



# **SIRE DISCUSSION PAPER**

**SIRE-DP-2013-42**

## **Development Accounting With Intermediate Goods**

Jan Grobovsek

University of Edinburgh

[www.sire.ac.uk](http://www.sire.ac.uk)

# DEVELOPMENT ACCOUNTING WITH INTERMEDIATE GOODS

JAN GROBOVŠEK

**ABSTRACT.** Do intermediate goods help explain relative and aggregate productivity differences across countries? Three observations suggest they do: (i) intermediates are relatively expensive in poor countries; (ii) goods industries demand intermediates more intensively than service industries; (iii) goods industries are more prominent intermediate suppliers in poor countries. I build a standard multi-sector growth model accommodating these features to show that inefficient intermediate production strongly depresses aggregate labor productivity and increases the price ratio of final goods to services. Applying the model to data, low and high income countries in fact reveal similar relative efficiency levels between goods and services despite clear differences in relative sectoral labor productivity. Moreover, the main empirical exercise suggests that poorer countries are substantially less efficient at producing intermediate relative to final goods and services. Closing the cross-country efficiency gap in intermediate input production would strongly narrow the aggregate labor productivity difference across countries as well as turn final goods in poorer countries relatively cheap compared to services.

## 1. INTRODUCTION

The value of intermediate production as a ratio of total output in a typical economy is about one half. Despite their quantitative importance, intermediate goods have so far received little attention in development accounting. This should *per se* not be of any concern if the efficiency of intermediate relative to final good production were not systematically different across countries and if the structure of input-output relations were not asymmetric across broadly-defined industries. My concern in this paper is threefold. First, I document that the above conditions for intermediate good-neutrality do not hold in the data. Second, I develop a simple growth model featuring two industries and two specializations (intermediate and final production) and use it to highlight some qualitative comparative static results. Third, I use the model to back out efficiency levels across countries to identify which industry-specializations pairs are particularly inefficient in poor countries. Importantly, this is done in a general equilibrium context in which intermediate input production is endogenous.

Two observations are key for the paper's motivation. First, different broadly-defined sectors have systematically distinct technological requirements as regards the demand for intermediates and vary systematically in their importance as suppliers of intermediates.

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UNIVERSITY OF EDINBURGH

*E-mail address:* `jan.grobovsek@ed.ac.uk`.

*Date:* 5 February, 2013.

I would like to thank Juan Carlos Conesa, Vasco Carvalho, Tim Kehoe, Nezih Guner, Albert Marcet, José Vicente Rodríguez Mora, Omar Licandro and Jordi Caballé for many helpful comments. I would also like to thank participants at the XV Workshop on Dynamic Macroeconomics at Vigo, the 2011 ENTER Jamboree in Tilburg, the 2011 EEA conference in Oslo, and workshop participants at the Universitat Autònoma de Barcelona, the University of Minnesota and the University of Edinburgh. An earlier version of this paper won the FEEM award for the best three papers by young economists at the EEA conference in Oslo. All errors are mine.

JEL codes: O10, O41, O47.

Key words: Development Accounting, Productivity, Intermediate Goods.

More to the point, when the economy is subdivided into goods and service industries, the former consume more intermediate value per unit of output, roughly 0.6 versus 0.4. In addition, goods represent a higher share in the composition of intermediate consumption in poor versus rich countries. This issue has been, to the best of my knowledge, largely overlooked in the recent literature on development accounting. It proves significant in interaction with a second set of empirical regularities. Namely, that in both industries the production of intermediates, relative to final goods, is relatively expensive in poor countries. This fact motivates an additional dichotomy between producers specializing in either final or intermediate production.

To measure sectoral efficiency levels across countries I fit the model to the data in two distinct development accounting exercises.<sup>1</sup> In the first exercise I use observations from the Groningen Growth and Development Centre (GGDC) for a sample of middle and high income countries in 1997 which features comparable intermediate and final (producer) prices. Three results stand out. First, comparing the least productive quintile of countries to the most productive quintile, the group of poor countries has an average aggregate labor productivity of one third yet an average *efficiency* level across all sectors of more than one half. Second, despite featuring relatively expensive final goods compared to services, poorer countries are by and large no more inefficient producing (final or intermediate) goods than services, which I dub industry-neutral technical change. Third, poorer countries appear particularly inefficient at producing intermediate rather than final goods and services, which is to say that technical change is not specialization-neutral.

Alternatively, I run a second exercise using data from the the World Input-Output Database (WIOD) in conjunction with final price data from the International Comparison Program (ICP) for 2005. This approach allows for a larger sample of more recent observations. It has the drawback, however, of being mute on industry-level producer prices which prevents a distinction between efficiency levels across specializations (i.e. intermediate versus final producers). The conclusion here is in line with the above findings. First, while the least productive quintile of countries have an average aggregate labor productivity of about one fifth compared to the richest quintile, their average efficiency level across all sectors is almost one half. Second, whereas in poorer countries final goods are expensive in relation to services, goods industries in these countries are not relatively less efficient than services industries (if anything it is the opposite).

The theoretical analysis of the model as well as counterfactual model-data specifications highlight the equilibrium outcomes. First, the inclusion of intermediate production leverages production inefficiencies, which are compounded through the relative scarcity of important production factors. This is all the more serious as poorer countries seem to be particularly inefficient producing intermediate rather than final goods. Second, as goods industries rely more heavily on the availability of intermediate inputs than services industries, less efficient economies feature lower *measured* relative labor productivity in (final as well as intermediate) goods versus services. This makes goods relatively expensive in poor countries. Again, the apparent fact that poorer countries are particularly inefficient in the production of intermediate inputs reinforces that effect. Third, while the cross-country shift in the nominal composition of intermediate inputs between intermediate goods and services suggests a strong complementarity between the latter, this has a negligible effect on the inference of sectoral efficiency levels.

The crucial message is that the efficiency of intermediate input production is responsible for a large part of the aggregate and relative sectoral labor productivity differences across countries. A simple counterfactual exercise stresses the impact of intermediate inputs in the accounting framework. If the poorest quintile of countries were somehow able

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<sup>1</sup>The term efficiency is used henceforth to denote real multi-factor productivity.

to adopt the average efficiency of intermediate good production of the richest quintile, their aggregate labor productivity (compared to the richest countries) is predicted to increase from about one third to two thirds (from about one fifth to more than half in the alternative specification). Also, in both specifications such a move would imply a radical shift in relative final prices - poor compared to rich countries would then feature relatively expensive final services rather than goods.

This paper is closely related to the literature on sectoral development accounting.<sup>2</sup> Based on final expenditure price data, Herrendorf and Valentinyi (2012) compute that low-income countries are particularly unproductive at producing goods as compared to services. This is in line with evidence from Bernard and Jones (1996a) who show that during the 1970's and 1980's OECD countries have experienced income convergence in services, but not in manufacturing.<sup>3</sup> On the other hand, Duarte and Restuccia (2010) present evidence, based on industry growth accounting and employment shares, that poorer countries are particularly unproductive in the agricultural and service sectors, but less so in manufacturing. My aim is to shed light on these conflicting pieces of evidence by stressing the importance of input-output patterns in determining relative sectoral productivities. Ngai and Samaniego (2009) similarly stress the importance of the composition of intermediate goods for productivity inferences, though their focus is on investment-specific technical change.<sup>4</sup> In general, sectoral growth accounting analyses across countries have been hampered by the availability of internationally comparable industry price data. Exceptions that do use sectoral industry prices and explicitly account for intermediate inputs include Jorgenson, Kuroda and Nishimizu (1987), Lee and Tang (2000) and van Ark and Pilat (1993) for specific country comparisons as well as Inklaar and Timmer (2007) for a larger set of countries. These studies differ, however, from the present paper in that intermediates inputs are exogenously retrieved from the data rather than a general equilibrium outcome.

The literature offers some support for the notion that the production of intermediate goods is particularly inefficient in poor countries. On the theoretical front, Acemoglu, Antràs and Helpman (2007) apply the incomplete contracts framework of Grossman and Hart (1986) and Hart and Moore (1990) to the analysis of contracts between producers and their specialized input suppliers. They find that a higher degree of contract incompleteness lowers the suppliers' incentive to invest and hence leads to underprovision of intermediate inputs. This fits well with empirical evidence provided by Nunn (2007) who argues that countries with more efficient contractual institutions tend to be richer and specialize in the production of goods that require special relationships with suppliers. An alternative reason for poor countries' low performance in producing intermediates could be a lower degree of competitive pressure. Amiti and Konings (2007) provide empirical support that the lowering of trade barriers in developing countries boosts productivity by increasing import competition in the market for intermediate goods. That foreign competitive pressures strongly boost productivity in a prominent intermediate good producing sector such as mining is also empirically documented in Galdón-Sánchez and Schmitz (2002). In addition, international trade frictions may inhibit the transfer of technology via the import of intermediate goods. In this sense Kasahara and Rodrigue (2008) and

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<sup>2</sup>See Caselli (2005) for an overview and applications of development accounting.

<sup>3</sup>Related early literature on cross-country convergence at the aggregate economy level includes amongst others Baumol (1986), Barro and Sala-i Martín (1992), Mankiw, Romer and Weil (1992) and Bernard and Jones (1996b). More recent articles on sectoral convergence using producer prices are Sørensen and Schjerning (2008) and Inklaar and Timmer (2009).

<sup>4</sup>The classical theoretical contributions on growth accounting with intermediate goods include amongst others Melvin (1969) and Hulten (1978).

Halpern, Koren and Szeidl (2011) estimate that imported intermediates strongly boost domestic firms' productivity in Chile and Hungary, respectively. Similarly, Goldberg, Khandelwal, Pavcnik and Topalova (2010) identify productivity gains from the import of a larger variety of intermediates in India.<sup>5</sup>

As intermediates are essential factors of production, a strand of the literature has focused on their under-provision as a substantial barrier to development. Jones (2011) shows theoretically how generic wedges that disperse the marginal productivity of intermediate goods, coupled with these goods' complementarity in production, substantially lower aggregate productivity.<sup>6</sup> His model builds on the seminal contribution of Mirrlees (1971) on the negative welfare effect of taxing intermediate inputs and the one of Kremer (1993) on the multiplier effect of complementarity in production. Ciccone (2002) is also a theoretical treatment of the process of industrialization as the deepening of intermediate good use intensity, based on evidence to that effect reported in Chenery, Robinson and Syrquin (1986). Adamopoulos (2011) studies the impact of a crucial intermediate input, transportation. He computes that poorer countries' relative high transportation costs strongly amplify their aggregate productivity gap. Similarly, Restuccia, Yang and Zhu (2008), using producer price data of the Food and Agriculture Organization (FAO), find that farms in poor countries face substantially higher relative prices for intermediate goods. This lowers their agricultural productivity, which in turn strongly diminishes aggregate productivity as resources are channelled into agriculture due to the negative income effect. Their interest in (real) physical intermediate input intensity as opposed to nominal intensity is very similar in spirit to Hsieh and Klenow (2007). They stress that poorer countries have lower investment rates in physical capital when measured in internationally comparable prices, but not in local prices. Here I highlight a similar phenomenon by claiming that a portion of poor countries' low productivity can be 'explained' by their low *real* investment rate in the intermediate production factor even when their nominal investment rate is just as high as in rich countries.

The organization of the paper is as follows. Section 2 presents the empirical evidence. Section 3 proposes the model environment. The theoretical results of the model are summarized in section 4. Section 5 presents the main empirical findings and their implications while section 6 repeats that exercise using alternative data. Section 7 concludes.

## 2. EMPIRICAL MOTIVATION

### 2.1. *Relative prices*

One of the most salient stylized features in development accounting is that at the level of final expenditure, goods (i.e. agricultural, industrial consumption and investment goods) are relatively more expensive than services in poorer countries. Figure 1 plots the relative price of final services to goods from the ICP 2005 round against GDP per capita.<sup>7</sup> These relative price differences are presumably informative about which are the 'problem sectors' in poor countries if one is interested in growth accounting at the final expenditure level. Herrendorf and Valentinyi (2012) use similar data to construct production functions for different sectors to back out sectoral TFP series. They find that the poorest countries are particularly inefficient at producing agricultural and investment

<sup>5</sup>In general, due to the rise of vertical specialization across countries intermediate inputs may have become an important source the increase in international trade over the last couple of decades, a point emphasized theoretically in Yi (2003).

<sup>6</sup>The dispersion of productivities *within* sectors as a source of large aggregate productivity differences has recently received a lot of attention. See for instance Banerjee and Duflo (2005), Guner, Ventura and Xu (2008), Restuccia and Rogerson (2008) and Hsieh and Klenow (2009).

<sup>7</sup>The construction of all the series in the following figures is described in the Appendix.

goods, and also inefficient at producing consumption goods, while being significantly less inefficient at producing services.

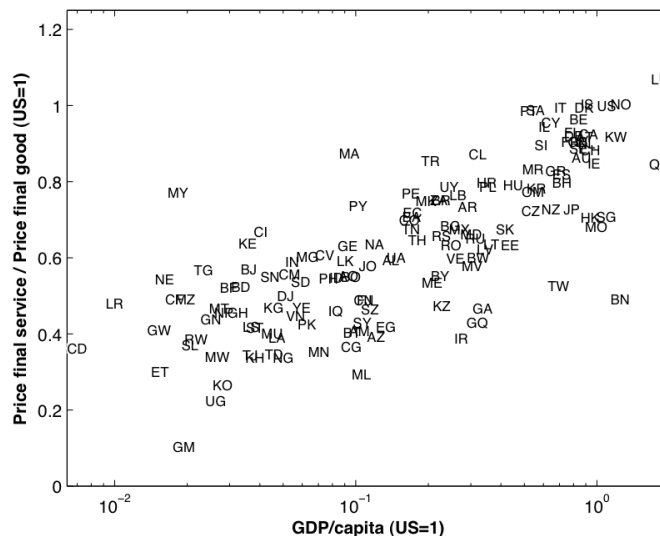


FIGURE 1. Price of final services relative to final goods

The drawback of such an approach is that it does not directly imply relative productivity differences at the industry level. This information, however, would be more valuable for researchers trying to micro-found productivity differences across countries and sectors that are related to inefficiencies at the level of the production unit. To circumvent this problem as well as the unreliability of price measurements across countries, Duarte and Restuccia (2010) use a structural transformation model to measure cross-country sectoral productivity differences for OECD countries and a smaller sample of middle income countries. They infer level differences from relative industry employment shares at a given moment in time and then use industry-based productivity growth data to measure productivity growth and hence productivity levels through time. Interestingly, and in stark contrast, they find that rich compared to poor countries have higher productivity levels in the production of agricultural goods and *services* but a less pronounced productivity advantage in manufacturing.

The difference in the two results may simply be due to the fact that Herrendorf and Valentinyi (2012) measure TFP while Duarte and Restuccia (2010) infer labor productivity. Yet since the sectoral physical and human capital factor shares used by Herrendorf and Valentinyi (2012) do not vary much between manufacturing and services, this seems unlikely. Rather, the conflicting evidence calls for an analysis involving the input-output process that translates production into final expenditure.

One indicator that intermediate goods play an essential role in development accounting is the fact that they appear to be relatively expensive in poor countries. This observation comes out of the only relatively large dataset on internationally comparable relative prices at the industry level, provided by the GGDC in conjunction with EU KLEMS, covering most OECD countries and several Central and Eastern European countries in the year 1997 (for further discussion see O'Mahony and Timmer (2009)). Figure 2 plots data for each sample country on the price of intermediate goods (services) relative to the price of final goods (services) against data on aggregate productivity per hour worked. The

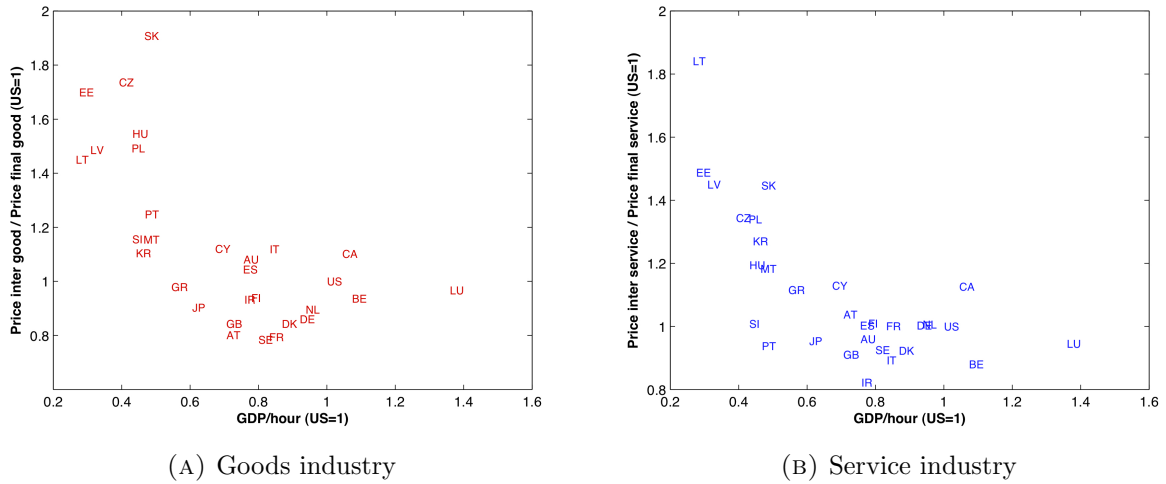


FIGURE 2. Price of intermediate goods (services) relative to final goods (services)

downward-sloping shape of the series suggests that in both industries - goods and services - intermediates are relatively expensive compared to final goods in lower income countries.<sup>8</sup>

## 2.2. Intermediate consumption and supply shares

Figure 3 summarizes the 2005 nominal intermediate consumption share (the value of an industry's intermediate consumption relative to output - the difference to one is the industry's value-added) across countries from internationally comparable input-output tables compiled for the World Input-Output Database (WIOD), against GDP per hour.<sup>9</sup>

Two trends stand out. First, for both sectors the ratios seem rather uncorrelated with GDP per capita.<sup>10</sup> This fact has been previously pointed out elsewhere for the overall intermediate consumption ratio in the economy (e.g. Jones (2011)). It runs counter, however, to the argument expressed in Chenery et al. (1986), according to which input-output ratios tend to rise during industrialization, possibly due to the adoption of different technological practices. In this paper I will abstract from arguments involving changes in technology and treat the input-output ratio of an industry as depending exclusively on a time-invariant factor share of inputs in the production function.<sup>11</sup> Rather, I wish to highlight the other feature that emerges from Figure 3, namely that industries vary substantially in their requirement of intermediate goods. The production of goods uses up relatively larger values of intermediate goods than the production of services. While the implication of differences in intermediate factor intensities across sectors on the analysis

<sup>8</sup>The sample includes 30 countries. The coefficient of correlation (t-statistic) is -0.67 (-4.83) for goods and -0.69 (-5.10) for services.

<sup>9</sup>This sample comprises 40 countries, including several low-income non-OECD countries such as India, China and Indonesia. For further details on the construction of internationally comparable input-output tables see Ahmad and Yamano (2006).

<sup>10</sup>The coefficient of correlation (t-statistic) is 0.05 (0.32) for goods and 0.33 (2.14) for services. The statistical significance for services is entirely driven by the outlier Luxembourg.

<sup>11</sup>The WIOD data, which start in 1995, suggest a slight secular shift towards an increase in factor intensities. The average intermediate factor intensity in 1995 for the goods and service industries is 0.64 and 0.39, respectively. For 2005 the numbers are 0.67 and 0.42, respectively. On the other hand, data for the US indicate remarkable stable factor intensities for manufacturing and services from 1960 until today - see Moro (2012b).



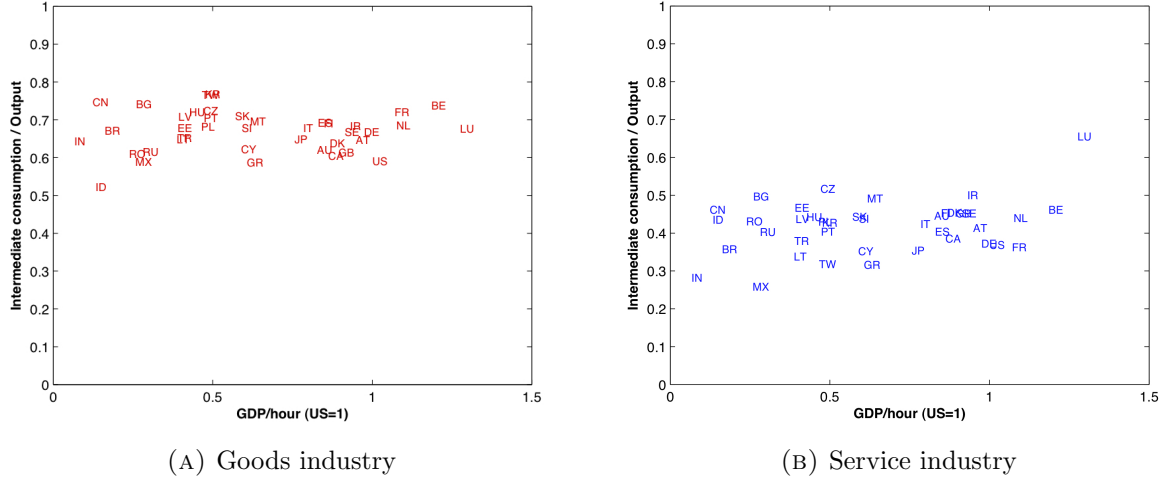


FIGURE 3. Nominal intermediate consumption intensity

of productivity has been known at least since Domar (1961) and Hulten (1978), it has received little attention in the latest literature on aggregate productivity across countries.<sup>12</sup>

The stability of aggregate intermediate factor shares across countries and industries does not, however, extend to the composition of intermediate consumption. Figure 4 shows that in higher income countries, industries producing goods (services) tend to spend a relatively less (more) on intermediates deriving from their own sector.<sup>13</sup> In lower income countries, goods industries therefore appear more prevalent as suppliers of intermediates in nominal terms.

### 3. ECONOMIC ENVIRONMENT

#### 3.1. Model description

I consider a closed economy that is static so the firms' and households' objectives only need to be specified over intratemporal choices.

##### 3.1.1. Production

All firms operate in a competitive environment. They specialize in producing either final or intermediate goods, indexed respectively by  $j \in \{f, m\}$ . At the final good level there is a representative firm indexed by  $i \in \{g, s\}$  in each of the two industries - goods and services.<sup>14</sup> It produces according to the constant returns to scale production function

$$y_{fi} = A_{fi} \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gfi}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sfi}^{\frac{\rho_i-1}{\rho_i}} \right)^{\frac{\sigma_i \rho_i}{\rho_i-1}} l_{fi}^{1-\sigma_i} \quad (1)$$

where  $y_{fi}$  and  $l_{fi}$  denote, respectively, firm  $fi$ 's output and labor input while  $x_{jfi}$  is the firm's demand for the intermediate good supplied by industry  $j$ .  $A_{fi} > 0$  is the firm's efficiency parameter,  $\sigma_i \in (0, 1)$  the composite intermediate good factor share,  $\rho_i \in [0, 1) \cup (1, \infty)$  the elasticity of substitution between the two intermediate inputs

<sup>12</sup>Differences in sectoral intermediate consumption shares have recently been exploited in the literature on macroeconomic volatility. See for instance Moro (2012b), Carvalho and Gabaix (forthcoming).

<sup>13</sup>The coefficient of correlation (t-statistic) is -0.73 (-7.05) for goods and 0.87 (10.67) for services.

<sup>14</sup>Goods will have as their empirical counterpart the industry labels A-F while services are comprised of industries G-Q.



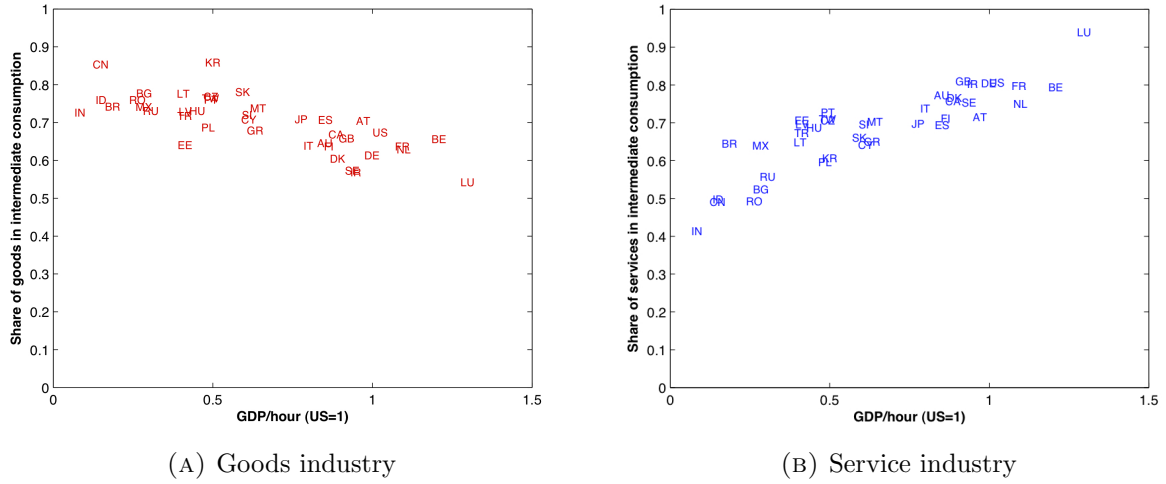


FIGURE 4. Intermediate consumption composition

and  $\gamma_{gi} \in (0, 1)$  their relative weights in production, with  $\sum_{j=s,g} \gamma_{ji} = 1$ . The firm's maximization of profits implies

$$\max_{x_{gfi} \geq 0, x_{sfi} \geq 0, l_{fi} \geq 0} (p_{fi} y_{fi} - p_{mg} x_{gfi} - p_{ms} x_{sfi} - w l_{fi}) \quad (2)$$

where  $p_{fi}$  is the price of the firm's output,  $p_{mj}$  the price of intermediate input  $j$  and  $w$  the wage rate.

Analogously, intermediate goods producers in each industry  $i$  produce according to

$$y_{mi} = A_{mi} \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gmi}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{smi}^{\frac{\rho_i-1}{\rho_i}} \right)^{\frac{\sigma_i \rho_i}{\rho_i-1}} l_{mi}^{1-\sigma_i}, \quad (3)$$

with  $A_{mi} > 0$ , and solve

$$\max_{x_{gmi} \geq 0, x_{smi} \geq 0, l_{mi} \geq 0} (p_{mi} y_{mi} - p_{mg} x_{gmi} - p_{ms} x_{smi} - w l_{mi}). \quad (4)$$

Notice that the technical parameters  $\sigma$ ,  $\rho$  and  $\gamma$  are assumed to vary across industries, but not across specializations or across countries. In contrast, efficiency  $A$  is specific to both industry and specialization and is thought of as the only variable that is country-specific. Finally, market clearing implies that

$$c_i = y_{fi}, \quad i \in \{g, s\}, \quad (5)$$

$$x_{ifg} + x_{ifs} + x_{img} + x_{ims} = y_{mi}, \quad i \in \{g, s\}. \quad (6)$$

where  $c_i$  is consumption of final good  $i$ .

At this point several clarifications are necessary. First, the breakup into two industries is not only driven by convenience and access to data. As argued in the previous section, there are grounds to believe that along the dimensions of interest here - intermediate goods trade and relative productivity - there is a clear-cut distinction between industries producing goods and those producing services. A further separation of the goods industry into consumption and investment goods would enrich the model by incorporating investment behavior. Similarly, distinguishing agriculture from manufacturing would allow the model to capture better the phenomenon of structural transformation. Yet both would come at the price of less analytical tractability of the central issue here.<sup>15</sup>

<sup>15</sup>This also allows to compare results with the literature that explicitly microfound relative sectoral efficiency differences across countries, typically framed within two sectors. One example is Buera, Kaboski

Second, the Cobb-Douglas specification between composite intermediate inputs and labor can be defended empirically by the argument of stable intermediate factor shares across countries as presented in Figure 3. The relative mix of industry-specific intermediate goods, however, is allowed to vary systematically with relative price changes, consistent with the discussed evidence in Figure 4.

Third, given the form of the production functions (1) and (3) I interpret  $A$  as factor-neutral efficiency. In this I follow Jones (2011) or the multi-factor analysis in the EU KLEMS data, which implicitly assumes that efficiency is embedded in intermediate goods as well as in other production factors. This is opposed to the alternative specification

$y = \left( \gamma_g^{\frac{1}{\rho}} x_g^{\frac{\rho-1}{\rho}} + \gamma_s^{\frac{1}{\rho}} x_s^{\frac{\rho-1}{\rho}} \right)^{\frac{\sigma\rho}{\rho-1}} (Bl)^{1-\sigma}$  where efficiency  $B = A^{1-\sigma}$  is purely embedded in labor.<sup>16</sup> Independently of the specification, however,  $A$  is thought of as capturing both actual (technical and organizational) efficiency as well as the use of additional production factors such as physical and human capital that are not explicitly modelled here.

### 3.1.2. Households

A representative household solves the problem  $\max_{c_g \geq 0, c_s \geq 0} u(c_g, c_s)$  subject to

$$p_{fg}c_g + p_{fs}c_s \leq w(l_{fg} + l_{fs} + l_{mg} + l_{ms})$$

and

$$l_{fg} + l_{fs} + l_{mg} + l_{ms} = 1. \quad (7)$$

For the main accounting exercise it is not necessary to specify the utility function. This only becomes necessary for computing counterfactuals as well as for the comparative static analysis of welfare. In this case the specification will be

$$u(c_g, c_s) = \left( \omega_g^{\frac{1}{\rho}} c_g^{\frac{\rho-1}{\rho}} + \omega_s^{\frac{1}{\rho}} c_s^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}} \quad (8)$$

where  $\rho \in [0, 1) \cup (1, \infty)$  denotes the elasticity of substitution between the two final consumption goods and  $\omega \in (0, 1)$  their relative weights, with  $\sum_{i=s,g} \omega_i = 1$ . This utility function implies that sectoral structural transformation is driven by relative price changes as proposed by Ngai and Pissarides (2007).<sup>17</sup> A second issue to note is that calling  $c$  a consumption good is a slight abuse of language. What is meant by  $c$  is actually more the final use of the good, i.e. it can be used for investment as well as consumption. Also, in view of the subsequent data analysis, note that in an open economy context  $c$  could equally represent an export (whether in the form of a final or an intermediate good - the crucial point is that it is not consumed as an intermediate in the home economy).

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and Shin (2011) who show how financial frictions in poor countries disproportionately affect the sector of tradables (i.e. goods).

<sup>16</sup>Moro (2012a) is one exception in the literature to use the alternative specification by which technology is not embedded in intermediate goods.

<sup>17</sup>Herrendorf, Rogerson and Valentinyi (forthcoming) analyze the relative merit of this specification compared to one based on income effects (as for instance in Kongsamut, Rebelo and Xie (2001)) in accounting for secular changes in expenditure shares on agricultural, manufactured and service goods in the US. They find that price effects are not an important driver of changes in the final expenditure. I nonetheless choose the above utility specification as it is more convenient to handle and because there is a clear cross-country correlation between the relative final price of goods to services and final expenditure shares. Herrendorf et al. (forthcoming) do not find such a correlation for the three expenditures items that they consider.

### 3.2. Equilibrium definition

The equilibrium is a list of production,  $y_{ji}$ , final consumption  $c_j$ , intermediate input demand for goods  $x_{gji}$  and services  $x_{sji}$ , labor allocation  $l_{ji}$ , prices  $p_{ji}$ ,  $\forall j \in \{f, m\}, i \in \{s, g\}$ , as well as the wage rate  $w$  such that:

- i) households take  $\{p_{fi}\}_{i \in \{s, g\}}$  and  $w$  as given and solve their problem;
- ii) the representative final good producer in industry  $i \in \{g, s\}$  takes input prices  $\{p_{mi}\}_{i \in \{s, g\}}$ , the wage  $w$  and output price  $p_{fi}$  as given and solves (2);
- iii) the representative intermediate good producer in industry  $i \in \{g, s\}$  takes prices  $\{p_{mi}\}_{i \in \{s, g\}}$  and the wage  $w$  as given and solves (4);
- iv) the goods markets clear so that (1), (3), (5) and (6) are satisfied  $\forall i \in \{g, s\}$ ;

## 4. THEORETICAL IMPLICATIONS

Assuming an interior solution, the equilibrium leads to a straightforward characterization, summarized in the Appendix. This subsection identifies the qualitative theoretical general equilibrium effect of movements in the efficiency parameters  $A$  on prices, intermediate input intensity and aggregate labor productivity. To highlight some of the effects I will consider some equilibrium outcomes under the following structural restriction.

**Assumption 1.** *Efficiency levels are structurally linked according to :*

$$A_{fs} = A_{fg}^\phi, \quad A_{ms} = A_{mg}^\phi, \quad A_{mg} = A_{fg}^\mu, \quad (9)$$

with  $\phi > 0$  and  $\mu > 0$ .

This assumption implies that the economy's efficiency is sufficiently characterized by  $A_{fg}$  and that  $\phi$  captures differences in sectoral growth across industries (goods and services) while  $\mu$  captures differences in sectoral growth across specializations (final and intermediate goods and services). When the assumption holds it is worthwhile to analyze the following scenarios.

**Definition 1. Industry-neutral technical change:**  $\phi = 1$  so that  $\frac{dA_{fg}}{A_{fg}} = \frac{dA_{fs}}{A_{fs}}$  and  $\frac{dA_{mg}}{A_{mg}} = \frac{dA_{ms}}{A_{ms}}$ .

**Definition 2. Specialization-neutral technical change:**  $\mu = 1$  so that  $\frac{dA_{fg}}{A_{fg}} = \frac{dA_{mg}}{A_{mg}}$  and  $\frac{dA_{fs}}{A_{fs}} = \frac{dA_{ms}}{A_{ms}}$ .

Considering the equilibrium outcome under these restrictions is of interest as the data analysis will show that depending on the data source, empirical estimates of  $\mu > 1$  and  $\phi \approx 1$  are reasonable if prices of intermediates inputs are available, while  $\phi \approx 1$  appears reasonable when these prices are not available (in which case  $\mu = 1$  by construction).

### 4.1. Prices

Combining (23) and (24) from the Appendix results in the following price ratio between specializations:

$$\frac{p_{mi}}{p_{fi}} = \frac{A_{fi}}{A_{mi}}, \forall i \in \{s, g\}. \quad (10)$$

Since production functions across specializations are identically parametrized, the price ratios between final and intermediate good suppliers in each industry is fully characterized by their relative efficiency. Note that the downward sloping price ratios across specializations in Figure 2 suggest that poorer countries are relatively inefficient at producing

intermediate goods in both industries. The final good price ratio  $p_{fs}/p_{fg}$  is implicitly pinned down by combining again (23) and (24):

$$\frac{p_{fs}}{p_{fg}} = \frac{(1 - \sigma_g) \sigma_g^{\frac{\sigma_g}{1-\sigma_g}} A_{fg} A_{mg}^{\frac{\sigma_g}{1-\sigma_g}} \left( \gamma_{ss} + \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{\rho_s - 1} \gamma_{gs} \right)^{\frac{\sigma_s}{(1-\sigma_s)(1-\rho_s)}}}{(1 - \sigma_s) \sigma_s^{\frac{\sigma_s}{1-\sigma_s}} A_{fs} A_{ms}^{\frac{\sigma_s}{1-\sigma_s}} \left( \gamma_{gg} + \gamma_{sg} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{1-\rho_g} \right)^{\frac{\sigma_g}{(1-\sigma_g)(1-\rho_g)}}}. \quad (11)$$

Because the two industries are cross-linked through trade in intermediate goods, the latter is independent of the specification of the utility function and only reflects underlying technological parameters. Combining (1) with (21) and (22) from the Appendix obtains an expression for the relative labor productivity between final good producers:

$$\frac{y_{fg}/l_{fg}}{y_{fs}/l_{fs}} = \frac{1 - \sigma_s p_{fs}}{1 - \sigma_g p_{fg}} \quad (12)$$

Comparing relative final prices across rich ( $R$ ) and poor ( $P$ ) countries therefore gives a one-to-one mapping to relative productivities in final goods since  $\frac{y_g^P/l_g^P}{y_s^P/l_s^P} / \frac{y_g^R/l_g^R}{y_s^R/l_s^R} = \frac{p_s^P/p_g^P}{p_s^R/p_g^R}$ . This is not to say, however, that this price ratio is also a relevant measure of relative *efficiencies* across industries, as formalized in the following Proposition.

**Proposition 1.** *Assume the economy experiences positive efficiency growth and that the structural relationship (9) holds. (i) Under industry-neutral technical change the relative price of final services to final goods  $p_{fs}/p_{fg}$  is increasing (decreasing) if and only if  $\sigma_g > (<) \sigma_s$ ; (ii) under specialization-neutral technical change  $p_{fs}/p_{fg}$  is increasing (decreasing) if and only if  $\phi < (>) \frac{1-\sigma_s}{1-\sigma_g}$ .*

*Proof.* Appendix. □

The data presented in the previous section (Figure 3) indicate that goods industries have a higher intermediate factor share than services ( $\sigma_g > \sigma_s$ ). The stylized fact that the relative value of  $p_{fs}/p_{fg}$  increases as a country catches up in development hence does not imply that convergence is necessarily accompanied by higher growth in the goods industry compared to services. Because the production of goods is more sensitive to the cost of intermediates, (industry-neutral) increases in efficiency are likely to magnify the labor productivity of the goods industry more than the one of the service industry.<sup>18</sup> It need not be therefore that poor countries are particularly inefficient at producing goods. The second part of Proposition 1 states that converging countries could indeed have faster growth in services compared to goods and still experience an increase in the ratio  $p_{fs}/p_{fg}$  as long  $\frac{1-\sigma_s}{1-\sigma_g} > \phi > 1$ , which is plausible. One implication of this is that even if rich countries were actually relatively better at producing services than goods (as may well have resulted from the analysis in Duarte and Restuccia (2010) if they had treated agriculture and manufacturing as one industry), goods may still turn out to be relatively cheaper in these countries due to the demand side of the input-output relationship. Not taking this relationship into account by focusing only on final goods can lead to a biased diagnostic of which industries are the ‘problem sectors’ of poor countries.

<sup>18</sup>This is analogous to international trade theories in the tradition of Heckscher and Ohlin where poor countries are thought of as being relatively unproductive in producing goods with high capital intensity and where capital endowments are fixed. Here intermediate inputs are not fixed, but their supply is relatively less abundant than labor in poor countries because their aggregate production is lower.

## 4.2. Intermediate good intensity

A common measure of interest in development accounting is the capital to output ratio. In a similar vein it is of interest to identify the intermediate good to output ratio. For this I define the composite intermediate input  $m$  demanded by specialized industry  $ji$

as  $m_{ji} \equiv \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gji}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sji}^{\frac{\rho_i-1}{\rho_i}} \right)^{\frac{\rho_i}{\rho_i-1}}$  and by  $\tilde{p}_{ji}$  its associated price so that  $\tilde{p}_{ji}m_{ji} = p_{mg}x_{gji} + p_{ms}x_{sji}$ . From the Cobb-Douglas specification of the production function it is clear that in equilibrium the value intensity of intermediates in production is

$$\frac{\tilde{p}_{ji}m_{ji}}{p_{ji}y_{ji}} = \frac{p_{mg}x_{gji} + p_{ms}x_{sji}}{p_{ji}y_{ji}} = \sigma_i, \quad \forall j \in \{f, m\}, i \in \{s, g\}. \quad (13)$$

By construction the intermediate consumption ratios in the two industries in nominal terms are constant across countries, which mimics the evidence in Figure 3. What does vary in value is the relative composition of the composite intermediate good. The combination of (10) with (21) and (22) obtains the relative share of the industries' intermediates that they derive from their own respective industry:

$$\begin{aligned} \frac{p_{mg}x_{ggg}}{p_{mg}x_{ggg} + p_{ms}x_{sgg}} &= \frac{\gamma_{gg}}{\gamma_{gg} + \gamma_{sg} \left( \frac{p_{ms}}{p_{mg}} \right)^{1-\rho_g}}, \quad \forall j \in \{f, m\} \\ &\equiv G_{gg} \in (0, 1) \end{aligned} \quad (14)$$

and

$$\begin{aligned} \frac{p_{ms}x_{sjs}}{p_{mg}x_{gjs} + p_{ms}x_{sjs}} &= \frac{\gamma_{ss}}{\gamma_{ss} + \gamma_{gs} \left( \frac{p_{ms}}{p_{mg}} \right)^{\rho_s-1}}, \quad \forall j \in \{f, m\} \\ &\equiv G_{ss} \in (0, 1). \end{aligned} \quad (15)$$

The *real* intensity in the composite intermediate good, however, is expected to vary across countries depending on the relative values of  $A$  as summarized in the following Proposition. In particular, one may be interested in the real intermediate intensity of final goods industries. These industries' output equals total value-added and hence their access to intermediate inputs is analogous to the availability of investment goods when the production function is expressed in terms of value-added.

**Proposition 2.** *Assume the economy experiences positive efficiency growth and that the structural relationship (9) holds. (i) Under industry-neutral technical change the real intermediate input intensity  $m_{fg}/y_{fg}$  is increasing (decreasing) if and only if*

*$\left( 1 - \frac{(\sigma_g - \sigma_s)(1 - G_{gg})}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_s(1 - \sigma_g)(1 - G_{ss}) + \sigma_g(1 - \sigma_s)(1 - G_{gg})} \right) \mu > (<) 1$ , and  $m_{fs}/y_{fs}$  is increasing (decreasing) if and only if  $\left( 1 + \frac{(\sigma_g - \sigma_s)(1 - G_{ss})}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})} \right) \mu > (<) 1$ ; (ii) under specialization-neutral technical change  $m_{fg}/y_{fg}$  is decreasing (increasing) and  $m_{fs}/y_{fs}$  is increasing (decreasing) if and only if  $\phi < (>) \frac{1 - \sigma_s}{1 - \sigma_g}$ .*

*Proof.* Appendix. □

Under industry-neutral technical change, for  $\sigma_g > \sigma_s$  it is expected that the real intermediate intensity of the final service industry increases as the economy grows. For the final goods industry the sign is not clear. Notice however that for a large enough  $\mu > 1$  (i.e. the technology in intermediate production grows sufficiently faster than in final production), intermediates are likely to become relatively cheap for the final goods industry as well so that it increases its real intermediate use. This is reminiscent of Hsieh and Klenow (2007) who show that poorer countries are likely to have a lower real capital

intensity because they are relatively inefficient at producing investment goods (as well as tradable consumption goods).

On the other hand, for specialization-neutral technical change such that  $\phi$  is close to 1 (i.e. in conjunction with approximate industry-neutral technical change) we can expect economic growth to have the following effect: goods industries are likely to *decrease* while service industries are likely to *increase* their intensity in intermediate inputs. The intuition for this is that technological growth tends to increase the relative price of (final and intermediate) services compared to goods. Since the composite intermediate input is a combination of goods and services, neutral technological growth renders intermediates relatively cheap for service industries and relatively expensive for goods industries.

#### 4.3. Aggregate productivity

Value-added in each specialized industry  $ji$  is defined as  $VA_{ji} \equiv p_{ji}y_{ji} - p_{mg}x_{gji} - p_{ms}x_{sji}$ . Plugging the values for  $x$  from (21) and (22) into the expression for (1) results in  $VA_{ji} = (1 - \sigma_i)p_{ji}y_{ji}$ . Nominal GDP (per unit of labor) is defined as  $GDP \equiv \sum_{j,i} VA_{ji}$ . Let the household's utility follow the specification (8) so that  $P \equiv (\omega_g p_{fg}^{1-\rho} + \omega_s p_{fs}^{1-\rho})^{\frac{1}{1-\rho}}$  be the ideal price deflator. As  $w = GDP$ , substituting (1) in (20) after plugging in (21) and (22) obtains the indirect utility function, and hence the ideal real GDP measure in this economy, as either one of two alternative expressions:

$$\begin{aligned} \frac{GDP}{P} &= \frac{(1 - \sigma_g) \sigma_g^{\frac{\sigma_g}{1-\sigma_g}} A_{fg} A_{mg}^{\frac{\sigma_g}{1-\sigma_g}} \left( \gamma_{gg} + \gamma_{sg} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{1-\rho_g} \right)^{\frac{\sigma_g}{(\rho_g-1)(1-\sigma_g)}}}{\left( \omega_g + \omega_s \left( \frac{p_{fs}}{p_{fg}} \right)^{1-\rho} \right)^{\frac{1}{1-\rho}}} \quad (16) \\ &= \frac{(1 - \sigma_s) \sigma_s^{\frac{\sigma_s}{1-\sigma_s}} A_{fs} A_{ms}^{\frac{\sigma_s}{1-\sigma_s}} \left( \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{\rho_s-1} \gamma_{gs} + \gamma_{ss} \right)^{\frac{\sigma_s}{(\rho_s-1)(1-\sigma_s)}}}{\left( \omega_s + \omega_g \left( \frac{p_{fs}}{p_{fg}} \right)^{\rho-1} \right)^{\frac{1}{1-\rho}}}. \end{aligned}$$

The differentiation of any of these expressions allows to analyze the relative impact of changes in efficiency levels on aggregate productivity. In particular, it is of interest to note which changes have more of an impact in poor versus rich countries.

**Proposition 3.** *Assume the economy experiences positive efficiency growth and that the structural relationship (9) holds. (i) Under industry-neutral technical change real theoretical GDP increases by  $\left( 1 + \frac{\sigma_g(1-\sigma_s)(1-O_s) + \sigma_s(1-\sigma_g)O_s + \sigma_g\sigma_s(2-G_{gg}-G_{ss})}{(1-\sigma_g)(1-\sigma_s) + \sigma_g(1-\sigma_s)(1-G_{gg}) + \sigma_s(1-\sigma_g)(1-G_{ss})} \mu \right) \frac{dA_{fg}}{A_{fg}}$ , where  $O_s \equiv \frac{p_{fs}c_s}{p_{fg}c_g + p_{fs}c_s} = \frac{\omega_s(p_{fs}/p_{fg})^{1-\rho}}{\omega_g + \omega_s(p_{fs}/p_{fg})^{1-\rho}} \in (0, 1)$ ; (ii) under specialization-neutral technical change real theoretical GDP increases by  $\frac{(1-\sigma_s)(1-O_s) + \sigma_s(1-G_{ss}) + [(1-\sigma_g)O_s + \sigma_g(1-G_{gg})]\phi}{(1-\sigma_g)(1-\sigma_s) + \sigma_g(1-\sigma_s)(1-G_{gg}) + \sigma_s(1-\sigma_g)(1-G_{ss})} \frac{dA_{fg}}{A_{fg}}$ .*

*Proof.* Appendix.  $\square$

Structural transformation implies that the expenditure share of services  $O_s$  is increasing with rising income levels. Also, the evidence in Figure 4 suggests that in poorer countries a larger fraction of intermediate inputs used by the goods industry derives from its own sector (relatively large  $G_{gg}$ ) while the opposite is true for the service industry (relatively low  $G_{ss}$ ). Under industry-neutral technical change growth is expected to be disproportionately beneficial for poorer countries. This is because they have a



rather high value of  $\sigma_g(1 - \sigma_s)(1 - O_s) + \sigma_s(1 - \sigma_g)O_s$  in the numerator (while the value of  $2 - G_{gg} - G_{ss}$  is qualitatively indeterminate), and a relatively low value of  $\sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})$  in the denominator. First, as goods industries are more intensive in intermediate inputs ( $\sigma_g(1 - \sigma_s) > \sigma_s(1 - \sigma_g)$ ), poor countries stand more to gain from higher efficiency in intermediate production as they spend a larger fraction of final consumption on goods. Second, poor countries use a higher fraction of goods in intermediate consumption while goods are more sensitive to changes in the availability of intermediates as explained in Proposition 1. In addition, the total benefit is more pronounced if the responsiveness of intermediate efficiency is strong (large  $\mu$ ). Taken together, if industry-neutral technical change is a good feature of the data, there is reason to believe that poor countries are more sensitive to changes in the efficiency with which intermediates are produced. Put otherwise, inefficiencies in the production of intermediate goods are likely to strongly decrease the GDP of poor countries due to complementarities in technology and preferences.

Under specialization-neutral technical change, poor countries again benefit disproportionately more from aggregate productivity changes due their larger consumption of goods intermediates (the denominator in the above expression). Apart from that, we also have that a low responsiveness of the service industry efficiency (small  $\phi$ ) tends to have a smaller impact in poorer countries since they have a lower exposure to the service industry in terms of consumption and intermediate supply.

## 5. ACCOUNTING AND COUNTERFACTUALS

In this section I infer the county-specific implied efficiency levels  $A$  for the sample of countries included in the GGDC/EU KLEMS 1997 benchmark study of cross-country price levels and quantities at the industry level. I use this dataset because it is the only one to my knowledge that provides comprehensive information on industry-based output and prices across countries.<sup>19</sup> Note that the construction of the model and the discussion of the theoretical results so far involved arguments based on Figures 1, 3 and 4 that derive from different (and broader) data sources. The qualitative trends reported there are very similar in the GGDC data.

### 5.1. Calibration

#### 5.1.1. Procedure

The method to construct the relevant data series is described in the Appendix. The calibration of the model proceeds in three steps. First, using first order conditions, I pin down the technology-related parameters  $\sigma_g$  and  $\sigma_s$  directly and infer  $\gamma_{gg}$  and  $\rho_g$  as well as  $\gamma_{ss}$  and  $\rho_s$  from minimizing the discrepancy between the data and model predictions across all countries in the sample. In the second step I back out the parameters  $A_{fg}$ ,  $A_{fs}$ ,  $A_{mg}$  and  $A_{ms}$  for all countries from first order conditions. Third, to close the model I infer the preference parameters  $\rho$  and  $\omega$  from minimizing the discrepancy between the data and model predictions. The resulting parameter values are reported in Table 1.

Matching the condition (13) for both sectors with the data on intermediate good shares for all sample countries I compute average values of  $\sigma_g = 0.570$  and  $\sigma_s = 0.358$ .<sup>20</sup> Using

<sup>19</sup>The methodology behind the dataset, in particular the derivation of industry and input prices, is described in detail in Inklaar and Timmer (2008).

<sup>20</sup>These values are lower than the ones suggested by Figure 3. The reason for this is that the GGDC data nets out intra-industry deliveries at the lowest level of aggregation (at 29 industries). For details see Inklaar and Timmer (2008), p 22.



$\gamma_{gg} + \gamma_{sg} = 1$  and  $\gamma_{gs} + \gamma_{ss} = 1$ , the conditions (14) and (15) can be rewritten to give

$$\log \left( \frac{p_{mg} (x_{gfg} + x_{gmg})}{p_{ms} (x_{sfg} + x_{smg})} \right)^k = \log \frac{\gamma_{gg}}{1 - \gamma_{gg}} + (\rho_g - 1) \log \left( \frac{p_{ms}}{p_{mg}} \right)^k + \varepsilon_k \quad (17)$$

and

$$\log \left( \frac{p_{ms} (x_{sfs} + x_{sms})}{p_{mg} (x_{gfs} + x_{gms})} \right)^k = \log \frac{\gamma_{ss}}{1 - \gamma_{ss}} + (1 - \rho_s) \log \left( \frac{p_{ms}}{p_{mg}} \right)^k + \varepsilon_k \quad (18)$$

for each country  $k \in \{1, 2, \dots, K\}$  where  $\varepsilon_k$  is assumed to be white noise. Using data on the observables on the left and right hand side the two separate OLS regression across all countries deliver  $\gamma_{gg} = 0.675$  and  $\rho_g = 0.191$  as well as  $\gamma_{ss} = 0.580$  and  $\rho_s = 0.273$ . Since both elasticities are less than unity, intermediate goods and intermediate services are gross complements in the composite intermediate input of both industries.

With the parameter values in hand there are sufficient observables to infer the four efficiency values  $A$  for each country from the model's equilibrium conditions. The price data  $(p_{mg}/p_{fg})^k$  and  $(p_{ms}/p_{fs})^k$  are directly informative about country  $k$ 's relative efficiency levels across specializations from (10). Data on relative hours worked in the goods-producing industry  $\frac{(l_{fg} + l_{mg})^k}{(l_{fg} + l_{mg} + l_{fs} + l_{ms})^k}$  are instructional about the relative productivity of that industry.<sup>21</sup> Aggregate productivity per hour worked  $Y^k$  is informative about the overall efficiency level. I choose to set the data measure of country  $k$ 's real GDP per hour worked  $Y^k$  equal to  $y_{fg} + (p_{fs}/p_{fg})^{US} y_{fs}$  so that the model's product is evaluated in terms of the US relative final price ratio (which is furthermore normalized to 1, as in the data).<sup>22</sup> Finally, a fifth identifying equation is needed to close the equilibrium. One could simply use the first order condition of the household. However, as countries differ significantly in terms of their final consumption patterns this method appears to lack robustness. Since the object of inquiry here is aggregate productivity I prefer to use data on relative final prices across countries  $(p_{fs}/p_{fg})^k$ . The resulting solution consists of the four efficiency levels  $A$  and as a by-product also includes all other equilibrium outcomes.

parameter	value	target
$\sigma_g$	0.570	$\sum_k \left( \frac{p_{mg}(x_{gfg} + x_{smg}) + p_{ms}(x_{sfg} + x_{gmg})}{p_{fg}y_{fg} + p_{mg}y_{mg}} \right)^k / K$
$\sigma_s$	0.358	$\sum_k \left( \frac{p_{mg}(x_{gfs} + x_{gms}) + p_{ms}(x_{sfs} + x_{sms})}{p_{fs}y_{fs} + p_{ms}y_{ms}} \right)^k / K$
$\gamma_{gg}, \rho_g$	0.675, 0.191	$\frac{p_{mg}(x_{gfg} + x_{gmg})}{p_{ms}(x_{sfg} + x_{smg})}, \frac{p_{ms}}{p_{mg}}$
$\gamma_{ss}, \rho_s$	0.580, 0.273	$\frac{p_{ms}(x_{sfs} + x_{sms})}{p_{mg}(x_{gfs} + x_{gms})}, \frac{p_{ms}}{p_{mg}}$
$\omega_g, \rho$	0.246, 0.754	$\frac{p_{fg}c_g}{p_{fs}c_s}, \frac{p_{fs}}{p_{fg}}$

TABLE 1. Benchmark calibration

<sup>21</sup>Note that more specific measures about hours worked across different specializations would be an ideal target yet are not available since industries are not partitioned according to specialization in the data.

<sup>22</sup>In the data, aggregate productivity across countries is evaluated in international prices. Using US prices, however, is a good first order approximation of international prices. This is because the country weight used for the construction of international prices is nominal GDP and therefore prices of large and rich countries (especially the US) are disproportionately represented.

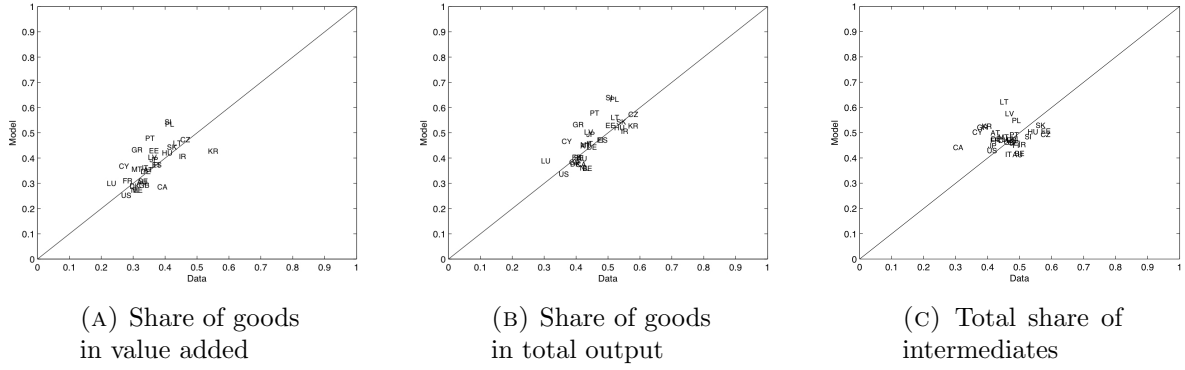


FIGURE 5. Model outcome versus data

In addition, I pin down the utility parameters for the purpose of performing counterfactual exercises. Each country's household condition (25) can be rewritten to the identifying equation

$$\log \left( \frac{p_{fg}c_g}{p_{fs}c_s} \right)^k = \log \frac{\omega_g}{1 - \omega_g} + (\rho - 1) \log \left( \frac{p_{fs}}{p_{fg}} \right)^k + \varepsilon_k. \quad (19)$$

where  $\varepsilon_{pk}$  is assumed to be white noise. I construct the left-hand side of the equation using data on  $\frac{p_{fg}c_{fg}}{p_{fs}c_{fs}}$  and perform an OLS regression to obtain values  $\omega_g$  and  $\rho$  that best match the household's first order condition with the data.<sup>23</sup> There is less than unitary substitutability between final goods, which is consistent with structural transformation as a result of faster labor productivity growth in the final goods industry.

### 5.1.2. Model-data match

The identifying structure imposed on the model targets country-specific relative prices and hours worked as well as the average input-output pattern (via the calibration). It hence does not target each country's sectoral allocation. Figure 5 reports the model's deviation from the data for each country in three variables of interest: the value-added share of goods-producing industries, the gross output share of goods-producing industries, and the aggregate share of intermediate consumption in gross output. A perfect match would be such that all the countries lie on the 45 degree line.

The model does reasonably well in matching the data on all three dimensions, with with few significant departures. The first two panels indicate that targeting hours worked in the goods industry also successfully reproduces the strong differences across countries in the relative nominal share of goods industries in production.

## 5.2. Results

Figure 6 presents the inferred efficiency levels. Each series is normalized so that the US level equals 1 and is plotted against data on the countries' aggregate hourly productivity. Several things stand out. First, and not surprisingly, high-income countries tend to be more efficient in all specialization-industry pairs. Second, in both specializations, the relationship between efficiency and aggregate productivity appears to be rather similar for goods and services. The more pronounced difference is across specializations: compared to poor countries, rich countries tend to be particularly more efficient at producing intermediate goods.

<sup>23</sup>GGDC does not provide data for final expenditure. For this I use data from the WIOD for the year 1997.



countries catch up in income they become relatively more efficient in producing intermediate rather than final goods and services.

### 5.3. Counterfactuals

#### 5.3.1. Counterfactual calibration

The foremost interest in the development accounting framework proposed in the present paper is the recognition that (i) the production of final and intermediate goods commands different efficiency levels across countries, that (ii) goods and services differ in their intensity of intermediate input use as well as in (iii) their prominence as suppliers of intermediates. Columns two through four of Table 2 present the effect of closing down any of these variations one at a time by comparing again the resulting technology levels between the bottom and top productive countries.

The efficiency levels inferred in the second column result from repeating the original calibration but ignoring equation (10) and setting  $A_{mg}^k = A_{fg}^k$  and  $A_{ms}^k = A_{fs}^k, \forall k$ . Compared to the benchmark, the efficiency gap between lower and higher income countries in final goods production significantly increases while the one in intermediate goods production decreases. Clearly, not accounting for poorer countries' inefficiency at producing intermediates overstates the overall efficiency gap between poor and rich countries to mimic their aggregate productivity differences and exaggerates in particular the gap between goods and services to mimic the price ratio differences in final goods. Note as well that the relative efficiency across sectors in poor countries now does not differ greatly from rich countries.

	benchmark	$A_{mg}^k = A_{fg}^k, \quad A_{ms}^k = A_{fs}^k$	$\sigma_g = \sigma_s = 0.451$	$\gamma_{gg} = 0.720, \gamma_{ss} = 0.573, \quad \rho_g = \rho_s \rightarrow 1$
$A_{fg}^P/A_{fg}^R$	0.723	0.575	0.593	0.727
$A_{fs}^P/A_{fs}^R$	0.619	0.539	0.701	0.621
$A_{mg}^P/A_{mg}^R$	0.469	0.575	0.386	0.471
$A_{ms}^P/A_{ms}^R$	0.445	0.539	0.503	0.446

TABLE 2. Counterfactual calibration

The third column reports the results from repeating the calibration exercise but setting  $\sigma_g = \sigma_s = 0.451$ , i.e. to the average aggregate intermediate share across countries. Ignoring differences in the demand intensity of goods versus service industries overturns the implied relative efficiency across industries in poor countries. As supported by the theoretical section, poor countries now appear significantly less productive in producing goods than services, reflecting their final price ratio.

Finally, the last column presents the results from the calibration that sets  $\rho_g = \rho_s \rightarrow 1$  to switch off the variation in the nominal composition of intermediates across countries. At the same time the share parameters  $\gamma_{gg}$  and  $\gamma_{ss}$  are set to average composition values across countries (0.720 and 0.573, respectively). Compared to the benchmark, there is no notable effect on the implied cross-country efficiency differences across sectors. This suggests that ignoring cross-country differences in the composition of intermediates may be of second-order importance to our exercise.

#### 5.3.2. Convergence scenarios

We next turn to the question of how aggregate and relative productivity react to changes in efficiency levels. Table 3 presents equilibrium outcomes from endowing the lowest income quintile countries with the average efficiency level of the richest quintile countries

in various sectors at a time while keeping other technology levels at the calibrated benchmark. This requires to close the equilibrium. For this I use the parametrized utility function and the resulting first order condition of the household, which captures a new equilibrium allocation of labor. Two statistics are of interest - the average relative final price ratio of the low-income vis-à-vis the high income group (0.824 in the data) and the average aggregate productivity (0.332 in the data). All efficiency levels of the rich group are kept constant as in the benchmark. Note the general equilibrium specification at baseline efficiency levels exactly reproduces the relative final price data since these are pinned down directly by the efficiency levels. It does not, however, exactly reproduce the level of GDP since labor allocations differ somewhat. Since the deviations are not substantial, there is hope that the the counterfactual equilibrium outcomes can be compared to the data.

In the initial scenario, poor countries are endowed with rich countries' efficiency in producing goods. This has a strong impact on the relative labor productivity of final goods versus services in poor countries. The increase in aggregate productivity, however, is not very large. This is partly due to the fact that the parametrized utility function underestimates the consumption share of final goods in the poorest country and by extension the amount of hours worked in the goods industry. An increase in the efficiency of producing goods hence does not have quite such a strong repercussion on these countries' aggregate productivity.<sup>25</sup> The opposite is true in the second scenario where low income countries are endowed with better technology in the service industry. In this case the model predicts an enormous aggregate productivity gain.

	$\frac{(p_{fs}/p_{fg})^P}{(p_{fs}/p_{fg})^R}$	$\frac{Y^P}{Y^R}$
data	0.824	0.332
baseline	0.824	0.348
$A_{fg}^k = A_{fg}^R, A_{mg}^k = A_{mg}^R$	1.504	0.507
$A_{fs}^k = A_{fs}^R, A_{ms}^k = A_{ms}^R$	0.513	0.630
$A_{fg}^k = A_{fg}^R, A_{fs}^k = A_{fs}^R$	0.692	0.542
$A_{mg}^k = A_{mg}^R, A_{ms}^k = A_{ms}^R$	1.175	0.642

TABLE 3. Convergence scenarios

Looking across specializations, note that an increase in the efficiency of final producers tends to make final services relatively cheaper. This is related to the fact that final services are relatively more sensitive to the efficiency in final rather than intermediate production. Ultimately, the largest aggregate productivity increases are to be expected from poor countries catching up in the production of intermediates. This is related both to the fact that their relative efficiency in this sector is low as well as to the multiplier effect created by higher efficiency in the production of intermediate inputs. Such a move also overturns the relative cost of final goods - final services are now relatively *expensive* in poor countries.

## 6. ALTERNATIVE ACCOUNTING EXERCISE

The above results hinge strongly on the identification of price ratios between intermediate and final goods from the GGDC dataset. It may be of concern that the low efficiency

<sup>25</sup>In the data the average share of hours worked in the goods industry in the six least productive countries is 0.47. At the calibrated efficiency levels and using the parametrized utility function this fraction decreases to 0.32.

level of the intermediate sector identified in lower income countries is due to mismeasurement, the choice of data aggregation and/or outliers in the given benchmark year. Also, the sample in the GGDC dataset only includes 30 countries, of which only a handful are middle-income and of which most share a common planned-economy history. In light of these drawbacks I present another quantification based on WIOD data in conjunction with final price data from the World Bank's ICP. The sample now includes more recent data (for 2005) and comprises a larger number of countries (forty). More importantly, there is a larger variation of countries in terms of their income per hour.

### 6.1. Calibration

The calibration follows the same procedure as the one in the previous section. The only difference is that the present dataset does not identify the relative price of intermediates versus final goods. As an alternative I use the identifying assumption  $\frac{p_{mg}}{p_{fg}} = 1$  and  $\frac{p_{ms}}{p_{fs}} = 1$ . This implies that  $\frac{p_{ms}}{p_{mg}} = \frac{p_{fs}}{p_{fg}}$  in equations (17) and (18). It also implies  $A_{fg} = A_{mg}$  and  $A_{fs} = A_{ms}$ . The estimated parameters from the regressions (17), (18) and (19) all indicate negative elasticities of substitution, namely  $\rho_g = -0.165$ ,  $\rho_s = -0.932$  and  $\rho = -0.481$ . Since negative elasticities are difficult to interpret economically I choose to set them to low positive values ( $\rho_g = \rho_s = \rho = 0.05$ ) and recompute the corresponding weights  $\gamma_{gg}$ ,  $\gamma_{ss}$  and  $\omega_g$ . The resulting parameters are summarized in Table 4.

parameter	value	target
$\sigma_g$	0.669	$\sum_k \left( \frac{p_{mg}(x_{gfg} + x_{smg}) + p_{ms}(x_{sfg} + x_{gms})}{p_{fg}y_{fg} + p_{mg}y_{mg}} \right)^k / K$
$\sigma_s$	0.418	$\sum_k \left( \frac{p_{mg}(x_{gfs} + x_{gms}) + p_{ms}(x_{sfs} + x_{gms})}{p_{fs}y_{fs} + p_{ms}y_{ms}} \right)^k / K$
$\gamma_{gg}, \rho_g$	0.657, 0.05	$\frac{p_{mg}(x_{gfg} + x_{gms})}{p_{ms}(x_{sfg} + x_{smg})}, \frac{p_{ms}}{p_{mg}}$
$\gamma_{ss}, \rho_s$	0.744, 0.05	$\frac{p_{ms}(x_{sfs} + x_{sms})}{p_{mg}(x_{gfs} + x_{gms})}, \frac{p_{ms}}{p_{mg}}$
$\omega_g, \rho$	0.342, 0.05	$\left( \frac{p_{fg}c_g}{p_{fs}c_s} \right)^k, \left( \frac{p_{fs}}{p_{fg}} \right)^k$

TABLE 4. Alternative benchmark calibration

Note that the nominal share of intermediates for both industries is now substantially higher as the WIOD does not net out intra-industry deliveries.

### 6.2. Results

Figure 7 presents the inferred efficiency levels where each series is normalized to the US and plotted against data on aggregate hourly productivity. Visually it is difficult to discern any particular difference in the relative efficiency between goods and services across countries of different income levels.

As before, we can compare the mean efficiency of the bottom versus the top quintile sample countries in terms of aggregate productivity, reported in the first column of Table 5.<sup>26</sup> The group of poor countries is a bit less than half as efficient as the group of rich countries, and it seems to be slightly less productive in the production of services vis-à-vis goods.

<sup>26</sup>The most productive countries in the sample (from top down) are: Luxembourg, Belgium, the Netherlands, France, the US, Germany, Australia and Ireland. The least productive are (from bottom up) India, China, Indonesia, Brazil, Romania, Mexico, Bulgaria and Russia.

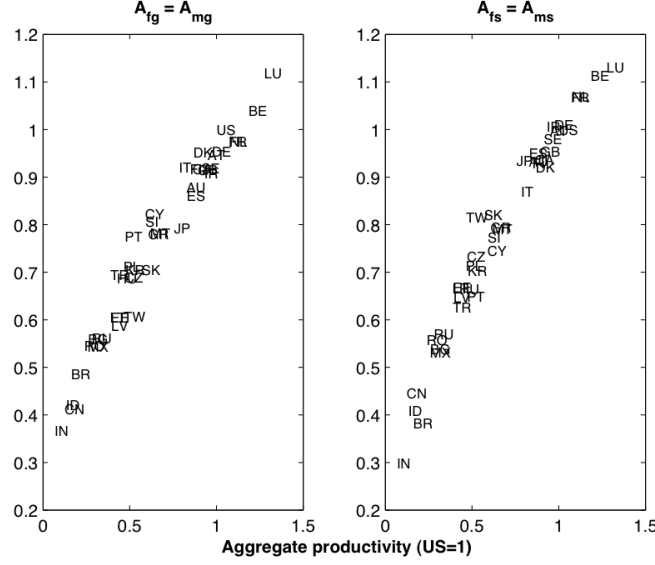


FIGURE 7. Alternative implied efficiency levels

Again, we can test the structural relationship posited in (9). Note that here we already assume by construction specialization-neutrality ( $\mu = 1$ ). Industry-neutrality in the form of  $A_{fs} = A_{ms} = A_{fg}^\phi = A_{mg}^\phi$ , on the other hand, is evaluated by the following regression:

$$\log \left( \frac{A_{fs}}{A_{fg}} \right)^k = \alpha_1 + \beta_1 \log A_{fg}^k + \varepsilon_k.$$

The corresponding estimate (t-statistic) is  $\hat{\beta}_1 = 0.087$  (0.974). Since  $\hat{\phi} = 1 + \hat{\beta}_1$  and  $\hat{\beta}_1$  is statistically insignificant at standard thresholds one can reasonably conclude that  $\hat{\phi} \approx 1$ . It appears that while the poorest countries have a somewhat lower relative efficiency in services, across the whole sample the relative labor productivity between industries is pretty similar across countries. This confirms the findings from the previous section, in particular in the case where specialization-neutrality is imposed (second column of Table 2).

### 6.3. Counterfactuals

#### 6.3.1. Counterfactual calibration

How sensitive are these efficiency levels with respect to the structure of the input-output relations? The second column of Table 5 reports the implied mean efficiency level of the lowest quintile group when abstracting from differences in intermediate intensity across industries, i.e. when  $\sigma_g = \sigma_s = 0.532$ , the average aggregate intermediate share across the sample. Conforming to the results in the previous section, poor countries now appear relatively inefficient in the production of goods so as to match the fact that these are relatively expensive in poorer countries.

	benchmark	$\sigma_g = \sigma_s = 0.532$	$\gamma_{gg} = 0.712, \gamma_{ss} = 0.733, \rho_g = \rho_s \rightarrow 1$
$A_{fg}^P/A_{fg}^R$	0.492	0.373	0.500
$A_{fs}^P/A_{fs}^R$	0.445	0.513	0.452

TABLE 5. Alternative counterfactual calibration



In addition, the third column reports the counterfactual calibration employing a unitary elasticity of substitution between intermediate goods and services, with the corresponding weights set to match the average composition of intermediates across countries. Compared to the benchmark, note that ignoring the strong complementarity between intermediate goods and services does not have strong repercussions other than accentuating somewhat the low relative inefficiency of poor countries in the production of services.

### 6.3.2. Convergence scenarios

Ultimately, Table 6 reports equilibrium outcomes from endowing the lowest income quintile countries with the average efficiency level of the richest quintile countries. It is noteworthy that poorer countries again seem to have more to gain from catching up in the efficiency of service-production rather than goods-production. Most importantly, however, we see that low-income countries are expected to experience the highest increases in GDP from converging to rich-country levels in intermediate production efficiency. The difference in the GDP gain compared to the convergence in final goods is due solely to the input-output pattern and the relatively high factor share of intermediate inputs. It is *not* due to poorer countries having lower efficiency in intermediate input production since here we imposed specialization-neutrality in the benchmark calibration. Besides, it is interesting to observe that endowing poorer countries with rich-country levels in intermediate production efficiency also makes poorer countries feature higher rather than lower relative labor productivity in final goods versus services.

	$\frac{(p_{fs}/p_{fg})^P}{(p_{fs}/p_{fg})^R}$	$\frac{Y^P}{Y^R}$
data	0.665	0.180
baseline	0.665	0.219
$A_{fg}^k = A_{fg}^R = A_{mg}^k = A_{mg}^R$	2.240	0.391
$A_{fs}^k = A_{fs}^R = A_{ms}^k = A_{ms}^R$	0.274	0.440
$A_{fg}^k = A_{fg}^R, A_{fs}^k = A_{fs}^R$	0.584	0.483
$A_{mg}^k = A_{mg}^R, A_{ms}^k = A_{ms}^R$	1.165	0.544

TABLE 6. Alternative convergence scenarios

## 7. CONCLUDING REMARKS

This paper identifies that the main driving factor behind aggregate and sectoral relative labor productivity differences across countries is the efficiency of intermediate good production. The technical structure of the input-output relationship is such that relatively minor inefficiencies in intermediate good production are magnified strongly. The natural question to ask is, why exactly are some countries so inefficient at producing these goods? The theory presented by Acemoglu et al. (2007) on contractual difficulties with specialized input suppliers may offer an important ingredient. Other theories may center on the inefficient involvement of government in either the procurement of intermediate goods or the procurement of infrastructure that is particularly crucial for smooth trade in intermediate inputs. Yet another theory may focus on low levels of competition for specialized inputs, especially when countries suffer from natural or artificial barriers to international trade. There is interest in directing future research in combining the leverage effects discussed in this paper with an explicit theory of efficiency in intermediate input production.

## 8. APPENDIX

## 8.1. Data

## 8.1.1. Figures

Figure 1. Figure 1 is based on the World Bank's International Comparisons Program 2005 benchmark data.<sup>27</sup> The sample includes 142 countries for which all relevant data are available. I first construct separate aggregate price levels for goods and services and then compute the ratio of the two. Price levels are given by the entries Price level index (indicator code PX.WL). Goods include Food and non-alcoholic beverages (1101), Alcoholic beverages and tobacco (1102), Clothing and footwear (1103), Housing, water, electricity, gas and other fuels (1104), Furnishings, household equipment and household maintenance (1105) as well as Gross capital formation (15). Services includes Health (1106), Transport (1107), Communication (1108), Recreation and culture (1109), Education (1110), Restaurants and hotels (1111) as well as Collective consumption expenditure by Government (14). Miscellaneous goods and services (1112) are omitted. The constructed series are geometric means with weights based on the expenditure shares (indicator code CD) of the sub-sectors. GDP per capita is computed by dividing Expenditures in international dollars (indicator code PP.CD) by the total population (indicator code POP).

Figure 2. Figure 2 computes relative prices from the GGDC Productivity Level Database for the benchmark year 1997.<sup>28</sup> Note that both series are ratios between intermediate and final goods prices. The series for intermediate good prices is based on the intermediate input price deflator, PPP\_IIS for services and the weighted average between the price of energy inputs (PPP\_IIE) and material inputs (PPP\_IIM) for goods. Each series is a geometric mean over all the two-digit sub-sectors in the dataset, the weights being the supply shares (IIS and IIE+IIM, respectively) to each sub-sector. The intermediate input price  $p_m$  is hence simply the mean over the prices that all the sub-sectors  $l$  in the economy (pertaining both to goods  $G$  and service  $S$  industries) spend on that particular intermediate input.

$$p_{ms} = \prod_{l \in G, S} PPP\_IIS_l^{\frac{IIS_l}{\sum_{l \in G, S} IIS_l}},$$

$$p_{mg} = \prod_{l \in G, S} \left( PPP\_IIE_l^{\frac{IIE_l}{\sum_{l \in G, S} (IIE_l + IIM_l)}} \times PPP\_IIM_l^{\frac{IIM_l}{\sum_{l \in G, S} (IIE_l + IIM_l)}} \right).$$

Next, the series for the final price is computed via the construction of the aggregate output price  $p_o$ , based on the output deflator (PPP\_SO). The output price for goods and services is a geometric mean of the sub-sectors where the weights are expenditures shares (SO).

$$p_{os} = \prod_{l \in S} PPP\_SO_l^{\frac{SO_l}{\sum_{l \in S} SO_l}},$$

$$p_{og} = \prod_{l \in G} PPP\_SO_l^{\frac{SO_l}{\sum_{l \in G} SO_l}}.$$

The sub-sectors comprising goods are: Electrical and optical equipment (30t33), Food products, beverages and tobacco (15t16), Textiles, textile products, leather and footwear (17t19), Manufacturing nec; recycling (36t37), Wood and products of wood and cork (20), Pulp, paper, paper products, printing and publishing (21t22), Coke, refined petroleum

<sup>27</sup>The data are available at [http://databank.worldbank.org/ddp/home.do?Step=2&id=4&hActiveDimensionId=ICP\\_4\\_Series](http://databank.worldbank.org/ddp/home.do?Step=2&id=4&hActiveDimensionId=ICP_4_Series)

<sup>28</sup>The data are available at [http://www.ggdc.nl/databases/levels/2008/data/benchmark\\_1997.xls](http://www.ggdc.nl/databases/levels/2008/data/benchmark_1997.xls)

products and nuclear fuel (23), Chemicals and chemical products (24), Rubber and plastics products (25), Other non-metallic mineral products (26), Basic metals and fabricated metal products (27t28), Machinery, nec (29), Transport equipment (34t35), Mining and quarrying (C), Electricity, gas and water supply (E), Construction (F), Agriculture, hunting, forestry and fishing (AtB). The sub-sectors comprising services are: Post and telecommunications (64), Trade (G), Transport and storage (60t63), Financial intermediation (J), Renting of m&eq and other business activities (71t74), Hotels and restaurants (H), Other community, social and personal services (O), Private households with employed persons (P), Public admin and defence; compulsory social security (L), Education (M), Health and social work (N), Real estate activities (70).

From here, I compute the final price  $p_f$  assuming that the output price is approximated by the geometric mean between the final and intermediate price. The weight of the intermediate price is simply the value of aggregate intermediate consumption on the good or service (the aggregate value of IIS and IIE+IIM, respectively) as a share of aggregate output (SO). The final price is hence implicitly defined from

$$p_{os} = p_{ms}^{\frac{\sum_{l \in G, S} IIS_l}{\sum_{l \in S} SO_l}} \times p_{ms}^{\frac{\sum_{l \in S} SO_l - \sum_{l \in G, S} IIS_l}{\sum_{l \in S} SO_l}},$$

$$p_{og} = p_{mg}^{\frac{\sum_{l \in G, S} (IIE_l + IIM_l)}{\sum_{l \in G} SO_l}} \times p_{mg}^{\frac{\sum_{l \in G} SO_l - \sum_{l \in G, S} (IIE_l + IIM_l)}{\sum_{l \in G} SO_l}},$$

This allows for the construction of  $\frac{p_{mg}}{p_{fg}}$  and  $\frac{p_{ms}}{p_{fs}}$ , both of which are normalized to 1 for the US. Finally, aggregate productivity in the data equals the ratio between value added of total industries VA (TOT) and total hours worked HOURS (TOT), divided by the total industry value added deflator PPP\_VA (TOT).

Figures 3 and 4. The intermediate consumption data underlying Figures 3 and 4 are obtained from the WIOD National Input-Output tables and National Supply and Use tables.<sup>29</sup> The intermediate consumption share for goods (respectively, services) of Figure 3 is constructed as follows. The numerator aggregates intermediate consumption from the use table at basic prices (USE\_bas) as well as net taxes (NetTaxes) from all suppliers (1-95) for industries AtB through to F (34t35 through to FISIM for services). This sum is divided by the total of gross output (USE\_bas, line GO) of categories AtB through to F (34t35 through to FISIM for services).

The share of goods (service) intermediates in total intermediate consumption of the goods (service) industry in Figure 4 is constructed similarly. The numerator consists of the sum of intermediate consumption from the use table at basic prices (USE\_bas) as well as net taxes (NetTaxes) from suppliers 1-45 (50-95 for services) for industries AtB through to F (34t35 through to FISIM for services). This sum is divided by the series of total intermediate consumption (for the respective industry) as described above.

Aggregate productivity is obtained from two data sources. The numerator consists of GDP in international dollars from the Total Economy Database of The Conference Board, series EKS GDP.<sup>30</sup> Total hours worked are obtained from the WIOD Socio-Economic Accounts.<sup>31</sup> The series used is Total hours worked by persons engaged (H\_EMP, TOT).

### 8.1.2. Calibration

Main accounting exercise. Practically all the series are based on the GGDC Productivity Level Database. For the construction of intermediate to final price ratios  $\frac{p_{mg}}{p_{fg}}$  and  $\frac{p_{ms}}{p_{fs}}$  as well as aggregate productivity  $Y$ , please refer to the above description of the data

<sup>29</sup>The data are available at [http://www.wiod.org/database/nat\\_suts.htm](http://www.wiod.org/database/nat_suts.htm)

<sup>30</sup>The data are available at <http://www.conference-board.org/data/economydatabase/>

<sup>31</sup>The data are available at <http://www.wiod.org/database/sea.htm>

underlying Figure 2. The final price ratio between services and goods  $\frac{p_{fs}}{p_{fg}}$  - normalized to 1 for the US - is constructed as explained above. Note that the definition of the sub-sectors composing the goods and the service industry, respectively, is of course identical to the one used in the construction of prices.

The series  $\frac{l_{fg}+l_{mg}}{l_{fg}+l_{mg}+l_{fs}+l_{ms}}$  is constructed by adding hours worked in all sub-sectors pertaining to goods and dividing by total hours worked. The industry-specific intermediate consumption shares are constructed as

$$\frac{p_{mg}(x_{gfg} + x_{smg}) + p_{ms}(x_{sfg} + x_{gms})}{p_{fg}y_{fg} + p_{mg}y_{mg}} = \frac{\sum_{l \in G} (IIS_l + IIE_l + IIM_l)}{\sum_{l \in G} SO_l},$$

$$\frac{p_{mg}(x_{gfs} + x_{gms}) + p_{ms}(x_{sfs} + x_{sms})}{p_{fs}y_{fs} + p_{ms}y_{ms}} = \frac{\sum_{l \in S} (IIS_l + IIE_l + IIM_l)}{\sum_{l \in S} SO_l},$$

The composition of intermediates used by the goods and service industries, respectively, is given by

$$\frac{p_{mg}(x_{gfg} + x_{gms})}{p_{ms}(x_{sfg} + x_{sms})} = \frac{\sum_{l \in G} (IIE_l + IIM_l)}{\sum_{l \in G} IIS_l},$$

$$\frac{p_{ms}(x_{sfs} + x_{sms})}{p_{mg}(x_{gfs} + x_{gms})} = \frac{\sum_{l \in S} IIS_l}{\sum_{l \in S} (IIE_l + IIM_l)}.$$

Finally, the construction of the final expenditure ratio  $\frac{p_{fg}c_g}{p_{fs}c_s}$  is constructed for the year 1997 from the WIOD data, as described in the following subsection.

Additional accounting exercise. The construction of the final price ratio is explained in the description of Figure 1. The series for intermediate consumption ratios and compositions as well as aggregate productivity are explained in the description of Figures 3 and 4. Hours worked in the goods industry is obtained from the WIOD Socio-Economic Accounts. I sum the series Total hours worked by persons engaged (H\_EMP), entries AtB through to F, and divide by the sum of total industries (TOT).

Finally, the ratio  $\frac{p_{fg}c_g}{p_{fs}c_s}$  is obtained from the WIOD Input Output tables as well. The numerator (denominator) consists of the sum over Final consumption on Expenditure (CONS), Gross Capital Formation (GCF) and Exports (EXP) of the use table at basic prices (USE\_bas) as well as net taxes (NetTaxes) from suppliers 1-45 (50-95 for the denominator).

## 8.2. Computations

### 8.2.1. Solution of the theoretical model

The firms' first order conditions with respect to  $l_{ji}$  in (2) and (4) give

$$\frac{w}{p_{ji}} \frac{l_{ji}}{y_{ji}} = 1 - \sigma_i, \forall j \in \{f, m\}, i \in \{s, g\}. \quad (20)$$

The first order conditions with respect to  $x_{gji}$  and  $x_{sji}$  are

$$\frac{p_{mg}}{p_{ji}} = A_{ji}\sigma_i \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gji}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sji}^{\frac{\rho_i-1}{\rho_i}} \right)^{\frac{1-(1-\sigma_i)\rho_i}{\rho_i-1}} \gamma_{gi}^{\frac{1}{\rho_i}} x_{gji}^{\frac{-1}{\rho_i}} l_{ji}^{1-\sigma_i}, \forall j \in \{f, m\}, i \in \{s, g\},$$

$$\frac{p_{ms}}{p_{ji}} = A_{ji}\sigma_i \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gji}^{\frac{\rho_i-1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sji}^{\frac{\rho_i-1}{\rho_i}} \right)^{\frac{1-(1-\sigma_i)\rho_i}{\rho_i-1}} \gamma_{si}^{\frac{1}{\rho_i}} x_{sji}^{\frac{-1}{\rho_i}} l_{ji}^{1-\sigma_i}, \forall j \in \{f, m\}, i \in \{s, g\},$$

which can be rewritten to,  $\forall j \in \{f, m\}, i \in \{s, g\}$ ,

$$x_{gji} = \left( \frac{p_{ji}}{p_{mg}} A_{ji} \sigma_i \right)^{\frac{1}{1-\sigma_i}} \left( \gamma_{gi} + \gamma_{si} \left( \frac{p_{ms}}{p_{mg}} \right)^{1-\rho_i} \right)^{\frac{(1-\sigma_i)\rho_i-1}{(1-\rho_i)(1-\sigma_i)}} \gamma_{gi} l_{ji}, \quad (21)$$

$$x_{sji} = \left( \frac{p_{ji}}{p_{ms}} A_{ji} \sigma_i \right)^{\frac{1}{1-\sigma_i}} \left( \gamma_{si} + \gamma_{gi} \left( \frac{p_{ms}}{p_{mg}} \right)^{\rho_i-1} \right)^{\frac{(1-\sigma_i)\rho_i-1}{(1-\rho_i)(1-\sigma_i)}} \gamma_{si} l_{ji}. \quad (22)$$

Combining these two equations with (20) and (1) gives,  $\forall i \in \{s, g\}$ ,

$$\frac{w}{p_{ig}} = \left( \frac{p_{ig}}{p_{mg}} \right)^{\frac{\sigma_g}{1-\sigma_g}} A_{ig}^{\frac{1}{1-\sigma_g}} \sigma_g^{\frac{\sigma_g}{1-\sigma_g}} (1-\sigma_g) \left( \gamma_{gg} + \gamma_{sg} \left( \frac{p_{ms}}{p_{mg}} \right)^{1-\rho_g} \right)^{\frac{\sigma_g}{(1-\sigma_g)(\rho_g-1)}} \quad (23)$$

$$\frac{w}{p_{is}} = \left( \frac{p_{is}}{p_{ms}} \right)^{\frac{\sigma_s}{1-\sigma_s}} A_{is}^{\frac{1}{1-\sigma_s}} \sigma_s^{\frac{\sigma_s}{1-\sigma_s}} (1-\sigma_s) \left( \gamma_{ss} + \gamma_{gs} \left( \frac{p_{ms}}{p_{mg}} \right)^{\rho_s-1} \right)^{\frac{\sigma_s}{(1-\sigma_s)(\rho_s-1)}} \quad (24)$$

The household's maximization problem implies:

$$\frac{p_{fs}}{p_{fg}} = \frac{u_{cs}}{u_{cg}} = \left[ \frac{\omega_s c_g}{\omega_g c_s} \right]^{\frac{1}{\rho}}. \quad (25)$$

These last five formulations, coupled with the clearing conditions (1),  $\forall i \in \{g, s\}$ , (3), (5), (6) and (7) fully characterize the equilibrium, leaving room for the normalization of one price.

### 8.2.2. Proof of Proposition 1

From (11) we have

$$\begin{aligned} \ln \frac{p_{fs}}{p_{fg}} &= \ln A_{fg} - \ln A_{fs} + \frac{\sigma_g}{1-\sigma_g} \ln A_{mg} - \frac{\sigma_s}{1-\sigma_s} \ln A_{ms} \\ &\quad + \frac{\sigma_g}{(\rho_g-1)(1-\sigma_g)} \ln \left( \gamma_{gg} + \gamma_{sg} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{1-\rho_g} \right) \\ &\quad - \frac{\sigma_s}{(\rho_s-1)(1-\sigma_s)} \ln \left( \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{\rho_s-1} \gamma_{gs} + \gamma_{ss} \right). \end{aligned}$$

Differentiation gives

$$\begin{aligned} \frac{d(p_{fs}/p_{fg})}{p_{fs}/p_{fg}} &= \Lambda \left( 1 + \frac{\sigma_g}{1-\sigma_g} (1-G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1-G_{ss}) \right) \frac{dA_{fg}}{A_{fg}} \\ &\quad - \Lambda \left( 1 + \frac{\sigma_g}{1-\sigma_g} (1-G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1-G_{ss}) \right) \frac{dA_{fs}}{A_{fs}} \\ &\quad + \Lambda \left( \frac{\sigma_g}{1-\sigma_g} - \frac{\sigma_g}{1-\sigma_g} (1-G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1-G_{ss}) \right) \frac{dA_{mg}}{A_{mg}} \\ &\quad - \Lambda \left( \frac{\sigma_s}{1-\sigma_s} - \frac{\sigma_g}{1-\sigma_g} (1-G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1-G_{ss}) \right) \frac{dA_{ms}}{A_{ms}} \end{aligned} \quad (26)$$

where

$$G_{gg} \equiv \frac{\gamma_{gg}}{\gamma_{gg} + \gamma_{sg} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{1-\rho_g}} \in (0, 1),$$

$$G_{ss} \equiv \frac{\gamma_{ss}}{\gamma_{ss} + \gamma_{gs} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{\rho_s - 1}} \in (0, 1),$$

$$\Lambda \equiv \left[ 1 + \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1 - \sigma_s} (1 - G_{ss}) \right]^{-1} \in (0, 1).$$

Industry-neutral technical change ( $\phi = 1$ ) gives

$$\frac{\frac{d(p_{fs}/p_{fg})}{p_{fs}/p_{fg}}}{\frac{dA_{fg}}{A_{fg}}} = \frac{(\sigma_g - \sigma_s) \mu}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})},$$

while specialization-neutral technical change ( $\mu = 1$ ) gives:

$$\frac{\frac{d(p_{fs}/p_{fg})}{p_{fs}/p_{fg}}}{\frac{dA_{fg}}{A_{fg}}} = \frac{(1 - \sigma_s) - (1 - \sigma_g) \phi}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})}$$

### 8.2.3. Proof of Proposition 2:

From the definition  $m_{ji} \equiv \left( \gamma_{gi}^{\frac{1}{\rho_i}} x_{gji}^{\frac{\rho_i - 1}{\rho_i}} + \gamma_{si}^{\frac{1}{\rho_i}} x_{sji}^{\frac{\rho_i - 1}{\rho_i}} \right)^{\frac{\rho_i}{\rho_i - 1}}$  and (1) and (3) results that

$$\frac{m_{fg}}{y_{fg}} = \sigma_g \frac{A_{mg}}{A_{fg}} \left( \gamma_{gg} + \gamma_{sg} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{1 - \rho_g} \right)^{\frac{1}{\rho_g - 1}},$$

$$\frac{m_{fs}}{y_{fs}} = \sigma_s \frac{A_{ms}}{A_{fs}} \left( \gamma_{ss} + \gamma_{gs} \left( \frac{A_{fs}}{A_{fg}} \frac{A_{mg}}{A_{ms}} \frac{p_{fs}}{p_{fg}} \right)^{\rho_s - 1} \right)^{\frac{1}{\rho_s - 1}}.$$

Differentiation and replacing  $\frac{d(p_{fs}/p_{fg})}{p_{fs}/p_{fg}}$  by (26) obtains

$$\begin{aligned} \frac{d(m_{fg}/y_{fg})}{m_{fg}/y_{fg}} &= G_{gg} \frac{dA_{mg}}{A_{mg}} - G_{gg} \frac{dA_{fg}}{A_{fg}} \\ &\quad - (1 - G_{gg}) \left( \frac{dA_{fs}}{A_{fs}} - \frac{dA_{ms}}{A_{ms}} \right) \\ &\quad - \Lambda (1 - G_{gg}) \left[ \begin{aligned} &\left( 1 + \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1 - \sigma_s} (1 - G_{ss}) \right) \frac{dA_{fg}}{A_{fg}} \\ &- \left( 1 + \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1 - \sigma_s} (1 - G_{ss}) \right) \frac{dA_{fs}}{A_{fs}} \\ &+ \left( \frac{\sigma_g}{1 - \sigma_g} - \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1 - \sigma_s} (1 - G_{ss}) \right) \frac{dA_{mg}}{A_{mg}} \\ &- \left( \frac{\sigma_s}{1 - \sigma_s} - \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1 - \sigma_s} (1 - G_{ss}) \right) \frac{dA_{ms}}{A_{ms}} \end{aligned} \right], \end{aligned}$$

$$\begin{aligned}
\frac{d(m_{fs}/y_{fs})}{m_{fs}/y_{fs}} &= G_{ss} \frac{dA_{ms}}{A_{ms}} - G_{ss} \frac{dA_{fs}}{A_{fs}} \\
&\quad - (1 - G_{ss}) \left( \frac{dA_{fg}}{A_{fg}} - \frac{dA_{mg}}{A_{mg}} \right) \\
&\quad + \Lambda (1 - G_{ss}) \left[ \begin{aligned} &\left( 1 + \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{fg}}{A_{fg}} \\ &- \left( 1 + \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{fs}}{A_{fs}} \\ &+ \left( \frac{\sigma_g}{1-\sigma_g} - \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{mg}}{A_{mg}} \\ &- \left( \frac{\sigma_s}{1-\sigma_s} - \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{ms}}{A_{ms}} \end{aligned} \right].
\end{aligned}$$

Industry-neutral growth ( $\phi = 1$ ) delivers:

$$\frac{\frac{d(m_{fg}/y_{fg})}{m_{fg}/y_{fg}}}{\frac{dA_f}{A_f}} = \frac{(1 - \sigma_g)(1 - \sigma_s) + \sigma_s(1 - \sigma_g)(1 - G_{ss}) + \sigma_s(1 - \sigma_g)(1 - G_{gg})}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_s(1 - \sigma_g)(1 - G_{ss}) + \sigma_g(1 - \sigma_s)(1 - G_{gg})} \mu - 1,$$

$$\frac{\frac{d(m_{fs}/y_{fs})}{m_{fs}/y_{fs}}}{\frac{dA_f}{A_f}} = \frac{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_g(1 - \sigma_s)(1 - G_{ss})}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})} \mu - 1.$$

while specialization-neutral growth ( $\mu = 1$ ) is given by:

$$\frac{\frac{d(m_{fg}/y_{fg})}{m_{fg}/y_{fg}}}{\frac{dA_{fg}}{A_{fg}}} = \frac{(1 - G_{gg}) [(1 - \sigma_g) \phi - (1 - \sigma_s)]}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})},$$

$$\frac{\frac{d(m_{fs}/y_{fs})}{m_{fs}/y_{fs}}}{\frac{dA_{fg}}{A_{fg}}} = \frac{(1 - G_{ss}) [(1 - \sigma_s) - (1 - \sigma_g) \phi]}{(1 - \sigma_g)(1 - \sigma_s) + \sigma_g(1 - \sigma_s)(1 - G_{gg}) + \sigma_s(1 - \sigma_g)(1 - G_{ss})}.$$

#### 8.2.4. Proof of Proposition 3:

Taking logs of (16), differentiating and replacing  $\frac{d(p_{fs}/p_{fg})}{p_{fs}/p_{fg}}$  by (26) gives

$$\begin{aligned}
\frac{d(GDP/P)}{GDP/P} &= \left[ 1 + \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) \right] \frac{dA_{fg}}{A_{fg}} + \left[ \frac{\sigma_g}{1 - \sigma_g} - \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) \right] \frac{dA_{mg}}{A_{mg}} \\
&\quad - \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) \left[ \frac{dA_{fs}}{A_{fs}} - \frac{dA_{ms}}{A_{ms}} \right] \\
&\quad - \Lambda \left[ \frac{\sigma_g}{1 - \sigma_g} (1 - G_{gg}) + O_s \right] \\
&\quad \times \left[ \begin{aligned} &\left( 1 + \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{fg}}{A_{fg}} \\ &- \left( 1 + \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) + \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{fs}}{A_{fs}} \\ &+ \left( \frac{\sigma_g}{1-\sigma_g} - \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{mg}}{A_{mg}} \\ &- \left( \frac{\sigma_s}{1-\sigma_s} - \frac{\sigma_g}{1-\sigma_g} (1 - G_{gg}) - \frac{\sigma_s}{1-\sigma_s} (1 - G_{ss}) \right) \frac{dA_{ms}}{A_{ms}} \end{aligned} \right].
\end{aligned}$$



where  $O_s \equiv \frac{\omega_s \left( \frac{p_{fs}}{p_{fg}} \right)^{1-\rho}}{\omega_g + \omega_s \left( \frac{p_{fs}}{p_{fg}} \right)^{1-\rho}}$ . Industry-neutral technical change ( $\phi = 1$ ) gives:

$$\frac{\frac{d(GDP/P)}{GDP/P}}{\frac{dA_{fg}}{A_{fg}}} = 1 + \frac{\sigma_g (1 - \sigma_s) (1 - O_s) + \sigma_s (1 - \sigma_g) O_s + \sigma_g \sigma_s (2 - G_{gg} - G_{ss})}{(1 - \sigma_g) (1 - \sigma_s) + \sigma_g (1 - \sigma_s) (1 - G_{gg}) + \sigma_s (1 - \sigma_g) (1 - G_{ss})} \mu,$$

while specialization-neutral technical change ( $\mu = 1$ ) gives:

$$\frac{\frac{d(GDP/P)}{GDP/P}}{\frac{dA_{fg}}{A_{fg}}} = \frac{(1 - \sigma_s) (1 - O_s) + \sigma_s (1 - G_{ss}) + [(1 - \sigma_g) O_s + \sigma_g (1 - G_{gg})] \phi}{(1 - \sigma_g) (1 - \sigma_s) + \sigma_g (1 - \sigma_s) (1 - G_{gg}) + \sigma_s (1 - \sigma_g) (1 - G_{ss})}.$$

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