World Productivity: 1996 - 2014*

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Abstract

We account for the sources of world productivity growth, using data for more than 36 industries and 40 economies and accounting for changes in the allocation of resources. Over time, productivity growth in advanced economies slowed but emerging markets grew more quickly, which kept global productivity growth relatively constant until 2010. World productivity growth is highly volatile from year to year, which primarily reflects shifts in the reallocation of labor. Deviations from PPP account for about a third of the shifts. Though markups are large and rise over time, their inclusion only modestly affects measured industry-level productivity growth. Instead, they affect the imputed importance of capital reallocation for world GDP growth.

Keywords: Growth accounting, misallocation, productivity, purchasing power parity, world economy.

JEL codes: F43, O47, O50.

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1 Introduction

We trace world productivity growth from 1996-2014 to its industry sources, using data on more than 36 industries and 40 countries. "World productivity" is often discussed in models of economic growth and innovation (e.g., Caselli & Coleman, 2006) in the context of a world technology frontier. But few studies formally account for world productivity growth. In this paper, we use new global growth-accounting techniques and datasets to decompose world GDP growth into parts driven by technology, labor, and capital—importantly, accounting for markups and factor reallocation.

Our results provide a clear narrative regarding global productivity. First, world productivity growth—measured as either Average Labor Productivity (ALP) or Total Factor Productivity (TFP)—is highly volatile from year to year and even over multi-year periods. Second, despite this volatility, the contribution of underlying productivity growth at a country-industry level (that is, the weighted average of productivity growth across the 36 industries in each of the 40 or so countries, for a total of some 1,440 country-industries) is relatively constant until the Great Recession. Since the Great Recession, growth in country-industry productivity (as well as in overall world productivity) has been markedly slower. Third, (net) reallocations of labor across countries are the major source of year-to-year volatility in world productivity growth—reconciling the first two results. Labor reallocation is, on average, a drag of about half a percentage point per year on world productivity growth, as hours typically grow faster in low-wage/low-productivity countries.

Mechanically, our labor-reallocation term, as in the broader growth-accounting literature, reflects the cross-sectional covariance between hours growth and wage levels. The effect arises because ALP or TFP weight all hours equally—wherever the work takes place. But wages differ substantially across countries. Firm optimization implies that these heterogeneous wages reflect the heterogeneous value of labor's marginal product. On average, labor hours have grown faster in low-wage/low-marginal-product locations, creating the persistent drag on productivity growth. But there is substantial time series variation in the cross-sectional covariance, creating the volatility.

We discuss several interpretations of labor reallocation. A natural interpretation is as shifts in the global misallocation of labor. Considerable research following Hsieh & Klenow (2009) argues that resource misallocation can explain TFP differences across countries. The same effect can work in the time series. If factor prices differ across firms, say because of distortionary taxes, then marginal value products won't be equalized. Global misallocation arguably rises if hours grow faster in low-wage countries, in the sense that global output would have risen by more if those hours had grown in a high-wage (high marginal product) country.

Our results do not hinge on this misallocation interpretation. One alternative is that productivity differences may be embodied in workers themselves. For example, wages may be lower in emerging market economies because educational attainment (and, as a result, productivity) is lower. Labor reallocation would appropriately capture these wage and productivity differences. But moving a worker from a low-wage to a high-wage country would *not* raise global output. That said, as we discuss in Section 5, the weight of the evidence is that moving such a worker would, in fact, raise his or her marginal product. In addition, even if moving the worker *would* raise global output, the reallocation might not be Pareto-efficient if each country has its own representative consumer.

Before we can reach the three broad conclusions above, we make three contributions. First, we develop a new growth-accounting decomposition that isolates distortions in product, labor, and capital markets. Second, to implement this decomposition, we use the World Input-Output Database (WIOD) as a global growth accounting database. We augment the 2016 vintage of the WIOD database with new data on capital services for industries across countries. Third, to allow for output distortions, we extend recent work by Barkai (2019) and Karabarbounis & Neiman (2018) to the world. Specifically, we estimate (rising) economic profits and (sizeable) markups of price over marginal cost across countries and industries. Interestingly, though profits and markups are quantitatively important—with both labor and capital shares of output falling—the broad narrative about global productivity is robust to whether we control for markups or not.

Our global growth accounting method builds on three strands of literature. The first focuses on cross-country productivity levels using economy-wide data (Conference Board, 2015; Feenstra *et al.*, 2015). These studies do not include industry-level data, so they do not estimate the industry origins of world productivity growth. Moreover, they also do not formally account for reallocation of resources across countries, which turns out to be quantitatively important in the data.

The second strand of the literature, based on the methodology pioneered by Domar (1962), Hulten (1978), and (especially) Jorgenson *et al.* (1987), studies productivity growth using industry-level data.[1] These studies analyze the industry origins of productivity growth and the importance of the factor reallocation, but only at the country level or for a few countries. Within countries, factor reallocation typically appears modest (e.g., Jorgenson *et al.*, 2016, Figure 14; Samuels, 2017) and, indeed, is often ignored. In a global setting, in contrast, we find that factor reallocation is of first order importance.[2]

The growth-accounting in this second strand of literature does not account for markup distortions in output markets. As a result, they show how to aggregate country-industry TFP growth, regardless of whether country-industry TFP growth represents changes in technology. In the presence of markups of price over marginal cost, these TFP changes are not, in general, technology changes.

The third strand of literature corrects country-industry TFP changes for markups. This literature goes back at least to Hall (1986). Most closely, we follow Basu & Fernald (2002) and related literature in aggregating productivity in an economy with distortions in product, capital, and labor markets. Baqaee & Farhi (2019b) is an important recent contribution. We develop a novel variant of this accounting that isolates the terms of interest.

Specifically, we start from a decomposition of world GDP growth, measured on the production side, that is similar to that in Jorgenson *et al.* (1987). We then extend it to the case with markups, along the lines of Basu & Fernald (1997) and Basu & Fernald (2002). Our decomposition isolates terms that represent factor reallocation and the effects of markup distortions.[3]

The data we use are two vintages (2013 and 2016) of the 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. Unfortunately, industry capital services are missing from the 2016 vintage of the data. We address this shortcoming by constructing the missing

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

[2] Wu (2016, Table 6.4), finds that factor reallocation in China, measured the same way we do, is large in magnitude and quite variable across subperiods. In our data, the labor reallocation effect is mainly across countries though some countries have sizeable within-country effects.

[3] The decomposition is also closely related to Hsieh & Klenow (2009). Our growth accounting requires little structure other than cost-minimization. We are then able to analyze observed shifts and reallocations, taking as given the (potentially) distorted equilibrium. But without additional structure (e.g., on the demand side of the economy), we cannot do counterfactuals the way Hsieh & Klenow (2009) can. Fernald & Neiman (2011) also discuss links between growth-accounting approaches and the Hsieh & Klenow (2009) approach, in a two-sector setting.

capital services data. We also estimate rates of pure economic profits and (under the assumption of constant returns to scale) markups for all countries and industries.

Our main takeaways—volatile world productivity, relatively smooth country-industry productivity, and a sizeable role for labor reallocation—are robust to the measurement assumptions we make. They hold for ALP, for TFP calculated under the Solow assumption of perfect competition (price equals marginal cost), and for TFP calculated using our estimated markup estimates.

The relative constancy of productivity at a country-industry level until the Great Recession masks a marked change in the regional composition of this part of world productivity growth. Consistent with other evidence, our results reveal a slowdown in growth in ALP and TFP for advanced countries starting in the second half of the 2000s, prior to the Great Recession.[4] At a global level, this slowdown is offset, however, by an acceleration of productivity growth in emerging economies, most notably India and China. After 2007 (for TFP) or 2010 (for labor productivity), the productivity slowdown is more widespread.

In addition to labor reallocation, our growth accounting method isolates the effect of capital reallocation. When we do not allow for markups of price over marginal cost, reallocations of capital have a substantial effect on growth. The bulk of this reallocation is across industries *within* countries rather than *across* countries: Within countries, capital input grows faster in industries with a higher apparent internal rate of return.

However, after accounting for markups, the implied effect of capital reallocation is small, since the high apparent internal rate of return to capital is reapportioned to pure economic profits. Markups also play a quantitatively important role in accounting for world output growth. Interestingly, the inclusion of markups has only a minor effect on the estimated country-industry contribution of technology to global productivity.

In most of our results, nominal values are measured in dollars converted using market exchange rates. Thus, the outsized role we find for labor reallocation hinges on the assumption that relative dollar-denominated wages are equal to relative marginal productivity levels of labor. 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. We can then

[4]See, for example, Fernald (2015), ECB (2017), and Fernald & Inklaar (2020).

measure relative productivity levels directly, rather than inferring them from factor prices.

With this in mind, we generalize the growth accounting methods we use to take into account deviations from PPP. This correction for PPP differentials accounts for only a third of the labor reallocation effect that arises using dollar-based measures of world GDP. Even after the PPP correction, labor reallocation is still, on net, a substantial drag on world productivity growth and contributes a lot to its volatility. This suggests that it is important to understand barriers to factor movements and distortions in labor markets when analyzing global economic performance.

2 Global growth accounting with distortions

In this section, we introduce a growth-accounting decomposition of world GDP that separates the parts of GDP growth accounted for by changes in technology, aggregate labor, and aggregate capital from the parts of GDP growth driven by changes in factor reallocation and markups.

Our decomposition draws on a long literature, starting with Hulten (1978), that traces aggregate productivity to its industry sources. Hulten considered the case where the market allocation of resources is efficient. Jorgenson *et al.* (1987) and Basu & Fernald (2002) extend Hulten's results to cases with market imperfections, including (in the latter case) imperfect competition. Because of these imperfections, the same factor of production may have a different value of its marginal product, depending on where it is used. Our decomposition builds on this literature.

The growth-accounting decomposition we develop here combines terms that isolate particular distortions. It is important to recognize that, with distortions, there is no unique decomposition and that the one applied depends on the research question. Our aim is to isolate the importance of growth in technology, capital, and labor for world GDP growth as well as the quantitative effects on world GDP growth of distortions in product, capital, and labor markets. The specific decomposition we use here is designed to do so. We discuss how it relates to others in the literature (including a recent contribution by Baqaee & Farhi (2019a,b)).

2.1 Producer level

This sub-section discusses the implications of distortions for productivity analysis at the producer level. The next sub-section discusses aggregation in this economy.

We analyze the static cost-minimizing decisions of producers to purchase inputs, and on how those decisions are affected by technology and factor prices. The (world) economy has n sectors, indexed by $i = 1 \ldots n$. Each sector reflects a particular country-industry combination. The sector takes technology, Z_i, as given; Z_i, and all variables below, have time subscripts that we suppress for readability. Producers pay R_i to rent capital, W_i to hire workers, and $\left(1+\tau_i^j\right) P_j$ to purchase intermediate inputs of product j (so P_j is the net price received by the producer of product j). Any (implicit or explicit) taxes on capital or labor usage are incorporated into the W_i and R_i. Such taxes would affect the interpretion of some of the effects, but not their derivations.

Producers choose factor inputs, $\left\{K_i, L_i, \{M_{i,j}\}_{j=1}^n\right\}$, to minimize their cost of production

$$R_i K_i + W_i L_i + \sum_j \left(1+\tau_i^j\right) P_j M_{i,j}, \tag{1}$$

subject to the constraint that they produce a given level of output

$$Y_i = F_i\left(K_i, L_i, \{M_{i,j}\}_{j=1}^n, Z_i\right). \tag{2}$$

Producers in sector i charge a price, P_i, that includes a potential net markup, μ_i, over marginal cost. In other words, if MC_i is marginal cost, then $(1+\mu_i) = P_i/MC_i$.

Firms' cost-minimizing first-order conditions for capital, labor, and intermediate inputs imply

$$\begin{aligned}
(1+\mu_i)R_i = P_i F_i^K \quad &, \text{where } F_i^K = \frac{\partial}{\partial K_i} F_i\left(K_i, L_i, \{M_{i,j}\}_{j=1}^n, Z_i\right), \\
(1+\mu_i)W_i = P_i F_i^L \quad &, \text{where } F_i^L = \frac{\partial}{\partial L_i} F_i\left(K_i, L_i, \{M_{i,j}\}_{j=1}^n, Z_i\right), \\
(1+\mu_i)\left(1+\tau_i^j\right) P_j = P_i F_i^j \quad &, \text{where } F_i^j = \frac{\partial}{\partial M_{i,j}} F_i\left(K_i, L_i, \{M_{i,j}\}_{j=1}^n, Z_i\right), \forall j.
\end{aligned} \tag{3}$$

These first-order conditions state that the value of the marginal products are a markup $(1+\mu_i)$ above the nominal cost of the factor to the producer. We can, equivalently, express these first-order conditions in terms of factor shares and output elasticities. For each input J in industry i, define $\tilde{s}_i^K$ as the share of cost of input J_i in total revenue (i.e., in nominal gross output). For example, for $J_i = L_i$, $\tilde{s}_i^L$ is labor's share in revenue, $\frac{W_i L_i}{P_i Y_i}$.

It follows that for any factor J_i, the output elasticity is a markup over the factor's revenue share:

$$\frac{F_i^J J_i}{Y_i} = (1 + \mu_i)\, \tilde{s}_i^J. \tag{4}$$

As is standard since Solow (1957), we differentiate the production function to express output growth, $\dot{y}_i$, as the output-elasticity-weighted growth in factor inputs plus the contribution of technological progress. We follow Hall (1990) and use (4) to substitute for the output elasticities (normalizing the elasticity with respect to technology to one, $F_i^Z Z_i / F_i = 1$). We find

$$\dot{y}_i = (1 + \mu_i) \left(\tilde{s}_i^K \dot{k}_i + \tilde{s}_i^L \dot{l}_i + \sum_j \tilde{s}_i^j \dot{m}_{i,j} \right) + \dot{z}_i. \tag{5}$$

If there are zero profits, then payments to factors of production exhaust revenue and the factor shares sum to one. The shares sum to less than one if there are pure economic profits. Although we have suppressed time subscripts, factor shares as well as the markup can vary with time.

Given data on factor shares and growth in inputs and output, any assumed markup μ_i implies a value for the residual measure of technology growth $\dot{z}_i$. In this sense, equation (5) can be viewed as an identity that relates inputs, output, markups, and technology. Of course, $\dot{z}_i$ only measures actual technology growth if the assumptions are correct.

Concretely, consider the Solow residual. If we assume constant returns and perfect competition ($\mu_i = 0$), then the factor shares sum to one and equation (5) defines $\dot{z}_i$ as the standard Solow residual. It can be calculated from the data even if markups and pure economic profits are *not* zero. In that case, of course, $\dot{z}_i$ is no longer (in general) a measure of technology change, so its economic interpretation is less clear.

Aggregate output is a value-added concept, which nets out intermediate-input use. So it is useful to re-express the industry expression (5) in terms of value added. The Divisia definition of industry value added is

$$\dot{v}_i = \frac{P_i Y_i}{P_i^V V_i} \left[\dot{y}_i - \sum_j \tilde{s}_i^j \dot{m}_{i,j} \right]. \quad (6)$$

Value added, as Basu & Fernald (1995) point out, is like a partial Solow residual: It subtracts revenue-share-weighted growth in intermediate inputs from gross-output growth, with no adjustment for markups. It then rescales by the ratio of nominal gross output to nominal value added from the point of view of the producer, where $P_i^V V_i = P_i Y_i - \sum_j \left(1 + \tau_i^j\right) P_j M_{i,j}$ (i.e., nominal gross output less payments to purchase intermediate inputs).

It will also be useful to write output growth identically as

$$\dot{y}_i \equiv \left(\frac{\mu_i}{1 + \mu_i} \right) \dot{y}_i + \left(\frac{1}{1 + \mu_i} \right) \dot{y}_i. \quad (7)$$

Substituting this expression into (5), we find

$$\dot{y}_i = \left(\frac{\mu_i}{1 + \mu_i} \right) \dot{y}_i + \left(\tilde{s}_i^K \dot{k}_i + \tilde{s}_i^L \dot{l}_i + \sum_j \tilde{s}_i^j \dot{m}_{i,j} \right) + \left(\frac{1}{1 + \mu_i} \right) \dot{z}_i \quad (8)$$

We can now substitute (8) into (6) to find

$$\dot{v}_i = \frac{P_i Y_i}{P_i^V V_i} \left(\frac{\mu_i}{1 + \mu_i} \right) \dot{y}_i + \left(s_i^K \dot{k}_i + s_i^L \dot{l}_i \right) + \left(\frac{1}{1 + \mu_i} \right) \dot{z}_i. \quad (9)$$

In this equation, s_i^K and s_i^L are payments to capital and labor, respectively, as shares of nominal value added. For example, $s_i^L = W_i L_i / (P_i^V V_i)$.

The second and third terms in equation (9) show that growth in value added depends on share-weighted growth in capital and labor and technology. With imperfect competition, however, value added-growth is not, in general, simply a function of these factors. Rather, as captured in the first term on the right-hand side, imperfect competition implies that there is an extra effect of inputs (including intermediates) and technology.[5]

[5] In the special case in which intermediate inputs and gross output are used in fixed proportions ($\dot{y}_i = \dot{m}_i = (\sum_j \tilde{s}_i^j \dot{m}_{i,j}) / \tilde{s}_i^M$ where $\tilde{s}_i^M = \sum_j \tilde{s}_i^j$), then it is straightforward to show that value-added growth can be written so that it does depend just on primary input growth; there is a "value-added' markup multiplying share-weighted primary input growth that exceeds the gross-output markup μ_i. Otherwise, intermediate inputs also matter (see Basu & Fernald (1997)). Equation (9) is agnostic about the production structure.

Note that we have made no assumptions so far about returns to scale (the sum of the output elasticities, $\sum_J \frac{F_i^J J_i}{Y_i}$).

2.2 Aggregate growth accounting

Divisia growth in aggregate real GDP is value-added-weighted growth in industry real value added:

$$\dot{v} = \sum_i s_i^V \dot{v}_i, \text{ where } s_i^V = \frac{P_i^V V_i}{P^V V} \text{ and } P^V V = \sum_i P_i^V V_i. \tag{10}$$

Substituting for industry value-added growth from equation (9) yields

$$\dot{v} = \sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i + \sum_i s_i^V s_i^K \dot{k}_i + \sum_i s_i^V s_i^L \dot{l}_i + \sum_i s_i^D \frac{\mu_i}{(1+\mu_i)} \dot{y}_i. \tag{11}$$

In this expression, the Domar (1962) weights of sector i are given by the ratio of nominal industry gross output to nominal aggregate value added, i.e.,

$$s_i^D = \frac{P_i Y_i}{P^V V}.$$

The first term in equation (11) relates aggregate output growth to the contribution of country-industry technology shocks. Dividing the Domar weight by the gross markup, $(1+\mu_i)$ removes the effect of the markup on prices from this term, so that it values technology shocks using marginal cost rather than prices. The second and third terms relate aggregate output growth to the contribution of country-industry capital and labor growth. The final term captures the "extra" value added that comes from markups and isn't already accounted for by primary inputs or by technology.

Of course, aggregate productivity is typically defined in terms of aggregate inputs. (For example, aggregate labor input is given by the sum of hours across country-industries, $L = \sum_i L_i$.) It will be useful to add and subtract growth in aggregate capital and labor. The resulting decomposition, which we will use for our analysis of world productivity, is

$$\begin{aligned}\dot{v} &= \sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i + s^K \dot{k} + s^L \dot{l} \\ &+ \sum_i s_i^D \frac{\mu_i}{(1+\mu_i)} \dot{y}_i + \sum_i s_i^V s_i^K \left(\dot{k}_i - \dot{k}\right) + \sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right).\end{aligned} \tag{12}$$

Here, the aggregate and sector-specific factor shares in value added equal

$$s^K = \sum_i s_i^V s_i^K, \text{ where } s_i^K = \frac{R_i K_i}{P_i^V V_i} \text{ and } s^L = \sum_i s_i^V s_i^L, \text{ where } s_i^L = \frac{W_i L_i}{P_i^V V_i}. \tag{13}$$

These shares include any implicit or explicit tax wedges in factor costs. For example, for labor they measure employee compensation from the point of view of employers.

Equation (12) allows us to account for the sources of growth in real value added in the world economy. The three terms in the first line are the direct effect of technology and the contributions of growth of aggregate capital and labor. The terms in the second line account for how the change in the global allocation of productive resources affects world GDP growth.

2.3 Interpreting changes in resource allocation

Because the terms in equation (12) that measure the effects of markups and changes in resource allocation turn out to be important in our results, we discuss each of them here.

Markups and product market distortions The first term on the second line of (12) captures the effect of markups. In a direct growth accounting sense, this term captures the fact that, with markups, the revenue-share-weighted growth in primary inputs doesn't capture the full productive effect of capital, labor, and intermediate input usage.

Clearly, markups are also related to static efficiency and welfare.[6] Markups most obviously lead to static efficiency losses by, for example, distorting the labor-leisure choice; or by distorting producers's choices about the use of intermediate versus primary inputs. Note also that we quantify the impact of resource changes starting from an already distorted allocation. In that case, output in sectors with high markups is relatively undersupplied. The markup term on the second line of

[6] This paragraph draws on the welfare discussion in Basu & Fernald (2002, p. 981-2).

(12) captures that output growth in sectors with markups alleviates this distortion.

Of course, the full dynamic general equilibrium effects of markups and the tradeoff between static markup distortions and dynamic Schumpeterian gains from innovation are complicated. We take the path of markups and technological change, Z_i, as given and without considerably more structure, which goes beyond the scope of this paper, we cannot quantify the full endogenous effects of markups.[7]

Labor-market distortions The final term of equation (12), $\sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right)$, captures the effect of reallocations of labor. As we explain below, these effects include reallocations that change the magnitude of static labor misallocation.

To better understand the interpretation of this labor-reallocation term, it will be useful to express it a different way. First, define the cross-sectional (across countries and industries) world average gross wage in a given year as $\overline{W} = \left(\sum_i W_i L_i\right)/L$. Second, note that, since world hours are the simple sum across country-industries, growth in world hours is

$$\dot{l} = \sum_i \left(\frac{L_i}{L}\right) \dot{l}_i = \sum_i \left(\frac{\overline{W} L_i}{\overline{W} L}\right) \dot{l}. \tag{14}$$

In the definition of labor reallocation, we use (14) to substitute for $\dot{l}$ and note that $s_i^V s_i^L = W_i L_i \,/\, PV$; the aggregate labor share is $s^L = \overline{W} L \,/\, PV$. We find:

$$\sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right) = \sum_i \left(\frac{\left(W_i - \overline{W}\right) L_i}{PV}\right) \dot{l}_i \tag{15}$$

$$= s_L \sum_i \left(\frac{W_i - \overline{W}}{\overline{W}}\right) \dot{l}_i. \tag{16}$$

This expression shows that, mechanically, the labor reallocation term entirely reflects the covariance of country-industry (gross) wages and growth in labor input. If wage differences do not covary with labor input growth, then labor reallocation is zero. In contrast, if labor grows faster in country-industries where it has a higher-than-average gross wage, then there is a positive reallocation. Other things equal, that reallocation boosts growth in output and aggregate TFP.

[7] Edmond *et al.* (2018) discuss the costs of markups in the context of a fully-specified model, and provide references to this literature.

Putting an economic interpretion on labor reallocation requires understanding the source of gross wage differences. Suppose that wages differ by country-industry because of differential taxes on labor, τ_i^L. Then $W_i = W\left(1+\tau_i^L\right)$ and $\overline{W(1+\tau^L)} = W\left(1+\overline{\tau^L}\right)$. Labor reallocation is then

$$\sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right) = s_L \sum_i \left(\frac{\tau_i^L - \overline{\tau^L}}{1+\overline{\tau^L}}\right)\dot{l}_i. \tag{17}$$

Labor reallocation is positive if we shift resources towards the industry with the higher distortionary tax. This is intuitive from the first-order condition (3). For given markups, the value of the marginal product (the right-hand side of (3)) rises if the gross wage rises (the left-hand side).[8]

Given (17), a natural interpretation of the labor reallocation term is that it reflects a change in static world misallocation, holding the effects of other distortions fixed. Consider the statically "efficient" allocation, defined as the allocation that maximizes global output from a given flow of labor. It is clear that differential country-industry taxes on labor, τ_i^L, can move the economy away from the allocation that maximizes output. In this situation, if labor "shifts" to where distortions are larger and where—according to the first-order conditions—there is a higher marginal product, then reallocation is positive. The allocation of resources moves closer to the output-maximizing allocation, so misallocation falls.[9] Note that this interpretation does not require that the same worker actually move from one location to another, just that labor grows faster in the high-distortion country-industry. The faster growth could reflect faster growth in the working-age population, a business cycle boom that raises the employment rate, or other factors.

Conceptually, this term is akin to changes in spatial misallocation discussed by Hsieh & Moretti

[8] The value of the marginal product also depends on the markup, which we account for in the markup-reallocation term. The labor reallocation term completely accounts for the change in output if there are no net markups ($\mu_i = 0$), as well as no changes in country-industry technology z_i, aggregate L or K, or in the distribution of K_i: $\dot{l} = \dot{k} = 0$, and for all i, $\dot{z}_i = \dot{k}_i = 0$. With these assumptions, the only change in the economy is in the distribution of L_i across country-industries. From (12), aggregate value added growth is then equal to the labor-reallocation term.

[9] As noted in footnote 8, this discussion holds the effects of other distortions fixed. In practice, the different distortions that we have identified could interact. For example, consider the stylized example from equation (17). Suppose $\tau_1^L = 0.2$, $\tau_2^L = 0$, and that $dL_1 = -dL_2 > 0$. But suppose also that $\mu_1 = 0$, while $\mu_2 = 0.2$. In this case, the value of the marginal product of labor is, in fact, equalized; and shifting the worker from firm 2 to firm 1 would not, in fact, change global output. Our decomposition isolates the distortions coming from markups (holding the distortion from labor taxes fixed) from the distortions coming from labor taxes (holding the distortion from markups fixed). Thus, it would measure this shift as a positive labor reallocation term along with a negative and offsetting markup reallocation term.

(2019). They argue that, based on productivity differences, there are too few people working in high-productivity San Francisco and New York, and too many working in less productive (and less-densely populated) U.S. regions. If, for any reason, labor input grows faster in high-productivity locations, then this source of misallocation will fall.

Globally, the same force is at work. Productivity in German car manufacturing is much higher than that in Mexico. This means that, from a global perspective, there is a misallocation of production factors. World GDP would increase if we moved resources, including workers, from Mexican to German car manufacturing (if we could).

Of course, the gross wage differentials observed in the data across countries might not simply reflect (implicit or explicit) distortionary taxes. Several alternatives are possible, including (but not limited to) the following. First, the difference in dollar-based wages could reflect differences in purchasing power across countries. We discuss how we adjust for PPP later in this subsection.

Second, suppose the wage differentials reflect barriers to mobility that prevent the equalization of wages from the point of view of workers. One could straightforwardly interpret this as a higher shadow tax on labor in high-wage countries (with the tax being paid to the worker), as in (17). But if different countries have different social welfare functions, it could be that the barriers to mobility are "efficient" from the point of view of the representative consumer in the high-wage country—for example, the representative consumer might not care about the utility of the immigrant who is arbitraging wage differences. This is not something we can assess from data alone.

Finally, note that for understanding productivity dynamics alone, it is not crucial to understand the source of the wage differences across countries. This is because we are measuring productivity using raw hours. An hour is an hour, whoever does the work, and whatever the skills or experience of the worker. The first-order conditions tell us that the wage should be proportional to the marginal product, whether the source of the productivity difference is the technology of the country-industry, or is embodied in the skills and experience of the worker. But of course, if an important source of the wage differences is embodied in the workers themselves—through education, for example—then it would not be the case that moving workers from, say, apparently low-wage Bangkok to high-wage Boston would actually raise global output. This issue of embodiment also matters for assessing the welfare consequences of labor reallocation. Hence, we return to this issue in Section 5.

Capital-market distortions The next-to-last term in (12), $\sum_i s_i^V s_i^K \left(\dot{k}_i - \dot{k}\right)$, captures how changes in the allocation of capital across countries and industries affects world GDP growth. The intuition for this capital-reallocation term is very similar to that of the labor-reallocation term. As with labor, the capital-reallocation term can be written in terms of the covariance of capital rental rates and capital growth across sectors. In a statically efficient allocation, the world capital stock is adjusted in every period to equate the rental rates, that is, the shadow values of capital across all sectors. As Hulten (1978) showed, if these shadow values are equalized, then this term is zero. Capital reallocation is positive if capital grows faster in sectors with high rental rates of capital—which, from the first-order conditions, implies high marginal products of capital. Holding the other terms in equation (12) fixed, that reallocation of capital contributes positively to world GDP growth. To the extent the differences in rental rates reflect distortions, such as distortionary capital taxes, output increases because capital misallocation falls.

Distortions in intermediate goods and services demand We explicitly consider distortions in intermediate goods demand in the form of the tax rates, τ_i^j. Changes in these tax rates, which have only a second-order effects on output growth, do not appear explicitly in our decomposition. Implicitly, these changes show up in the impact of the intermediates' demand distortions on the marginal products of capital and labor. As a result, these second-order impacts of distortions in intermediates demand show up as part of the factor reallocation terms of capital and labor.

Impact of deviations from PPP In practice, when one considers industries with many different types of output, the units of measurement of the marginal products of capital and labor differ. That is, in agriculture, the marginal products are measured in terms of agricultural products while in metal manufacturing they are measured in terms of metal.

To compare these marginal products across industries one needs to translate them into common units. This is most naturally done by using relative output prices and that is what is captured by the value-added shares, s_i^V. For our global analysis of productivity, we face another choice, namely what unit to express these prices in.

For our baseline results, we use U.S.-dollar-denominated prices. In that case, the reallocation terms in (12) measure the degree to which production factors disproportionately grow in industries with high dollar-denominated marginal products. The use of U.S.-dollar-denominated prices makes sense if all goods and services are tradable. In the case of our car manufacturing example, Volkswagen will focus on the dollar-denominated marginal products when it decides on where to produce Beetles that it sells on the global car market.

However, the Balassa-Samuelson (BS)-effect (Balassa, 1964; Samuelson, 1964) implies that for non-tradable goods and services, there might be persistent deviations in relative dollar-denominated marginal products from relative physical marginal products. These differences are reflected in deviations from PPP. To take this into account, we also present a set of results in which we use PPP-dollar denominated value-added shares for s_i^V. As we discuss in the next section, this requires the use of a newly-constructed dataset with country-industry level PPP price deflators.

2.4 Discussion of alternative aggregation equations

The industry-to-aggregate relationships in Hulten (1978) and Jorgenson *et al.* (1987) are special cases of equation (12). Hulten considers the no-markup case (for all i, $\mu_i = 0$) and where all purchasers face the same input costs for capital and labor. Jorgenson *et al.* retain the the no-markup assumption, but allow purchasers to face different input prices.

Basu & Fernald (2002) extend Jorgenson *et al.* to allow for imperfect competition. Basu & Fernald and Basu *et al.* (2006) note that as the first-order conditions in (3) show, markups create a wedge between the "cost" of a factor and the value of its marginal product.[10] Indeed, the social value of the marginal product depends on the markup of the *purchasing* industry. As a result, if markups differ across industries, then the effect on aggregate output depends on how the extra output is allocated across uses. Basu & Fernald (2002, p.979) chose a benchmark allocation rule for production where intermediate inputs are used in fixed proportions to output. [11] If this assumption is relaxed, then there is an additional aggregation term in the Basu & Fernald (2002) equation for the reallocation of intermediate inputs.

Given this lack of uniqueness in the aggregation, other papers have made different choices about the allocation rule. These include Petrin & Levinsohn (2013), Osotimehin (2019) and, more recently,

[10] It is the *value* of the marginal product that matters for aggregate output, not the marginal revenue product. The reason is that aggregate output is valued using prices (marginal rates of substitution).

[11] This assumption is consistent with typical representative-agent models with imperfect competition, e.g., Rotemberg & Woodford (1995)

Baqaee & Farhi (2019a,b). Baqaee & Farhi take as their benchmark for measuring aggregate technology the case where, following an industry technology shock, all uses of industry output (final expenditures and uses as intermediate inputs) expand in equal multiplicative proportions. They argue that this allocation rule is more natural in some settings.

The different decompositions in the literature can all be interpreted as accounting identities. That is, all of them are equally "correct" in an accounting sense, in that all of them describe the data perfectly. But if the benchmark assumptions are not correct, the terms might not necessarily have a clear economic interpretation.[12]

In this regard, note that the identities include the industry growth-accounting relationship (5). As noted, that equation can be considered an identity linking output, inputs, assumed markups, and technology: Given the first three, the fourth (technology) is pinned down as a residual.

Relative to the existing literature, the decomposition in (12) does not take an explicit stand on what is being held fixed. Rather, it isolates the effects of markups and differential factor prices across country-industries. Our decomposition is thus well-suited to quantify the effect of shifts in the misallocation of resources on world GDP over time.[13] It is not suited, however, to do a *sources-of-growth* accounting that is used to split up world GDP growth in parts due to capital, labor, and technology growth. Such an accounting exercise would involve splitting up gross output growth, $\dot{y}_i$ in (12) into parts due to capital, labor, technology, and intermediate inputs.[14]

[12]The Baqaee & Farhi (2019b) aggregation equation has very strong data requirements; the authors are not able to estimate all the pieces of their equation directly. In addition, their maintained assumptions include constant returns to scale. Although they argue that some sources of non-constant returns can be accommodated, the interpretation of the terms in their equation in a world with increasing returns remains unclear. In contrast, our equation, and the one in Basu & Fernald (2002) requires no assumptions at all on returns to scale. That said, when we implement the aggregation equation (12), we impose constant returns in order to measure markups.

[13]As a practical matter, our decomposition has the advantage that we are able to isolate the distortion terms even when we are limited to using data on average labor productivity rather than TFP. Neither the Basu-Fernald nor Baqaee-Farhi aggregation equations easily allow this use.

[14]One additional difference between our analysis and that in Baqaee & Farhi (2019a,b) is that we do not transform all "distortions" (including differential factor prices) into markups. This turns out to be important, because the effects of markups and differential factor prices yield three separate terms in our decomposition that each coincide with terms already used in other growth accounting decompositions. Hence, our derivation helps show how the decomposition in Baqaee & Farhi (2019b) is related to conventional growth accounting results.

3 WIOD-data

For the empirical implementation of our global growth accounting method with distortions, 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.[15] Two vintages of the WIOD have been released, one in 2013 and one in 2016. We calculate results using both of them. We merge data from two additional sources with the WIOD: Data from Timmer *et al.* (2007) for the construction of PPP deflators and data from OECD (2017) for capital price deflators used for the 2016 vintage of WIOD. (Appendix C.2 details how we merge these data.)

For all variables, we approximate continuous-time growth rates in with log-changes. We measure the time-varying factor shares for any given year t as the average share in years t and $t-1$.

3.1 Comparison across vintages and with other data sources

The two vintages differ somewhat in the industries, countries, and years covered. Important for our analysis is that 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 qualitative differences in results due to differences in countries and industries covered as well as methodological differences in the construction of variables.

Table 1 compares the two vintages of the WIOD that we use. The top part of the table shows the difference in coverage between the vintages in terms of years, countries, and industries.

The sample of countries is largely comparable across vintages. The 2016 vintage contains three more countries than the 2013, namely Norway, Switzerland, and Croatia. These countries are relatively small, so the average share of world GDP covered is similar in the two vintages. At times, we aggregate our results into regions or country blocks, as shown in Table C.11 in Appendix C.2.

We also present results for major sectors of the economy (listed in Table C.12 in Appendix C.2). Each of these sectors comprises ISIC industries for which the WIOD data are reported. Even though the 2016 vintage of the data contains many more industries than the 2013 vintage (see Table

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

1), the major sectors that we focus on are consistent over time and across vintages.

Two differences between the vintages are important to note for the interpretation of our results. First, 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.[16] Second, the 2016 vintage does not contain data on capital price deflators. We supplement the available WIOD data and constructed such deflators using data from OECD (2017).

For the overlapping years, aggregates from the two vintages line up closely, as well as with world-level aggregates from the World Bank (2018).[17] Figure 1 shows that the real GDP growth pattern in the WIOD data mimics that of world GDP.[18] Both show an acceleration in world GDP growth after 2000 up until the Great Recession in 2008. Global economic activity shrank in 2008, causing a dip in world GDP before accelerating again during the recovery phase of 2009-2014. 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. The fact that the WIOD data show the same qualitative patterns as those from the World Bank (2018) makes us confident they capture the main movements at a global level.

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

3.2 Implementation of world productivity growth measurement

The WIOD-SEA dataset contains measures that correspond to many of the terms in (12): Nominal and real gross output, labor inputs, and compensation. What is not directly reported, for one or both of the vintages, are measures related to capital input and markups.

Gross output and value added: Nominal gross output, P_iY_i, nominal value added, $P_i^V V_i$, along with quantity and price indexes are directly reported. The growth in real gross output, $\dot{y}_i$, and real value added $\dot{v}_i$ can be calculated directly.

[16] We discuss these differences in more detail in Appendix C.2.

[17] Value added in World Bank (2018) is measured at purchaser's prices while WIOD-SEA value added is reported at basic prices. The difference is taxes on products and imports, i.e. τ_i^j in our theoretical framework. Of course, our data also do not cover all countries in the world.

[18] See Appendix C.1.1 for a comparison of nominal GDP measures.

Labor input and compensation Hours, i.e., labor input, L_i, are included in the data for all industries and countries and the growth rate of hours, $\dot{l}_i$, can thus be directly calculated. In addition, the compensation of labor, i.e. $W_i L_i$ is also directly reported.

Markups and payments to capital To implement our growth accounting equation, (12), we require markups for all 1400 industries (in the 2013 vintage of data, where we have 35 industries in 40 countries). Relatedly, we need capital shares based on required payments to capital, which do not include pure profits. We estimate required payments to capital and infer the level of markups, μ_i, in a similar manner to Barkai (2019) and Karabarbounis & Neiman (2018).

The part of nominal value added that is not paid to labor consists of required payments to capital plus pure economic profits. Denoting profits by Π_i, we can write

$$P_i^V V_i - W_i L_i = R_i K_i + \Pi_i. \tag{18}$$

We first estimate required payments to capital, $R_i K_i$, as explained below. Second, we impose constant returns to scale and back out a markup consistent with the implied profit rate.[19] We follow Hall & Jorgenson (1969) to estimate a required return on capital, R_i, in a user-cost framework by assuming that the nominal capital service flows equal the nominal replacement value of the capital stock (reported in the data) times a real user cost of capital. This real user cost consists of a nominal return on capital corrected for depreciation and capital price inflation. We use the 10-yr BBB U.S. nominal corporate bond rate as the nominal rate.[20]

Second, to back out the country-industry-specific markups from the profit estimates, we follow much of the recent literature and assume constant returns to scale at the industry level. With this assumption, profits $\Pi_i = (\mu_i/(1+\mu_i))\, P_i Y_i$. [21]

[19] Recent literature such as Karabarbounis & Neiman (2018) point out that "profits" potentially include payments for unmeasured capital, notably intangible capital, as well as pure economic profits. Hence, if the accounting identity in (18) is applied to data that does not include these and other intangibles, then the right-hand side includes the implicit compensation net of the implicit investment flow. We note that even our measures of standard capital do not include land or inventories. As a result, we are bound to find higher profit estimates than datasets that do include these types of capital.

[20] Our qualitative results are similar when we use the 10-year U.S. treasury yield, e.g. Schmelzing (2017)

[21] One alternative approach, pursued by Baqaee & Farhi (2019b), would be to use direct estimates of firm-level markups, e.g. those by Loecker & Eeckhout (2017, 2018). As Traina (2018) discusses, these estimates directly pertain to the wedge between price and marginal cost and their magnitude critically hinges on what is assumed to make up variable costs for firms. In our aggregate growth accounting framework such markups would not be the

3.3 Calculating results in four steps

The advantage of using the WIOD-SEA data is that they cover a broad set of industries for not only advanced but also for emerging economies. The disadvantage is that some variables in the data are less reliably measured, especially for the latter group of countries.

With these data limitations in mind, we construct the decomposition in (12) in four steps. First, we start with a decomposition that uses the most reliably measured components. Namely, we consider ALP growth and ignore markups. This relies only on value-added and hours growth.

To begin, recall that $\dot{v} = \sum_i s_i^V \dot{v}_i$ and, trivially, note that world labor growth, $\dot{l}$, equals $\sum_i s_i^V \dot{l}$. Using these expressions, and subtracting and adding $\sum_i s_i^V \dot{l}_i$, we can write world ALP growth as

$$\dot{alp} = \dot{v} - \dot{l} \;\; = \;\; \sum_i s_i^V \dot{alp}_i + \sum_i s_i^V \left(\dot{l}_i - \dot{l} \right) \tag{19}$$

Here, the first term on the right-hand side is the contribution of country-industry specific ALP growth. The second term reflects shifts in hours growth across country-industries. Some algebraic manipulation shows that the second term can be written as $\sum_i \left(\frac{L_i}{L}\right) \left(\frac{P_i^V V_i / L_i}{P^V V / L} - 1\right) \dot{l}_i$,[22] which will, in general, be nonzero if nominal value added per hour worked differs across country-industries. Nominal value added per hour worked might, in turn, differ across country-industries for efficient reasons (such as differences in factor shares) or because of wedges (such as factor-price wedges or markups). For this reason, it is useful to decompose the shift-in-hours term into two pieces:

$$\sum_i s_i^V \left(\dot{l}_i - \dot{l} \right) = \sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l} \right) + \sum_i s_i^V \left(1 - s_i^L\right) \left(\dot{l}_i - \dot{l} \right). \tag{20}$$

The first piece is the labor-reallocation term from equation (12); as discussed in Section 2.3, this

right measure because they would also be non-zero in the case of fixed operating costs or entry costs in which firms' individual technology exhibits decreasing returns to scale (increasing marginal cost in variable factors) but aggregate technology exhibits constant returns to scale and the market allocation is efficient, e.g. Hopenhayn & Rogerson (1993). A second alternative approach, following Hall (1990) and Basu & Fernald (1997), estimates industry returns to scale and markups jointly. That approach is more data intensive than is possible with 1400 or more industries in 40 countries. But constant returns is not innocuous here. For example, Ho & Ruzic (2019) find that in U.S. manufacturing, profit rates rose in the 1990s and 2000s despite roughly constant markups, because returns to scale fell (from increasing to approximately constant).

[22] To see this, note that, since $\sum_i s_i^V = \sum_i \frac{P_i^V V}{P^V V} = 1$ and $\dot{l} = (L_i \,/\, L)\, \dot{l}_i$, we can write the second term on the right-hand-side of (19) as $\sum_i \left(\frac{P_i^V V}{P^V V} - L_i/L\right) \dot{l}_i = \sum_i \left(\frac{L_i}{L}\right) \left(\frac{P_i^V V_i/L_i}{P^V V/L} - 1\right) \dot{l}_i$.

term may be non-zero if there are wage differences across country-industries. In case of a statically efficient allocation of resources, this term would be zero. The second piece is a residual, reflecting other differences in factor shares or markups that may affect nominal value-added per hour (which might or might not be efficient).

After presenting these labor-productivity results, we move to the second step, which adds capital to the above decomposition but maintains the assumption of no markups. That is, it considers a version of the full TFP decomposition in (12) under the assumption of zero markups ($\mu_i = 0$). This step assumes that $s_i^K = (1 - s_i^L)$; capital's rental rate in each industry is whatever is needed for this to be true. These results are useful because they directly allow for the comparison with results from other studies that use standard TFP measures calculated under the assumption of constant returns and zero markups, such as those based on Jorgenson *et al.* (1987).

In the third step, we present the full decomposition (12), including non-zero markups. This enables us to quantify the impact of changes in product-market distortions on world GDP growth. By comparing the results from this step with those from step two, we can assess how markups affect global productivity growth estimates.

In the final step of our analysis, we consider the impact of deviations from PPP on the decomposition (12). For this we construct PPP value-added measures by country-industry and use them to construct value-added shares, s_i^V, in terms of 2005 PPP dollars rather than current U.S. dollars.[23] So, our final set of results implements a PPP value-added share weighted version of (12).

4 Results

We use the two WIOD vintages to construct annual estimates of each of the components of equations (12) and (19). The key takeaways from this section are that (i) world productivity growth is volatile from year to year or over multi-year periods, even though (ii) underlying country-industry productivity growth is relatively smooth; and (iii) Reallocation, particularly labor reallocation, explains the bulk of the high-frequency volatility in world productivity.

Before we present the growth-accounting results in the steps described in the previous section,

[23] Appendix C.2.4 discusses how we construct these PPP measures. Because we use country-industry level PPP data there can be different degrees of deviation from PPP across industries within a country.

we first discuss the value-added and factor shares that help put the subsequent results in context.

Value-added and factor shares

In some form or another, all our results based on (12) are weighted averages of growth rates across industries by country. The weights are the country-industry share in world value-added, either in current U.S. dollars or in 2005 PPP dollars. It is thus important to understand the main properties of these shares.

In terms of current U.S. dollars, the U.S. and Japan are the two largest individual economies, together covering more than 40 percent of world GDP. The share of the U.S. and Japan in world GDP has declined over the 19 years in our sample. This is mainly because of the relatively strong growth performance of China, whose value-added share increased by 10 percentage points.

There are notable differences between value-added shares by country in terms of current U.S. dollars and in terms of PPP dollars. The main difference between the PPP-based and dollar-based valued-added shares is that, due to high PPP prices in the U.S., the U.S. value-added share in U.S. dollars is much higher than in PPP dollars. China and India are the two countries whose value-added shares increase the most when the unit of measurement is changed from current U.S. dollars to 2005 PPP dollars. Both of their shares more than double. This is consistent with the BS-effect that more productive economies tend to have "overvalued" currencies.

No matter whether we use dollar-denominated or PPP-denominated value-added shares, manufacturing, trade, and Finance, Insurance, and Real Estate (FIRE) are the sectors with the highest value-added shares. These shares do not fluctuate much across the subperiods we consider. Agriculture and manufacturing have slightly higher PPP-shares than dollar shares, while those in FIRE and business services are slightly lower. This reflects that the latter two sectors are larger in advanced economies, especially the United States.

The other shares that matter for the decomposition in (12) are factor shares. Figure 2 plots the global factors shares from 1996-2014 for both vintages of the data. It reveals that the global labor share has declined, as documented by Karabarbounis & Neiman (2014). However, the decline in the labor share pales in comparison to the movements in the factor shares of capital and profits. Just like Barkai (2019) for the United States, we find that the capital share in world GDP has declined substantially, by more than 10 percentage points, since 1996. The joint declines of the labor and capital shares are absorbed by an increase in the profit share. By the end of the sample, pure profits amount to nearly 20% of world GDP.

These profits are concentrated in manufacturing, trade, and FIRE. Most notably, profit rates in FIRE showed the largest increase over the sample. Markups are particularly high in manufacturing in China and in FIRE in the United States.

Although the estimated profits and markups are high, it is important to note that our main takeaways below are robust to whether or not we account for markups.

Growth-accounting results

We now turn to the growth-accounting results. As discussed, we proceed in four steps: (1) (relatively well measured) labor productivity, (2) conventional TFP, (3) markup-adjusted TFP, and (4) PPP- and markup-adjusted TFP. Each step requires additional, stronger assumptions to construct the data. Nevertheless, the main takeaways remain remarkably consistent throughout this progression, indicating that the data assumptions do not drive the results.

For each step, we group the results by WIOD vintage and, further, 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. The 2001-2004 and 2005-2007 periods exist in both WIOD vintages, allowing a direct comparison of results. We focus primarily on the qualitative results that both vintages have in common, rather than on the precise numbers.[24]

Step 1: World labor productivity growth

In this step, we implement the world ALP decomposition in equation (19). We begin graphically with Figure 3, which illustrates the three key takeaways that apply throughout the four-step analysis that follows. For visual clarity, we show the data only from the 2016 WIOD vintage.

First, the dark line in the figure shows the substantial volatility in world ALP growth, $\dot{v} - \dot{l}$.

[24]Section C.1 of the Appendix includes the underlying details relevant for the points we make in the main text.

Second, the light line shows the much smoother contribution of country-industry ALP growth, $\sum_i s_i^V \dot{alp}_i$. For example, the country-industry growth rate stays relatively constant in the 2003-2007 period; and it drops much less than world ALP growth in 2009 or 2011. Algebraically, equation (19) shows that the difference between the two lines reflects shifts in hours across industries with different levels of labor productivity, $\sum_i s_i^V \left(\dot{l}_i - \dot{l}\right)$. This effect includes the contribution of labor reallocation, $\sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right)$. The third takeaway is the year-to-year volatility of this labor reallocation term, which explains much of the difference between the volatile world ALP growth and the smooth country-industry labor productivity growth.

Table 2 shows the detailed subperiod numbers for the two vintages. The rows correspond to components of equation (19). Line 1 of the table shows world GDP growth in each period. During the Great Recession period (2008-10, shown in the 2016 vintage), output grows much more slowly than in any previous period; it is followed by a sizeable recovery in 2011-14. Line 2 shows growth in world hours. Comparing the 2001-2004 and 2005-2007 periods across vintages, one can see the discrepancy in hours growth across vintages that we discussed in Subsection 3.1. Specifically, world growth in hours in the 2016 vintage was about 1-1/4 percent lower from 2001-04 than in the 2013 vintage, but then was about 1/2 percentage point higher from 2005-07. These revisions, though large, do not substantially affect the key takeaways from this section.

Lines 3, 4, and 8 show the key takeaways from implementing equation (19). Line 3 shows World ALP growth, which is output growth (line 1) less hours growth (line 2). Lines 4 and 8 decompose this growth into (line 8) the part that reflects country-industry ALP growth, $\sum_i s_i^V \dot{alp}_i$; and (line 4) the part that reflects shifts in hours across country-industries, $\sum_i s_i^V \left(\dot{l}_i - \dot{l}\right)$. By construction, line 3 is the sum of lines 4 and 8.

Line 3 shows the first key takeaway: World ALP growth is volatile across the five subperiods that we distinguish. During the expansion of the late 1990's, world ALP growth was above 2 percent. Growth declined substantially in the early 2000's and (in both vintages) rebounded sharply in the mid-2000's. During the Great Recession (2008-10), world ALP growth retreated to under 1 percent per year. In the 2011-14 period, world ALP growth got even worse, turning sharply negative.

Line 8 shows the second key takeaway, which is the relatively smooth evolution of ALP growth at a country-industry level, $\sum_i s_i^V \dot{alp}_i$. Indeed, country-industry ALP growth was relatively constant at about 2 percent per year—regardless of which vintage you look at—over the first four of the five subperiods we consider. A sharp deterioration in country-industry ALP growth is apparent only in the final 2011-14 subperiod. Even there, country-industry growth remains positive, despite the sharply negative growth rate in world ALP from line 3.

The third takeaway, from lines 4 and 5, is that the bulk of the variation in world ALP growth arises from substantial volatility in the effects of shifting hours, notably labor reallocation. This follows from the first two takeaways, given that the contribution of shifting hours (line 4) is, as an accounting identity, the difference between the volatile growth rate of world ALP growth and the relatively smooth contribution of country-industry specific ALP.

As discussed in section 3.3, this shift-in-hours term reflects the cross-sectional covariance of labor growth and nominal value added per hour. Those differences could be efficient—reflecting, say, technological heterogeneity in factor shares across industries. Or they could be related to wedges, such as markups or labor taxes. For this reason, line 5 of Table 2 breaks out labor reallocation, $\sum_i s_i^V s_i^L \left(\dot{l}_i - \dot{l}\right)$. This piece, as discussed in Section 2.3, reflects the cross-sectional covariance of wages and labor growth. Wage differences are plausibly related to efficiency and welfare (though, as discussed in Section 2.3, the efficiency and welfare consequences are not entirely clearcut). This labor-reallocation term in line 5 carries over to the TFP decompositions below.

Within labor reallocation, what turns out to be quantitatively most important is reallocations across countries, reported in line 7 of the table.[25] These shifts are, on average, a drag on world GDP growth of between around 0.4 and 0.5 percentage points. This reflects the fact that hours growth in emerging economies, where wages are lower, has typically outpaced hours growth in developed economies. The first-order conditions interpret these shifts as a reallocation of labor from high to low marginal-product-of-labor countries, as valued using measured prices. This cross-country term was slightly positive during the expansion in developed economies from 2005-2007. In contrast, the term was more negative in periods when there was a bigger wedge in hours growth between emerging and developed economies, as in 2001-2004, 2008-2010, and 2011-2014. Note also, from line 6, that shifts in the within-country reallocation of labor contribute little to world GDP growth.

Table 3 decomposes the contribution of country-industry ALP growth into its regional com-

[25] See Appendix A for more details on how we split misallocation term into within- and across-country components.

position. It shows that the *composition* of this component across countries has changed notably over time. In terms of the cross-country details, these results are in line with studies that document a broad productivity slowdown in industrialized countries starting in the early 2000's (e.g., Cette *et al.*, 2016). We find that the contribution of country-industry specific ALP growth of these countries (United States, Japan, and the United Kingdom in particular) 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.

What this result points out is how important it is to do growth accounting on a global scale to understand shifts in the center of gravity of global productivity growth. This is especially important during the 1996-2014 period that we consider, because of the growth performance of emerging economies in Asia.

Step 2: World TFP growth without markups

In step two, we explicitly account for capital and focus on TFP rather than ALP growth. That is, we implement equation (12) assuming net markups are zero everywhere. Table 4 shows the results. Lines 1 (GDP growth) and lines 7 and 8 (hours reallocation within and across countries) repeat lines that were in the ALP results in Table 2. Line 3 (hours growth) is now rescaled by s^L. Given this, our discussion here focuses primarily on the contribution of aggregate capital growth (Line 2), world TFP growth (Line 4), capital reallocation (Lines 5 and 6), and country-industry specific TFP growth (Line 10). Line 9 shows shifts in markups, which are assumed to be zero in this step.

Line 2 shows the contribution of aggregate capital growth, $s^K \dot{k}$, to world GDP growth for the subperiods in our data. There is a substantial discrepancy between the two vintages for the overlapping periods 2001-2004 and 2005-2007. This mainly reflects the lower labor share (and, hence, higher residual capital share, $1 - s^L$) in the 2016 vintage, as shown in Figure 2.

Line 4 shows that our first takeaway also holds for TFP: As with world ALP growth, world

TFP growth is volatile across the five subperiods that we consider. Line 10 translates the second takeaway to TFP growth: As with ALP growth, the country-industry component of TFP growth, $\sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i$, is much less volatile than world TFP growth. Country-industry TFP growth was relatively strong prior to 2008, and then (looking at the 2016 vintage) stepped down markedly. Country-industry TFP growth was modestly negative from 2008-10 and was only weakly positive from 2011-2014 (both in the 2016 vintage).

Lines 5 and 6 show that, when we do not account for markups, we find sizable effects of capital reallocation on world GDP growth. Most of this capital-reallocation effect occurs between industries *within* countries (Line 5) rather than *across* countries (Line 6). This capital reallocation is largely due to two sectors: Trade, transportation, and utilities as well as business services. The reallocation of capital across countries accounts for a much smaller part of world GDP growth. The reallocation contributions in Lines 5 and 6 of Table 4 are positive, which reflects that capital grows faster in industries and countries for which the implied internal rate of return to capital (i.e., the implied marginal product of capital under the assumption of no markups) is higher.

Finally, we note again that lines 7 and 8 show the third takeaway—volatile labor reallocation. Labor reallocation is somewhat more volatile across subperiods than capital reallocation.

As we showed earlier in this section, our estimates imply that profits make up a substantial, and increasing, fraction of world GDP. The results without markups ignore this evidence. So, in the next step we redo our decomposition, accounting for the role of markups.

Step 3: World TFP growth with markups

Table 5 shows that our main results also hold when we explicitly account for markups. There are some notable differences when we allow for markups. Starting in line 2 with the contribution of world capital to growth, a substantial part of the growth contribution of aggregate capital from Table 4 is attributable to markups in Table 5. The reason is that without markups, capital's weight was $(1 - s^L)$. With markups and profits, however, this weight is split between capital and profits, $s^K + s^\Pi$. This recharacterization reduces the contribution of capital growth in Line 2 of Table 5 for all subperiods. In fact, accounting for markups reduces the measured contribution of aggregate capital growth to world GDP growth by 0.26 and 0.57 percentage points in the 2013 and 2016 vintages of the data respectively.

Not only is the contribution of capital to world GDP growth lower when we account for markups, it is also remarkably constant, with a mean of 0.78, across subperiods and vintages. Moreover, the large differences across vintages in the contribution of aggregate capital growth for the periods 2001-2004 and 2005-2007 that we found in Line 2 of Table 4 almost disappear.

Compared with Table 4, the lower contribution of aggregate capital growth results in somewhat higher world TFP growth in line 4 of Table 5. That said, world TFP growth remains quite volatile across subperiods and slows substantially after 2007.

A big difference between the results with and without markups is the implied contribution of capital reallocation to World GDP growth, reported in Lines 5 and 6 of the respective tables. After accounting for markups in Table 5, the measured effect of capital reallocation *within* countries (line 5) is much smaller, particularly in the 2013 vintage. If our markup estimates are accurate, it suggests that we found spurious effects of capital reallocation in Table 4 because we misassessed capital rental rates (and implied marginal products of capital). With or without markups, the effect of changes in the *cross-country* reallocation of capital (line 6) remains negligible.[26]

Line 9 of Table 5 reports the impact of markups on world GDP growth. These shifts add around half a percentage point annually to world GDP growth over the period we consider. Our detailed results indicate that the effect of shifts in markups on world GDP growth is mainly due to manufacturing, trade, and FIRE in China and the United States.

Finally, Line 10 of Table 5 lists the part of world GDP growth accounted for by country-industry specific TFP growth. The picture here is very similar as for the contribution of country-industry specific ALP growth in Line 8 of Table 3. Before 2008 the contribution of country-industry specific TFP growth to world productivity was relatively constant at around 1.2 percent. After that, country-industry specific TFP growth declined to near zero during global financial crisis and recovered only modestly afterwards.

It is striking that allowing for markups makes a minimal difference to line 10. Rather, the effect of markups in line 9 largely comes out of a reduced contribution from capital (line 2) and

[26]The careful reader might wonder why there is any capital reallocation term left, given we are assuming the same nominal return everywhere. One reason is that there are differences in the levels and growth rates of capital deflators across countries, in part reflecting different capital mixes (which we do not control for). For the same reason, there are differences in average depreciation rates across countries.

within-country capital reallocation (line 5).

Just like for ALP, the relative constancy of the number reported in Line 10 of Table 5 for before 2008 masks a shift in technology growth from advanced economies to emerging economies, especially from 2005-2007. This can be seen from Table C.7, which splits Line 10 up by country.

Step 4: PPP value-added share weighted results

A striking takeaway from the first three steps is that labor reallocation explains much of the volatility in world productivity, as well as being a consistent drag on world growth. These first three steps valued world output using current dollars. A natural question is whether these findings reflect true differences in labor's marginal productivity across countries, or rather the effects of exchange rates? Table 6 addresses this question by quantifying the impact of deviations from PPP on the decomposition in equation (12). Here, country-industry value-added shares are measured in terms of 2005 PPP dollars rather than current U.S. dollars. Although the specific numbers are quite different, our qualitative results are robust to deviations from PPP.

Line 1 of Table 6 shows that PPP-weighted world GDP grows much faster than current-dollar-weighted GDP growth. The reason is that PPP value-added shares in world GDP tend to be higher than dollar shares for emerging economies; these economies tend to grow faster than average. The growth rate also appears somewhat more volatile. In contrast, comparing lines 2 and 3 with the same lines in Table 5, the contributions of aggregate capital and labor growth are not much changed.[27]

World TFP growth, reported in Line 4, is higher for the PPP-weighted case than for the dollar-weighted case. This follows from having faster growth in GDP (line 1) along with roughly similar contributions from capital and labor (lines 2 and 3). World TFP growth remains highly volatile across subperiods as well as slows down after 2007.

Comparing Lines 4 and 10 of Table 6 we find that fluctuations in PPP-deflated world TFP growth are much larger than those in country-industry PPP-deflated TFP growth. This is similar to what we found for dollar-weighted ALP and TFP growth as well (and was our first two takeaways). Moreover, even though level of country-industry TFP growth is higher in the PPP-weighted data, the pattern over time is similar to the dollar-weighted results.

[27] The numbers do not match exactly since our sample changed slightly due to PPP data availability. See Table C.10 in Appendix C.2 for more details.

Deviations from PPP do have a marked impact on the contributions of capital and labor reallocation, especially across countries, to world GDP growth. The impact of the cross-country capital reallocation in Line 6 of Table 6 is large compared to that in Table 5, in which it was negligible. This potentially reflects that capital flows across the world to equate dollar-denominated returns on investment across country-industry combinations. Equating these dollar-denominated returns is not the same as equating physical marginal products.

For the changes in labor reallocation we find the opposite. Labor reallocation is less important when we consider the PPP-weighted results in Table 6. A portion of cross-country labor reallocation in the dollar-weighted results in Table 5 reflects economic activity shifting to sectors with an international cost advantage. These are industries with low relative wages compared to relative productivity levels—most obviously, manufacturing in China and India.

The labor reallocation results imply that deviations from PPP only account for about a third of the total impact of labor reallocation reported in the earlier tables. Thus, even after adjusting for PPP, labor reallocation remains a drag on world GDP growth as well as being an important source of volatility in world TFP.

Finally, shifts in markups (line 9) contribute slightly more to world GDP growth when PPP-deflated than current-dollar weighted. This is largely due to markups in (Chinese) manufacturing.

5 Interpreting the cross-country reallocation of labor

This section explores sources of wage differences across countries and industries which is important for understanding the labor reallocation term. As discussed in section 2.3, labor reallocation reflects the covariance of wage differences with labor growth. Wage differences between emerging and advanced economies are large, which is what allows this term to be quantitatively significant.

One interpretation of wage differences, besides barriers to movement of workers, is that some or all of the observed wage differences across countries reflect worker productivity differences—most saliently, arising from differences in educational attainment—that are "embodied" in workers. There are large differences in human capital across countries.[28]

[28] See for example, Klenow & Rodriguez-Clare (1997), Prescott (1997), Hall & Jones (1999), Hendricks (2002), Caselli (2005), Schoellman (2011), and Hendricks & Schoellman (2017), among others.

In our data, we are able to implement a crude human capital adjustment in the 2013 vintage of WIOD (through 2007). This alternative implementation does not change our qualitative results. The 2013 vintage of WIOD provides information on industry labor hours and compensation based on three broad skill groups (low-, medium-, high-skilled).[29] These data allow for a crude accounting of cross-country differences in skill distributions. To do so, we treat the hours worked by each of these skill groups as a separate factor of production, L_i^τ, where $\tau \in \{L, M, H\}$. The production function from equation (2) becomes

$$Y_i = F_i\left(K_i, L_i^L, L_i^M, L_i^H, \{M_{i,j}\}_{j=1}^n, Z_i\right). \tag{21}$$

The resulting decomposition of aggregate TFP growth differs from the ones we presented before in three ways. First, aggregate growth of the labor input is measured as a share-weighted average of growth in hours of each skill group. Second, this redefinition also affects our measures of aggregate and industry TFP, since each type of labor is effectively treated as a separate input.[30] Finally, and most importantly, labor reallocation in this case is a weighted average of labor reallocation across the three types of labor.[31]

Table 7 shows the results of the decomposition with three skill types. The earlier findings regarding the importance of cross-country labor reallocations are robust to this extension. Comparing lines 7 and 14 show that, as before, the volatility of world TFP growth is mainly driven by the cross-country labor reallocation term; country-industry TFP growth (line 19) remains very smooth. The cross-country labor reallocation term not only fluctuates a lot, but lines 15 through 17 show that its contribution to world TFP growth is almost always negative for each skill group. Thus, even within skill groups, hours typically grow faster in countries with relatively low wages.

Unfortunately, the three skill groups are crude—capturing only broad buckets of years of schooling, and with no controls for the quality of education. Nevertheless, cross-country analyses of wages

[29]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).

[30]The production function in (21) allows for shifts in the contribution of labor "composition," or "quality." For example, suppose that total hours are constant, but the low skilled work less while the high skilled work more. Since the high-skilled wage is higher, effective share-weighted labor input increases. For industry TFP, the contribution from hours shifting (at least on average) to the high skilled was previously attributed to technology.

[31]We defer the details of this decomposition to Appendix B.

of migrants suggest that, even if we could correct for cross-country human capital differences within these skill groups, we would still find the reallocation of hours to be a drag on world GDP. In particular, Hendricks (2002), Schoellman (2011), and Hendricks & Schoellman (2017) use the wages of immigrants before and after migration to quantify cross-country differences in wages per unit of human capital. These studies show that, after controlling for selection, wage gains from migrating to the U.S. are large. They are larger for workers who earned lower wages in the country of origin than for workers with high wages in those countries.

Thus, if wages per unit of human capital reflect marginal products of labor measured in constant quality units, then our observation that hours grow faster in countries with lower wages implies that hours grow faster in countries with lower wages per unit of human capital. Hence, correcting for human capital does not overturn our conclusion that the reallocation of labor is a drag on world TFP growth as well as being a substantial source of volatility.[32]

6 Conclusion

We provide new global growth-accounting results from a novel growth decomposition that nests standard decompositions but allows for markups as well as factor "wedges." We implement this decomposition using data on 35 or more industries and 40 or more countries from 1996-2014.

Empirically, we find three main results: (i) world productivity is volatile from year to year and even over multi-year periods, even though (ii) the average rate of producivity growth across country-industries is comparatively smooth; (iii) labor reallocation is the primary source of the volatility in world productivity growth, as well as being a persistent drag on growth. These takeaways apply whether we use labor productivity or TFP, whether or not we control for markups, and whether or not we adjust for PPP.

The quantitative importance of labor reallocation arises from the well-known heterogeneity in wages around the world. Previous research has not examined how this heterogeneity affects productivity measurement. The intuition is straightforward. Cost-minimizing first-order conditions imply that observed differences in (equilibrium) wages correspond to differences in marginal products of

[32]This holds even when we account for PPP data, though the contribution of labor reallocation across countries declines, which is again the same qualitative result we had before.

labor. Labor input has typically grown faster in low-wage/low marginal-product locations, creating a persistent drag of around 1/2 percent per year for world productivity growth. But over time, the cross-sectional covariance of wages and hours growth varies substantially which, in turn, leads to considerable variability in world productivity.

Our growth-accounting methodology and results extend the insights of the so-called "misallocation" literature (following Hsieh & Klenow (2009)) to the time-series domain. That literature highlights the importance of the allocation of resources for productivity. Recent critiques of misallocation estimates (e.g., Haltiwanger *et al.* (2018)) have highlighted the strong assumptions made in the literature. In contrast, our approach should be more robust to these concerns: For growth rates, we show how to account for the effects of changing resource allocation with few structural assumptions beyond cost-minimization.

Importantly, our results do not require a misallocation interpretation. Certainly, it is natural to interpret labor reallocation as capturing shifts in global misallocation, where the global "optimum" is defined as the allocation of labor that would maximize global output. As Hsieh & Moretti (2019) argue for the United States, output rises if we shift, or "reallocate," labor input from low-marginal-product to high-marginal-product locations. Nevertheless, our positive results do not hinge on this normative misallocation interpretation. For example, low wages could reflect low skills, so that the marginal product is associated with the worker, not with the location. In that case, shifting a given worker from one country to another would not, in fact, change global output. That said, the evidence suggests that shifting workers from a low-wage to a high-wage country would, in fact, raise their marginal products. More generally, if each country has its own representative consumer, resource shifts that raise global output might not be Pareto-efficient.

Our results provide new insights into at least two other recent literatures. First, a growing recent literature examines the role of markups and rising profits. We extend Barkai (2019) to emerging markets. We estimate that markups are widespread and that profits rise steadily across a wide range of countries. Indeed, both labor and capital shares fall. Interestingly, although profits and markups are quantitatively important—with both labor and capital shares of output falling—the broad narrative about global productivity is robust to whether we control for markups or not.

Second, a sizeable strand of literature has highlighted the slowdown in recent decades in advanced-economy productivity growth. We provide broader context for this finding: At a global level, the advanced-economy slowdown in country-industry productivity growth in the 2000s is offset until the Great Recession by a rising contribution from emerging markets. World productivity growth (and world country-industry productivity growth) only consistently slows after the Great Recession.

Thus, our analysis shows how important it is to do growth accounting on a global scale to understand shifts in the center of gravity of global productivity growth. With the rise of emerging economies in Asia, this global perspective has become increasingly essential.

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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	✓	✓
Capital	✓	✓
. . . Nominal current cost	✓	✓
. . . Investment	✓	
. . . Capital deflators	✓	

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). The 2016 vintage contains incomplete capital data, especially capital deflators. We construct them by merging data from OECD (2017) and extrapolating from the 2013 vintage for variables unavailable. See the Appendix for details.

Table 2: Summary of global ALP growth accounting: 1996-2014

SEA vintage			2013				2016				
			1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
line	description	notation									
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
4)	Relative hours growth	$(\dot{l}_i - \dot{l})$	-0.19	-2.22	0.95	-0.58	-0.79	0.82	-0.71	-1.49	-0.62
5)	...Reallocation of hours	$s_i^L(\dot{l}_i - \dot{l})$	-0.01	-1.34	0.50	-0.33	-0.56	0.35	-0.36	-0.97	-0.44
6)	...within countries		0.07	-0.02	0.15	0.06	0.03	0.08	0.08	0.09	0.07
7)	...across countries		-0.08	-1.32	0.35	-0.39	-0.6	0.27	-0.44	-1.07	-0.51
8)	Country-industry ALP growth	$\dot{alp}_i$	2.14	2.11	2.20	2.15	1.94	1.98	1.70	0.67	1.53

Note: Lines in this table correspond to parts of equation (19). Reported are contributions to average annual growth rates in percentage points over various subperiods.

Table 3: Contribution of country-industry specific ALP growth, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	1.77	1.78	1.21	1.63	1.66	0.92	0.57	0.30	0.89
United States	0.75	1.01	0.42	0.76	0.92	0.38	0.54	-0.00	0.46
Great Britain	0.11	0.13	0.10	0.11	0.13	0.05	0.03	0.01	0.06
Japan	0.31	0.25	0.19	0.26	0.27	0.12	-0.08	0.06	0.11
Euro Area	0.33	0.23	0.30	0.29	0.21	0.23	0.04	0.16	0.16
Other Advanced	0.27	0.16	0.20	0.21	0.13	0.14	0.04	0.07	0.10
Emerging	0.38	0.33	1.00	0.51	0.27	1.06	1.12	0.36	0.66
Brazil	0.04	-0.00	0.02	0.02	-0.02	-0.00	0.27	-0.05	0.04
China	0.30	0.28	0.53	0.35	0.23	0.67	0.65	0.59	0.52
India	0.06	0.02	0.17	0.07	0.05	0.13	0.12	-0.11	0.04
Russia	-0.02	0.04	0.11	0.03	0.05	0.09	0.09	0.02	0.06
Other Emerging	-0.00	-0.01	0.17	0.04	-0.04	0.17	-0.01	-0.09	-0.00
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 8 in Table 2 in percentage points over various subperiods.

Table 4: Summary of global TFP growth accounting without markups: 1996-2014

SEA vintage			2013				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 capital growth	$s^K\dot{k}$	0.98	0.94	1.26	1.04	1.54	1.50	1.18	1.18	1.35
3)	World hours growth	$s^L\dot{l}$	0.71	1.44	0.23	0.83	0.67	0.48	-0.04	1.89	0.82
4)	World TFP growth	$\dot{tfp}$	1.65	0.12	2.21	1.28	0.11	1.67	-0.23	-0.50	0.20
	Misallocation of capital	$s_i^K(\dot{k}_i - \dot{k})$	0.76	0.28	0.43	0.52	0.22	0.36	0.29	0.26	0.28
5)	...within countries		0.63	0.20	0.30	0.40	0.16	0.25	0.14	0.18	0.18
6)	...across countries		0.13	0.09	0.13	0.11	0.06	0.11	0.14	0.09	0.10
	Misallocation of hours	$s_i^L(\dot{l}_i - \dot{l})$	-0.01	-1.34	0.50	-0.33	-0.56	0.35	-0.36	-0.97	-0.44
7)	...within countries		0.07	-0.02	0.15	0.06	0.03	0.08	0.08	0.09	0.07
8)	...across countries		-0.08	-1.32	0.35	-0.39	-0.6	0.27	-0.44	-1.07	-0.51
9)	Shifts in markups	$\frac{\mu_i}{1+\mu_i}\dot{y}_i$	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00
10)	Country-industry TFP growth		0.91	1.18	1.28	1.09	0.46	0.96	-0.16	0.21	0.36

Note: Lines in this table correspond to parts of equation (12). Reported are contributions to average annual growth rates in percentage points over various subperiods. These are results with no markups. Hence line 9 consists of zeros.

Table 5: Summary of global TFP growth accounting *with* markups: 1996-2014

SEA vintage			2013				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 capital growth	$s^K \dot{k}$	0.79	0.74	0.80	0.78	0.89	0.86	0.75	0.63	0.78
3)	World hours growth	$s^L \dot{l}$	0.71	1.44	0.23	0.83	0.67	0.48	-0.04	1.89	0.82
4)	World TFP growth	$t\dot{f}p$	1.84	0.32	2.67	1.54	0.76	2.32	0.21	0.05	0.77
	Misallocation of capital	$s_i^K(\dot{k}_i - \dot{k})$	0.21	0.03	0.06	0.11	0.17	0.18	0.23	0.24	0.20
5)	...within countries		0.23	0.06	0.11	0.14	0.07	0.14	0.07	0.06	0.08
6)	...across countries		-0.02	-0.03	-0.05	-0.03	0.09	0.04	0.16	0.18	0.12
	Misallocation of hours	$s_i^L(\dot{l}_i - \dot{l})$	-0.01	-1.34	0.50	-0.33	-0.56	0.35	-0.36	-0.97	-0.44
7)	...within countries		0.07	-0.02	0.15	0.06	0.03	0.08	0.08	0.09	0.07
8)	...across countries		-0.08	-1.32	0.35	-0.39	-0.6	0.27	-0.44	-1.07	-0.51
9)	Shifts in markups	$\frac{\mu_i}{1+\mu_i}\dot{y}_i$	0.51	0.39	0.94	0.58	0.46	0.85	0.29	0.59	0.55
10)	Country-industry TFP growth		1.13	1.24	1.17	1.18	0.7	0.93	0.04	0.19	0.46

Note: Lines in this table correspond to parts of equation (12). Reported are contributions to average annual growth rates in percentage points over various subperiods. Results with markups.

Table 6: Summary of global PPP-TFP growth accounting *with* markups: 1996-2014

SEA vintage			2013				2016				
line	description	notation	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
1)	World GDP growth	$\dot{v}$	5.42	5.33	8.02	6.04	5.07	7.91	3.33	5.58	5.45
2)	World capital growth	$s^K\dot{k}$	0.75	0.71	0.77	0.74	0.87	0.87	0.79	0.69	0.80
3)	World hours growth	$s^L\dot{l}$	0.75	1.39	0.21	0.83	0.65	0.43	-0.03	1.82	0.79
4)	World TFP growth	$\dot{tfp}$	3.92	3.24	7.04	4.47	3.56	6.62	2.57	3.08	3.87
	Misallocation of capital	$s_i^K(\dot{k}_i - \dot{k})$	0.32	0.17	0.26	0.25	0.38	0.61	0.80	0.68	0.61
5)	...within countries		0.20	0.07	0.15	0.15	0.08	0.16	0.04	-0.00	0.07
6)	...across countries		0.11	0.10	0.11	0.11	0.3	0.45	0.76	0.68	0.54
	Misallocation of hours	$s_i^L(\dot{l}_i - \dot{l})$	0.02	-1.12	0.60	-0.21	-0.23	0.53	-0.03	-0.44	-0.08
7)	...within countries		0.08	-0.19	0.36	0.06	0.15	0.34	0.25	0.27	0.25
8)	...across countries		-0.06	-0.93	0.23	-0.28	-0.38	0.19	-0.28	-0.70	-0.33
9)	Shifts in markups	$\frac{\mu_i}{1+\mu_i}\dot{y}_i$	0.60	0.60	1.46	0.81	0.69	1.18	0.55	0.77	0.79
10)	Country-industry TFP growth		2.99	3.59	4.72	3.62	2.71	4.29	1.25	2.06	2.55

Note: Lines in this table correspond to parts of equation (12). Reported are contributions to average annual growth rates in percentage points over various subperiods. Results with markups.

Table 7: Summary of global TFP growth accounting *with* markups and labor quality: 1996-2007

line	description	notation	1996-2000	2001-2004	2005-2007	All
1)	World GDP growth	$\dot{v}$	3.33	2.51	3.70	3.15
2)	World capital growth	$s^K \dot{k}$	0.79	0.74	0.80	0.78
3)	World hours growth across skills	$s^{L\tau} \dot{l}^{\tau}$	1.53	2.17	0.88	1.58
4)	...low-skilled		-0.02	0.14	-0.04	0.03
5)	...medium-skilled		0.73	0.82	0.16	0.62
6)	...high-skilled		0.82	1.21	0.76	0.94
7)	World TFP growth	$\dot{tfp}$	1.01	-0.41	2.02	0.79
	Misallocation of capital	$s_i^K(\dot{k}_i - \dot{k})$	0.21	0.03	0.06	0.11
8)	...within countries		0.23	0.06	0.11	0.14
9)	...across countries		-0.02	-0.03	-0.05	-0.03
	Misallocation of hours	$s_i^{L\tau}(\dot{l}_i^{\tau} - \dot{l}^{\tau})$	-0.63	-1.88	0.01	-0.89
10)	within countries		-0.01	-0.11	0.09	-0.02
11)	...low-skilled		0.00	-0.01	0.03	0.00
12)	...medium-skilled		-0.01	-0.06	0.04	-0.02
13)	...high-skilled		-0.00	-0.03	0.02	-0.01
14)	across countries		-0.62	-1.78	-0.08	-0.87
15)	...low-skilled		-0.17	-0.26	-0.03	-0.16
16)	...medium-skilled		-0.35	-0.81	0.09	-0.39
17)	...high-skilled		-0.11	-0.71	-0.14	-0.32
18)	Shifts in markups	$\frac{\mu_i}{1+\mu_i}\dot{y}_i$	0.51	0.39	0.94	0.58
19)	Country-industry TFP growth		0.93	1.06	1.01	0.99

Note: Lines in this table correspond to parts of equation (27). Reported are contributions to average annual growth rates in percentage points over various subperiods. Results with markups.

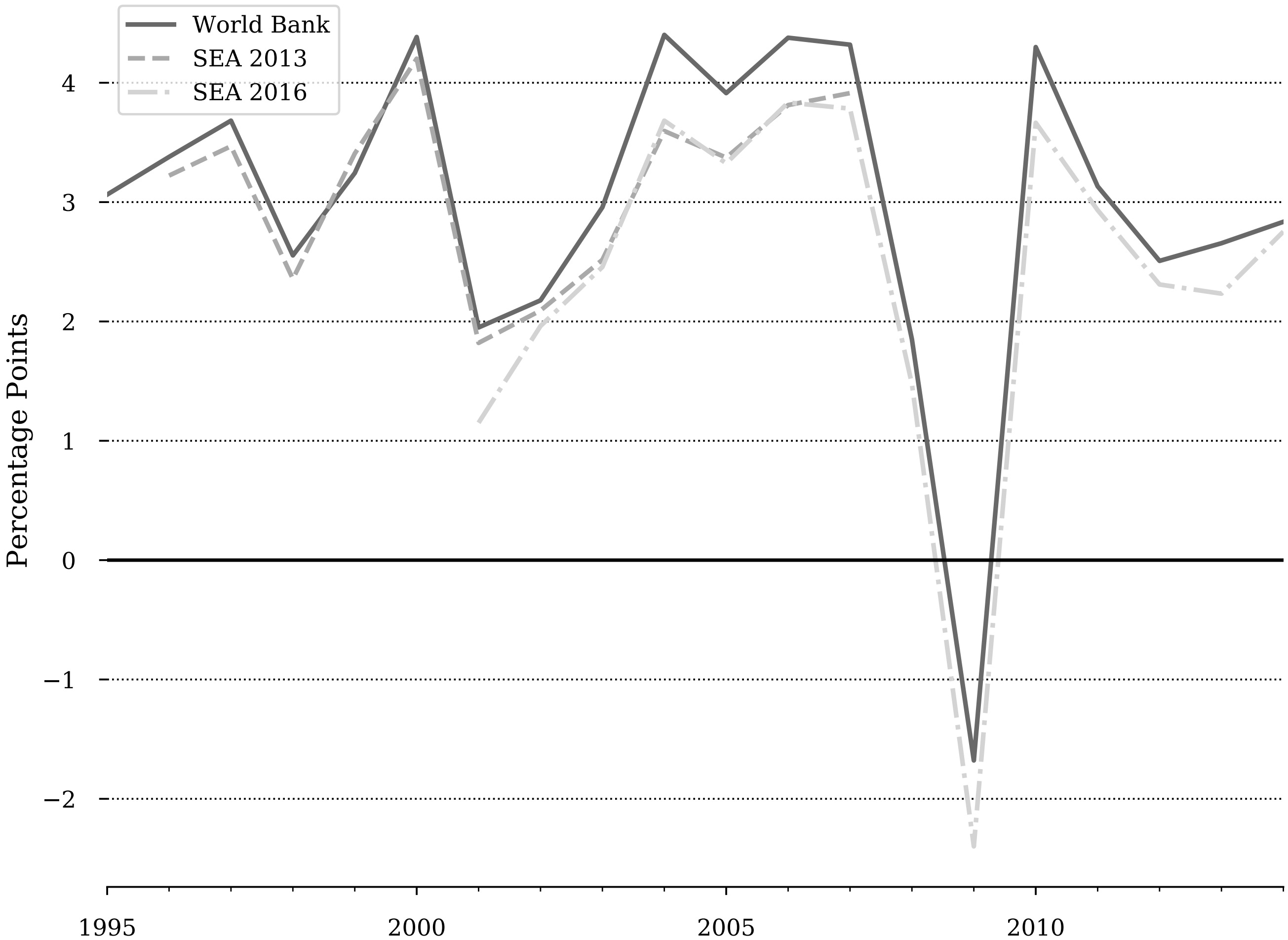

Figure 1: Growth in world real GDP in WIOD-SEA and World Development Indicators (WDI)

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.

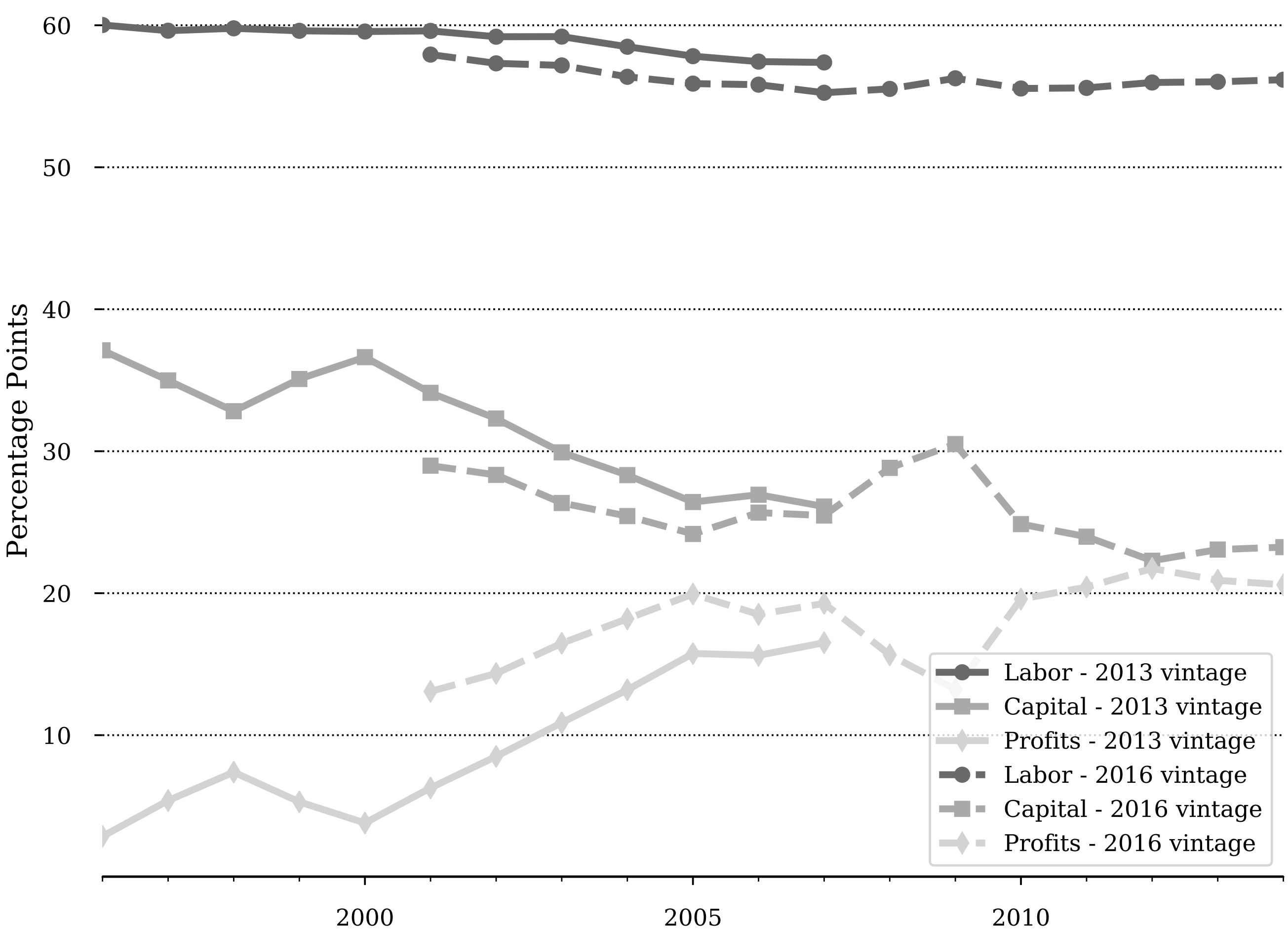

Figure 2: World factor shares for both vintages of WIOT
Source: Timmer (2012), OECD (2017), and authors' calculations.

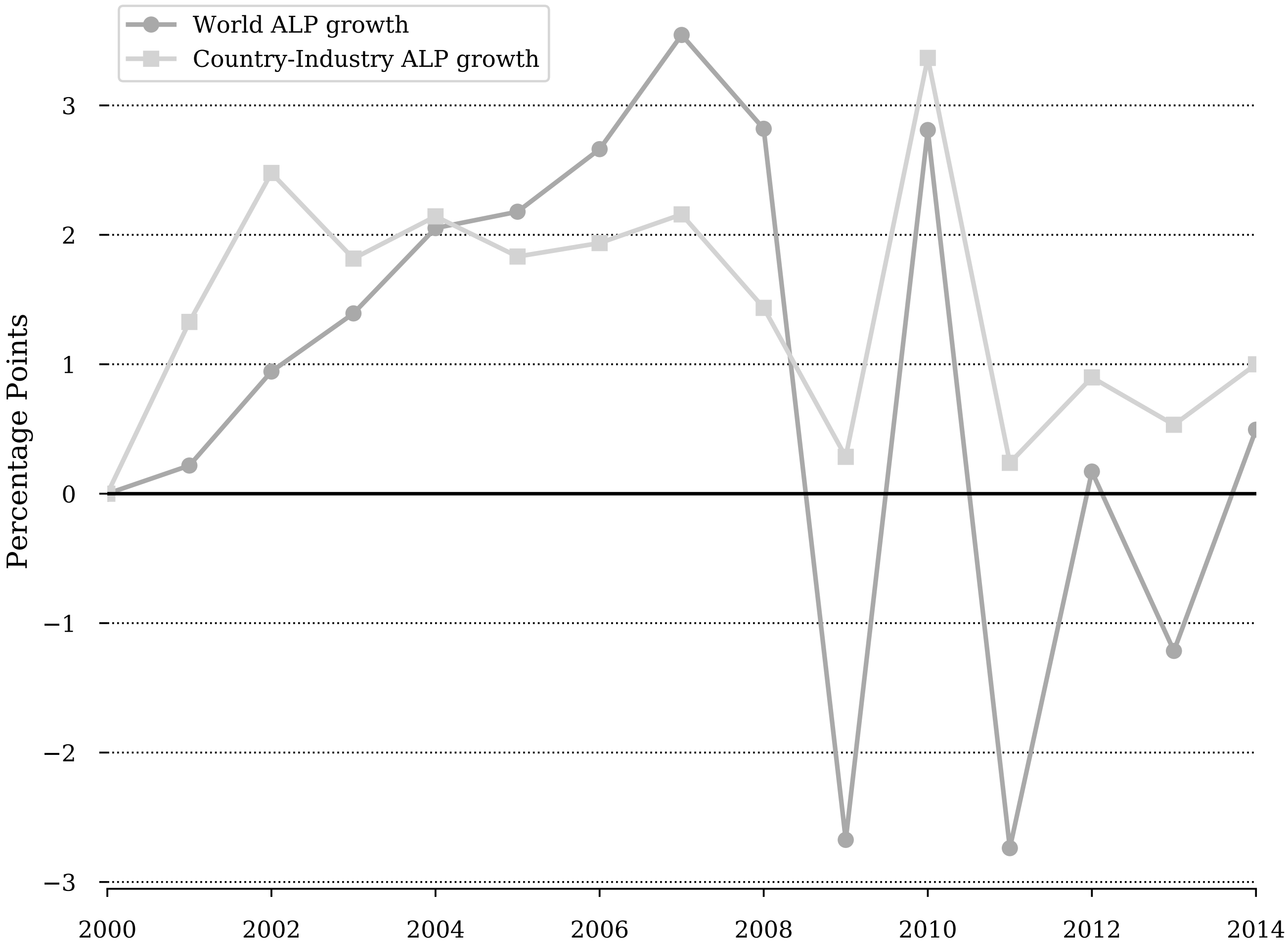

Figure 3: ALP growth: World vs. country-industry component, vintage 2016.
Source: Timmer (2012), OECD (2017), and authors' calculations.

A Accounting for within- and across-country contributions

As mentioned in the main text, we split up the contribution of shifts in misallocation into with-country component and across-country one. We elaborate here how we do this. We focus on equation (12), but the same calculations can be applied to shifts-in-hours term in (19) and (20) as well.

Remember that the index i in equation (12) represents a country-industry pair. We rewrite this equation again with a new indexation: i for industry and c for country:

$$\begin{aligned} \dot{v} &= \sum_c \sum_i \frac{1}{(1+\mu_{ci})} s^D_{ci} \dot{z}_{ci} + s^K \dot{k} + s^L \dot{l} \\ &+ \sum_c \sum_i s^D_{ci} \frac{\mu_{ci}}{(1+\mu_{ci})} \dot{y}_{ci} + \sum_c \sum_i s^V_{ci} s^K_{ci} \left(\dot{k}_{ci} - \dot{k} \right) + \sum_c \sum_i s^V_{ci} s^L_{ci} \left(\dot{l}_{ci} - \dot{l} \right). \end{aligned} \tag{22}$$

We can now split up the capital and labor misallocation terms into within- and across-country component. For example, labor misallocation term can be written as

$$\sum_c \sum_i s^V_{ci} s^L_{ci} \left(\dot{l}_{ci} - \dot{l} \right) = \sum_c s^V_c \sum_i \frac{s^V_{ci} s^L_{ci}}{s^V_c} \left(\dot{l}_{ci} - \dot{l}_c \right) + \sum_c s^V_c s^L_c \left(\dot{l}_c - \dot{l} \right), \tag{23}$$

where

$$s^L_c = \left(\frac{\sum_i s^V_{ci} s^L_{ci}}{s^V_c} \right), \text{ and } s^V_c = \sum_i s^V_{ci}. \tag{24}$$

Equation (23) splits up the labor misallocation terms into two parts: within-country misallocation of labor which is the first term on the RHS, and across-country component which is the second term. A positive within-country misallocation of labor states that hours are growing faster in industries that on average have higher labor share and contribute more to the country GDP. Higher labor share means that the wages are on average higher in these industries which indicates higher marginal product of labor. Hence, a positive term means that there are productivity gains from changes in the misallocation of labor within the country.

Similarly, a positive across-country misallocation means that hours are growing faster in countries with higher labor share and contribute more to world GDP. This will result in less misallocation of labor and contribute positively to world TFP growth. The capital misallocation term can be split up in a similar way.

B Growth accounting with labor skill levels

Let $\tau \in \{L, M, H\}$ denotes the three labor inputs based on skill. Our raw accounting identity is the following (equation (11) in the main text):

$$\dot{v} = \sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i + \sum_i s_i^V s_i^K \dot{k}_i + \sum_i s_i^V s_i^L \dot{l}_i + \sum_i s_i^D \frac{\mu_i}{(1+\mu_i)} \dot{y}_i. \tag{25}$$

Before rearranging this equation to get equation (12), we can manipulate the labor term to reflect labor quality. Assuming we have three categories for labor (Low, Medium, and High skilled), the above equation would be:

$$\dot{v} = \sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i + \sum_i s_i^V s_i^K \dot{k}_i + \sum_i \sum_{\tau \in \{L,M,H\}} s_i^V s_i^{L\tau} \dot{l}_i^\tau + \sum_i s_i^D \frac{\mu_i}{(1+\mu_i)} \dot{y}_i. \tag{26}$$

We now add and subtract aggregate share-weighted factor growth to this equation. For labor, there are three types of aggregate workers, so we add and subtract $\sum_{\tau \in \{L,M,H\}} s^{L\tau} \dot{l}^\tau = \sum_{\tau \in \{L,M,H\}} \sum_i s_i^V s_i^{L\tau} \dot{l}^\tau$. We arrive at the modified version of the main equation:

$$\begin{aligned} \dot{v} \;=\; & \sum_i \frac{1}{(1+\mu_i)} s_i^D \dot{z}_i + s^K \dot{k} + \sum_{\tau \in \{L,M,H\}} s^{L\tau} \dot{l}^\tau \\ + \; & \sum_i s_i^D \frac{\mu_i}{(1+\mu_i)} \dot{y}_i + \sum_i s_i^V s_i^K \left(\dot{k}_i - \dot{k}\right) + \sum_{\tau \in \{L,M,H\}} \sum_i s_i^V s_i^{L\tau} \left(\dot{l}_i^\tau - \dot{l}^\tau\right). \end{aligned} \tag{27}$$

The final term is the change in labor reallocation. It is now the weighted average of labor reallocation across the three types of labor. Aggregate and industry TFP also change, because we now allow for shifts in the contribution of aggregate labor quality. For aggregate TFP, these shifts show up in the share-weighted growth in labor input in the final term on the first line. For industry

TFP, we were previously attributing to technology a part of each industry's growth that is due to labor shifting among education groups.

To see the contribution of labor quality more explicitly, note that the aggregate labor share, s^L, is the sum of the labor shares across the three types of labor, $\sum_{\tau\in\{L,M,H\}} s^{L\tau}$. Hence, following Jorgenson *et al.* (1987), we can write the contribution-of-aggregate-labor term in the first line as the sum of share-weighted hours growth plus the change in aggregate labor quality:

$$\sum_{\tau\in\{L,M,H\}} s^{L\tau}\dot{l}^{\tau} = s^L\dot{l} + \sum_{\tau\in\{L,M,H\}} s^{L\tau}\left(\dot{l}^{\tau} - \dot{l}\right) \tag{28}$$

Returning to the labor reallocation term, it will be useful for intuition to express it a different way. First, define the average wage for each type of worker as $W^{\tau} = \left(\sum_i W_i^{\tau} L_i^{\tau}\right)/L^{\tau}$. Second, note that growth in hours of type τ is

$$\dot{l}^{\tau} = \sum_i \left(\frac{L_i^{\tau}}{L^{\tau}}\right)\dot{l}_i^{\tau} = \sum_i \left(\frac{W^{\tau}L_i^{\tau}}{W^{\tau}L^{\tau}}\right)\dot{l}_i^{\tau}. \tag{29}$$

We can now now return to the definition of the labor reallocation term, and substitute in for $\dot{l}^{\tau}$. We find:

$$\sum_{\tau\in\{L,M,H\}} \left(\left(\sum_i s_i^V s_i^{L\tau}\dot{l}_i^{\tau}\right) - s^{\tau}\dot{l}^{\tau}\right) = \sum_{\tau\in\{L,M,H\}} \left(\sum_i \frac{W_i^{\tau}L_i^{\tau}}{PV}\dot{l}_i^{\tau} - \sum_i \frac{W^{\tau}L_i^{\tau}}{PV}\dot{l}_i^{\tau}\right) \tag{30}$$

$$= \sum_{\tau\in\{L,M,H\}} \sum_i \left(\frac{\left(W_i^{\tau} - W^{\tau}\right)L_i}{PV}\right)\dot{l}_i^{\tau} \tag{31}$$

Our earlier intuition for labor reallocation was that, if labor grows faster in country-industries where it has a higher than average wage, then this is an improvement in reallocation. Other things equal, that shift boosts growth in output and aggregate TFP. With multiple types of labor, the nuance is that the shift has to take place within a given type of labor. This difference may matter in the data. For example, suppose we see a shift in the data from labor in advanced economies to labor in emerging markets. Some of the cross-country wage differential in our earlier equation presumably reflects differences in the mix of skills across countries–so we need to compare the shifts within skill groups.[33]

C Detailed results and data

C.1 Detailed results

C.1.1 Comparison with World-Bank aggregates

Figure C.1 shows how nominal GDP in our data, measured in current US$, lines up with world GDP. The short-dashed line shows the level of nominal GDP in our sample countries in the 2013 vintage of the data. The other dashed line is the 2016 vintage of the data. Both of these lines are below the World GDP solid line, reflecting 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.

Our time series for PPP-deflated world GDP growth lines up closely with that published by the World Bank in World Bank (2018). This is evident in Figures C.2 and C.3, which show the World GDP-PPP and its growth in our data versus that of the World Bank.

C.1.2 Value-added and factor shares by country and industry

Dollar-denominated value-added shares for the different periods by country and industry are reported in Tables C.1 and C.3, respectively. Similar PPP-weighted shares are listed in Tables C.2 and C.4, respectively. Profit shares by industry are reported in Table C.5.

C.1.3 Detailed contributions to world ALP and TFP growth

The contributions of country-industry TFP growth, $\dot{z}_i$, by country/region for calculations based on dollar-weighted world GDP without taking into account markups are listed in C.6, while these contributions with markups are in C.7. The contribution of shifts in misallocation due to markups

[33] The same intuition holds for capital reallocation. Capital reallocation reflects differential user costs across country-industries for computers, or for machine tools, or for office buildings. The reason we think the capital-reallocation term should be small with an external user cost is that the user cost differences should presumably be small. Of course, there could still be differences to the extent we treat the capital-gains term as country-industry specific, or if there are differential tax wedges.

by region is reported in Table C.8 while the same contribution by industry can be found in Table C.9.

C.2 Data

C.2.1 Countries and industries

The countries in each of the vintages as well as in the sample for PPP results are listed in Table C.10. Throughout, we present these results for a set of regions that are the same across both vintages. The regions are listed in Table C.11. The industries were classified into major categories, listed in Table C.12, in order to be consistent with the North American Industry Classification System (NAICS).

C.2.2 Main variables used for our analysis

- **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.

- **Labor**: Number of employees (thousands) and total hours worked by persons engaged (millions) provide information on the growth in hours along with misallocation 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). In SEA 2013, 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, however, is absent in SEA 2016.

- **Capital**: Data on the current cost replacement value of the capital stock (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 misallocation of capital across countries and industries. For the 2013 vintage gross fixed capital formation and its associated volume index are used to calculate the implicit capital price deflator which is then used to construct a volume index for the real capital stock. For the 2016 vintage, the current cost replacement value of the capital stock by country-industry is deflated by a constructed capital price deflator. For country-industry combinations for which these deflators are available in OECD (2017), these deflators are taken from the STAN database for the industry at the lowest level of aggregation that contains the industry in our data. For country-industry combinations for which the capital price deflator is not available in STAN, we use the implicit capital price deflator from the closest corresponding industry in the 2013 vintage and then extrapolate it assuming a constant growth rate for the years 2008-2014.

- **Profits**: Profits are calculated as value added minus compensation minus capital service flows. The latter are calculated assuming an external rate of return equal to the U.S. corporate 10-yr BBB rate. We use the exchange rate to express the capital price deflator in each country in U.S. dollars. This allows us to calculate the capital price inflation in U.S. dollars, i.e. π^K_{USD}. Capital service flows for each country-industry combination are then calculated as

$$\left(i_{BBB} - \pi^K_{USD} + \delta_i\right) P^K_i K_i \tag{32}$$

  Here, i_{BBB} is the nominal BBB 10-yr corporate bond rate and δ_i is the average capital depreciation rate implied by the 2013 vintage capital data. In addition, $P^K_i K_i$ is the nominal replacement value of the capital stock. For the empirical implementation we have smoothed out fluctuations in π^K_{USD} by using the average over vintage sample.

C.2.3 Construction of capital deflators for 2016 vintage

A major source of discrepancies between the 2013 and 2016 vintages is differences in the nominal replacement value of the capital stocks. For the 2013 vintage, when available, they are taken from EU and US KLEMS data. For the 2016 vintage, when available, they are taken from the OECD STAN database. Other values are imputed. However, even those that are taken from these two data sources seem to be very different.

We have merged the the capital deflators from STAN into our data for the 2016 vintage. They are consistent with the nominal replacement values used and, for the countries for which we can obtain them, make our growth rate of the capital stock consistent with OECD STAN. For the other countries, we extrapolated the capital deflators from the 2013 vintage for the years we have missing data.

Depreciation rates are calculated by industry for the 2013 and applied to both the 2013 and 2016 vintages of the data.

C.2.4 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, $\mathcal{P}_{i,t}$, is the number of U.S. dollars in 2005 per unit of output in country-industry i 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

$$\mathcal{P}_{i,t} = \frac{\$/GO_{i,t}}{\$/USGDP_t} = \frac{USGDP_t}{GO_{i,t}} \text{ for } t = 2005. \tag{33}$$

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

Using these two time series, we can construct

$$\mathcal{P}_{i,t} = \mathcal{P}_{i,2005} \frac{P_{i,t}/P_{i,2005}}{\mathcal{P}_t/\mathcal{P}_{2005}}. \tag{34}$$

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 country-industry i in year t, i.e. $P_{i,t}Y_{i,t}$, into units of U.S. GDP. Let $Y^*_{i,t}$ be output in country-industry i in year t measured in PPP units of U.S. GDP in the same period, then we can calculate it through

$$Y^*_{i,t} = \frac{P_{i,t}Y_{i,t}}{\mathcal{P}_{i,t}} \frac{1}{\mathcal{P}_t} = \frac{P_{i,t}Y_{i,t}}{P^*_{i,t}}, \text{ where } P^*_{i,t} = \mathcal{P}_{i,t}\mathcal{P}_t. \tag{35}$$

This equation means the following. The inverse of $\mathcal{P}_{i,t}$ converts dollars of nominal gross output of country-industry i 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 country-industry i in year t is the difference between nominal gross output and the nominal value of intermediate inputs.

$$P^V_{i,t}V_{i,t} = P_{i,t}Y_{i,t} - \sum_{i'} P_{i',t}M_{i',t}. \tag{36}$$

Now PPP adjusted value added of sector i during year t, i.e. $V_{i,t}^{*}$, is obtained by PPP adjusting each of the individual nominal components. That is,

$$V_{i,t}^{*} = \frac{P_{i,t}Y_{i,t}}{P_{i,t}^{*}} - \sum_{i'} \frac{P_{i',t}M_{i',j',t}}{P_{i',t}^{*}}. \tag{37}$$

The implicit PPP deflator of value added of sector i in year t is then given by

$$P_{i,t}^{V*} = \frac{P_{i,t}^{V}V_{i,t}}{V_{i,t}^{*}}. \tag{38}$$

The calculation of (37) 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

$$P_{i,t}^{M*} = \sum_{i'} \frac{P_{i',t}M_{i',t}}{\sum_{i''} P_{i'',t}M_{i'',t}} P_{i',t}^{*}. \tag{39}$$

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 $P_{i,t}^{M*}$ for each sector i 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, (38).

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

Table C.1: Dollar-denominated value-added shares, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	0.88	0.87	0.83	0.86	0.88	0.84	0.78	0.71	0.81
United States	0.33	0.37	0.33	0.34	0.37	0.33	0.29	0.27	0.32
Great Britain	0.05	0.05	0.05	0.05	0.05	0.06	0.05	0.04	0.05
Japan	0.17	0.14	0.11	0.15	0.13	0.10	0.09	0.08	0.10
Euro Area	0.24	0.22	0.24	0.23	0.23	0.24	0.24	0.20	0.23
Other Advanced	0.09	0.09	0.10	0.09	0.10	0.11	0.11	0.12	0.11
Emerging	0.13	0.14	0.16	0.14	0.14	0.16	0.22	0.29	0.20
Brazil	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.03
China	0.04	0.05	0.06	0.05	0.05	0.06	0.10	0.14	0.09
India	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02
Russia	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.03	0.02
Other Emerging	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: Reported are contributions by country/region in percentage points over various subperiods.

Table C.2: PPP-denominated value-added shares, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	0.72	0.69	0.65	0.69	0.70	0.65	0.60	0.55	0.62
United States	0.27	0.26	0.25	0.26	0.27	0.25	0.23	0.21	0.24
Great Britain	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Japan	0.10	0.09	0.08	0.09	0.08	0.08	0.07	0.06	0.07
Euro Area	0.22	0.21	0.19	0.21	0.22	0.20	0.18	0.16	0.19
Other Advanced	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08
Emerging	0.28	0.32	0.36	0.31	0.31	0.35	0.40	0.45	0.37
Brazil	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
China	0.11	0.14	0.17	0.13	0.14	0.17	0.21	0.25	0.19
India	0.05	0.06	0.06	0.06	0.05	0.06	0.07	0.08	0.06
Russia	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Other Emerging	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: Reported are contributions by country/region in percentage points over various subperiods.

Table C.3: Dollar-denominated value-added shares, by industry: 1996-2014

SEA vintage	2013				2016				
Industry	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Agriculture	0.05	0.04	0.05	0.05	0.04	0.05	0.06	0.07	0.06
Construction	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Nondurables manuf	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11
Durables manuf	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.07
Trade Trans Utilities	0.20	0.20	0.19	0.20	0.19	0.19	0.19	0.19	0.19
FIRE	0.16	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.16
Business services	0.09	0.10	0.10	0.10	0.14	0.14	0.14	0.13	0.14
Education Healthcare	0.08	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.08
Hospitality	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.03
Personal services	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03
Government	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
Households	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: Reported are contributions by industry in percentage points over various subperiods.

Table C.4: PPP-denominated value-added shares, by industry: 1996-2014

SEA vintage	2013				2016				
Industry	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Agriculture	0.09	0.08	0.07	0.08	0.09	0.07	0.06	0.06	0.07
Construction	0.07	0.06	0.06	0.07	0.06	0.06	0.04	0.03	0.05
Nondurables manuf	0.15	0.14	0.15	0.15	0.13	0.14	0.17	0.20	0.16
Durables manuf	0.05	0.06	0.07	0.06	0.06	0.08	0.10	0.12	0.09
Trade Trans Utilities	0.17	0.19	0.19	0.18	0.19	0.20	0.19	0.19	0.19
FIRE	0.15	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.14
Business services	0.08	0.09	0.09	0.09	0.12	0.12	0.12	0.11	0.12
Education Healthcare	0.08	0.08	0.08	0.08	0.08	0.07	0.06	0.06	0.07
Hospitality	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.02
Personal services	0.04	0.04	0.03	0.04	0.03	0.02	0.02	0.02	0.02
Government	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06
Households	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: Reported are contributions by industry in percentage points over various subperiods.

Table C.5: Profits as a percentage of world GDP, by industry: 1996-2014

SEA vintage	2013				2016				
Industry	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Agriculture	0.63	0.85	1.40	1.06	1.20	1.86	1.86	2.49	2.02
Construction	0.55	0.71	1.02	0.82	0.67	0.99	0.84	1.04	0.97
Nondurables manuf	1.83	2.17	3.02	2.72	2.49	2.98	2.47	2.80	3.06
Durables manuf	0.49	0.35	0.74	0.67	0.68	1.05	0.63	0.70	0.95
Trade Trans Utilities	2.33	3.01	4.01	3.58	3.82	4.50	3.91	4.86	4.88
FIRE	-2.10	1.23	3.65	1.47	4.49	5.46	4.52	6.96	6.27
Business services	0.73	0.79	1.19	1.08	1.57	1.79	1.44	1.57	1.97
Education Healthcare	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hospitality	0.39	0.49	0.55	0.52	0.59	0.63	0.48	0.48	0.61
Personal services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Households	-0.00	-0.00	-0.00	-0.00	0.01	0.01	0.01	0.01	0.01
Total	4.96	9.72	15.96	12.25	15.53	19.24	16.16	20.92	20.74

Note: Reported are contributions by industry in percentage points over various subperiods.
Profits in Education/Healthcare, Personal care, Government, and Households are set to zero by construction.

Table C.6: Contribution of country-industry specific TFP growth, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	0.64	0.82	0.47	0.66	0.29	0.33	-0.45	0.10	0.08
United States	0.22	0.51	-0.02	0.26	0.16	0.00	0.06	-0.02	0.05
Great Britain	0.03	0.06	0.05	0.04	0.09	0.04	-0.00	0.01	0.04
Japan	0.06	0.12	0.17	0.10	-0.03	0.18	-0.19	0.10	0.02
Euro Area	0.18	0.07	0.18	0.15	0.05	0.13	-0.25	0.05	0.00
Other Advanced	0.15	0.06	0.09	0.11	0.02	-0.02	-0.07	-0.04	-0.03
Emerging	0.26	0.35	0.80	0.44	0.15	0.59	0.27	0.09	0.24
Brazil	0.01	-0.00	-0.02	-0.00	-0.01	-0.04	-0.02	-0.14	-0.06
China	0.21	0.29	0.56	0.33	0.15	0.45	0.24	0.29	0.27
India	0.03	0.01	0.08	0.04	0.01	0.05	0.02	-0.13	-0.02
Russia	-0.03	0.03	0.06	0.02	0.04	0.06	0.04	0.03	0.04
Other Emerging	0.04	0.02	0.12	0.05	-0.04	0.07	-0.01	0.04	0.01
Total	0.91	1.18	1.28	1.09	0.45	0.91	-0.17	0.19	0.34

Note: Reported are contributions by country/region to line 10 in Table 4 in percentage points over various subperiods. Results without markups.

Table C.7: Contribution of country-industry specific TFP growth, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	0.92	0.99	0.63	0.88	0.52	0.42	-0.22	0.10	0.22
United States	0.17	0.08	0.10	0.12	0.28	0.06	0.16	-0.09	0.10
Great Britain	0.20	0.09	0.17	0.16	0.08	0.04	-0.03	0.03	0.03
Japan	0.23	0.20	0.21	0.22	0.05	0.20	-0.15	0.09	0.05
Euro Area	0.05	0.07	0.06	0.06	0.06	0.09	-0.16	0.08	0.03
Other Advanced	0.27	0.55	0.09	0.32	0.05	0.03	-0.04	-0.01	0.01
Emerging	0.19	0.25	0.54	0.31	0.17	0.49	0.25	0.06	0.23
Brazil	0.01	0.01	0.10	0.03	-0.01	-0.04	0.02	-0.09	-0.03
China	-0.02	0.02	0.05	0.01	0.11	0.37	0.15	0.28	0.22
India	0.03	0.01	0.08	0.04	0.02	0.04	0.04	-0.08	0.00
Russia	0.19	0.21	0.31	0.23	0.02	0.05	0.03	-0.02	0.02
Other Emerging	0.00	-0.01	-0.01	-0.01	0.03	0.07	0.01	-0.03	0.02
Total	1.13	1.25	1.17	1.18	0.70	0.91	0.03	0.18	0.45

Note: Reported are contributions by country/region to line 10 in Table 5 in percentage points over various subperiods. Results with markups.

Table C.8: Contribution of markups to world GDP growth, by country/region: 1996-2014

SEA vintage	2013				2016				
Country/region	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Advanced	0.36	0.18	0.42	0.31	0.32	0.46	-0.04	0.25	0.24
United States	0.22	0.10	0.18	0.17	0.14	0.15	-0.06	0.17	0.10
Great Britain	0.03	0.03	0.04	0.03	0.01	0.01	0.03	-0.01	0.01
Japan	-0.00	-0.02	-0.01	-0.01	-0.01	-0.01	-0.02	-0.00	-0.01
Euro Area	0.06	0.04	0.11	0.06	0.11	0.19	-0.02	0.01	0.07
Other Advanced	0.05	0.03	0.10	0.06	0.07	0.12	0.03	0.08	0.07
Emerging	0.15	0.19	0.53	0.26	0.14	0.40	0.33	0.34	0.30
Brazil	0.01	0.00	0.02	0.01	0.01	0.04	0.04	0.03	0.03
China	0.04	0.10	0.31	0.13	0.08	0.14	0.19	0.14	0.14
India	0.02	0.02	0.05	0.03	0.03	0.05	0.05	0.05	0.04
Russia	0.00	0.03	0.06	0.02	0.03	0.07	0.03	0.04	0.04
Other Emerging	0.08	0.04	0.09	0.07	-0.01	0.10	0.02	0.08	0.05
Total	0.51	0.39	0.94	0.58	0.46	0.85	0.29	0.59	0.55

Note: Reported are contributions by country/region to line 9 in Table 5 in percentage points over various subperiods.

Table C.9: Contribution of markups to world GDP growth, by industry: 1996-2014

SEA vintage	2013				2016				
Industry	1996 - 2000	2001 - 2004	2005 - 2007	All	2001 - 2004	2005 - 2007	2008 - 2010	2011 - 2014	All
Agriculture	0.02	0.02	0.04	0.03	0.02	0.03	0.04	0.10	0.05
Construction	0.02	0.02	0.05	0.03	0.02	0.06	0.02	0.05	0.04
Nondurables manuf	0.08	0.07	0.19	0.10	0.05	0.14	0.04	0.09	0.08
Durables manuf	0.05	0.04	0.10	0.06	0.04	0.09	0.03	0.03	0.04
Trade Trans Utilities	0.16	0.15	0.23	0.17	0.13	0.22	0.07	0.15	0.14
FIRE	0.08	0.05	0.21	0.10	0.17	0.20	0.06	0.13	0.14
Business services	0.07	0.02	0.09	0.06	0.02	0.08	0.02	0.04	0.04
Education Healthcare	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hospitality	0.01	0.01	0.02	0.02	0.01	0.02	0.00	0.01	0.01
Personal services	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Households	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00
Total	0.51	0.39	0.94	0.58	0.46	0.85	0.29	0.59	0.55

Note: Reported are contributions by country/region to line 9 in Table 5 in percentage points over various subperiods.

Table C.10: 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 C.11: Country Classification

Region	Country
Euro Area	Germany, France, Austria, Italy, Belgium, Cyprus, Spain, Estonia, Finland, Greece, Ireland, Lithuania, Luxembourg, Latvia, Malta, Netherlands, Portugal, Slovakia, Slovenia
Other Advanced	Canada, South Korea, Taiwan, Australia, Switzerland, Denmark, Sweden, Norway, Bulgaria, Czech Republic, Croatia, Hungary, Poland, Romania
Other Emerging	Indonesia, Turkey, Mexico

Table C.12: 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).

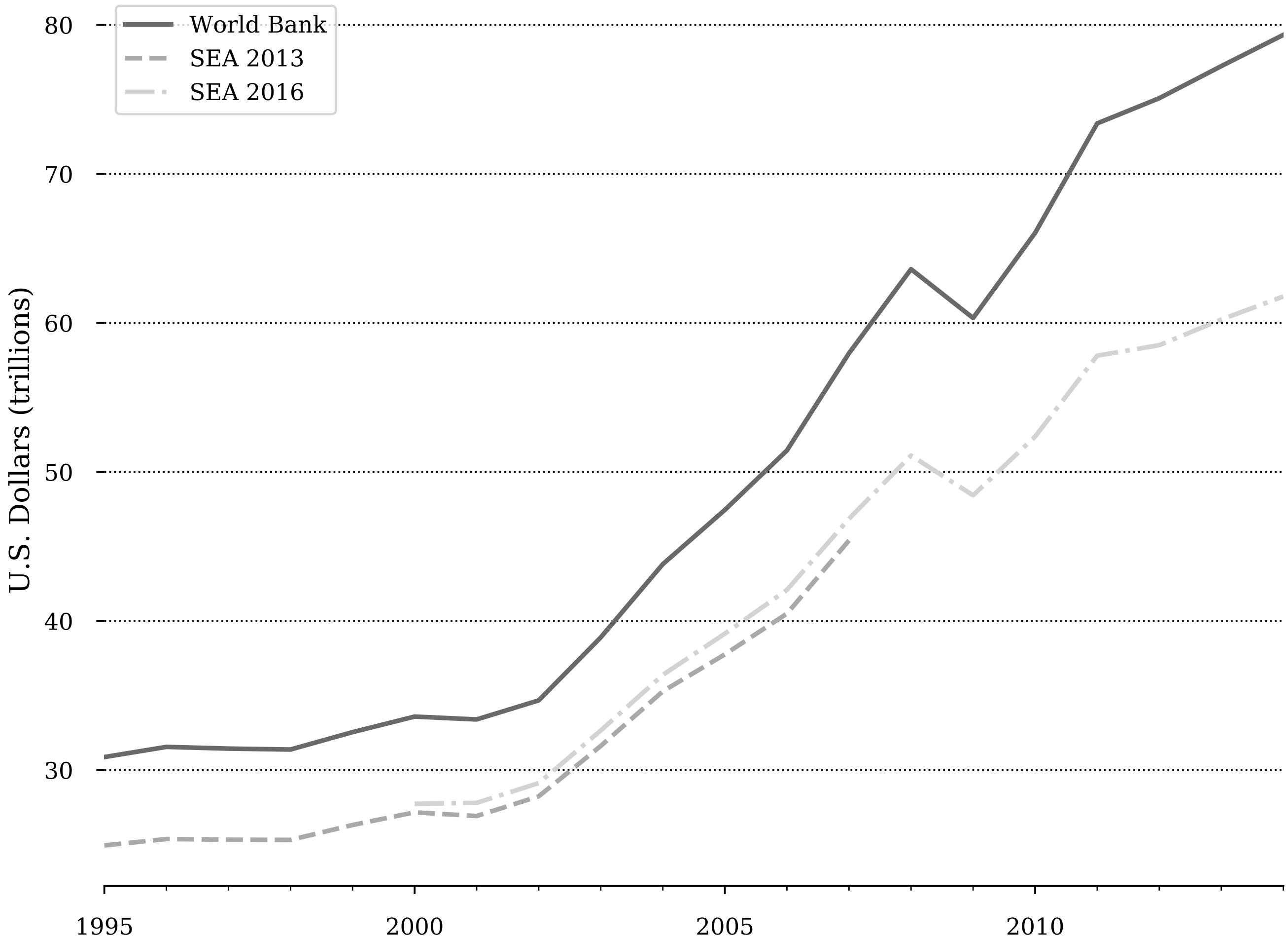

Figure C.1: Nominal world GDP in WIOD-SEA and WDI

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. $.

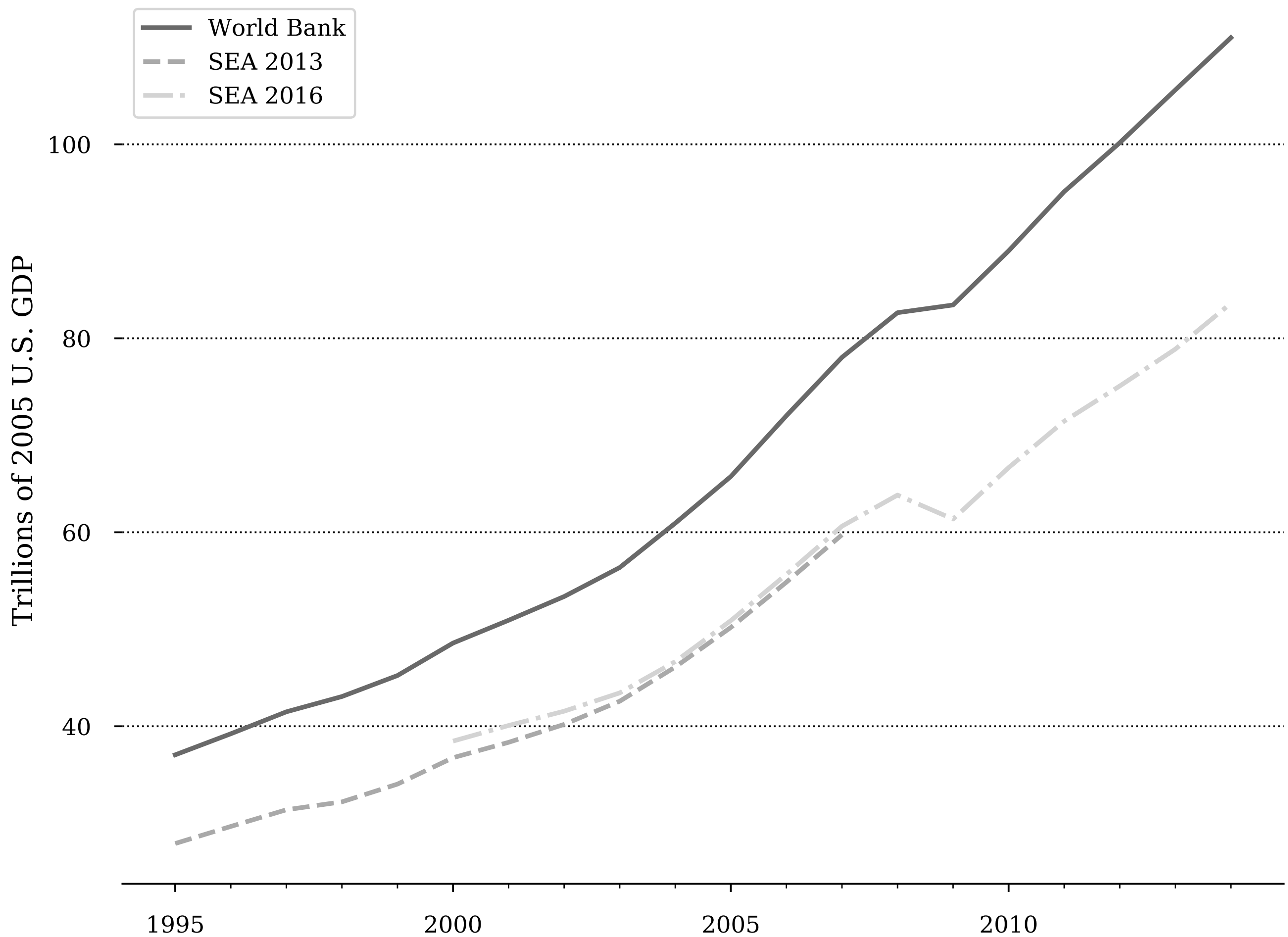

Figure C.2: World GDP PPP in WIOD-SEA and WDI

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.

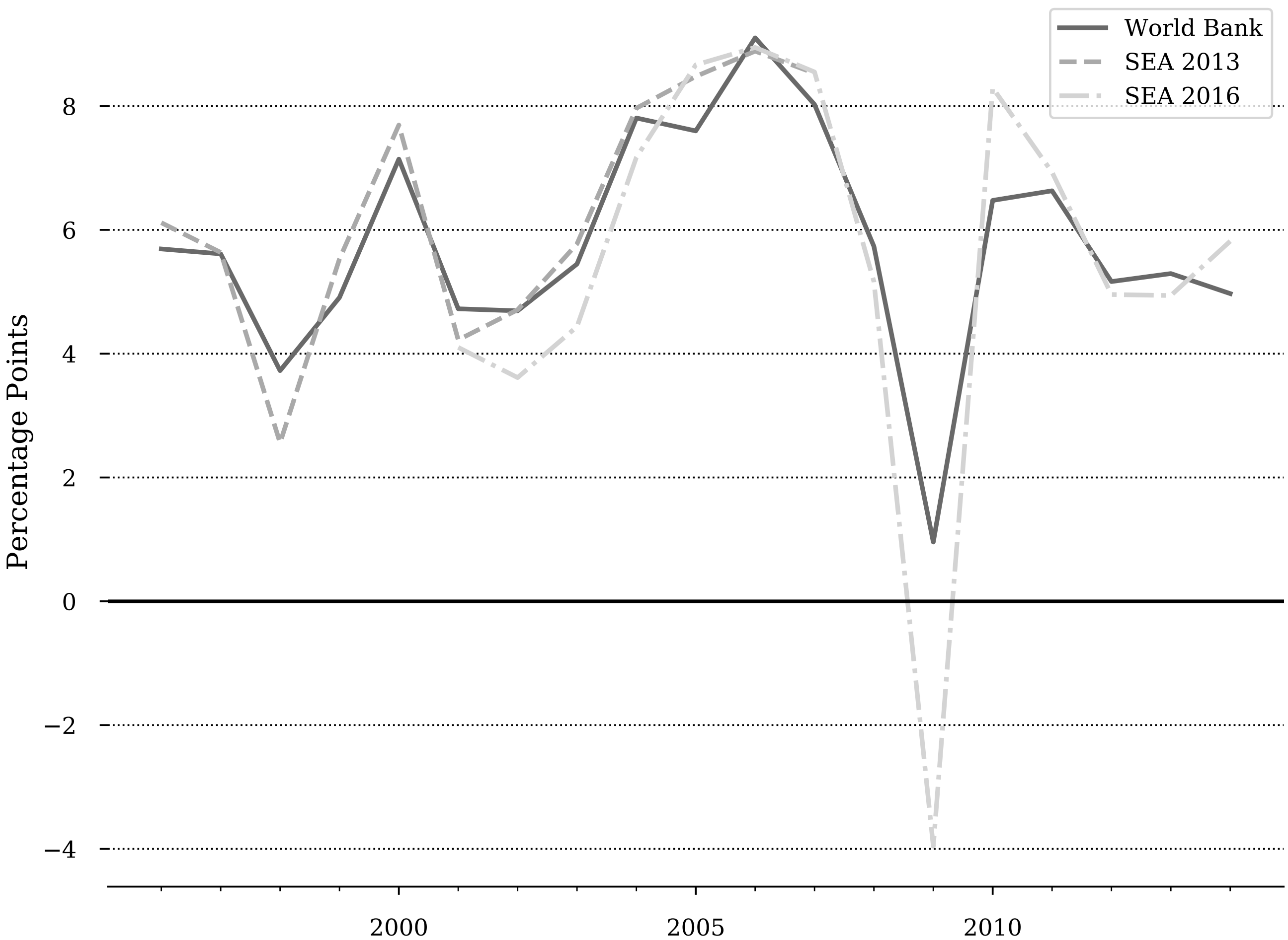

Figure C.3: Growth in world GDP PPP in WIOD-SEA and WDI

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.