower price. In that case, one can link technical change in foreign upstream stages of production to the decline in prices of final goods in the domestic market. Surprisingly, Gu and Yan (2017) do not find that the relationship between final output prices and effective MFP is stronger than for final output prices and standard MFP. This may be due to a mismatch in the deflators of foreign output and the deflators for imported input at home. We will return to this price measurement issue later. Timmer and Ye (2018) provide a wider analysis of production patterns and productivity in GVCs. We will present their framework and extend it to a dual price setting to make the link with analyses of international price competitiveness. Perhaps most importantly, we will highlight and discuss some new conceptual issues that arise when applying traditional growth accounting in a GVC context.

18.2.2 Measuring productivity in GVCs

This section gives a mathematical exposition of a framework to measure productivity in a multi-country production setting, following and extending Timmer and Ye (2018). There are S sectors and N countries. Each country-sector produces one good such that there are SN products. We use the term country-sector to denote a sector in a country, such as the French chemicals sector or the German transport equipment sector. Output in each country-sector is produced using domestic production factors and intermediate inputs, which may be sourced domestically or from foreign suppliers. Let $\mathbf{y}$ be the vector of production of dimension (SN × 1), which is obtained by stacking gross output levels in each country-sector. Define $\mathbf{f}$ as the vector of dimension (SN × 1) that is constructed by stacking world demand for final output from each country-sector. World final demand is the summation of demand from any country. For a particular intermediate good, let i be the source country, j be the destination country, s be the source sector, and t be the destination sector. We define a global intermediate input coefficients matrix $\mathbf{A}$ of dimension (SN × SN). The elements $a_{ij}(s,t) = m_{ij}(s,t)/y_j(t)$ describe the output from sector s in country i used as intermediate input by sector t in country j, expressed as a ratio of output in the latter sector. Columns in the matrix $\mathbf{A}$ describe how the products of each country-sector are produced using a combination of various intermediate products, both domestic and foreign.[1]

For a given set of final output $\mathbf{f}$ one can write associated output as:

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} \tag{18.1}$$

[1] Although we will apply annual data in our empirical analysis, time subscripts are left out in the following discussion for ease of exposition.

where $\mathbf{I}$ is an (SN $\times$ SN) identity matrix with ones on the diagonal and zeros elsewhere. The element in row m and column n of the $(\mathbf{I}-\mathbf{A})^{-1}$ matrix gives the total gross output of sector m needed for production of one unit of final output of product n. To see this, one can apply information in the A matrix in a recursive procedure as follows. Let $\mathbf{z}$ be an SN column vector with a one for the element representing say iPhones assembled in China, and all other elements are zero. Then $\mathbf{Az}$ is the vector of intermediate inputs, both Chinese and foreign, that are assembled, such as the hard-disk drive, battery, and processors. But these intermediates need to be produced as well and $\mathbf{AAz}$ indicates the intermediate inputs needed to produce $\mathbf{Az}$. This continues until the mining and drilling of basic materials such as metal ore, sand, and oil required to start the production process. Summing up across all stages, one derives the gross output levels for all SN country-industries generated in the production of iPods by $(\mathbf{I}-\mathbf{A})^{-1}\mathbf{z}$, since the summation over all rounds is a geometric series $\left(\sum_{k=0}^{\infty}\mathbf{A}^k\mathbf{z}\right)$ that converges to $(\mathbf{I}-\mathbf{A})^{-1}\mathbf{z}$.The matrix $(\mathbf{I}-\mathbf{A})^{-1}$ is famously known as the Leontief inverse.[2]

Using the Leontief inverse we can derive the total factor requirements of a unit of final output by netting out all intermediate input flows. Let us define $l_i(s)$ as the labor per unit of gross output in sector s in country i and create the row-vector $\boldsymbol{l}$ containing these "direct" labor coefficients. Then the total (direct plus indirect) labor requirements per unit of final output can be derived as

$$\boldsymbol{\Lambda} = \widehat{\boldsymbol{l}}(\mathbf{I}-\mathbf{A})^{-1} \tag{18.2}$$

in which a hat-symbol indicates a diagonal matrix with the elements of the vector on the diagonal. $\boldsymbol{\Lambda}$ is the matrix of dimension (SN $\times$ SN) with an element *(n,m)* indicating the amount of labor in country-sector m needed in the production of one unit of final output by country-sector n, referred to as the total labor coefficient. (Note that we analyze the input needed *per unit of output* such that there is no need to post multiply with $\mathbf{f}$.)

Similarly for capital, let $k_i(s)$ be the capital per unit of gross output in sector s in country i and create the row-vector $\boldsymbol{k}$ containing the "direct" capital coefficients. Then the total (direct plus indirect) capital requirements per unit of final output can be derived as

$$\mathbf{K} = \widehat{\boldsymbol{k}}(\mathbf{I}-\mathbf{A})^{-1} \tag{18.3}$$

with $\mathbf{K}$ the matrix of dimension (SN $\times$ SN) with an element *(n,m)* indicating the amount of capital in country-sector m needed in the production of one unit of final output by country-sector n, referred to as the total capital coefficient.

Using these total factor requirements matrices, we can define factor cost shares in a GVC of a final product. At this point we first need to define prices of output and factor inputs. Let $\mathbf{p}$ be a (row) vector of output prices for products from each country-sector, $\mathbf{w}$ the (row) vector of hourly wage rates, and $\mathbf{r}$ the (row) vector of capital rental prices. We allow output and factor input prices to differ across sectors and countries.[3] Value added in a country-sector is defined in the standard way as gross output value (at basic prices) minus the cost of intermediate inputs (at purchasers' prices), that is, it is given by $\mathbf{p}(\mathbf{I}-\mathbf{A})$. The rental price includes an "ex post" rate of return on capital in the parlance of the Jorgensonian framework such that capital compensation (the rental price times the quantity of capital) plus labor compensation (wage times

[2] This is under empirically mild conditions. See Miller and Blair (2009) for a good starting point on input–output analysis.

[3] For ease of exposition we assume here that there is only one price for the output of each country-sector, and this price is paid by all intermediate and final users. This assumption is loosened up in the empirical application later.

hours worked) equals gross value added. Then the following accounting identity holds:

$$\mathbf{p}(\mathbf{I}-\mathbf{A}) = \mathbf{w}\widehat{\boldsymbol{l}} + \mathbf{r}\widehat{\boldsymbol{k}} \quad (18.4)$$

Postmultiplying both sides of Eq. (18.4) with the inverse of (**I-A**) and substituting from Eqs. (18.2) and (18.3) we arrive at an important result: the output price of a final product (from a given country-sector) can be rewritten as a linear combination of the prices of all factors that were directly *and indirectly* needed in its production, or

$$\mathbf{p} = \mathbf{w}\boldsymbol{\Lambda} + \mathbf{r}\mathbf{K} \quad (18.5)$$

with $\boldsymbol{\Lambda}$ and **K** the matrices with total labor and capital coefficients as defined earlier. The identity in Eq. (18.5) forms the basis for deriving cost shares of labor and capital in the GVC of a particular product. Through appropriate selection of elements in the matrices $\boldsymbol{\Lambda}$ and **K**, one may trace the country-sector origins of these factor costs. We will use this decomposition in the next section to investigate the shifting factor shares in GVCs of manufacturing products.

The cost shares and quantities derived above can be used to measure total factor productivity (TFP) growth in the production of a final good in a GVC. We use the concept of TFP here rather than MFP, as in the vertically integrated production function all factor inputs are accounted for (in any country-industry) in contrast to the standard industry (single stage) case which only covers factor inputs in that industry. The consolidated data provide the opportunity to use the standard approach in growth accounting in measuring productivity assuming a final output production function with arguments based on total (direct and indirect) labor and capital used. Let G be a translog production function for a final product j: $f_j = G_j(\boldsymbol{\lambda}_j, \boldsymbol{\kappa}_j, T)$ where $\boldsymbol{\lambda}_j$ is the column vector of total labor requirements for product j from $\boldsymbol{\Lambda}$, and similarly $\boldsymbol{\kappa}_j$ a column of **K**. T denotes technology. Under the standard assumptions of constant returns to scale and perfect input markets such that input prices reflect marginal revenue (an issue to which we will return later) we can define the (primal) TFP growth in the GVC of product j by the weighted rate of decline of its total labor and capital requirements (as these are given per unit of output):

$$\frac{\partial \mathrm{TFP}_j}{\partial t} \equiv -\boldsymbol{\alpha}_j^L \frac{\partial \ln \boldsymbol{\lambda}_j}{\partial t} - \boldsymbol{\alpha}_j^K \frac{\partial \ln \boldsymbol{\kappa}_j}{\partial t} \quad (18.6)$$

where $\partial \ln \boldsymbol{\lambda}_j / \partial t$ is a (column) vector containing the differentials of the logarithms of all elements in $\boldsymbol{\lambda}_j$. The weights are given by $\boldsymbol{\alpha}_j^L$, a (row) vector of value shares with elements reflecting the costs of labor from all country-sectors used in the production of one unit of product j, and similarly for the capital value shares given in $\boldsymbol{\alpha}_j^K$. Summed over all contributing sectors and countries, the elements in $\boldsymbol{\alpha}_j^L$ add up to the labor share in final output of j, and similarly for capital.

Adding log output growth to the left- and right-hand sides and rearranging delivers the familiar growth accounting decomposition, yet now in the context of a GVC:

$$\frac{\partial \ln \mathbf{y}_j}{\partial t} \equiv \boldsymbol{\alpha}_j^L \frac{\partial \ln \widetilde{\boldsymbol{\lambda}}_j}{\partial t} + \boldsymbol{\alpha}_j^K \frac{\partial \ln \widetilde{\boldsymbol{\kappa}}_j}{\partial t} + \frac{\partial \mathrm{TFP}_j}{\partial t} \quad (18.7)$$

with $\frac{\partial \ln \widetilde{\boldsymbol{\lambda}}_j}{\partial t}$ the growth in total labor input, and similarly $\frac{\partial \ln \widetilde{\boldsymbol{\kappa}}_j}{\partial t}$ the growth in total capital input. The equation shows that growth in (final) output in a country-industry can be decomposed into the contribution of growth in labor $\boldsymbol{\alpha}_j^L \frac{\partial \ln \widetilde{\boldsymbol{\lambda}}_j}{\partial t}$, the contribution of the growth in capital $\boldsymbol{\alpha}_j^K \frac{\partial \ln \widetilde{\boldsymbol{\kappa}}_j}{\partial t}$, and TFP growth $\frac{\partial \mathrm{TFP}_j}{\partial t}$ along the GVC. Note that TFP growth measured in this way represents the improvement in the overall efficiency with which factor inputs in the GVC are being used. To measure productivity growth rates over discrete time periods rather than instantaneously the average value shares over the sample period can be used as weights $\boldsymbol{\alpha}_j^L$ and $\boldsymbol{\alpha}_j^K$ according to the so-called Tornqvist-Divisia productivity index (see Jorgenson et al., 1987).

One might also be interested in the price competitiveness of the country-industry producing good j. To analyze this one can define the dual (price) representation of TFP growth in a GVC as follows:

$$\frac{\partial \mathrm{TFP}_j}{\partial t} \equiv -\frac{\partial \mathrm{p}_j}{\partial t} + \boldsymbol{\alpha}_j^L \frac{\partial \ln \mathbf{w}_j}{\partial t} + \boldsymbol{\alpha}_j^K \frac{\partial \ln \mathbf{r}_j}{\partial t} \tag{18.8}$$

such that

$$\frac{\partial \mathrm{p}_j}{\partial t} \equiv \boldsymbol{\alpha}_j^L \frac{\partial \ln \mathbf{w}_j}{\partial t} + \boldsymbol{\alpha}_j^K \frac{\partial \ln \mathbf{r}_j}{\partial t} - \frac{\partial \mathrm{TFP}_j}{\partial t} \tag{18.9}$$

Eq. (18.9) provides insights into the determinants of price competitiveness of the country-industry producing good j. It shows that the output price will decline when factor prices decline, which may be in the domestic economy, but also abroad. Also, output price will decline when there is positive TFP growth in the chain, again not necessarily in those stages that are carried out domestically. It indicates the impact of factor price and technology developments abroad for the price competitiveness of the domestic economy.

One important consequence is that international competitiveness of countries and firms are becoming increasingly connected. Arguably, much of the offshoring by advanced countries was driven by a search for lower labor costs in the newly opening economies and this would be reflected in a higher share of imported intermediates. The (price) competitiveness of an industry thus no longer depended only on domestic factor prices and MFP, but also on access to cheap foreign inputs. For example, a firm in an advanced country might improve its price competitiveness by offshoring to cheaper labor locations or by improving the efficiency with which existing inputs are being used.

18.2.3 Data

A key empirical obstacle in this line of research is the lack of statistical information on GVCs. Standard statistical firm-level surveys typically provide only the amount of inputs and outputs of the firm. These are recorded with little, or no, detail on the identity and location of the input providers and output buyers. Put otherwise, only one stage of production is identified with no information on the previous or next stage. Statistical institutes combine this information with other information, such as detailed trade and production data, in a coherent supply and use framework to generate national input–output (IO) tables. The IO tables can be used to construct "synthetic" value chains assuming the same technology is used in all stages of production, such that IO tables can be applied recursively as described above. Recently, national IO tables have been linked together with bilateral trade data to form world IO tables (WIOTs) that contain information on intersectoral as well as intercountry flows of goods and services, such as the OECD Tiva (see https://oe.cd/tiva) and the WIOD (see https://www.wiod.org). Los et al. (2015) show how one use the information from WIOTs to derive the value added contributions from all countries (and industries) in the GVC of a particular final output. Timmer et al. (2014) extend this with information on wages and employment from the WIOD to construct labor and capital shares in GVCs. We follow their lead using data from the WIOD 2013 release, which includes current as well as constant price WIOTs.

18.2.4 GVCs and the measurement of intermediate input prices

The GVC approach provides additional insights into the sources of competitiveness beyond the insights from the traditional growth accounting for a single country-industry. In the traditional approach developments abroad would be summarized into changes of a price measure of imported inputs without information on its drivers (productivity or factor price changes abroad). Moreover, it relies strongly on the assumption that prices of intermediate inputs are well measured. Only in that case the price of value added can be properly measured through separate deflation of gross output and all intermediate inputs, also known as double deflation. However, double deflation is becoming increasingly difficult as production fragmentation progresses. There is increasing doubt about the reliability of price indices for imported intermediates due to the practice of intrafirm transfer pricing and more generally inadequate statistical systems to monitor prices of imports (see Houseman et al., 2011). One area of concern is in the price measurement of intangible service flows such as the provision of marketing and technical knowledge including software and data-services. Intangibles are becoming increasingly important in production, but so far their measurement is elusive (see Corrado et al. (2012) for pioneering attempts and Houseman and Mandel (2015) for an overview).

A special case of mismeasurement that recently attracted attention is the measurement of input price change in the presence of offshoring. Reinsdorf and Yuskavage (2018) conclude that for the case of the United States, "changes in prices paid for intermediate inputs caused by offshoring are not tracked in any index. The U.S. Bureau of Economic Analysis (BEA) uses producer price indexes (PPIs) to deflate the domestically sourced items and MPIs to deflate foreign sourced items, but neither of these indexes would follow an item as it moved from domestic production to offshore production." In a conservative estimate, Reinsdorf and Yuskavage (2018) found that mismeasurement of import prices related to sourcing change appears to be responsible for about a tenth of the speedup in measured productivity growth during 1996–2005. They also found it to be highly unevenly distributed across sectors and particularly pertain to the manufacturing sector, as earlier suggested by Houseman et al. (2011). It seems reasonable to assume that these mismeasurements in productivity are proportional to the share of import in intermediate use, and thus to be larger for countries that are smaller and much more open than the United States.

Mismeasurement of intermediate input prices leads to a problem of attribution of productivity growth across industries (and countries). Triplett (1996) shows that in the case of measuring productivity in the US production of computers, the use of alternative quality-adjusted prices leads to radically different assessments of the location of productivity, which may be in the computer industry itself, or in the semiconductor industry that delivers the main inputs to the computer industry, or even further back in the chain, namely the manufacturing of semiconductor machinery. Similarly, mismeasurement of prices of imported intermediates might obscure the geographical location of productivity growth in GVCs. The robustness of analyses such as in Gu and Yan (2017) who allocate productivity growth in a GVC to various stages of production across countries depends crucially on the quality of the price statistics used. In this paper we will restrict ourselves to analyses of input and TFP growth for the chain as a whole which do not require the use of intermediate input deflators.

18.3 Growth accounts for global value chains

18.3.1 Illustrative example

We illustrate our GVC methodology by decomposing the growth of final output from the transport equipment industry (NACE rev. 1 industries 34 and 35) in South Korea, in short "Korean cars." Final output includes the value added in the last stage of production, which will take place in South Korea by definition, but also the value added by all other activities in the chain which take place anywhere in the world. To decompose value added in production, we make use of the decomposition method outlined in Section 18.2 and given in Eq. (18.5).

The geographical origin of the value added in production of Korean cars in 1995 and in 2008 reveals striking developments. Between 1995 and 2008, the share of domestic value added decreased from 76 to 70% of the value of a Korean car. Conversely foreign value increased from 24 to 30%. With the new availability of cheap and relatively skilled labor, firms from South Korea relocated parts of the production process to other countries. At the same time, the industry quickly globalized by sourcing more and more from abroad. With additional information on the quantity of factors used in each country we can provide a growth accounting decomposition of the growth rate of final output of Korean automotives using Eq. (18.7). Data on workers are measured by the number of hours, classified on the basis of educational attainment levels as defined in the International Standard Classification of Education (ISCED): low-skilled (ISCED categories 1 and 2), medium-skilled (ISCED 3 and 4), and high-skilled (ISCED 5 and 6). Capital stock volumes are measured on the basis of capital stocks of reproducible assets as covered in national account statistics measured at 1995 constant price. Note that we have information on inputs used in 35 industries in 41 economies such that contributions in a particular GVC can be made in potentially 1435 ($=35 \times 41$) country-industries.

The results are shown in Table 18.1: final output volumes of Korean automotives increased by 69 log points over the period from 1995 to 2007. This was mainly due to increases in the use of capital both domestically and abroad, together accounting for about a quarter of the increase in final output. The number of workers employed in production increased as well, yet with a clear difference between the structure and growth of labor demand domestically and abroad. Demand for low-skilled workers within South Korea declined rapidly, while demand for low-skilled abroad increased. The highest growth is in demand for high-skilled workers both at home and abroad contributing 11 and 6% to final output growth, respectively. Productivity growth is derived as a residual as in Eq. (18.6). It is growing fast by more than 0.50 log points over this period, contributing 60% of final output growth over this period. Clearly, growth in the South Korean car GVC is mostly driven by a more efficient use of the factor inputs. These factor inputs are increasingly located abroad.

18.3.2 General patterns of productivity growth and input use in GVCs

What are the general patterns of input and productivity growth in GVCs? As for cars finalized in South Korea, we decompose growth in GVCs of manufactured goods that are finalized in 21 advanced countries, including 15 European countries, Australia, Canada, Japan, South Korea, Taiwan, and the United States. We have data for output from 13 manufacturing industries, which are groups of two digit industries according to ISIC rev.3. So all in all, we will study the production structure of 273 ($=13 \times 21$) GVCs. In Table 18.2 we provide the growth accounts for each of the 13 manufacturing product groups, weighted across the 21 finalizing countries with the shares in total final output across all advanced countries. The results are depicted in Fig. 18.1.

Global output growth has been high during 1995–2007 for final electronic goods (including computers and electrical machinery), transport equipment, and chemicals. It has declined for textiles (including wearing apparel), shoes, and wood products. Two observations stand out with respect to the contribution of labor to output growth. First, the quantity of low-skilled work used in GVCs has been declining in most GVCs. This is not so surprising for GVCs in which output is declining as well, but

TABLE 18.1 Growth accounting for vertical production of automotives from South Korea.

	Cost shares in GVC (%)		Quantities (1995 = 1)		Contribution to output growth	
	1995	**2007**	**1995**	**2007**	**Log pts**	**%**
Factors in South Korea						
Low-skilled labor	12.2	4.4	1.00	0.42	−7.2	−10.5
Medium-skilled labor	26.7	23.8	1.00	0.99	−0.3	−0.4
High-skilled labor	17.0	20.5	1.00	1.52	7.8	11.3
Capital	20.6	21.5	1.00	1.53	8.9	13.0
Factors outside South Korea						
Low-skilled labor	2.9	2.7	1.00	1.68	1.5	2.1
Medium-skilled labor	6.6	6.1	1.00	2.40	5.6	8.1
High-skilled labor	3.2	3.8	1.00	2.97	3.8	5.5
Capital	10.7	17.2	1.00	1.68	7.3	10.6
Total all factor inputs			1.00	1.31	27.3	39.7
Total factor productivity			1.00	1.51	41.5	60.3
Final output	100.0	100.0	1.00	1.99	68.8	100.0

Note and source: Own calculation based on Eq. (18.7) using data from WIOD, November 2013 release. The shares and volumes for factors abroad are based on summations across 39 countries and the rest-of-the-world region. Capital growth is proxied by growth in capital stocks. Input quantities are set to 1 in 1995. Numbers may not add due to rounding.

we find it to be also true for fast-growing products such as electronics and nonelectrical machinery. The quantity of unskilled work only increased in the rapidly expanding GVCs of transport equipment and chemicals. Second, the use of high-skilled work has increased in all industries, except the ones in which output declined. Even more strongly, it appears that there is a strict ordering: for each product group it is true that the growth rate of low-skilled work is lower than for medium-skilled work, which is again lower than for high-skilled work.

The bottom part of the graph shows the contribution of the growth in each input to final output growth. Growth in capital input appears to be an important source of growth in most GVCs, typically accounting for 40% of output growth or more. The notable exception is for electronics, as capital input growth was fast in an absolute sense, but slow compared to output growth. Growth in high-skilled work contributed positively to all GVCs, except, again, in electronics. On the other hand, growth contributions from medium-skilled workers were small or even negative. Not surprisingly, growth contributions from low-skilled work are negative, given its absolute decline noted above. Note that for industries that are shrinking (negative growth of final output), contributions to growth from factor inputs are positive when the input shrinks as well. This explains the "positive" contributions of low-skilled worker growth to the growth in final output of textiles, for example.

Another main conclusion from the table is that TFP growth is positive in all GVCs. It ranges from 7.5% in basic metals to 72% in electronics. Clearly, technological change was such that inputs were used more efficiently in the global

TABLE 18.2 Final output growth decomposition for manufacturing product groups, 1995–2007.

Final output group	Food	Textile	Shoes	Wood	Paper	Chemical	Plastic	Non-metal	Metal	Machinery	Elec-tronics	Transport equipment	Other manufac-turing
ISIC	**15t16**	**17t18**	**19**	**20**	**21t22**	**24**	**25**	**26**	**27t28**	**29**	**30t33**	**34t35**	**36t37**
Cost shares (%) in 1995													
Low-skilled	15.6	22.8	27.9	18.0	12.9	11.9	14.8	16.3	16.3	14.7	12.3	13.2	18.1
Medium -skilled	29.3	31.4	27.2	35.2	31.2	26.1	31.7	30.7	33.0	35.3	32.8	35.5	34.7
High-skilled	14.4	14.1	12.3	13.4	17.8	16.6	15.3	14.0	14.2	16.7	18.9	17.6	15.9
Capital	40.7	31.6	32.6	33.4	38.1	45.5	38.2	39.0	36.5	33.2	36.0	33.7	31.4
Cost shares (%) in 2007													
Low-skilled	10.4	15.4	18.1	11.3	8.7	7.9	10.0	10.3	9.9	9.2	7.5	8.2	11.5
Medium -skilled	28.5	32.6	29.4	34.7	28.5	23.3	30.0	28.8	29.2	31.5	28.9	30.5	31.0
High-skilled	17.6	19.1	16.6	17.0	22.7	19.4	19.1	17.6	16.3	19.6	24.6	20.7	18.9
Capital	43.4	33.0	35.9	37.0	40.2	49.4	41.0	43.3	44.5	39.7	39.0	40.5	38.5
Quantity growth (log points)													
Low-skilled	−38.0	−79.8	−56.8	−61.0	−15.3	6.8	−18.6	−27.2	−27.2	−16.1	−35.0	5.2	−32.0
Medium -skilled	−5.8	−62.6	−37.9	−39.5	−7.0	18.8	−2.5	−4.1	−0.6	1.5	−8.3	21.2	−9.7
High-skilled	17.2	−31.2	−5.8	−11.2	22.4	43.1	23.3	26.7	28.3	28.6	17.0	45.5	17.4
Capital	11.0	−43.6	−24.7	−26.5	25.7	34.6	14.0	7.2	8.7	25.8	15.9	42.1	8.8
Final output	9.3	−44.2	−33.1	−18.4	20.9	38.1	20.9	14.7	6.5	26.3	66.5	43.2	5.2
TFP	9.3	22.3	11.2	16.6	13.7	15.2	21.0	15.2	7.5	20.8	72.3	21.6	13.0
Contribution to final output growth (%)													
Low-skilled	−64.9	41.1	53.8	53.1	−22.1	−6.0	−27.2	−41.8	−82.7	−19.2	−8.2	−8.1	−142.5
Medium -skilled	−35.1	62.3	46.2	88.4	−19.4	0.9	−21.5	−28.9	−63.5	−15.4	−14.2	2.8	−127.7
High-skilled	20.7	20.4	13.1	13.6	14.8	14.4	9.3	22.1	35.2	10.9	−0.9	13.6	20.1
Capital	78.4	26.7	20.7	35.0	61.4	50.6	38.7	45.4	94.8	44.7	14.6	41.7	101.1
TFP	100.8	−50.5	−33.9	−90.2	65.3	40.0	100.6	103.3	116.2	79.0	108.6	50.0	249.0

Note: See Table 18.1. Based on GVCs ending in 21 advanced countries, weighted by share in final output across all countries.
TFP, total factor productivity.

production of goods. TFP growth can account for all output growth in food, plastic, nonmetallic minerals, metal products, electronics, and other manufacturing. In some case it even accounts for more than 100% of output growth as the quantity of some inputs is shrinking. The contribution of TFP to growth in chemicals and transport equipment is relatively limited, although still accounting for 50 and 40% of output growth, respectively. It accounts for 65% of output growth in plastics, and for 79% in machinery.

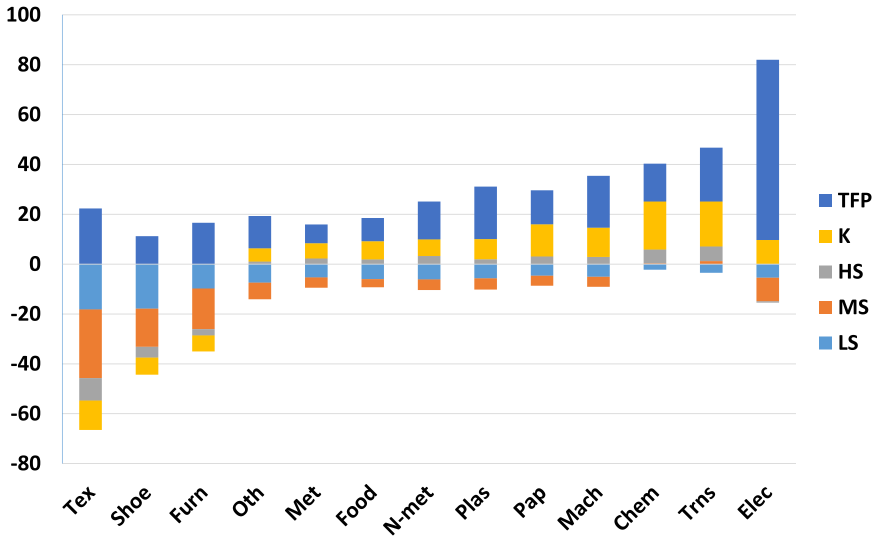

FIGURE 18.1 Accounting for final output growth of global value chains, 1995–2007. HS, high-skilled; K, capital; LS, low-skilled; MS, medium-skilled; TFP, total factor productivity. *Source: Table 18.2.*

18.4 Factor substitution bias in measuring GVC TFP

The application of growth accounting in GVCs raises new questions about the underlying fundamentals of the accounting framework. One key assumption in the growth accounting method is the assumption that each input is paid its marginal product. In that case, the growth of aggregate input can be measured as a weighted growth of the detailed inputs with cost shares as weights. Here we will focus on the case of labor input measurement and discuss to what extent this assumption is valid when applied in a GVC setting with labor input from various countries.

In the analysis so far, we have measured the growth of labor input of a given type as a weighted growth of labor of this type classified by country c. So

$$\Delta ln \mathrm{L}_e = \sum_c \alpha_{c,\,e} \Delta ln \mathrm{L}_{c,e} \qquad (18.10)$$

with $\alpha_{c,e} = \mathrm{w}_{c,e}\mathrm{L}_{c,e} \Big/ \sum_c \mathrm{w}_{c,e}\mathrm{L}_{c,e}$, the share of worker type e in country c in the overall wages paid in the GVC to this type of worker. The implicit assumption is one of perfect competition in factor markets: for example, when Chinese workers (of a given educational attainment type) are paid \$5 per hour (at exchange rate), while US workers (of the same type) are paid \$10, then the contribution of growth in Chinese workers to output growth is assumed to be only half the contribution of a similar growth in US workers. This might be a reasonable assumption for high-skilled workers, but it is less obvious that this also holds for less skilled workers. We know that integration of labor markets across countries is still incomplete such that wage differentials are not necessarily arbitraged away. Interestingly, this measurement problem in labor input has a strong similarity to the problem of import substitution bias in the measurement of intermediate input prices discussed above. The price measurement problem arises as there is a substitution of a more expensive input for a similar cheaper variety. In analogy, shifts in the distribution of hours worked from lower- to higher-wage countries might not picked up correctly by the labor input index in Eq. (18.10) when the workers are comparable across countries, that is, have the same marginal productivity.[4] It seems clear that much of the offshoring trends and GVC development is driven by a strong cost-saving motive of multinational firms. This hypothesis is congruent with a strong increase in the share of so-called "factorless income" in GVCs, that is, the part of value added that cannot be allocated to labor or capital (measured with an ex ante rate of return), as documented by Chen et al. (2018).

Can we put bounds on the size of the problem of labor substitution for TFP measurement in GVCs? To this end, we make an extreme assumption and assume that the marginal productivity of worker of a given type is equal across all countries. In that case, one can aggregate workers across countries, $L_e = \sum L_{c,e}$, such that growth in the aggregate labor input index is then given by

$$\Delta \widetilde{ln L}_e = \sum_c s_{c,e} \Delta ln L_{c,e} \tag{18.11}$$

with weights $s_{c,e} = L_{c,e} \Big/ \sum_c L_{c,e}$. It can be easily shown that the difference between the aggregate labor indices in Eqs. (18.10) and (18.11) is given by difference in the weights α and s. The difference $\Delta ln L_e - \Delta \widetilde{ln L}_e$ is akin to what is called "labor quality" in the Jorgenson framework (see e.g., Jorgenson et al., 1987). But note that the interpretation here is the opposite: we assume that there is no quality difference across countries for a given type of worker, and hence the difference is an indicator of the mismeasurement of aggregate labor input in GVCs. When there is a shift in employment of identical jobs in the GVC from advanced to poor countries (with lower wages), then use of the standard index $\Delta ln L_e$ will lead to an *under*estimation of the labor input, and an *over*estimation of TFP in the GVC as it is measured as a residual. Fig. 18.2 shows the magnitudes of the potential mismeasurement of TFP in GVCs when using the standard index.

Fig. 18.2 shows the Kernel density plots for TFP growth in 273 GVCs (the same set as above) for the period 1995–2007, measured according to four alternatives. TFPraw is the TFP growth in the GVC when using the standard methodology in which each input in each country-industry is treated as a different input, as in Eq. (18.10). TFP4 is the other extreme in which inputs are assumed to be identical across countries (and industries), as we discussed above. Put otherwise, growth in each factor input (low-, medium-, and high-skilled labor as well as capital) is calculated as the growth of the aggregate of the factor across all countries as in Eq. (18.11). These four inputs are subsequently weighted with their aggregate factor cost share. For

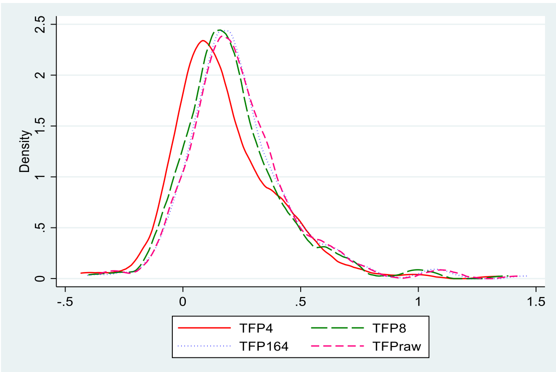

FIGURE 18.2 Alternative measures of total factor productivity (TFP) growth rates in global value chains (GVCs). Note: TFP growth rate in 273 GVCs according to four alternatives for the measurement of factor inputs: TFP4 (total input across all countries), TFP8 (domestic inputs and foreign inputs separately), TFP164 (inputs separately per country), and TFPraw (inputs per country-industry).

[4] This is most easily seen in the dual approach: assume no change in country-industry wages and a one-off shift of jobs to cheaper places. If the cost decline is fully reflected in output price, then there will be measured TFP growth, although there is no change in productivity as the same amount of labour inputs is being used as before.

comparison we also provide two intermediate alternatives: separate aggregation of domestic and foreign factor inputs, thus $2 \times 4 = 8$ inputs (TFP8), and separate aggregation of factor inputs within each of the 41 economies (across industries), thus $41 \times 4 = 164$ inputs (TFP164).[5]

We find that in general, the various TFP alternatives are highly correlated across GVCs. A GVC with a high TFP growth relative to other GVCs according to the standard method is likely to have also a high relative TFP growth when using the alternative measures. The correlation of TFPraw with TFP4 is 0.92 (0.89 for rank correlation), with TFP8 0.97 (0.96) and with TFP164 0.99 (0.99). The (unweighted) mean TFP growth in the set of 273 GVCs is 17.8 log points for TFP4, 21.3 for TFP8, 23.7 for TFP164, and 23.9 for TFPraw. So indeed TFPraw (the standard methodology) would overestimate TFP by 6.1 log points, in case our extreme case holds, namely that there is no difference in marginal productivity across countries for a given input type (TFP4). Thus we conclude that it is likely that TFP growth in GVCs will be overestimated when using the assumption of perfect competition in global factor markets. Our most extreme estimate suggest that the magnitude of this overestimation may be sizable, leading to an overestimation of TFP growth by almost a third.

18.5 Concluding remarks

In this paper we pioneered the application of the canonical KLEMS framework as developed by Dale Jorgenson and collaborators in the context of a GVC that spans countries across borders. We developed measures of factor inputs and of TFP growth in GVCs and showed how existing data from the WIOD can be used to make a decomposition of final output growth. We highlighted a particular issue that arises in the context of GVCs, which is the measurement of labor input when factor prices are not equalized across countries. We show that this might lead to sizable mismeasurement of TFP in GVCs, requiring further analysis into the validity of the perfect market assumption underlying growth accounting. All in all, the analysis presented here demonstrates that the canonical KLEMS framework is versatile and when appropriately modified, can also be applied outside the traditional confines of analyses of economic growth in individual countries and industries to wider analyses of GVCs. More than 50 years after its introduction the growth accounting framework of Jorgenson and Griliches (1967) is still a useful guide for the measurement of production output and inputs in the world economy.

References

Aulin-Ahmavaara P: Effective rates of sectoral productivity change, *Economic Systems Research* 11(4):349–363, 1999.

Baldwin R: *The great convergence*, Harvard University Press.

Buckley PJ, Strange R: The governance of the global factory: location and control of world economic activity, *Academy of Management Perspectives* 29(2):237–249, 2015.

Chen W, Los B, Timmer MP: *Factor incomes in global value chains: the role of intangibles*, NBER Working Paper No. 25242, 2018.

Corrado C, Haskel J, Iommi M, Jona-Lasinio C: *Intangible capital and growth in advanced economies: measurement and comparative results*, CEPR Discussion Papers 9061, 2012.

Domar ED: On the measurement of technological change, *The Economic Journal* 71(284):709–729, 1961.

Durand R: Canadian input–output-based multi-factor productivity accounts, *Economic Systems Research* 8(4): 367–390, 1996.

Gu W, Yan B: Productivity growth and international competitiveness, *Review of Income and Wealth* 63: S113–S133, 2017.

[5] These alternatives are all using index numbers, invoking strong assumptions about the substitutability of factor inputs. Alternatively, TFP can be measured using an econometric approach (see Jorgenson (2000)). Timmer and Ye (2018) report on an application of the econometric approach to producer behavior in a GVC.

Houseman S, Kurz C, Lengermann P, Mandel B: Offshoring bias in US manufacturing, *The Journal of Economic Perspectives* 25(2):111–132, 2011.

Houseman SN, Mandel B, editors: *Measuring globalization: better trade statistics for better policy* (vol. 1). W.E. Upjohn Institute for Employment Research.

Hulten CR: Growth accounting with intermediate inputs, *The Review of Economic Studies* 45(3):511–518, 1978.

Johnson RC, Noguera R: Accounting for intermediates: production sharing and trade in value added, *Journal of International Economics* 86(2):224–236, 2012.

Jorgenson DW: *Econometrics*, *Econometric modelling of producer behavior*, vol. 1. MIT Press.

Jorgenson DW: Production and welfare: progress in economic measurement, *Journal of Economic Literature* 56(3): 867–919, 2018a.

Jorgenson DW: The world klems initiative: measuring productivity at the industry level. In Grifell-Tatjé E, Knox Lovell CA, Sickles RC, editors: *The Oxford handbook of productivity analysis*, Oxford University Press, pp 663–698.

Jorgenson DW, Fukao K, Timmer MP, editors: *The world economy: growth or stagnation?* Cambridge University Press.

Jorgenson DW, Gollop FM, Fraumeni BM: *Productivity and U.S. economic growth*, Harvard University Press.

Jorgenson DW, Griliches Z: The explanation of productivity change, *The Review of Economic Studies* 34(99):249–280, 1967.

Leontief WW: Quantitative input and output relations in the economic systems of the United States, *The Review of Economic Statistics* 18(3):105–125, 1936.

Los B, Timmer MP, de Vries GJ: How global are global value chains? A new approach to measure international fragmentation, *Journal of Regional Science* 55(1):66–92, 2015.

Miller RE, Blair PD: *Input-output analysis: foundations and extensions*, Cambridge University Press.

Pasinetti LL: *Lectures on the theory of production*, Columbia University Press.

Reinsdorf M, Yuskavage R: Offshoring, sourcing substitution bias, and the measurement of growth in US gross domestic product and productivity, *Review of Income and Wealth* 64(1):127–146, 2018.

Rymes TK: The measurement of capital and total factor productivity in the context of the Cambridge Theory of Capital, *Review of Income and Wealth* 18(1):79–108, 1972.

Timmer MP, Dietzenbacher E, Los B, Stehrer R, de Vries GJ: An illustrated user guide to the world input–output database: the case of global automotive production, *Review of International Economics* 23(3):575–605, 2015.

Timmer MP, Erumban AA, Los B, Stehrer R, de Vries GJ: Slicing up global value chains, *The Journal of Economic Perspectives* 28(2):99–118, 2014.

Timmer MP, Ye X: Productivity and substitution patterns in global value chains. In Grifell-Tatjé E, Knox Lovell CA, Sickles RC, editors: *The Oxford handbook of productivity analysis*, Oxford University Press, pp 699–724.

Triplett JE: High-tech industry productivity and hedonic price indices. In *OECD Proceedings: industry productivity, international comparison and measurement issues*, 1996, pp 119–142.

Wolff EN: Productivity measurement within an input-output framework, *Regional Science and Urban Economics* 24(1): 75–92, 1994.