World Productivity: 1996 - 2014*

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Abstract

We account for the sources of world GDP growth using data for 40 major economies and 36 industries from the World Input-Output Database from 1996 to 2014. We find that the contribution of productivity growth at the country-industry level to world GDP growth is relatively constant and that the recent productivity slowdown in industrialized countries is largely offset, at the world level, by productivity growth in emerging economies. Most of the fluctuations in world productivity growth are the result of shifts in the distribution of employment across countries and industries. This shift in employment to countries with lower average labor productivity and wages is a drag on the growth of aggregate productivity in the world. Using new data on PPP-based value-added measures by country and industry, we show that about a third of this shift, however, seems to reflect employment growing in countries, most notably China and India, and industries that benefit from an international cost advantage in terms of deviations from PPP.

Keywords: World GDP growth, productivity, purchasing power parity.

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1 Introduction

We account for world productivity growth from 1996-2014 by combining data on more than 36 industries and 40 countries. Though world productivity is a concept that is often discussed in models of economic growth and innovation (Caselli & Colman, 2006) in the context of a world technology frontier, there are very few studies that formally account for world productivity growth. In this paper, we use global growth accounting techniques to measure growth in the world level of average labor productivity and decompose it into its main sources.

Our analysis builds on two strands of the literature. The first strand measures cross-country productivity levels using economy-wide data (Conference Board, 2015; Feenstra *et al.* , 2015). Because studies that are part of this strand do not include industry-level data, they do not provide an estimate of the industry-origins of world productivity growth. Moreover, they also do not formally account for reallocation of resources across countries. The second strand of the literature, based on the methodology pioneered by Domar (1962), Hulten (1978), and Jorgenson *et al.* (1987), consists of studies of productivity growth using industry-level data at the country level or for limited number countries.[1] These studies do analyze the industry-origins of productivity growth and the importance of the reallocation of production factors, but only at the country level or for a few countries.

Similar to the first strand of the literature, we analyze the growth in productivity defined at the world level. Our analysis, however, is based on industry-level rather than on economy-wide data. This enables us to generalize the methodology used in the second strand to apply it at a global scale. As a result we can account for the country- and industry- origins of the growth in world productivity as well as for the importance of the reallocation of productive resources between industries and countries for world productivity growth.

For our analysis, we use two vintages of the World Input-Output Database (WIOD), described in Timmer (2012) and Timmer *et al.* (2015). These data cover input-output and productivity data for more than 40 countries and 36 industries from 1996-2014. These countries cover about 80 percent of World GDP measured in dollars over the years in the sample. The aggregated real GDP growth for these countries lines up closely with estimates of world GDP growth by the World Bank.

[1]Among the many studies in this literature are Byrne *et al.* (2016) and Oliner & Sichel (2000) for the U.S. Xu (2011) for China, Das *et al.* (2016) for India, and Rao & van Ark (2013) For Europe.

Our analysis consists of two steps. In the first step we apply a generalized version of Jorgenson *et al.* (1987) to the growth of the aggregate Average Labor Productivity (ALP) level across the countries in our sample.[2] Our results in this step confirm previously documented facts about productivity growth across industries for smaller samples of countries. In addition, they allow us to assess the importance of each country and the effect of the reallocation of production factors across countries for world productivity growth.

Just like other studies, we find that capital deepening and the reallocation of capital across industries, especially in Finance, Insurance, and Real Estate (FIRE) and business services, played an outsized role for world ALP growth in the late 1990s and early 2000s (e.g Oliner & Sichel, 2000). Consistent with other evidence, our results reveal a slowdown in ALP growth for advanced industrialized countries starting in the second half of the 2000s.[3] We also find that the reallocation of labor across industries within countries contributes substantially to aggregate productivity growth.[4]

Analyzing productivity growth at the world level, we are able to put the above facts in a more global perspective. For example, globally we did not see much of a productivity slowdown in the mid 2000s. This is because the productivity slowdown in advanced economies was largely offset by productivity growth in other countries, most importantly in China and India. Thus, what looks like a productivity slowdown in advanced economies appear to be a shift in the cross-country composition of world productivity growth in our analysis. Just like country-level analyses, we find an important role for the reallocation of labor, not only between industries, but also across countries. In particular, our standard growth accounting method interprets the fact that hours growth is higher in countries with lower wages as a shift in production towards countries with lower productivity levels. Thus, the catch up of emerging economies with industrialized countries is accounted for as a drag on world productivity growth.

The latter interpretation of our global growth accounting results hinges on the assumption that relative dollar-denominated wages are equal to relative marginal productivity levels of labor.

[2] Our main focus is on ALP because we do not have data on capital inputs for all years in our sample. For those years for which we do, we supplement the results on ALP growth with additional results on Total Factor Productivity (TFP).

[3] See, for example, Byrne *et al.* (2016), ECB (2017) , and OECD (2017a)

[4] This is consistent with country- and region-level evidence, as in Wu (2016) for China and Hofman *et al.* (2016) for Latin America.

In order to drop this assumption we extend data from Inklaar & Timmer (2014) and construct Purchasing Power Parity (PPP) data at the country-industry level for all countries, industries, and years in our sample. These PPP data allow us to measure relative productivity levels directly, rather than having to infer them from factor prices.

With this in mind, we generalize the growth accounting methods we use to take into account deviations from PPP. This enables us to split the effect of the reallocation of labor on world productivity into a part due to economic activity shifting to countries that have a cost advantage and to a part that reflect relative productivity differences.

Using this PPP-based productivity accounting we find that China and India have a large cost advantage over U.S.. This advantage has barely eroded over the 15 years in our sample. It largely reflects that China's and India's share of PPP-deflated world GDP is higher than their share of dollar-denominated GDP, because of deviations of exchange rates from PPP.

Because China, India, and other Asian countries whose PPP-share in the world economy is higher than their dollar-denominated share grew faster than other countries over our sample period, PPP-deflated world productivity growth is much higher than the one that is implied by the conventional measure of world GDP growth based on dollar values. This is consistent with World Development Indicators (WDI) data from the World Bank (2018). We still find that the reallocation of labor towards low-wage countries is a substantial drag on PPP-deflated world productivity growth. Only about a third of this effect is accounted for by cost differentials across countries rather than relative productivity differentials.

These results suggest that it is important to take into account PPP differentials when one wants to understand world productivity trends. In particular, this helps us quantify the extent to which the direction shifts in the global allocation of resources is related to deviations from neoclassical assumptions that point to the possible misallocation of global resources, in the sense of Hsieh & Klenow (2009). Specifically, the reallocation of labor hours across countries and across industries within countries can be interpreted as the deviation from efficient allocations based on neoclassical assumptions.

These deviations account for the bulk of the variation in world ALP growth. Specifically, reallocation of labor hours across countries are much higher than this reallocation within countries across industries. This points to the fact that global factors of production are much more misallocated than within-country factor misallocation. Globalization, by increasing the factor reallocation within countries to absorb the gains from trade is not fully successful in terms of reallocating the factors of production across countries. There are a variety of reasons for this phenomenon. Political economy considerations are an important part of the reason that labor cannot move freely across borders.

Studies of gains from removing the barriers to factor movements across political borders usually find large effects on output and capital accumulation. For example, Klein & Ventura (2009) show that a hypothetical creation of a common labor market within NAFTA results in an increase in output in North America by 10.5%. In this paper, we quantify this misallocation of resources and find that the bulk of the variation in world ALP growth is due to factor misallocation across countries.

2 WIOD-data

We use Socio-Economic Accounts (SEA) data from the WIOD. The reason we use these data is that it is the only productivity dataset that covers a broad set of industries across the major world economies.[5] There are two vintages of the WIOD that have been released, namely one in 2013 and one in 2016. We calculate results using both of them.

These two vintages do not only differ in the industries, countries, and years covered, but also in the productivity variables included. The way we structure our results in the rest of this paper is chosen in order to fully utilize all data available and standardize the results across the two vintages for the overlapping variables for comparison purposes. Thus, to understand our results it is useful to first familiarize oneself with the available data. This is why we start our paper with this section on the dataset.

[5] Other datasets, like Conference Board (2015) and Feenstra *et al.* (2015) only provide aggregate data at the country level. The closest alternative dataset is the Organization for Economic Cooperation and Development (OECD)'s STAN database (OECD, 2017b). However, it covers fewer years and countries than the WIOD data we use.

2.1 Data vintages and available variables

Table 1 provides a comparison of the two vintages of the WIOD that we use for our study. The top part of the table shows the difference in coverage between the vintages in terms of years, countries, and industries.

Important for our analysis is that the years in the samples in the two vintages contain an overlapping period from 2000-2007. We use this period in the rest of the paper to compare results across vintages to make sure that there are no major material qualitative differences in results due to differences in countries and industries covered as well as methodological differences in the construction of variables.

The sample of countries in the data is largely comparable across vintages. The 2016 vintage contains three more countries than the 2013, namely Norway, Switzerland, and Croatia. The economies of these countries make up a relatively small fraction of world GDP. This can be seen from the average share of world GDP covered in the data, reported in Table 1. Throughout, we aggregate our results by country into regions. These regions include the individual major world economies as well as groups of countries organized by geographical location.[6]

We present our results for major sectors of the economy, which are listed in Table B.3 in Appendix B. Each of these sectors are made up of ISIC industries for which the WIOD data is reported. Even though the 2016 vintage of the data contains many more industries than the 2013 vintage (see Table 1), the major sectors that we focus on are consistent over time and across vintages.

Both vintages contain data on value added by country and industry and associated deflators. The main difference between the two vintages is the available data on factor inputs. In terms of labor, both vintages contain data on hours worked, which we use as our main measure of the labor input. In addition, the 2013 vintage has more granular data on hours worked by low-, medium-, and high-skilled workers, which form the basis for our measure of labor quality growth.[7]

Throughout the rest of this paper the baseline measure of productivity growth that we focus on is ALP growth, i.e. growth in output per hour. This contrasts with most growth accounting studies that focus on TFP growth. We do this because data on capital inputs is only available for

[6] The specific regions we use are listed in Table B.2 in Appendix B.

[7] Details on how these variables are defined and measured are in Appendix B.

the 2013 and *not* for the 2016 vintage of the WIOD (see Table 1). For the 2013 vintage for which we do have information on capital inputs, we split ALP growth up into capital deepening and TFP components.

2.2 Comparison across vintages and with other data sources

For the overlapping years the two vintages of the data line up very closely in terms of aggregates. Moreover, both vintages closely follow world-level aggregates, published as part of World Bank (2018).

Figure 1 shows how nominal GDP, measured in current US$, in our data lines up with world GDP. The short-dashed line is time series for the level of nominal GDP in the sample countries in the 2013 vintage of the data, which the other dashed line is the 2016 vintage of the data. Both of these lines are below the solid line, i.e. world GDP, which reflects that our sample of countries covers about 80 percent of global economic activity (in dollars). The 2016 vintage is a bit higher in the overlapping period because of the inclusion of Croatia, Norway, and Switzerland.

The growth pattern in the WIOD data mimics that of nominal world GDP. There is an acceleration in world GDP after 2000 up until the Great Recession in 2008. Global economic activity shrunk in 2008 causing a dip in world GDP before accelerating again during the recovery phase of 2009-2014. The fact that WIOD data shows the same qualitative patterns makes us confident about capturing the main economic movements at a global level.

Of course, the growth rate of nominal GDP reflects movements in both prices and quantities. Figure 2 solely focuses on the quantities in that it compares the growth rate of real GDP in our data with that of world GDP, from World Bank (2018). It shows that the growth rate of real GDP in our data both is of the same order of magnitude as well as exhibits the same fluctuations as the growth rate of world real GDP. The main difference is that world real GDP growth is a bit higher from 2002 than in our data because our sample of countries does not include many fast-growing emerging economies.

So, our sample covers over three quarters of the global economy and the growth rate in GDP that we decompose in the rest of this paper closely resembles that of the world economy.

3 Global growth-accounting framework

The starting point of our global growth-accounting framework is the observation that the growth rate of world real GDP, which we denote by $\dot{v}$ and is plotted in Figure 2, is a nominal value-added share weighted sum across countries, c, and industries, i of the growth rates of real value added, $\dot{v}_{i,j}$. Here, the $\dot{}$ operator is the time derivative in continuous time.[8] As we derive in Appendix A, this weighted average for world real GDP growth can be written as

$$\dot{v} = \sum_c \sum_i s_{ic}^V \dot{v}_{ic}, \tag{1}$$

where the nominal value added share is given by

$$s_{ic}^V = \frac{P_{ic}^V V_{ic}}{PV}, \text{ where } PV = \sum_c \sum_i P_{ic}^V V_{ic} \tag{2}$$

Here V_{ic} is real value added in industry i in country c and P_{ic}^V is the associated value-added deflator. Thus $P_{ic}^V V_{ic}$ is nominal value added produced in industry i in country c and the sum across industries and countries, PV, is nominal world GDP.

Growth in real value added produced in industry i in country c can be traced back to three sources: (i) growth in the capital stock used in production, $\dot{k}_{ic}$, (ii) growth in the hours worked of workers at different skill types, τ, which we denote by $\dot{l}_{ic}^{\tau}$, and (iii) growth in TFP, i.e. $\dot{z}_{ic}$.

Growth in TFP is the difference between real value added growth and the value-added factor share weighted average of the growth rates of input. Under standard neoclassical assumptions, commonly used in growth-accounting analyses (e.g. Jorgenson *et al.* , 1987), this can be interpreted as growth in technology.

In our particular case, this means that TFP growth in industry i in country c equals

$$\dot{z}_{ic} = \dot{v}_{ic} - s_{ic}^K \dot{k}_{ic} - \sum_{\tau \in \{L,M,H\}} s_{ic}^{\tau} \dot{l}_{ic}^{\tau}. \tag{3}$$

Here, s_{ic}^K is the share of value added paid to capital in industry i in country c and s_{ic}^{τ} is the share

[8] For notational simplicity, we derive all our results in continuous time and approximate them in discrete time in the data using Tornqvist indices.

of value added paid in compensation to workers of skill type τ. These factor shares add up to one, such that

$$1 = s_{ic}^{K} + \sum_{\tau \in \{L,M,H\}} s_{ic}^{\tau} = s_{ic}^{K} + s_{ic}^{L}, \text{ where } s_{ic}^{L} = \sum_{\tau \in \{L,M,H\}} s_{ic}^{\tau}. \tag{4}$$

Combining equations (1) and (3) we can write world GDP growth as a weighted average of capital growth, hours growth, and TFP growth in each of the industries in the countries in the world. This yields

$$\dot{v} = \sum_{c}\sum_{i} s_{ic}^{V} s_{ic}^{K} \dot{k}_{ic} + \sum_{c}\sum_{i}\sum_{\tau \in \{L,M,H\}} s_{ic}^{V} s_{ic}^{\tau} \dot{l}_{ic}^{\tau} + \sum_{c}\sum_{i} s_{ic}^{V} \dot{z}_{ic}. \tag{5}$$

This is the core decomposition that we are going to use in the rest of this paper.

However, to make it more interpretable, we introduce some additional notation and rearrange some terms. Our choice of these terms is determined by two things. The first is to focus on world ALP growth as well as consider factor input growth at the country level. The second is to aggregate the individual components of (5) to match the available variables described in Table 1.

To split terms up into parts at the world, country, and country-industry levels, we consider factor input growth at the world level, i.e. $\dot{k}$ and $\dot{l}$, at the country level, i.e. $\dot{k}_j$ and $\dot{l}_j$, and then, the ones in (1), at the country-industry level. Table 2 shows the notation we use for the corresponding factor shares.

In Appendix A, we show how we insert the terms related to global and country-level factor input growth in equation (1) to obtain the following expressions.

$$\begin{aligned} \dot{v} &= \dot{l} + \dot{alp} && (6)\\ &= \dot{l} + \left(\rho_i^L + \rho_c^L\right) + \sum_{c}\sum_{i} s_{ic}^{V} \dot{alp}_{ic} && (7)\\ &= \dot{l} + s^K(\dot{k} - \dot{l}) + \left(\rho_i^L + \rho_c^L\right) + \left(\rho_i^{K,L} + \rho_c^{K,L}\right) + \rho_L^{\tau} + \sum_{c}\sum_{i} s_{ic}^{V} \dot{z}_{ic}. && (8) \end{aligned}$$

The reason we introduce these three expressions is because they correspond to the different levels of detail at which the variables are reported in the two vintages of the dataset.

The top expression, i.e. (6), reflects that output in the world grows when the number of hours in the world increases, captured by $\dot{l}$, or when the amount of output per hour increases. The latter, i.e. $\dot{alp}$, is world ALP growth.

The second expression, i.e. (7), splits world ALP growth into terms related to the reallocation of labor, explained below, and country-industry specific growth rates of ALP, i.e. $\dot{alp}_{i,j}$. This second expression is the one we use for the 2016 data vintage for which we do not have capital data.

The final expression, i.e. (8), captures that, at the lowest level of aggregation we consider, we distinguish eight different factors that drive world GDP growth. The last seven terms, that exclude hours growth $\dot{l}$, add up to world ALP growth. These terms have the following interpretation.

The first, i.e. $s^K(\dot{k} - \dot{l})$, captures the part of output growth due to the increase in the number of machines and other capital goods per worker. This is known as capital deepening. We measure capital deepening here at the global level.

The second, ρ_i^L, third, ρ_c^L, and sixth terms, ρ_L^τ reflect that not every additional hour worked results in the same amount of additional output. The growth-accounting assumptions we use here imply that factor prices reflect relative marginal products. In that case, the output elasticity of an hour worked in industry i in country c at skill level τ is proportional to $s_{ic}^V s_{ic}^\tau$. Thus, the second term on the right-hand side of (1) weighs the growth rate of labor of each type by its varying contribution to output. This contrasts with the global growth rate of hours, $\dot{l}$, which weighs every hour the same.

For the purpose of our analysis we account for the differences in the output elasticities of labor at both the country level as well as within-country across industries. With this in mind, we rewrite this second term on the right-hand side of (1) as

$$\sum_c \sum_i \sum_{\tau \in \{L,M,H\}} s_{ic}^V s_{ic}^\tau \dot{l}_{ic}^\tau = s^L \dot{l} + \sum_c s_{ic}^V s_{ic}^L \left(\dot{l}_{ic} - \dot{l}_j\right) + \sum_c s_j^V s_j^L \left(\dot{l}_j - \dot{l}\right) \tag{9}$$

$$+ \sum_c \sum_i \sum_{\tau \in \{L,M,H\}} s_{ic}^V s_{ic}^\tau \left(\dot{l}_{ic}^\tau - \dot{l}_{ic}\right)$$

$$= s^L \dot{l} + \left(\rho_i^L + \rho_c^L\right) + \rho_L^\tau. \tag{10}$$

The term $s^L \dot{l}$ is already included in the first two terms of equation (8).

The term ρ_i^L accounts for the extent to which hours growth within countries takes place in industries with above average marginal products of labor. In country-specific growth-accounting studies this is often referred to as the reallocation effect of labor (e.g Oliner & Sichel, 2000; Wu, 2016, for U.S. and China respectively).

In addition to quantifying the importance of the within-country reallocation of labor, our global growth accounting allows us to assess the contribution of *cross-country* reallocation of labor to world productivity and GDP growth. This contribution is captured by ρ_j^L. It measures the extent to which world GDP growth is affected by hours growth disproportionately occuring in countries with above (or below) average marginal products of labor, where these marginal products are assumed to be proportional to wages.

Finally, ρ_L^τ accounts for the effect of the change in the composition of labor across skill-types within industries on world GDP growth. The calculation of this term requires data on hours by education level which are only available in the 2013 vintage of the WIOD data (see Table 1). The three education levels for which we have data are a relatively coarse level of aggregation compared to other analyses of labor quality (e.g. Bosler *et al.* , 2017).

In a similar manner, the fourth and fifth terms, i.e. $\rho_i^{K,L}$ and $\rho_j^{K,L}$, capture the reallocation of capital, rather than labor. That is, $\rho_i^{K,L}$ measures the extent to which within-country capital deepening takes place in industries with higher marginal products of capital. While, $\rho_j^{K,L}$ quantifies the contribution to world output growth if capital deepening taking place in countries with higher marginal products of capital.

Finally, the last term of (8) reflects the contribution of TFP growth in each of the industries in the countries in our sample to world GDP growth. One might be inclined to think that this is world TFP growth, but it is not.

World TFP growth, which we denote by $\dot{tfp}$, is the Solow residual at the world level. That is, it is measured as the growth rate of world GDP minus the factor-share weighted average of the world-level labor and capital inputs. This yields,

$$\begin{aligned} \dot{tfp} &= \dot{v} - s^L \dot{l} - s^K \dot{k} = \dot{alp} - s^K \left(\dot{k} - \dot{l} \right) \\ &= \left(\rho_i^L + \rho_c^L \right) + \left(\rho_i^{K,L} + \rho_c^{K,L} \right) + \rho_L^\tau + \sum_c \sum_i s_{ic}^V \dot{z}_{ic}. \end{aligned} \tag{11}$$

Note that, to calculate world TFP growth, we need data on capital inputs, which, as shown in Table 1, we only have for the 2013 vintage of the WIOD. Just like world ALP growth, world TFP growth is driven both by TFP growth at the country-industry level as well as the reallocation of production factors across countries and industries.

3.1 Results

We use the two WIOD vintages to construct annual estimates of each of the components of equation (6). We group the results into five subperiods: (*i*) the 1990's expansion, 1996-2000, (*ii*) the 2001 recession and recovery, 2001-2004, (*iii*) the mid-2000's expansion, 2005-2007, (*iv*) the Great Recession and early recovery, 2008-2010, and (*v*) the recovery from the Great Recession, 2011-2014, which is the period of the Euro crisis in many countries in our sample. We also report results for all the years in each of the vintages.

The results are listed in Table 3. Each of the rows in the table corresponds to a component of equation (6). The columns are grouped by vintage and contain average annual growth rates of each of the components for over the period. For example, the third number reported in line 1 of the table shows that, according to the 2013 vintage of the WIOD, world GDP growth averaged 3.70 percent a year from 2005-2007. The sixth number in the same row indicates that, according to the 2016 vintage, this was 3.65 percent instead.[9] It is this growth rate of world GDP in line 1 of the table that we decompose in the lines below.

By comparing the 2001-2004 and 2005-2007 periods across vintages in line 2 of the table, one can see that there is a discrepancy between the two data vintages in terms of hours growth. In particular, hours growth in the 2001-2004 periods is half as much in the 2016 vintage as in the 2013 vintage. This is largely due to the different ways hours growth in China and India are constructed in the two vintages.[10] With this difference in hours growth across data vintages in mind, we mainly focus on the qualitative results that both vintages have in common in the rest of our discussion rather than on the precise numbers.

[9]Note that the difference between these two numbers is due to revisions of the source data as well as due to a slightly different sample of countries across vintages.

[10]We discuss these differences in more detail in Appendix B.

World ALP growth

Line 3 of the table shows that there are sizable fluctuations in world ALP growth across the five subperiods that we distinguish. During the expansion of the late 1990's, world ALP growth was above 2 percent. It declined substantially in the early 2000's and rebounded during the mid-2000's before declining during the global financial crisis and the Great Recession and its aftermath. Lines 4-6 of the table illuminate the main source of these fluctuations.

In particular, these lines reveal that the fluctuations in world ALP growth in line 3 of Table 3 are mainly driven by the "reallocation" of labor, in particular across countries. To see this, note that, as we derived in (7), world ALP growth is the sum of the contribution of country-industry specific ALP growth rates to world GDP growth, line 6, and the contributions of the reallocation of labor within-country across industries, line 4, and across countries, line 5.

To start with the last of these lines first, line 6 of the table shows that the contribution of country-industry specific ALP growth was relatively constant over the first four of the five subperiods we consider and declined in the last subperiod from 2011-2014. This relatively constant contribution of country-industry specific ALP growth then implies that the bulk of the fluctuations in world ALP growth come from the reallocation of labor across industries within countries and across countries. This is borne out by lines 4 and 5 of Table 3.

Line 4 shows how hours growth within countries disproportionately occurs in industries with high (nominal) value added per hour. This means that the reallocation of hours within countries across industries tends to contribute positively to world ALP growth. This contribution is relatively constant, except for during the period of the global financial crisis and Great Recession during which it was pulled down by job losses in manufacturing industries.

Line 5 shows that the fact that hours growth in emerging economies, where nominal value added per hour is lower, tends to outpace hours growth in developed economies means that the reallocation of labor across countries is, on average, a drag on world ALP growth. This is because our global growth-accounting method interprets the shift in the distribution of hours worked from high-value-added to low-value-added countries as a shift of labor from high productivity to low productivity activities. This contribution of the cross-country reallocation of labor is more negative in periods when there is a bigger wedge in hours growth between emerging and developed economies, as in

2001-2004, 2008-2010, and 2011-2014. It was slightly positive during the expansion in developed economies from 2005-2007.

The relative importance of the three components that make up world ALP for its fluctuations is illustrated in Figure 3. The top panel of the figure shows the three components of lines 4-6 of Table 3 for the 2013 vintage for the five subperiods we consider while the bottom panel shows them for the 2016 vintage. Country-industry specific ALP growth, depicted by the black bars and listed as line 6 in the table, contributes around 2 percent to world ALP growth except for during the last period. In terms of levels, it is the main contributor to world ALP growth. Most of the fluctuations in world ALP growth come from the country labor reallocation, listed as line 5 in the table.

We interpret the country reallocation terms as global misallocation. Factors of production cannot move freely across borders so that labor hours are growing with different pace in different geographical locations. These locations have different value-added shares and their contribution to world productivity growth differ. As a result, fast labor hours growth in countries where the value-added share is lower acts as a drag on world ALP growth. With costless factor mobility across political borders, world ALP growth would be faster. That is why these reallocation terms can be viewed as global misallocation of resources.

The fairly constant contribution of country-industry ALP growth masks that the *composition* of this component across countries has changed notably over time. This can be seen from Table 4. It splits line 6 of Table 3 up by country/region. Our results are line with studies that document a broad productivity slowdown in industrialized countries starting in the early 2000's (Byrne *et al.* , 2016; OECD, 2017a). We find that the contribution of country-industry specific ALP growth of these countries (United States, Japan, and the United Kingdom in particlar) declines in the last three periods in our sample that cover 2005-2014. The global productivity impact of this slowdown was largely offset by an increase in the contributions of country-industry specific ALP growth to world GDP growth of Brazil, Russia, India, and China (BRIC countries). The contribution of BRIC countries' country-industry specific ALP to world productivity growth declined during 2011-2014. This, together with country-industry specific ALP growth in the United States, is the main driver of the decline in world ALP growth during that period that is evident from the bottom panel of Figure 3.

Capital deepening, labor quality, and world TFP growth

For the 2013 vintage of the data we have information on growth in capital stocks and hours by skill-type that allows us to further decompose country-industry specific ALP growth into underlying components related to capital deepening, the reallocation of capital deepening, labor quality growth, and country industry-industry specific TFP growth. We report these results in lines 7-12 of Table 1. For the 2016 vintage these lines in the table contain missing values because, as we reported in Table 1, the 2016 vintage neither contains the data on capital stocks nor on hours by skill-types needed to calculate these results.

In terms of capital deepening, lines 7-9, each of the three periods that we distinguish shows a very different pattern. In the late 1990's the Information and Communication Technology (ICT) revolution led to capital deepening in industries that specifically benefited from the new technological developments (FIRE, Trade, Transportation, Business services, and manufacturing). This is reflected by capital deepening and the its reallocation across industries contributing more than a percentage point over this period. The recession of the early 2000s caused a decline in labor hours growth and since the capital stock responds more slowly to business cycles than labor hours, it resulted in increases in capital-labor ratios in countries affected by the slowdown. Since these countries tended to be higher income countries with higher marginal products of capital, this resulted in a positive contribution of reallocation of capital deepening across countries. During the 2005-2007 capital deepening contributed over a percentage point to world GDP growth. Half of this turns out to be in FIRE. Contrary to the end of the 1990's, this disproportionate capital deepening in FIRE does not contribute positively to the reallocation of capital deepening. In fact, it results in small negative contribution instead. This reflects that, instead of focused on ICT, this capital deepening had its roots in housing and real estate.

The contribution of labor quality growth to world GDP growth, to the extent it is captured by changes in the distribution of hours over the three skill-types we have data on, was relatively constant, at around 2 percentage points, over the three periods covered in the 2013 vintage of our data.

Finally, lines 11 and 12 of Table 1 show the qualitative picture for world TFP growth is remarkably similar to that for world ALP growth. That is, while there are substantial fluctuations in world TFP growth, line 12, across periods that we consider, the contribution of country-industry specific TFP growth, line 11, does not fluctuate much.

In short, the results in Table 1 indicate that the reallocation of production factors across industries and countries accounts for the bulk of variations in world productivity growth aggregates. Moreover, the reallocation of capital across industries and countries as well as that of labor across industries tends to contribute positively to world productivity and GDP growth. The reallocation of labor across countries is accounted for as a substantial drag on world productivity and GDP growth, however.

In the next two sections we further investigate this drag and to what extent it reflects deviations from the assumption that relative wages across countries and industries reflect relative marginal products of labor.

4 Country-industry level PPP data

In the previous section we found that the reallocation of labor across countries acts as a large drag on world productivity growth. This reflects that relatively high hours growth in countries with low wages is assumed to reflect labor growing in countries where it has a lower marginal product.

However, because we use dollar denominated measures of wages and value-added these presumed productivity differences might be spurious because of deviations from PPP. A better measure of relative marginal productivity of labor across countries is one based on PPP deflated value added measures. However, such PPP measures are not available at the country-industry level at which we do our analysis. In this section we explain how we combine the results from Timmer *et al.* (2007) and Inklaar & Timmer (2014) with the WIOD to obtain time series of PPP-deflated value added for (most) countries and industries in our sample.

4.1 Construction of data

We construct our country-industry specific value-added deflators in three steps. In the first, we match the country-industry specific *gross output* PPP deflators for 2005 provided by Inklaar &

Timmer (2014) to countries and industries in our dataset.[11] In the second step, we extrapolate these 2005-baseyear PPP level estimates using time series for country-industry specific gross output price deflators from WIOD. In the final step, we double deflate value added for each industry. For this double deflation we use the gross output PPP deflators for the deflation of intermediate inputs provided by each of the industries. We assume that the PPP deflator for intermediate inputs bought from countries that are not covered in our dataset is the same as that for the ones bought from the WIOD sample countries. The math involved in these steps is explained in detail in Appendix A. This calculation is possible because WIOD input-output tables provide data on the source of intermediate inputs used by country and industry.

The result of these three steps are estimates of real value added at the country-industry level, measured in units of 2005 U.S. real GDP. To show that this way of constructing these data delivers results that are consistent with more aggregate cross-country estimates of PPP-deflated output from other sources, we compare our data with those sources below.

4.2 Comparison with other data sources

PPP-based value-added shares tend to put more weight on developing countries than the dollar-denominated weights that we used for our analysis in the previous section. This is largely because the dollar is the world's reserve currency. Since the sample of countries in our dataset is skewed towards the industrialized economies in the world, it covers a smaller share of world GDP measured in PPP-deflated units as in dollar-denominated values. This can be seen from the two lines in Table 1 that list dollar-denominated as well as PPP-deflated average shares of world GDP covered in our data.

Figure 4 compares the time series of PPP-deflated GDP from our two data vintages with that published in World Bank (2018). The first thing to note is that the PPP-deflated WIOD-SEA data exhibit the same main fluctuations as PPP-deflated world GDP growth published by the World Bank. One notable thing is that the Great Recession, which affected advanced industrialized economies more than emerging economies, is more pronounced in our data than in that of the World

[11] Some countries in our data are not covered in the PPP data and, thus, the PPP results we present in the rest of this paper are for a narrower sample (see Table B.1). The industry classification for the PPP data is based on the 2013 vintage of the WIOD. For the 2016 vintage we use the industry crosswalk provided in Gouma *et al.* (2018).

Bank.

Just like for the dollar-denominated measures, plotted in 2, the data in the overlapping period across the two vintages is very similar with the 2016 vintage capturing a little more economic activity because of the inclusion of a few more countries.

Finally, during the last decade covered by our data the World Bank measure of world GDP diverges from our measure because growth in countries not included in our data exceeded that in the countries in our dataset. As can be seen from Figure 5, which plots the growth rates of the time series, this is largely due to the effect of the Great Recession. During the other years, the PPP-deflated GDP growth implied by our data closely follows the growth rate of PPP-deflated world GDP, published in World Bank (2018).

5 PPP-based accounting

In terms of notation, we consider the difference between world GDP growth based on dollar-denominated value-added weights, $\dot{v}$, and that based on PPP-based value-added weights, $\dot{v}^*$. This difference is the wedge in growth rates plotted in Figures 2 and 5 respectively. We use the $*$ for all PPP-based measures. In particular, $\dot{v}^*_{ic}$ is the growth rate of PPP-deflated value added in country c and industry i and $s^{V^*}_{ic}$ is the share of the corresponding industry in world GDP measured in PPP, i.e in V^*.

Given this notation, the difference between $\dot{v}$ and $\dot{v}^*$ can be split up into two parts. These two parts reflect that dollar-denominated world GDP grows slower than PPP-deflated world GDP for two reasons. First, because dollar-denominated value added grows slower than PPP-deflated value added on average across industries in the world, i.e. because $\dot{v}_{ic} - \dot{v}^*_{ic}$ tends to be negative. Second, because dollar-denominated value added shares are lower than PPP-based shares for fast-growing industries.

These two reasons are quantified by the respective terms in the following equation

$$\gamma^V = \frac{1}{2}\sum_i \sum_c \left(s^V_{ic} + s^{V^*}_{ic}\right)\left(\dot{v}_{ic} - \dot{v}^*_{ic}\right) \text{ and } \gamma^s = \frac{1}{2}\sum_i \sum_c \left(\dot{v}_{ic} + \dot{v}^*_{ic}\right)\left(s^V_{ic} - s^{V^*}_{ic}\right), \tag{12}$$

which are the result of a standard shift-share decomposition of the wedge $\dot{v} - \dot{v}^*$. Thus, this allows us to write

$$\dot{v} = \gamma^V + \gamma^s + \dot{v}^*. \tag{13}$$

Of course, our interest is not in world GDP but in world ALP growth, denoted as $\dot{alp}$ for the dollar-share weighted measure of world GDP growth and as $\dot{alp}^*$ for the PPP-share weighted measure. In Appendix A we show world GDP growth, $\dot{v}$, can be written as the sum of the two shift-share terms introduced above and world ALP-PPP growth. In turn, similar to $\dot{alp}$, world ALP-PPP growth, $\dot{alp}^*$, can be further split up in term related to the reallocation of labor and country-industry specific ALP-PPP growth. That is,

$$\begin{aligned} \dot{v} &= \dot{l} + \dot{alp} \\ &= \dot{l} + \gamma^V + \gamma^s + \dot{alp}^* \\ &= \dot{l} + \gamma^V + \gamma^s + \rho_i^{V^*} + \rho_c^{V^*} + \rho_i^L + \rho_c^L + \sum_i \sum_c s_{ic}^{V^*} \dot{alp}_{ic}^*. \end{aligned} \tag{14}$$

In this case there are two additional terms related to the reallocation of labor as compared to equation (8), namely

$$\rho_i^{V^*} = \sum_c \sum_i \left(s_{ic}^{V^*} - s_{ic}^V\right) \left(\dot{l}_{ic} - \dot{l}_c\right) \text{ and } \rho_j^{V^*} = \sum_c \left(s_c^{V^*} - s_c^V\right) \left(\dot{l}_c - \dot{l}\right). \tag{15}$$

These terms capture the effect of the reallocation of labor through deviations from PPP. Note that country-industries for which $s_{ic}^{V^*} > s_{ic}^V$ are ones that have lower than average PPP-prices per dollar. These relatively low PPP prices per dollar can be interpreted as a cost advantage. Thus, these terms capture to what extent the reallocation of labor to country-industries with a cost-advantage contributes to world ALP-PPP growth. The first term quantifies the importance of this within countries and across industries while the second measures the importance of the shift of labor inputs towards countries with a cost advantage.

5.1 Sources of world GDP growth expanded with PPP measures

Table 5 lists the results obtained using (14) for the two data vintages and the same five subperiods we covered before. Its format is similar to Table 3 to accommodate comparisons across tables. In fact, lines 1 through 3 of the tables are the same, up to the effect of the difference in the sample of countries covered.[12] Line 3 lists world ALP growth, i.e. $\dot{alp} = \dot{v} - \dot{l}$.

Line 6 contains PPP-based world ALP growth, i.e. $\dot{alp}^* = \dot{v}^* - \dot{l}$. The difference between lines 3 and 6 is $\dot{v} - \dot{v}^*$. This difference can be gleaned from figures 2 and 5. They show that the growth rate of PPP-deflated world GDP from Figure 5 is almost twice as high as that of dollar-weighted world real GDP growth plotted in Figure 2. Lines 4 and 5 of Table 5 split this difference up into the terms introduced in (12).

Line 4 shows that, starting in the early 2000's the fact that growth tends to be higher in countries whose PPP-based value-added shares exceed their dollar-based ones adds about two percentage points a year to world ALP-PPP growth relative to world ALP growth. Figure 6 illustrates the regional sources of the deviation of PPP-based value added shares from dollar-based shares over time.

It shows that the magnitude of γ^s reported in line 4 of Table 5 is largely due to the relatively high wedges in China and India between the two measures as well as in the United States and Japan, but in the opposite direction. The figure shows that $s^{V^*} > s^V$ in China and India and that this wedge has not move much over time. While for the U.S. and Japan $s^{V^*} < s^V$. Though our PPP-deflated value added measures are potentially subject to measurement issues, the order of magnitude of these wedges is so large that they are unlikely to be driven by these measurement issues. Instead, these deviations from PPP are indicative of substantial and persistent cost advantages for India and China in world production.

Line 5 of Table 5 lists the part of the wedge between $\dot{v}$ and $\dot{v}^*$ that is due to differential growth rates between PPP-deflated country-industry value added and dollar-denominated value added, i.e. $\dot{v}_{ic} - \dot{v}^*_{ic}$. These differences in country-industry specific real value added growth across measures reflect movements in the relative price of gross-output in the respective industries relative to U.S. GDP.

Because we construct PPP value-added deflators using the double deflation method described in Appendix A, the movements in gross-output prices relative to U.S. GDP affects the growth rate of PPP-deflated value added both through the deflation of gross output as well as through the

[12] The countries covered in the two vintages and the PPP data are listed in Table B.1 in Appendix B.

deflation of the intermediate inputs used. Intuitively, the results for the term γ^V reported in line 5 suggest that economic activity disproportionately takes place in sectors whose relative dollar price of output declines relative to the U.S. GDP deflator.

Lines 7 and 8 in Table 5 are the same as lines 4 and 5 from Table 3. They reflect the degree to which hours growth occurs in countries with higher dollar-denominated value added per hour. Line 8, which replicates line 5 from Table 3 that points to the reallocation of labor across countries, acts as a large drag on world productivity growth. This is because, if PPP holds, relatively high hours growth in countries with low wages reflects labor is growing in countries where it has a lower marginal product. However, this does not have to be the case under deviations from PPP.

In terms of our PPP-based results, we are interested in this reallocation weighted by PPP-deflated value added per hour instead because that is the preferred cross-country comparable measure of productivity. The terms ρ_i^V and ρ_j^V in lines 9 and 10 show the degree to which the reallocation of hours towards country-industries with a higher PPP shares than dollar-denominated shares, i.e. industries with an international cost advantage, affect PPP-based world productivity growth.

From line 9 we see that, even within countries, hours growth disproportionately happens in industries with a cost advantage. This cost-advantage effect of the reallocation of labor is of the same order of magnitude as the conventional reallocation of labor term, reported in line 7, that has been emphasized in several other growth accounting studies (e.g. Wu, 2016, for China). This is mainly driven by China and India. The contributions of other countries to this term are negligible.

Line 10 from Table 5 shows the degree to which the drag of cross-country reallocation of labor on world GDP and productivity growth is offset by deviations from PPP. Comparing lines 8 and 10 in the table we find that about a third of the imputed drag of the international reallocation of labor is accounted for by PPP deviations. The remaining two thirds capture that, as emerging economies grow and catch up with industrialized ones, the shift in world employment towards these economies slows down productivity growth at the world level.

Finally, line 11 conveys qualitatively the same result as line 6 from Table 3. Namely, the contribution of country-industry specific ALP growth to world productivity, in this case measured in PPP terms, has been relatively constant over the 18 years covered in our sample. Under the surface of this aggregate number, we again find that it hides a shift in the country contributions from industrialized economies to BRIC countries.

6 Conclusion

World productivity—whether measured by average labor productivity (world GDP per hour) or by the world Solow residual—is highly volatile from year-to-year and even over multiple-year periods. In this paper, we find that shifts in the distribution of employment across industries and countries with different factor prices explains this volatility. Standard growth-accounting interprets these differences in factor prices as reflecting differences in marginal products. These differences are only partially accounted for by differences in price levels (or cost levels) across countries, as measures by PPPs.

Our conclusions on the role of factor reallocations as a source of world productivity volatility complement a large literature on misallocation within countries. This literature (Hsieh & Klenow, 2009) typically finds that factor misallocation across uses with differing marginal products can explain a considerable share of the productivity differences across countries. Our analysis finds that variations in factor distribution is also important in the time series dimension.

In contrast to the volatility of aggregate world productivity, the contribution of productivity growth at the county-industry level is relatively smooth. This finding mirrors the finding in country studies that "non-technological" terms explain a lot of the variance in aggregate country-level productivity (Basu & Fernald, 2002).

The relative smoothness of productivity growth at a country-industry level masks important differences across regions. In advanced economies, productivity growth slowed down after the mid-2000s. But at a world level, this slowdown has been, largely or completely, offset by faster growth in China, India, and other emerging markets. Using output measured at market exchange rates, productivity slowed down globally after 2007. At PPP, the slowdown returned growth rates to their early 2000s levels.

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Table 1: Comparison of WIOD-SEA vintages

Description	*Vintage* 2013	2016
	Coverage	
Years	1995-2007	2000-2014
Number of countries	40	43
Average share of world GDP		
... dollar denominated	80	82
... PPP deflated	76	77
Number of industries	35	56
Industry classification	ISIC v3	ISIC v4
	Factor inputs	
Hours	✓	✓
... by skill level	✓	
Capital	✓	

Note: Both vintages contain data on value added by country and industry as well as value added deflators and factor prices for inputs for which data is available. The 2013 vintage includes incomplete data for 2008-2011 that we do not use in our analysis. Share of world GDP reported in percentage of dollar-denominated world value added from World Bank (2018).

Table 2: Aggregation of inputs and factor shares to country- and world-levels

Variable	*Skill-type*		*Country-industry*		*Country*		*Global*
Value-added (in dollars)	-		$\sum_c \sum_i s_{ic}^V$	=	$\sum_c s_j^V$	=	1
Value-added (PPP)	-		$\sum_c \sum_i s_{ic}^{V*}$	=	$\sum_c s_j^{V*}$	=	1
Capital	-		$\sum_c \sum_i s_{ic}^V s_{ic}^K$	=	$\sum_c s_j^V s_j^K$	=	s^K
Labor	$\sum_c \sum_i \sum_{\tau \in \{L,M,H\}} s_{ic}^V s_{ic}^\tau$	=	$\sum_c \sum_i s_{ic}^V s_{ic}^L$	=	$\sum_c s_j^V s_j^L$	=	s^L

Table 3: Summary of global growth accounting: 1996-2014

SEA vintage			Release 2013				Release 2016				
line	description	notation	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
1.	World GDP growth	$\dot{v}$	3.33	2.51	3.70	3.15	2.31	3.65	0.91	2.56	2.37
2.	World hours growth	$\dot{l}$	1.18	2.44	0.39	1.40	1.16	0.85	-0.07	3.38	1.46
3.	World ALP growth	$\dot{alp}$	2.15	0.07	3.31	1.75	1.15	2.80	0.98	-0.82	0.90
	Reallocation of hours										
4.	…within country across industries	ρ_i^L	0.14	0.11	0.52	0.23	0.21	0.33	0.02	0.31	0.23
5.	…across countries	ρ_j^L	-0.13	-2.16	0.58	-0.63	-1.00	0.49	-0.74	-1.80	-0.85
6.	Country-industry ALP growth	$\dot{alp}_{i,j}$	2.14	2.11	2.20	2.15	1.94	1.98	1.70	0.67	1.53
7.	World capital deepening	$\dot{k} - \dot{l}$	0.50	-0.05	1.10	0.47	-	-	-	-	-
	Reallocation of capital deepening										
8.	…within country across industries	$\rho_i^{K,L}$	0.56	0.06	-0.06	0.24	-	-	-	-	-
9.	…across countries	$\rho_j^{K,L}$	0.18	0.92	-0.11	0.35	-	-	-	-	-
10.	Labor quality growth	ρ_τ^L	0.20	0.18	0.16	0.18	-	-	-	-	-
11.	Country-industry TFP growth	$\dot{tfp}_{i,j}$	0.71	1.00	1.11	0.910	-	-	-	-	-
Addendum:											
12.	World TFP growth	$\dot{tfp}$	1.65	0.12	2.21	1.28	-	-	-	-	-

Note: Lines in this table correspond to part of equation (6). Reported are contributions to average annual growth rates in percentage points over various subperiods. World TFP growth is lines $(3 - 7 = 4 + 5 + 8 + 9 + 10 + 11)$. Totals do not add up due to rounding.

Table 4: Contribution of country-industry specific ALP growth, by country/region: 1996-2014

	Release 2013				Release 2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
United States	0.75	1.01	0.42	0.76	0.92	0.38	0.54	-0.00	0.46
China	0.30	0.28	0.53	0.35	0.23	0.67	0.65	0.59	0.52
Japan	0.31	0.25	0.19	0.26	0.27	0.12	-0.08	0.06	0.11
Germany	0.11	0.08	0.13	0.10	0.11	0.11	0.01	0.03	0.06
France	0.12	0.07	0.05	0.09	0.06	0.05	0.04	0.05	0.05
Great Britain	0.11	0.13	0.10	0.11	0.13	0.05	0.03	0.01	0.06
Brazil	0.04	-0.00	0.02	0.02	-0.02	-0.00	0.27	-0.05	0.04
Italy	0.03	-0.00	0.00	0.01	-0.01	-0.02	-0.03	0.01	-0.01
Russia	-0.02	0.04	0.11	0.03	0.05	0.09	0.09	0.02	0.06
India	0.06	0.02	0.17	0.07	0.05	0.13	0.12	-0.11	0.04
Other America	0.07	-0.02	0.05	0.04	-0.05	0.02	0.01	0.03	-0.00
Other Asia	0.11	0.08	0.27	0.14	0.05	0.26	0.01	-0.10	0.04
Other Euro Area	0.08	0.08	0.11	0.09	0.05	0.09	0.02	0.07	0.06
Other Europe	0.05	0.06	0.05	0.05	0.09	0.04	-0.00	0.03	0.04
Other Oceania	0.03	0.02	-0.00	0.02	0.02	-0.01	0.01	0.03	0.01
Total	2.14	2.11	2.20	2.15	1.94	1.98	1.70	0.67	1.53

Note: Reported are contributions by country/region to line 6 in Table 3 in percentage points over various subperiods.

Table 5: Summary of PPP-based global growth accounting: 1996-2014

SEA vintage			Release 2013				Release 2016				
line	description	notation	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
1.	World GDP growth	$\dot{v}$	3.27	2.46	3.69	3.10	2.16	3.63	0.90	2.57	2.32
2.	World hours growth	$\dot{l}$	1.25	2.49	0.33	1.43	1.19	0.79	-0.08	3.34	1.45
3.	World ALP growth	$\dot{alp}$	2.02	-0.04	3.36	1.67	0.96	2.85	0.98	-0.77	0.88
	Growth wedge: Dollars vs PPP										
4.	Value added share differentials	γ^s	-0.06	-1.03	-2.02	-0.87	-0.39	-2.10	-2.92	-2.19	-1.81
5.	Growth differentials	γ^V	-2.01	-2.08	-2.83	-2.24	-1.84	-3.11	0.38	-1.17	-1.45
6.	World ALP-PPP growth	$\dot{alp}^*$	4.09	3.08	8.20	4.78	3.19	8.05	3.52	2.60	4.13
	Reallocation of hours										
7.	...within country across industries	ρ_i^L	0.15	0.12	0.53	0.23	0.20	0.32	0.02	0.32	0.22
8.	...across countries	ρ_c^L	-0.14	-2.19	0.65	-0.63	-1.04	0.56	-0.77	-1.76	-0.84
	PPP-differentials / cost advantage										
9.	...within country across industries	$\rho_i^{V^*}$	0.14	-0.15	0.63	0.17	0.42	0.51	0.40	0.21	0.38
10.	...across countries	$\rho_c^{V^*}$	0.11	0.63	-0.18	0.21	0.20	0.32	0.02	0.32	0.22
11.	Country-industry ALP-PPP growth	$\dot{alp}_{ic}^*$	3.84	4.67	6.58	4.80	3.21	6.82	3.56	3.24	4.07

Note: The lines in this table correspond to the terms in (14).

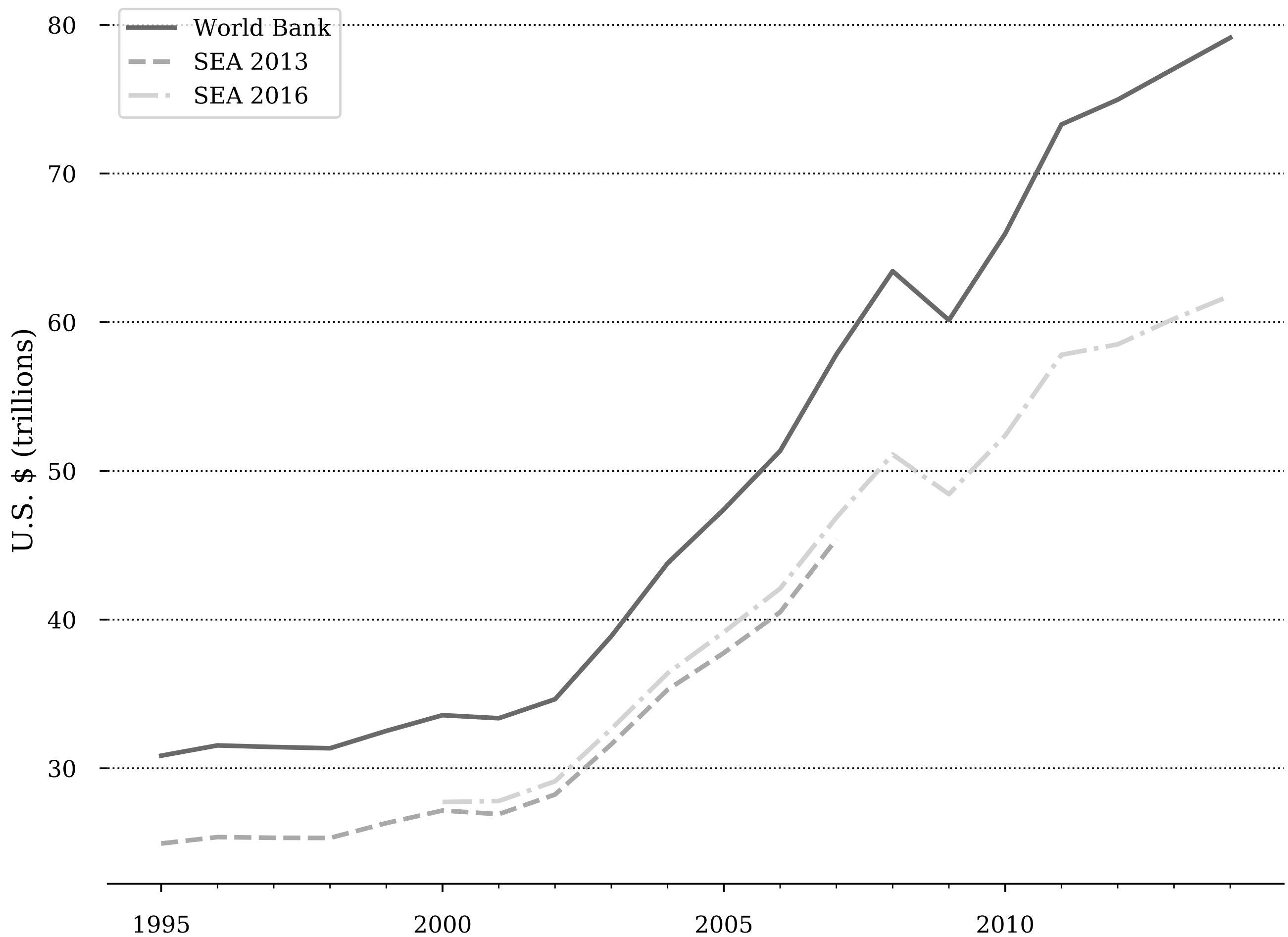


Figure 1: Nominal world GDP in WIOD-SEA and WDI

Source: Timmer (2012) and World Bank (2018).

Note: SEA data is total nominal value added for all industries and countries in both vintages of the WIOD. All measures are reported in current U.S. $.

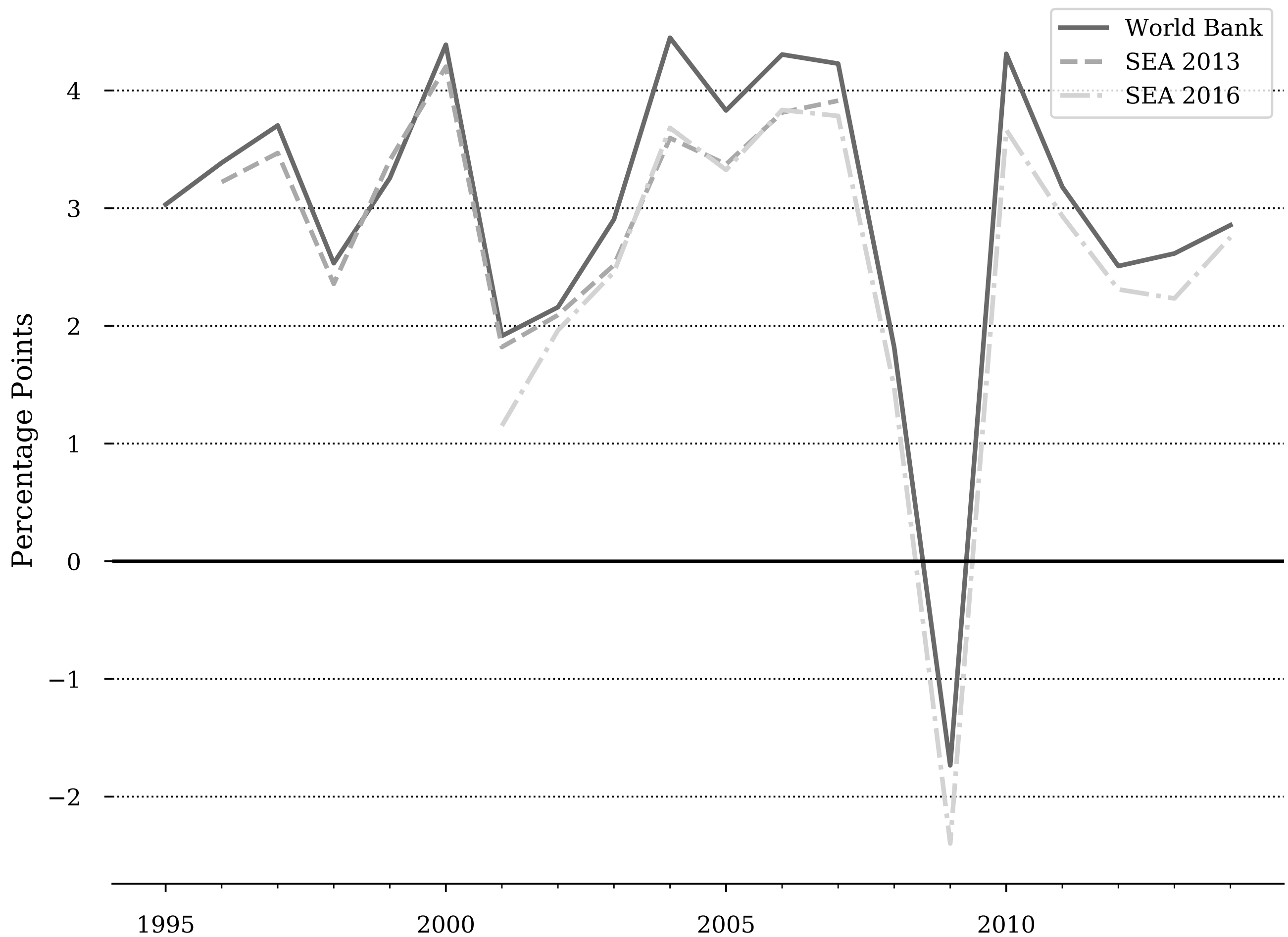


Figure 2: Growth in world real GDP in WIOD-SEA and WDI

Source: Timmer (2012) and World Bank (2018).

Note: World real GDP growth is constructed as dollar-denominated value-added share weighted average of real GDP or real country-industry value-added growth.

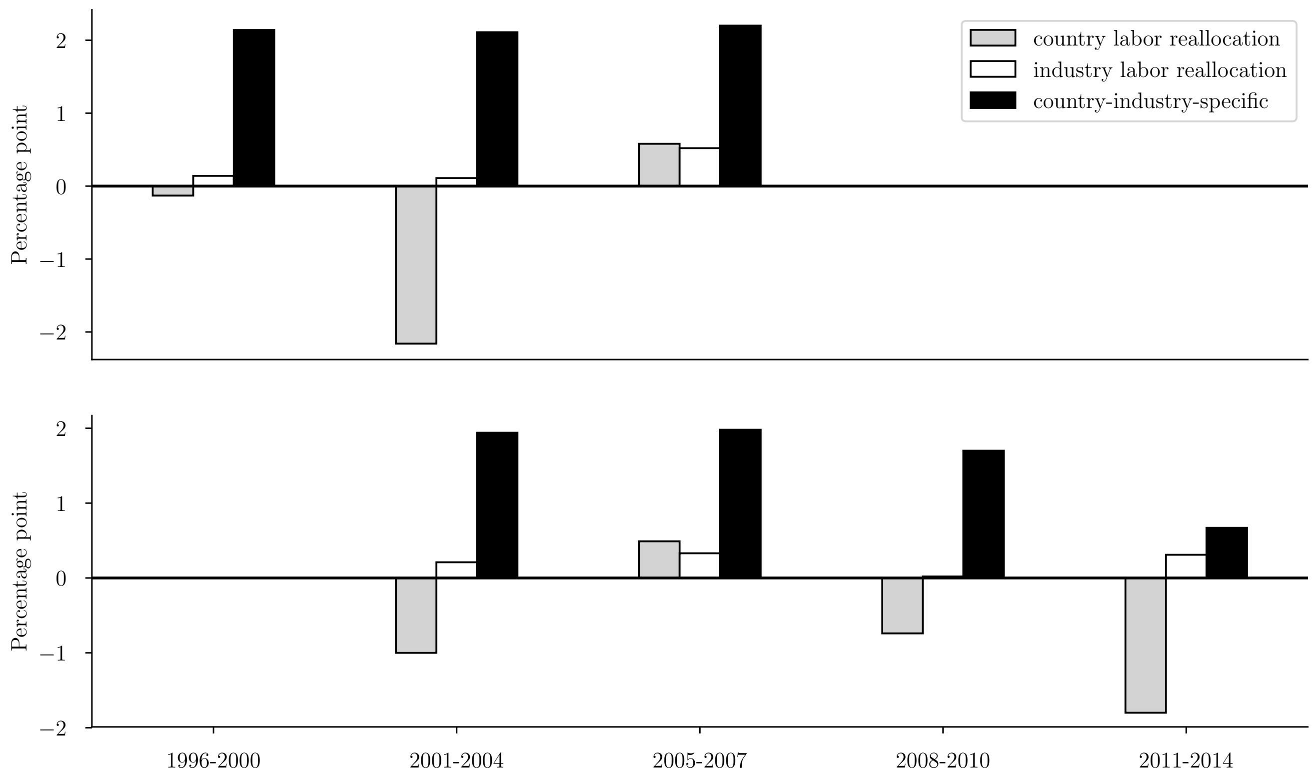


Figure 3: Contributions to world ALP growth by source and by WIOD-SEA vintage

Source: Timmer (2012) and authors' calculations.

Note: Reported are percentage point contributions to average annual world ALP growth. The top panel shows results for the 2013 and the bottom for the 2016 vintage of the data.

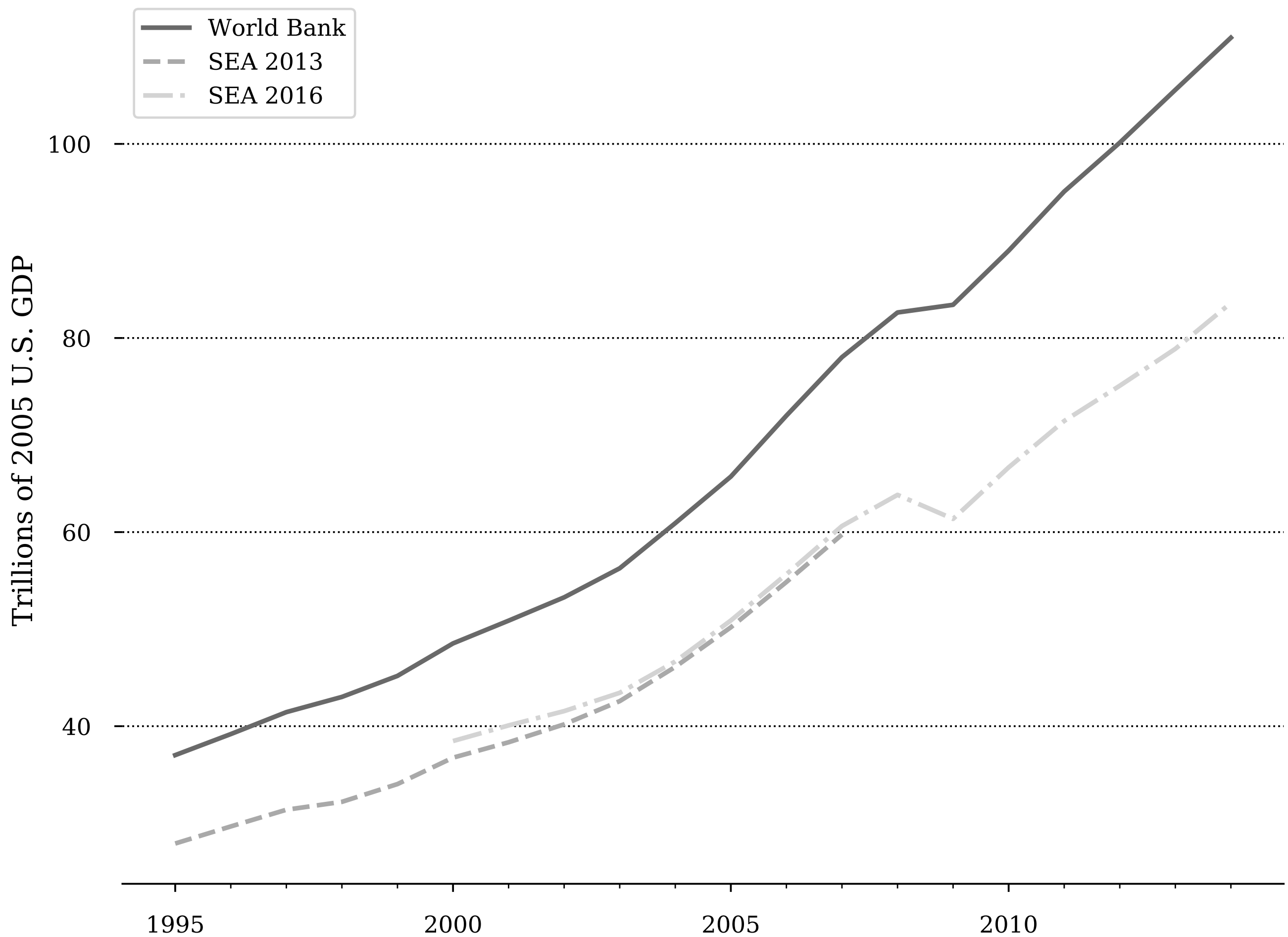


Figure 4: World GDP PPP in WIOD-SEA and WDI

Source: Timmer (2012), and World Bank (2018), and authors' calculations.
Note: SEA data is total value added PPP for all industries and countries in both vintages of the WIOD. All measures are reported in U.S. $ of 2005 U.S. GDP.

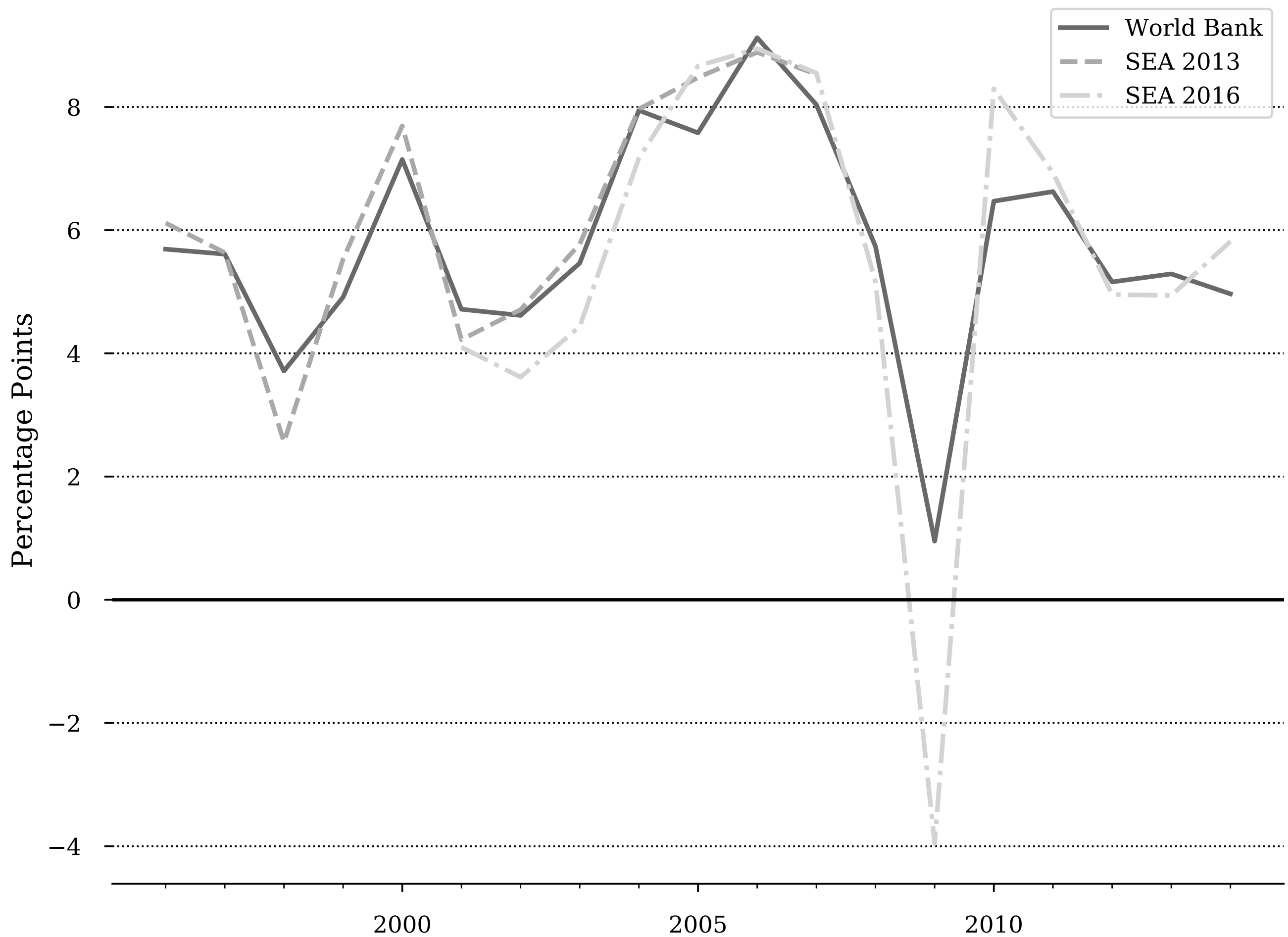
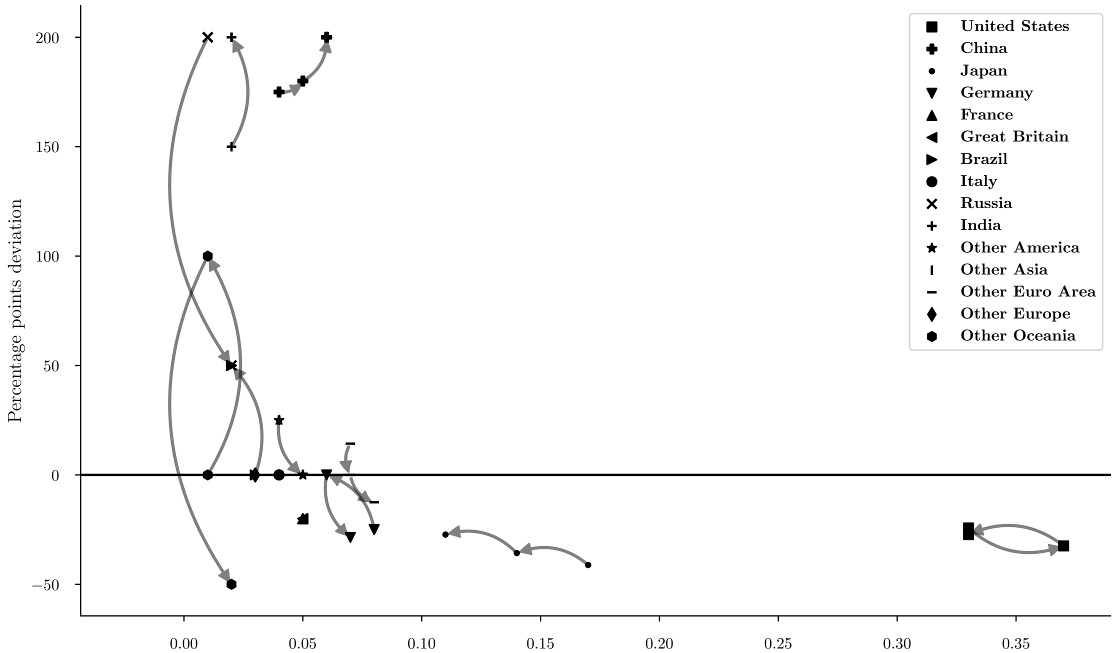


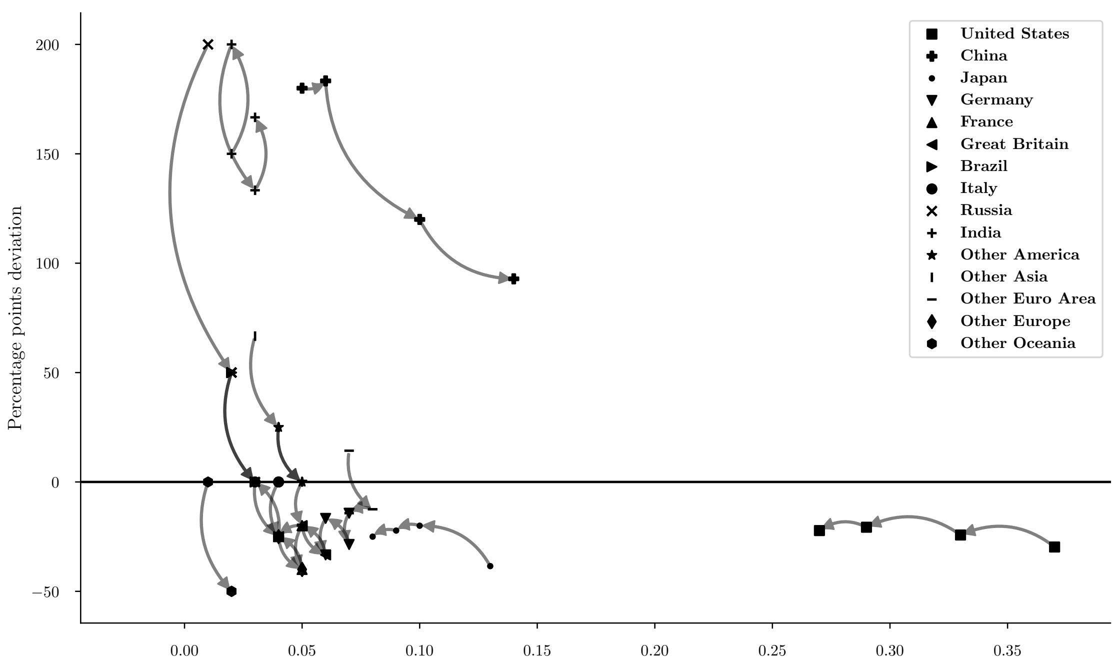
Figure 5: Growth in world GDP PPP in WIOD-SEA and WDI

Source: Timmer (2012), and World Bank (2018), and authors' calculations.

Note: World GDP PPP growth is constructed as real PPP-adjusted value-added share weighted average of nominal GDP or real country-industry value-added PPP growth.



(a) 2013 vintage



(b) 2016 vintage

Figure 6: Deviation of PPP-deflated from dollar-denominated value added share

Source: Timmer (2012), SEA 2013, and authors' calculations.

Note: The x-axis shows the PPP-deflated average value added share of each country in each of the subperiods. The y-axis is the percentage deviation of dollar-denominated value-added share from the PPP-deflated value added share over the subperiods introduced in the text. The direction of the arrows shows the direction of time (1996-2000, 2001-2004, 2005-2007, 2008-2010, 2011-2014).

A Mathematical derivations

This appendix contains the derivations of the growth accounting equations we use for the calculation of the results in the main text. Most growth accounting methods applied in this paper have been used in other papers and we simply re-derive them here for reference purposes.

Our main derivations are done in continuous time and throughout we drop the time subscript, t. Small letters denote logarithms and changes over time are denoted by a dot.

A.1 Country-industry-level growth accounting

We consider an industry i and country c that is made up of firms that all produce gross output with a constant-returns-to-scale (CRS) production technology. Each firm is a price taker and we denote the price at which it sells its output by P_{ic}.

Each of these firms also takes as given the factor prices it pays for its inputs. These inputs consist of (*i*) capital, (*ii*) hours worked by workers of three different skill levels, which we denote by high/medium/low, and (*iii*) intermediate inputs. We denote the associated factor prices as (*i*) R_{ic}, which is the nominal rental rate of capital, (*ii*) W_{ic}^{H}, W_{ic}^{M}, and W_{ic}^{L}, which are the nominal hourly wages of the workers of high/medium/low skill levels respectively, and (*iii*) P_{ic}^{X}, which is the price of intermediate inputs for the industry.

We assume that all firms in the sector flexibly adjust their factor inputs to maximize profits. This assumption, combined with that of CRS, implies that factor prices reflect marginal products and that the growth rate of output in industry i in country c equals the factor-share weighted average of the growth rate of inputs plus the rate of TFP growth.

To formalize this result, we define the industry-wide level of gross output as Y_{ic} and the five respective types of factor inputs as K_{ic}, L_{ic}^{H}, L_{ic}^{M}, L_{ic}^{L}, and X_{ic}. Given this notation, we can decompose output growth into the parts due to the growth of factor inputs and the part due to TFP growth. In particular, we can write

$$\dot{y}_{ic} = \tilde{s}_{ic}^{K}\dot{k}_{ic} + \sum_{\tau\in\{H,M,L\}} \tilde{s}_{ic}^{\tau}\dot{l}_{ic}^{\tau} + \tilde{s}_{ic}^{X}\dot{x}_{ic} + \dot{\tilde{z}}_{ic}. \tag{16}$$

Here $\tilde{s}_{ic}^{K}$, $\tilde{s}_{ic}^{H}$, $\tilde{s}_{ic}^{M}$, $\tilde{s}_{ic}^{L}$, and $\tilde{s}_{ic}^{X}$ are the revenue shares of the five respective factor inputs. TFP growth in the sector is denoted by $\dot{\tilde{z}}_{ic}$.[13] Equation (16) is the growth-accounting equation that forms the basis for the rest of our analysis.

In order to analyze aggregate TFP it is more convenient to write everything in terms of value added, V_{ic}, rather than gross output, Y_{ic}. Nominal value added, $P_{ic}^{V}V_{ic}$, of a sector is the difference between total revenue and expenditures on intermediate inputs, such that

$$P_{ic}^{V}V_{ic} = P_{ic}Y_{ic} - P_{ic}^{X}X_{ic}. \tag{17}$$

Taking the time derivative of the above equation we obtain that changes in nominal value added over time can be split up as follows

$$P_{ic}^{V}V_{ic}\dot{p}_{ic}^{V} + P_{ic}^{V}V_{ic}\dot{v}_{ic} = P_{ic}Y_{ic}\dot{p}_{ic} + P_{ic}Y_{ic}\dot{y}_{ic} - P_{ic}^{X}X_{ic}\dot{p}_{ic}^{X} - P_{ic}^{X}X_{ic}\dot{x}_{ic}. \tag{18}$$

The above equation can be simplified by dividing both sides by nominal value added and using the fact that

$$\frac{P_{ic}Y_{ic}}{P_{ic}^{V}V_{ic}} = \frac{1}{1-\tilde{s}_{ic}^{X}} \text{ and that } \frac{P_{ic}^{X}X_{ic}}{P_{ic}^{V}V_{ic}} = \frac{\tilde{s}_{ic}^{X}}{1-\tilde{s}_{ic}^{X}}. \tag{19}$$

This yields that

$$\dot{p}_{ic}^{V} + \dot{v}_{ic} = \left(\frac{1}{1-\tilde{s}_{ic}^{X}}\right)\dot{p}_{ic} + \left(\frac{1}{1-\tilde{s}_{ic}^{X}}\right)\dot{y}_{ic} - \left(\frac{\tilde{s}_{ic}^{X}}{1-\tilde{s}_{ic}^{X}}\right)\dot{p}_{ic}^{X} - \left(\frac{\tilde{s}_{ic}^{X}}{1-\tilde{s}_{ic}^{X}}\right)\dot{x}_{ic}. \tag{20}$$

This equation allows us to define a quantity and price index for value added. In particular, the growth rate of real value added, i.e. of the quantity index, equals

$$\dot{v}_{ic} = \left(\frac{1}{1-\tilde{s}_{ic}^{X}}\right)\dot{y}_{ic} - \left(\frac{\tilde{s}_{ic}^{X}}{1-\tilde{s}_{ic}^{X}}\right)\dot{x}_{ic}, \tag{21}$$

[13] We denote TFP as defined in terms of the gross output production technology as $\tilde{Z}$. This is because we use Z for value-added TFP below.

while that of the price index is given by

$$\dot{p}_{ic}^{V} = \left(\frac{1}{1-\tilde{s}_{ic}^{X}}\right)\dot{p}_{ic} - \left(\frac{\tilde{s}_{ic}^{X}}{1-\tilde{s}_{ic}^{X}}\right)\dot{p}_{ic}^{X}. \tag{22}$$

Combining equation (21) with the one for the growth rate of gross output, i.e. (16), we can write real value added growth as a weighted average of capital and labor growth plus value-added TFP growth. That is,

$$\dot{v}_{ic} = s_{ic}^{K}\dot{k}_{ic} + \sum_{\tau\in\{L,M,H\}} s_{ic}^{\tau}\dot{l}_{ic}^{\tau} + \dot{z}_{ic}. \tag{23}$$

The shares in this equation are value-added shares and TFP growth is that of value-added TFP, such that

$$s_{ic}^{\tau} = \frac{\tilde{s}_{ic}^{\tau}}{1-\tilde{s}_{ic}^{X}} \text{ for } \tau\in\{K,L,M,H\} \text{ and } \dot{z}_{ic} = \frac{\dot{\tilde{z}}_{ic}}{1-\tilde{s}_{ic}^{X}}. \tag{24}$$

A.2 Global growth accounting

The final step is to aggregate the decomposition of value-added growth across industries and countries. Aggregate value-added growth, i.e. World GDP growth, is the nominal value-added share weighted average of the industry-country value added growth rates. Thus, World TFP growth is defined as

$$\dot{v} = \sum_{c}\sum_{i} s_{ic}^{V}\dot{v}_{ic}, \tag{25}$$

where the nominal value added share is given by

$$s_{ic}^{V} = \frac{P_{ic}^{V}V_{ic}}{\sum_{s}\sum_{r}P_{rs}^{V}V_{rs}} = \frac{P_{ic}^{V}V_{ic}}{PV}, \tag{26}$$

where PV is nominal world GDP.

Combining this with (23) allows us to decompose World GDP growth into parts due to capital, labor, and TFP growth. This decomposition reads

$$\dot{v} = \sum_{c}\sum_{i} s_{ic}^{V}s_{ic}^{K}\dot{k}_{ic} + \sum_{c}\sum_{i}\sum_{\tau\in\{L,M,H\}} s_{ic}^{V}s_{ic}^{\tau}\dot{l}_{ic}^{\tau} + \sum_{c}\sum_{i} s_{ic}^{V}\dot{z}_{ic}. \tag{27}$$

This decomposition is in terms of value-added share weighted growth rates of factor inputs.

However, these weighted averages are not the same as the growth rates of aggregate factor inputs that one would construct for the world as a whole. The next step is to define these world-level factor inputs and to include them in the above decomposition of world GDP growth.

World capital growth: First let's focus on the growth of the world capital stock. We have price and quantity indices for capital stocks by industry and across countries, P_{ic}^{K} and K_{ic} respectively. This allows us to construct the nominal replacement value of the capital stock by industry, $P_{ic}^{K} K_{ic}$. Simple aggregation of these replacement values yields the nominal replacement value of the world productive capital stock as

$$P^{K} K = \sum_{c} P_{c}^{K} K_{c} = \sum_{i} P_{i}^{K} K_{i} = \sum_{i} \sum_{c} P_{ic}^{K} K_{ic}. \tag{28}$$

This allows us to calculate quantity indices for capital at the country, the industry, and the world levels. The growth rates of these respective indices are given by

$$\dot{k}_{c} = \sum_{i} \left(\frac{P_{ic}^{K} K_{ic}}{P_{c}^{K} K_{c}} \right) \dot{k}_{ic},\ \dot{k}_{i} = \sum_{c} \left(\frac{P_{ic}^{K} K_{ic}}{P_{i}^{K} K_{i}} \right) \dot{k}_{ic},\ \text{and}\ \dot{k} = \sum_{i} \sum_{c} \left(\frac{P_{ic}^{K} K_{ic}}{P_{c}^{K} K_{c}} \right) \dot{k}_{ic}. \tag{29}$$

Thus, the growth rates of the quantity indices of capital are *replacement-value* share weighted averages of the growth rates of the underlying capital stocks. These weights are thus different than the *value-added* share weights in (27).

Using the definition of world capital stock growth above, we write the capital growth component of (27) in terms of the growth of the world capital stock and terms that account for the reallocation of capital between sectors and countries.

To do so, we first define the world GDP shares by country and industry as

$$s_{c}^{V} = \sum_{i} s_{ic}^{V},\ \text{and}\ s_{i}^{V} = \sum_{c} s_{ic}^{V}. \tag{30}$$

This allows us to define the respective capital factor shares at the country, industry, and world levels as

$$s_{c}^{K} = \left(\frac{\sum_{i} s_{ic}^{V} s_{ic}^{K}}{s_{c}^{V}} \right),\ s_{i}^{K} = \left(\frac{\sum_{c} s_{ic}^{V} s_{ic}^{K}}{s_{i}^{V}} \right),\ \text{and}\ s^{K} = \sum_{i} \sum_{c} s_{ic}^{V} s_{ic}^{K}. \tag{31}$$

Using these definitions of the capital stock indices and factor shares at the country, industry, and world level, we write the contribution of capital growth to world GDP growth in terms of the following three components.

$$\sum_c \sum_i s_{ic}^V s_{ic}^K \dot{k}_{ic} = \sum_c s_c^V \sum_i \left(\frac{s_{ic}^V s_{ic}^K}{s_c^V} \right) \left(\dot{k}_{ic} - \dot{k}_c \right) + \sum_c s_c^V s_c^K \left(\dot{k}_c - \dot{k} \right) + s^K \dot{k} \tag{32}$$

$$= \rho_i^K + \rho_c^K + s^K \dot{k}. \tag{33}$$

Here, ρ_i^K is the contribution of reallocation of capital between industries. That is, ρ_i^K is positive if capital inputs grow faster in industries with higher marginal products of capital compared to the rest of the country. Similarly, ρ_c^K measures the effect of reallocation of capital across countries and is positive if capital growth is higher in countries with higher marginal products of capital. Finally, $s^K \dot{k}$. measures the contribution of world capital growth to world GDP growth.

World labor input (hours) growth: We can do a similar transformation for the labor inputs. This transformation is slighly simpler. Because all labor inputs are reported in hours worked, there is no need to construct quantity indices for the three labor inputs. The quantity of labor inputs used, in terms of hours, can be directly obtained from the data. Thus, we calculate the labor inputs for industries, countries, and the world as

$$L_{ic} = \sum_{\tau \in \{H,M,L\}} L_{ic}^\tau,\ L_i = \sum_c L_{ic},\ L_c = \sum_i L_{ic}, \text{ and } L = \sum_i L_i = \sum_c L_c. \tag{34}$$

In addition, we define the corresponding factor shares as

$$\tilde{s}_{ic}^L = \sum_{\tau \in \{H,M,L\}} s_{ic}^\tau,\ s_c^L = \left(\frac{\sum_i s_{ic}^V \tilde{s}_{ic}^L}{s_c^V} \right),\ s_i^L = \left(\frac{\sum_c s_{ic}^V \tilde{s}_{ic}^L}{s_i^V} \right),\ s^L = \sum_i \sum_c s_{ic}^V \tilde{s}_{ic}^L. \tag{35}$$

The contribution of hours growth to world GDP growth can now be written as

$$\sum_c \sum_i \sum_{\tau \in \{L,M,H\}} s_{ic}^V s_{ic}^\tau \dot{l}_{ic}^\tau = \sum_c \sum_i s_{ic}^V \tilde{s}_{ic}^L \sum_{\tau \in \{L,M,H\}} \left(\frac{s_{ic}^\tau}{\tilde{s}_{ic}^L} \right) \left(\dot{l}_{ic}^\tau - \dot{l}_{ic} \right) + \tag{36}$$

$$\sum_c s_c^V \sum_i \left(\frac{s_{ic}^V \tilde{s}_{ic}^L}{s_c^V} \right) \left(\dot{l}_{ic} - \dot{l}_c \right) + \sum_c s_c^V s_c^L \left(\dot{l}_c - \dot{l} \right) + s^L \dot{l}. \tag{37}$$

In order to write everything in terms of capital-to-labor growth (capital deepening), note that the sum of capital and labor shares in the country-industry and aggregate levels sum up to one: $\tilde{s}^L_{ic} + s^K_{ic} = 1$ and $s^L + s^K = 1$. Substituting for the labor shares in the above, we have

$$\sum_c \sum_i \sum_{\tau \in \{L,M,H\}} s^V_{ic} s^\tau_{ic} \dot{l}^\tau_{ic} = \sum_c \sum_i s^V_{ic} \tilde{s}^L_{ic} \sum_{\tau \in \{L,M,H\}} \left(\frac{s^\tau_{ic}}{\tilde{s}^L_{ic}} \right) \left(\dot{l}^\tau_{ic} - \dot{l}_{ic} \right) + \tag{38}$$

$$\sum_c s^V_c \sum_i \left(\frac{s^V_{ic}}{s^V_c} \right) \left(\dot{l}_{ic} - \dot{l}_c \right) + \sum_c s^V_c (\dot{l}_c - \dot{l}) + \left(1 - s^K\right) \dot{l} - \tag{39}$$

$$\sum_c s^V_c \sum_i \left(\frac{s^V_{ic} s^K_{ic}}{s^V_c} \right) \left(\dot{l}_{ic} - \dot{l}_c \right) - \sum_c s^V_c s^K_c \left(\dot{l}_c - \dot{l} \right) \tag{40}$$

$$= \rho^L_\tau + \rho^L_i + \rho^L_c + \left(1 - s^K\right) \dot{l} - \rho^L_{K_i} - \rho^L_{K_c}. \tag{41}$$

Because we distinguish between different types of labor, we have additional reallocation terms in this case. The term ρ^L_τ measures the effect of the reallocation of labor between skill-groups with industry-country combinations. This is a measure of the effect of labor quality growth on GDP growth. Similarly to the capital reallocation terms, ρ^L_i quantifies the effect of the reallocation of labor between industries but within countries on world GDP growth and ρ^L_c is the contribution of the reallocation of labor between countries to world GDP growth. $\rho^L_{K_i}$ is the contribution of the reallocation of labor between industries but within countries with lower capital share (higher labor share) and $\rho^L_{K_c}$ is the contribution of labor between countries with lower capital share (higher labor share) to world GDP growth.

Combining the capital and labor input growth and substituting in equation (27), we have

$$\dot{v} = \dot{l} + \rho^\tau_L + s^K(\dot{k} - \dot{l}) + \rho^L_i + \rho^L_c + \left(\rho^K_i - \rho^L_{K_i}\right) + \left(\rho^K_c - \rho^L_{K_c}\right) + \sum_c \sum_i s^V_{ic} \dot{z}_{ic} \tag{42}$$

We can combine the reallocation of capital between industries ρ^K_i and the reallocation of labor between industries with higher capital share $\rho^L_{K_i}$ to obtain a term $\rho^{K,L}_i$ which captures the reallocation of capital deepening to industries with higher capital share

$$\rho^{K,L}_i = \rho^K_i - \rho^L_{K_i} = \sum_c s^V_c \sum_i \left(\frac{s^V_c s^K_c}{s^V_c} \right) \left[\left(\dot{k}_{ic} - \dot{l}_{ic} \right) - \left(\dot{k}_c - \dot{l}_c \right) \right]. \tag{43}$$

We can do a similar combining for the reallocation of capital across countries ρ_c^L and the reallocation of labor across countries with higher capital share $\rho_{K_i}^L$ to obtain a term $\rho_c^{K,L}$ that captures the reallocation of capital deepening across countries with higher capital share

$$\rho_c^{K,L} = \rho_c^K - \rho_{K_c}^L = \sum_c s_c^V s_c^K \left[\left(\dot{k}_c - \dot{l}_c \right) - \left(\dot{k} - \dot{l} \right) \right]. \tag{44}$$

Thus, the world GDP growth is

$$\dot{v} = \dot{l} + s^K(\dot{k} - \dot{l}) + \left(\rho_i^L + \rho_c^L\right) + \left(\rho_i^{K,L} + \rho_c^{K,L}\right) + \rho_L^\tau + \sum_c \sum_i s_{ic}^V \dot{z}_{ic}. \tag{45}$$

World average labor productivity growth: We define world average labor productivity growth, $\dot{l}_p$, as the difference between world GDP growth and labor hours growth. That is,

$$\begin{aligned} \dot{alp} &= \dot{v} - \dot{l} && (46) \\ &= \left(\rho_i^L + \rho_c^L\right) + \sum_c \sum_i s_{ic}^V \dot{alp}_{ic} && (47) \\ &= s^K(\dot{k} - \dot{l}) + \left(\rho_i^L + \rho_c^L\right) + \left(\rho_i^{K,L} + \rho_c^{K,L}\right) + \rho_L^\tau + \sum_c \sum_i s_{ic}^V \dot{z}_{ic}, && (48) \end{aligned}$$

where $\dot{alp}_{i,j} = \dot{v}_{i,j} - \dot{l}_{i,j}$, is average labor productivity growth in industry i in country c. Thus, world average labor productivity growth is the sum of the effect of capital deepening, reallocation of labor across countries and industries, reallocation of capital deepening across countries and industries, reallocation of labor between skill-groups and country-industry tfp growth.

World TFP growth: We define world TFP growth, $\dot{tfp}$, as the difference between world average labor productivity growth and capital deepening. That is,

$$\begin{aligned} \dot{tfp} &= \dot{alp} - s^K \left(\dot{k} - \dot{l}\right) && (49) \\ &= \left(\rho_i^L + \rho_c^L\right) + \left(\rho_i^{K,L} + \rho_c^{K,L}\right) + \rho_L^\tau + \sum_c \sum_i s_{ic}^V \dot{z}_{ic}. && (50) \end{aligned}$$

Thus, world GDP growth is the sum of the contributions by labor input growth, average labor productivity growth and world TFP growth. World TFP growth, in turn, consists of six different parts: (*i*) cross-industry reallocation of labor within countries (*ii*) cross-country reallocation of labor, (*iii*) cross-industry reallocation of capital deepening within countries, (*iv*) cross-country reallocation of capital deepening, (*v*) reallocation of labor between skill groups and (*vi*) country-industry TFP growth.

A.3 Construction of PPP-deflated value-added

In this section, we explain in more detail how we constructed a measure of PPP-deflated value added by double-deflating the benchmark PPP relative prices constructed by Timmer *et al.* (2007) and Inklaar & Timmer (2014).

PPP benchmark prices

The PPP benchmark tables report relative prices of industry gross output for industries and countries in the dataset. The numeraire good is US GDP in 2005, i.e. the relative price of US GDP in the benchmark table is 1. This means the relative price reported, $\mathcal{P}_{i,j,t}$, is the number of U.S. dollars in 2005 per unit of output in industry i in country c in 2005 relative to the number of U.S. dollars in 2005 per unit of U.S. GDP. It is useful to consider this in mathematical form

$$\mathcal{P}_{i,j,t} = \frac{\$/GO_{i,j,t}}{\$/USGDP_t} = \frac{USGDP_t}{GO_{i,j,t}} \text{ for } t = 2005. \tag{51}$$

The first step is to calculate a time series for $\mathcal{P}_{i,j,t}$ for $t \neq 2005$. This can be done by using the time series for the price index for gross output in industry i in country c in year t, i.e. $P_{i,j,t}$, as well as the U.S. GDP deflator, $\mathcal{P}_t$.

Using these two time series, we can construct

$$\mathcal{P}_{i,j,t} = \mathcal{P}_{i,j,2005} \frac{P_{i,j,t}/P_{i,j,2005}}{\mathcal{P}_t/\mathcal{P}_{2005}}. \tag{52}$$

This gives us a time series of PPP conversion rates of the real gross output values into U.S. GDP.

Dollars to PPP, denominated in US GDP

The conversion factor derived above then allows us to convert nominal gross output in industry i in country c in year t, i.e. $P_{i,j,t}Y_{i,j,t}$, into units of U.S. GDP. Let $Y^*_{i,j,t}$ be output in industry i in country c in year t measured in PPP units of U.S. GDP in the same period, then we can calculate it through

$$Y^*_{i,j,t} = \frac{P_{i,j,t}Y_{i,j,t}}{\mathcal{P}_{i,j,t}}\frac{1}{\mathcal{P}_t} = \frac{P_{i,j,t}Y_{i,j,t}}{P^*_{i,j,t}}, \text{ where } P^*_{i,j,t} = \mathcal{P}_{i,j,t}\mathcal{P}_t. \tag{53}$$

This equation means the following. The inverse of $\mathcal{P}_{i,j,t}$ converts dollars of nominal gross output of industry i in country c in year t into dollars of nominal U.S. GDP in year t according to the PPP adjustment. Dividing these dollars by the U.S. GDP deflator then gives the quantity of U.S. GDP produced in the sector.

Now, this allows us to calculate PPP adjusted *gross output*. However, what we really want to calculate is PPP adjusted *value added*. To obtain this, we need to do an additional calculation.

Value added in terms of PPP

To PPP adjust value added, we basically PPP adjust the nominal gross output and intermediate inputs terms in the definition of value added. That is, nominal value added of industry i in country c in year t is the difference between nominal gross output and the nominal value of intermediate inputs.

$$P^V_{i,j,t}V_{i,j,t} = P_{i,j,t}Y_{i,j,t} - \sum_{i'}\sum_{j'} P_{i',j',t}X_{i',j',t}. \tag{54}$$

Now PPP adjusted value added of industry i in country c during year t, i.e. $V^*_{i,j,t}$, is obtained by PPP adjusting each of the individual nominal components. That is,

$$V^*_{i,j,t} = \frac{P_{i,j,t}Y_{i,j,t}}{P^*_{i,j,t}} - \sum_{i'}\sum_{j'} \frac{P_{i',j',t}X_{i',j',t}}{P^*_{i',j',t}}. \tag{55}$$

The implicit PPP deflator of value added of industry i in country c in year t is then given by

$$P^{V*}_{i,j,t} = \frac{P^V_{i,j,t}V_{i,j,t}}{V^*_{i,j,t}}. \tag{56}$$

The calculation of (55) involves figuring out the intermediate inputs from all over the world using the WIOT and this requires using the input-output tables.

The other problem is that we cannot PPP adjust all intermediate inputs. One way of dealing with it is to use the same PPP deflator for the intermediate inputs for which we have no data compared to those for which we have data. The PPP deflator of the intermediate inputs that are covered is calculated using

$$P_{i,j,t}^{X*} = \sum_{i'} \sum_{j'} \frac{P_{i',j',t} X_{i',j',t}}{\sum_{i''} \sum_{j''} P_{i'',j'',t} X_{i'',j'',t}} P_{i',j',t}^{*}. \tag{57}$$

where i' and j' cover the intermediate inputs for which PPP adjusted deflators are measured. We then use this to deflate all the nominal intermediate inputs.

So, practically, we calculate $P_{i,j,t}^{X*}$ for each industry i, country c, and year t for all the intermediate inputs for which we have PPP adjusted gross output deflators. We then deflate *all* nominal intermediate inputs by this deflator to calculate PPP adjusted value added. We then calculate the implied PPP adjusted value-added deflator, (56).

This then allows us to calculate all the PPP adjusted data that we need for our analysis.

A.4 Accounting for the importance of deviations from PPP

We denote PPP-deflated value added by v^*. Our calculations include both the growth rate of world GDP calculated using dollar-denominated value-added share weights, i.e.

$$\dot{v} = \sum_{i} \sum_{c} s_{ic}^{V} \dot{v}_{ic}, \tag{58}$$

and the growth rate of PPP-deflated world GDP, calculated using PPP-based value-added share weights, i.e.

$$\dot{v}^* = \sum_{i} \sum_{c} s_{ic}^{V^*} \dot{v}_{ic}^{*}. \tag{59}$$

Using a shift-share analysis, we can split up the difference between dollar-weighted and PPP-weighted world GDP growth as follows

$$\dot{v} = (\dot{v} - \dot{v}^*) + \dot{v}^* \tag{60}$$

$$= \frac{1}{2}\sum_i \sum_c \left(s_{ic}^V + s_{ic}^{V^*}\right)(\dot{v}_{ic} - \dot{v}_{ic}^*) + \frac{1}{2}\sum_i \sum_c (\dot{v}_{ic} + \dot{v}_{ic}^*)\left(s_{ic}^V - s_{ic}^{V^*}\right) + \dot{v}^*. \tag{61}$$

The first term on the right-hand side of this equation captures the part of the difference between the two world GDP growth measures that is due to countries-industries with high value-added shares growing faster in dollar-denominated value added than in PPP-deflated value added. The second term is the part of the difference due to the differences in the dollar- and PPP-denominated value-added shares.

In terms of ALP growth, we can write the above equation as

$$\dot{v} = \dot{l} + \dot{alp} \tag{62}$$

$$= \dot{l} + (\dot{v} - \dot{v}^*) + \dot{alp}^* \tag{63}$$

$$= \dot{l} + (\dot{v} - \dot{v}^*) + \sum_i \sum_c s_{ic}^{V^*}\left(\dot{v}_{ic}^* - \dot{l}\right) \tag{64}$$

$$= \dot{l} + (\dot{v} - \dot{v}^*) + \sum_i \sum_c s_{ic}^{V^*}\left(\dot{v}_{ic}^* - \dot{l}_{ic}\right) + \sum_i \sum_c s_{ic}^{V^*}\left(\dot{l}_{ic} - \dot{l}\right) \tag{65}$$

$$= \dot{l} + (\dot{v} - \dot{v}^*) + \sum_i \sum_c s_{ic}^{V^*}\left(\dot{v}_{ic}^* - \dot{l}_{ic}\right) \tag{66}$$

$$+ \sum_i \sum_c \left(s_{ic}^{V^*} - s_{ic}^V\right)\left(\dot{l}_{ic} - \dot{l}\right) + \sum_i \sum_c s_{ic}^V\left(\dot{l}_{ic} - \dot{l}\right) \tag{67}$$

The latter term in this equation is the reallocation of labor term we included in our previous accounting exercise. The first term of the last line of this equation, i.e.

$$\rho^{V^*} = \sum_i \sum_c \left(s_{ic}^{V^*} - s_{ic}^V\right)\left(\dot{l}_{ic} - \dot{l}\right) \tag{68}$$

captures the effect of the reallocation of labor through deviations from PPP. Note that country-industries for which $s_{ic}^{V^*} > s_{ic}^V$ are ones that have lower than average PPP-prices per dollar. These relatively low PPP prices per dollar can be interpreted as a cost advantage. Thus, this term captures to what extent the reallocation of labor to country-industries with a cost-advantage contributes to world ALP-PPP growth. We split the above term up into parts for within-country between industries and across countries

$$\rho^{V^*} = \sum_i \sum_c \left(s_{ic}^{V^*} - s_{ic}^{V}\right)\left(\dot{l}_{ic} - \dot{l}\right) = \sum_c \sum_i \left(s_{ic}^{V^*} - s_{ic}^{V}\right)\left(\dot{l}_{ic} - \dot{l}_c\right) + \tag{69}$$

$$\sum_c \left(s_c^{V^*} - s_c^{V}\right)\left(\dot{l}_c - \dot{l}\right) \tag{70}$$

$$= \rho_i^{V^*} + \rho_c^{V^*} \tag{71}$$

Using this result, we can then split up dollar-denominated world GDP growth into the following terms:

$$\dot{v} = \dot{l} + \frac{1}{2}\sum_i \sum_c \left(s_{ic}^{V} + s_{ic}^{V^*}\right)\left(\dot{v}_{ic} - \dot{v}_{ic}^*\right) + \frac{1}{2}\sum_i \sum_c \left(\dot{v}_{ic} + \dot{v}_{ic}^*\right)\left(s_{ic}^{V} - s_{ic}^{V^*}\right) + a\dot{l}p^* \tag{72}$$

$$= \dot{l} \tag{73}$$

$$+\frac{1}{2}\sum_i \sum_c \left(s_{ic}^{V} + s_{ic}^{V^*}\right)\left(\dot{v}_{ic} - \dot{v}_{ic}^*\right) + \frac{1}{2}\sum_i \sum_c \left(\dot{v}_{ic} + \dot{v}_{ic}^*\right)\left(s_{ic}^{V} - s_{ic}^{V^*}\right) \tag{74}$$

$$+\rho_i^{V^*} + \rho_c^{V^*} + \rho_i^{L} + \rho_c^{L} \tag{75}$$

$$+\sum_i \sum_c s_{ic}^{V^*} a\dot{l}p_{ic}^*. \tag{76}$$

The terms in this equation each correspond to lines in Table 5.

B Data details

Table B.1: List of countries in each vintage of SEA and the ones that have PPP data

	Country	SEA 2013	SEA 2016	PPP
1.	Australia	✓	✓	✓
2.	Austria	✓	✓	✓
3.	Belgium	✓	✓	✓
4.	Bulgaria	✓	✓	✓
5.	Brazil	✓	✓	✓
6.	Canada	✓	✓	✓
7.	Switzerland		✓	
8.	China	✓	✓	✓
9.	Cyprus	✓	✓	✓
10.	Czech Republic	✓	✓	✓
11.	Germany	✓	✓	✓
12.	Denmark	✓	✓	✓
13.	Spain	✓	✓	✓
14.	Estonia	✓	✓	✓
15.	Finland	✓	✓	✓
16.	France	✓	✓	✓
17.	United Kingdom	✓	✓	✓
18.	Greece	✓	✓	✓
19.	Croatia		✓	
20.	Hungary	✓	✓	✓
21.	Indonesia	✓	✓	✓
22.	India	✓	✓	✓
23.	Ireland	✓	✓	✓
24.	Italy	✓	✓	✓
25.	Japan	✓	✓	✓
26.	South Korea	✓	✓	✓
27.	Lithuania	✓	✓	✓
28.	Luxembourg	✓	✓	✓
29.	Latvia	✓	✓	✓
30.	Mexico	✓	✓	✓
31.	Malta	✓	✓	✓
32.	Netherlands	✓	✓	✓
33.	Norway		✓	
34.	Poland	✓	✓	✓
35.	Portugal	✓	✓	✓
36.	Romania	✓	✓	✓
37.	Russia	✓	✓	✓
38.	Slovakia	✓	✓	✓
39.	Slovenia	✓	✓	✓
40.	United States	✓	✓	✓
41.	Turkey	✓	✓	✓
42.	Taiwan	✓	✓	
43.	United States	✓	✓	✓

Table B.2: Country Classification

Classification	Country
United States	
China	
Japan	
Germany	
France	
Great Britain	
Brazil	
Italy	
Russia	
India	
Other America	Canada and Mexico
Other Asia	Indonesia, Republic of Korea, Turkey and Taiwan
Other Euro Area	Austria, Belgium, Cyprus, Spain, Estonia, Finland, Greece, Ireland, Lithuania, Luxemberg, Latvia, Malta, Netherlands, Norway, Portugal, Slovakia, Slovenia
Other Europe	Bulgaria, Croatia, Czech Republic, Denmark, Hungary, Poland, Romania, Sweden, Switzerland
Other Oceania	Australia

The industries were classified into major categories in table (B.3) in order to be consistent with the North American Industry Classification System (NAICS):

Table B.3: Industry Classification

Major sector	ISIC v3 industries included[1]
Agriculture	Agriculture, Forestry, Fishing and Hunting, Mining
Construction	Construction
Nondurable manufacturing	Manufacturing
Durable manufacturing	Manufacturing
Trade, transportation and utilities	Wholesale Trade, Retail Trade, Transportation and Warehousing, Utilities
Finance, insurance and real estate (FIRE)	Finance and Insurance, Real Estate Rental and Leasing
Business services	Information, Professional, Scientific, and Technical Services, Management of Companies and Enterprises
Education and healthcare	Educational Services, Health Care and Social Assistance
Hospitality	Accommodation and Food Services
Personal services	Arts, Entertainment, and Recreation, Other Services, Administrative and Support and Waste Management and Remediation Services
Government	Public Administration
Households	

[1] For WIOD vintage 2016 ISIC v4 industries are aggregated to ISIC v3 using the crosswalk provided in the data documentation (Gouma *et al.* , 2018).

- **Gross Value Added**: This is the gross value added at current basic prices (in millions of national currency). The volume index which is normalized to 100 in 1995 and the price level normalized to 100 in 1995 are provided in the tables. The volume index of gross value added is the foundation of GDP growth calculation. We use the exchange rates provided in WIOD to express the nominal values in current U.S. Dollars. These exchange rates, however, are not PPP adjusted.

- **Capital**: Data on capital compensation (in millions of national currency) and nominal gross fixed capital formation (in millions of national currency) along with the volume and price index of the latter is used to calculate capital deepening and reallocation of capital across countries and industries.

- **Labor**: Number of employees (thousands) and total hours worked by persons engaged (millions) provide information on the growth in hours along with reallocation of labor across countries and industries. It should be mentioned that the data on hours worked in China were imputed for the period 2008-2014 from the International Labor Organization (ILO). Data on labor compensation (in millions of national currency) and total hours worked are decomposed based on skill level of the labor into three broad groups: low-, medium- and high-skill. Labor skill types are 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). This decomposition forms the basis of our labor quality growth measurement.