DEVELOPMENT ACCOUNTING WITH INTERMEDIATE GOODS

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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 multisector growth model accomodating these features to show that inefficient intermediate production strongly depresses aggregate productivity and increases the price ratio of final goods to services. Applying the model to data for middle and high income countries, I find that poorer countries are only modestly less efficient at producing goods than services, but substantially less efficient at producing intermediate relative to final goods and services. If all countries had the intermediate production efficiency of the US, the aggregate productivity gap between the lowest and highest income countries in the sample is predicted to shrink by roughly two thirds while cross-country differences in the final price ratio would virtually vanish.

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 up in the data. Second, I develop a simple growth model featuring two industries and two specializations (intermediate and final production) and propose some analytical qualitative results based on a plausible input-output structure. Third, I use the model to back out efficiency levels across countries to identify which industry-specializations pairs are particularly inefficient in poor countries.

Two observations are key for the paper's motivation. First, different broadly-defined sectors have systematically distinct technological requirements as regards the use of intermediates and vary systematically in their importance as suppliers of intermediates. More to the point, when the economy is subdivided into goods and service industries, the former consume more intermediate value per unit of output, approximately 0.57 versus 0.36. Goods industries also supply a relatively larger share of intermediates in poor

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compared to rich countries. This issue has been, to the best of my knowledge, largely overlooked in the recent literature on development accounting, but proves significant in interaction with another set of empirical regularities. This is the fact that for the same industry, intermediate goods, relative to final goods, appear to be relatively expensive in poor countries. It motivates the additional dichotomy between firms specializing in either final or intermediate production.

The main theoretical results are the following. First, it is shown that the price of final goods relative to final services is expected to be lower in less efficient economies even if their efficiency in the goods industry is no lower relative to the one in the service industry. Rather, because the goods industry is a more intensive intermediate input user than the service industry, low efficiency in all industry-specialization pairs renders the goods industry relatively less productive than the service industry as intermediate resources are relatively scarce compared to labor. Second, it is shown that if relative to poor countries, rich countries were particularly more efficient at producing intermediate goods and services, then all specialization-industry pairs except for specialized intermediate goods (as opposed to service) producers are likely to increase their *real* intensity use of intermediates. This happens despite the fact that intensity is by construction identical in value terms. Third, compared to percent increases in the efficiency of final good production, a percent increase in the efficiency of intermediate input production has a relatively stronger impact on theoretical aggregate productivity in poor countries than in rich countries. This is because poor countries not only have higher final expenditure shares on goods than services, they also spend larger fractions of intermediate consumption on goods than on services. In turn, goods - in both specializations - are more sensitive to increases in intermediate production efficiency than services. In other words, observed complementarities in the production of intermediate goods strongly leverage inefficiencies of intermediate input production.

For the quantitative part I employ the EU Klems dataset for a sample of middle and high income countries which features comparable intermediate and final prices and quantities. The results suggest that compared to rich countries, poor countries are less efficient across the board in all industry-specialization pairs. More interestingly, poorer countries are only modestly less efficient at producing (final or intermediate) goods than services. Moreover, poorer countries are particularly less efficient at producing intermediate rather than final goods and services. The fact that final goods are relatively more expensive in poor countries than final services hence does not result so much from the fact that these countries are particularly worse at producing goods compared to services. Rather, it is due to the fact that poor countries are relatively inefficient at producing *intermediates*.

The model offers a straightforward method to gauge the separate effects created by the input-output structure and by efficiency differences across specializations. I find that ignoring the fact that intermediate and final good production is done at different efficiency levels substantially increases the perceived efficiency gap that poor countries have in producing goods rather than services. Also, poor countries in this context appear much less efficient at producing both final goods and services than in the benchmark case. In a similar fashion, ignoring the intermediate input demand asymmetry between goods and services also strongly exaggerates the poor countries' efficiency gap between the production of goods and services. Ignoring the supply asymmetry creates an analogous effect, though it is quantitatively less important. A development accounting exercise ignoring these features is therefore likely to underestimate poor countries' efficiency in producing final goods and services and is furthermore likely to exaggerate especially their inefficiency in creating goods vis-à-vis services.

A simple counterfactual exercise stresses the impact of intermediate inputs in the accounting framework. If middle income countries were somehow able to adopt the US efficiency of intermediate good production, their aggregate productivity (compared to the richest countries) is predicted to increase from about 0.47% to 0.84%. Also, such a move would almost equalize the final good price ratios across poor and high income countries. This finding is important. It states that the efficiency of intermediate good production is responsible for the bulk of the aggregate and relative productivity differences across countries.

The paper is closely related to the literature on sectoral development accounting. Based on final expenditure price data, Herrendorf and Valentinyi (forthcoming) compute that poor countries are particularly bad at producing goods as compared to services. On the other hand, Duarte and Restuccia (2010) present evidence, based on industry growth accounting and the pattern of structural transformation, that poorer countries are particularly unproductive in the agriculture and services sectors, but not so much 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.[1]

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 (2008) 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 is 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).

As intermediates are essential factors of production, a strand of the literature has focused on their underprovision as a substantial barrier to development. Jones (forthcoming) shows theoretically how generic wedges that disperse the marginal productivity of intermediate goods, coupled with these goods' complementarity in production, leads to substantial leverage effects on productivity.[2] 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 problem 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 some evidence to that effect reported in Chenery, Robinson and Syrquin (1986). Restuccia, Yan and Zhu (2008), based on producer price data of the Food and Agriculture Organization (FAO), find that farms in poor countries

[1] The classical theoretical contributions on growth accounting with intermediate goods include amongst others Melvin (1969) and Hulten (1978).

[2] The dispersion of productivities *within* sectors as a source of large aggregate productivity differences has recently received a lot of attention as well. See for instance Banerjee and Duflo (2005), Guner, Ventura and Yi (2008), Restuccia and Rogerson (2008) and Hsieh and Klenow (2009).

face substantially higher relative prices for intermediate goods. This lowers their agricultural productivity, which in turn strongly diminishes aggregate productivity as due to the negative income effect most resources are channeled into agriculture. Finally, the interest in (real) physical intermediate input intensity as opposed to value 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 at internationally comparable prices, but not at local prices. Here I highlight a similar phenomenon by claiming that a portion of poor countries' low productivity can be 'explained' by their low investment rates in the production factor intermediate goods.

The organization of the paper is as follows. Section 1 presents the empirical evidence. Section 2 proposes the model environment. The theoretical results of the model are summarized in section 3 while section 4 explores the data implications following the calibration of the model. Section 5 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 (agricultural, industrial consumption and investment goods) are relatively more expensive than services in poorer countries. Figure (1) reproduces the data to that effect from the World Bank's International Comparisons Program.[3] 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 (forthcoming) 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 goods, and also inefficient at producing consumption goods, while much less inefficient at producing services.

The trouble with 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 is related to inefficiencies at the level of the production unit. To circumvent this problem, Duarte and Restuccia (2009) 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 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 much higher productivity levels in the production of agricultural goods and services but not so much in manufacturing.

The difference in the two results may of course only be due to the fact that Herrendorf and Valentinyi (forthcoming) measure TFP while Duarte and Restuccia (2010) infer productivity, but since the sectoral physical and human capital factor shares used by Herrendorf and Valentinyi (forthcoming) do not vary much between manufacturing and services, this seems unlikely. Rather, the conflicting evidence calls for an analysis that explicitly takes into account the input-output pattern in the economy in determining the relative sectoral productivity levels. Such an analysis could explain why in poor countries sectors producing goods appear to be relatively less productive than service sectors

[3]The construction of all the series in the following Figures is described in the Appendix.

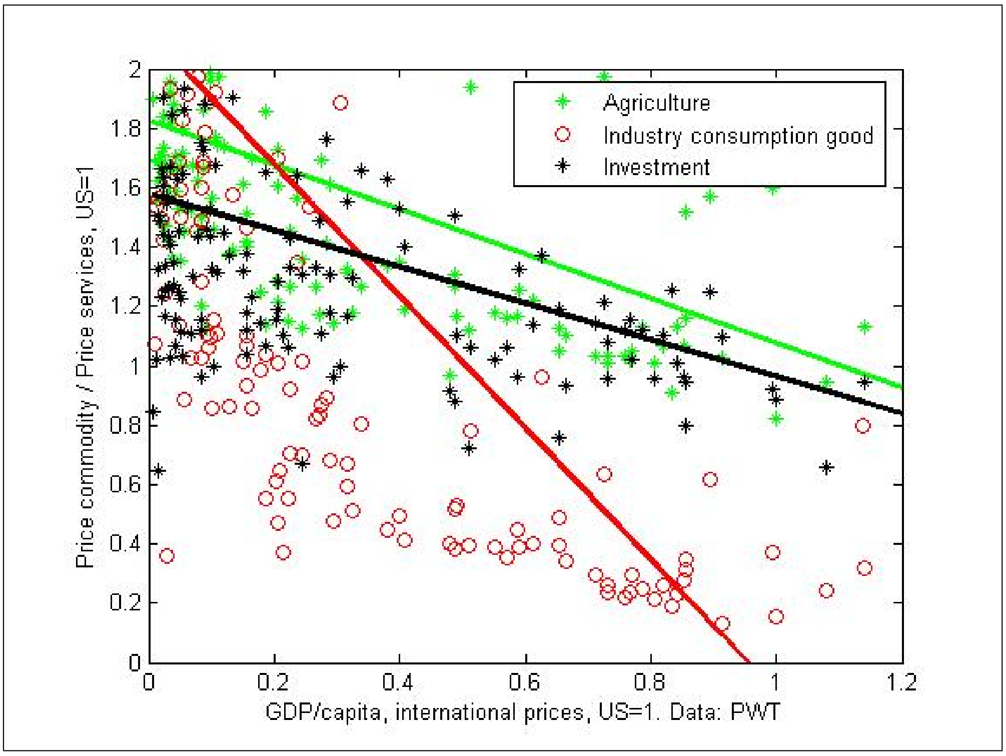

FIGURE 1. Relative price of expenditure items

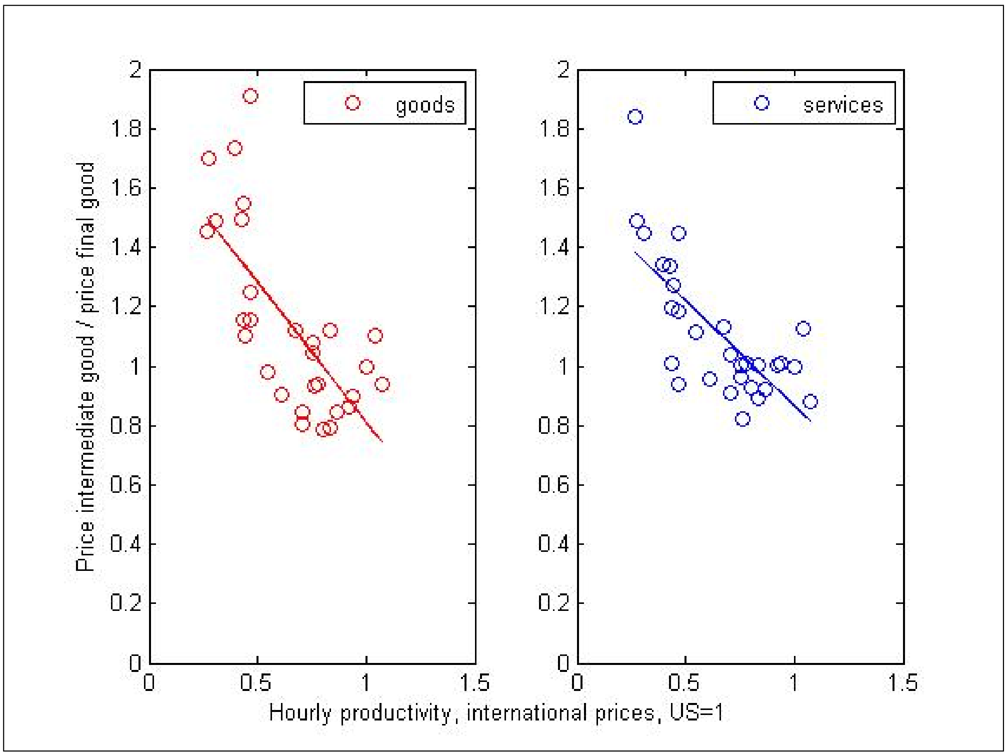

FIGURE 2. Relative cost of intermediate to final goods

measured at final expenditure level, while the result is partially reversed at the industry level.

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 dataset on internationally comparable relative prices at the industry level, provided by EU Klems and covering most OECD countries and several Central and Eastern European countries (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 hourly productivity. The downward-sloping shape of the series suggests that in both industries - goods and services - intermediates are particularly expensive compared to final goods in poor countries.

2.2. *Intermediate consumption and supply shares*

Figure (3) summarizes the intermediate consumption factors (value of an industry's intermediate good consumption needed for one unit of output value - the difference to one is the industry's value-added) across countries from internationally comparable input-output tables (for further details see Ahmad and Yamano (2006)). Each dot represents the ratio of country-year pairs for broadly defined industries, plotted against the country's GDP per capita in that year.[4]

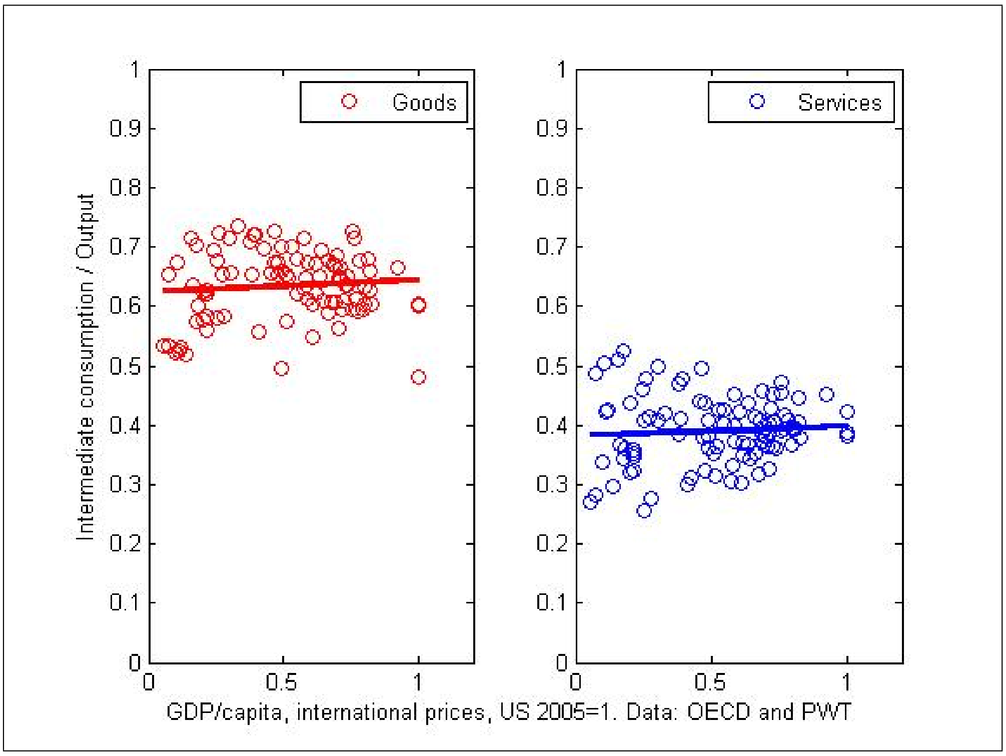

FIGURE 3. Intermediate factor shares

Two apparent trends stand out. First, for both sectors the ratios seem rather uncorrelated with GDP per capita. This fact has been previously pointed out elsewhere for the overall intermediate consumption ratio in the economy (e.g. Jones (forthcoming)). It runs counter, however, to the argument expressed in Chenery, Robinson and Syrquin (1986), according to which input-output ratios may have increased during industrialization in several developing countries, possibly due to the adoption of different technological practices.[5] In this paper I will abstract from arguments involving changes in technology and

[4]The sample includes OECD as well as several non-OECD countries. GDP per capita values are taken from the Penn World Tables. The years are 1995, 2000 and 2005.

[5]This study is related to the analysis of the economy by means of the Leontieff matrix and has its roots in the identification of optimal demand stimulus. In particular, the concern there is with the 'technical

treat the input-output ratio of an industry as depending exclusively on a time-invariant factor share of inputs in the production function. Rather, I wish to highlight the other feature that emerges from Figure (3), namely that industries vary substantially in their requirement of intermediate goods. In particular, the figure shows that the production of goods uses up relatively larger values of intermediate goods than the production of services. I claim that this is an aspect that may not have received sufficient attention in the latest literature on aggregate productivity across countries.

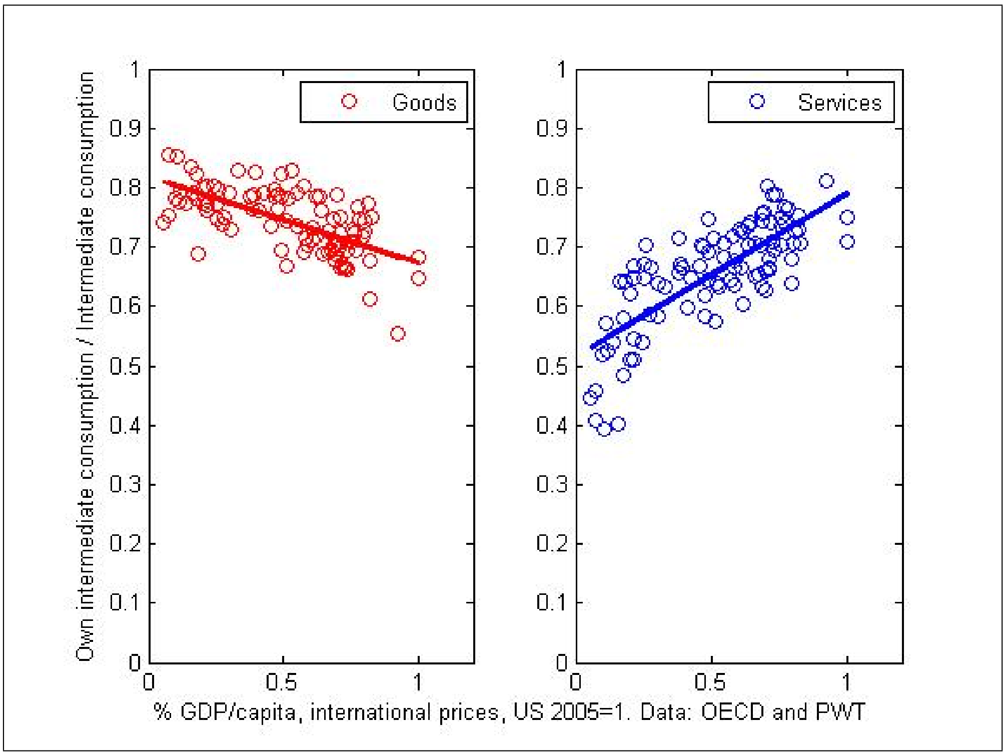

FIGURE 4. Shares of intermediates from same own industry

The constancy of aggregate intermediate factor shares across countries and industries does not, however, extend to a finer breakdown of intermediate goods by types. Figure (4) shows that as countries grow richer, industries producing goods tend to use rather less intermediates deriving from their own sector, as a share of their total intermediate good consumption, while service industries tend to use rather more intermediates deriving from their own sector. Goods intermediates are therefore relatively more prevalent in poorer countries.

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

coefficients', i.e. the multiplier value of demand in upstream sectors due to a percentage increase in a final demand sector.

there is a representative firm indexed by $i \in \{g, s\}$ in each of the two industries - goods and services[6] - producing according to the constant returns to scale production function

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

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 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

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

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

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

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

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

Notice that the technical parameters σ, ρ and γ 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 varies across countries. Also, note that specialized intermediate good producers use part of their output as an input. Market clearing implies that

$$c_i = y_{fi}, \ i \in \{g, s\}, \tag{5}$$

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

where c_i is consumption of final good i.

At this point several clarifications are necessary. First, note that the distinction between two industry is not only related to 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 breakdown of the goods industry into consumption and investment goods would enrich the model by incorporating investment behavior. Similarly, a breakdown into agriculture and 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.[7]

Second, the Cobb-Douglas specification between composite intermediate inputs and labor can be defended empirically by the argument of stable intermediate factor shares

[6]Goods will have as their empircial counterpart the industry labels A-F while services industries G-Q.

[7]This also allows to compare results with the literature that explicitly microfounds relative sectoral efficiency differences across countries and which is usually framed within two sectors. One example is Buera, Kaboski and Shin (forthcoming) who show a theoretically how in poorer countries the efficiency of tradables suffers more from financial frictions than the one of non-tradables.

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 function (1) and (3) I interpret A as factor-neutral efficiency. In this I follow Jones (2009) or the multifactor 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.[8] 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 modeled here.

3.1.2. *Households*

A representative household solves the problem

$$\max_{c_g\geq 0, c_s\geq 0} u(c_g, c_s) = \max_{c_g\geq 0, c_s\geq 0} \left(\omega_g^{\frac{1}{\rho}} c_g^{\frac{\rho-1}{\rho}} + \omega_s^{\frac{1}{\rho}} c_s^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}} \tag{7}$$

subject to

$$p_{fg}c_g + p_{fs}c_s \leq w\left(l_{fg} + l_{fs} + l_{mg} + l_{ms}\right) \tag{8}$$

and

$$l_{fg} + l_{fs} + l_{mg} + l_{ms} = 1, \tag{9}$$

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 in production, with $\sum_{i=s,g} \omega_i = 1$.

The utility function is similar to the one in Ngai and Pissarides (2007), implying that observed secular changes in the expenditure composition between final goods are driven by relative price changes, the so-called Baumol disease.[9] A second thing 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).

3.2. *Equilibrium definition*

The equilibrium is a list of production, $\{y_{ji}\}_{j\in\{f,m\},i\in\{s,g\}}$, final consumption demand $\{c_j\}_{j\in\{f,m\}}$, intermediate good demand $\{x_{nji}\}_{j\in\{f,m\},i,n\in\{s,g\}}$, labor allocations $\{l_{ji}\}_{j\in\{f,m\},i\in\{s,g\}}$, prices $\{p_{ji}\}_{j\in\{f,m\},i\in\{s,g\}}$, and the wage rate w such that:

i) households take $\{p_{fi}\}_{i\in\{s,g\}}$ and w as given and solve (7) subject to (8) and (9);

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[8]Moro (2007) is one exception in the literature to use the alternative specification by which technology is not embedded in intermediate goods.

[9]Herrendorf, Rogerson and Valentinyi (2009) analyze the relative merits 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 in the US. They find that it matches the data better when each consumption item is a composite of the value-added provided by its industry, while income effects are important when items are identified according to the final product classification, as I do in this paper. I nonetheless choose the above utility specification because all relevant datasets point to strong relative price differences across countries at different stages of development, something that Herrendorf, Rogerson and Valentinyi (2009) cannot identify from the historical US final product data. In any case, most of the ensuing theoretical results and empirical inferences about efficiency parameters do not depend on the utility specification (only international GDP comparisons do).

ii) the representative final good producer in industry $i \in \{g, s\}$ takes input prices $\{p_{mi}\}_{i\in\{s,g\}}$, 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 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, which is described in detail 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 productivity. For this I consider a setup where efficiency levels A in all countries (or alternatively a rich benchmark country) are fixed while the ones in a relatively poor country of interest experience simultaneous positive changes, which is to say that the country converges in income. I will consider two possible scenarios, defined as follows:

Definition 1. ***Industry-neutral growth****: Percent changes in efficiency across industries are identical conditional on the specialization, i.e.* $\frac{dA_f}{A_f} \equiv \frac{dA_{fg}}{A_{fg}} = \frac{dA_{fs}}{A_{fs}}$ *and* $\frac{dA_m}{A_m} \equiv \frac{dA_{mg}}{A_{mg}} = \frac{dA_{ms}}{A_{ms}}$.

Definition 2. ***Specialization-neutral growth****: Percent changes in efficiency across specializations are identical conditional on the industry, i.e.* $\frac{dA_g}{A_g} \equiv \frac{dA_{fg}}{A_{fg}} = \frac{dA_{mg}}{A_{mg}}$ *and* $\frac{dA_s}{A_s} \equiv \frac{dA_{fs}}{A_{fs}} = \frac{dA_{ms}}{A_{ms}}$.

4.1. *Prices*

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

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

Since production functions across specializations are identically parameterized, 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 worse 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):

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

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 productivity between final good producers:

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

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 becomes more efficient across the board in the sense that dA_{fg}, dA_{fs}, dA_{mg}, $dA_{ms} > 0$. (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 $\frac{dA_g/A_g}{dA_s/A_s} > (<) \frac{1-\sigma_g}{1-\sigma_s}$.*

Proof. Appendix. □

The data presented in the previous section (Figure 3) indicates that goods industries have higher intermediate factor shares 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 goods production (versus services) is more sensitive to the cost of intermediates, (industry-neutral) increases in efficiency are likely to magnify the productivity of the goods industry more than the one of the services industry.[10] 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}. 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 on which industries are the 'problem sectors' of poor countries.

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 industry and specialization-specific intermediate good to output ratios. 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 $\widetilde{p}_{ji}$ its associated price so that $\widetilde{p}_{ji}m_{ji} = p_{mg}x_{gji} + p_{ms}x_{sji}$. From the Cobb-Douglas specification of the production function it is clear that in equilibrium the value intensity of intermediates in production is

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

By construction the intermediate consumption ratios in the two industries in value 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

[10] This is analogous to international trade theories in the tradition of Hekscher and Ohlin where poor countries are thought of as being relatively unproductive in producing goods with high capital intensity, 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.

of (10) with (21) and (22) obtains the relative share of the industries' intermediates that they derive from their own respective industry:

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

and

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

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.

Proposition 2. *Assume the economy becomes more efficient across the board in the sense that dA_{fg}, dA_{fs}, dA_{mg}, $dA_{ms}>0$. (i) Under industry-neutral technical change the real intermediate input intensity m_{mg}/y_{mg} is decreasing (increasing) if and only if $\sigma_g>(<)\ \sigma_s$, m_{ms}/y_{ms} is increasing (decreasing) if and only if $\sigma_g>(<)\ \sigma_s$, m_{fg}/y_{fg} is increasing (decreasing) if and only if $\frac{(1-\sigma_g)(1-\sigma_s)+\sigma_s(1-\sigma_g)(1-\Gamma_{ss})+\sigma_s(1-\sigma_g)(1-\Gamma_{gg})}{(1-\sigma_g)(1-\sigma_s)+\sigma_s(1-\sigma_g)(1-\Gamma_{ss})+\sigma_g(1-\sigma_s)(1-\Gamma_{gg})}\frac{dA_m/A_m}{dA_f/A_f}>(<)\ 1$, and m_{fs}/y_{fs} is increasing (decreasing) if and only if $\frac{(1-\sigma_g)(1-\sigma_s)+\sigma_g(1-\sigma_s)(1-\Gamma_{gg})+\sigma_g(1-\sigma_s)(1-\Gamma_{ss})}{(1-\sigma_g)(1-\sigma_s)+\sigma_g(1-\sigma_s)(1-\Gamma_{gg})+\sigma_s(1-\sigma_g)(1-\Gamma_{ss})}\frac{dA_m/A_m}{dA_f/A_f}>(<)\ 1$; (ii) under specialization-neutral technical change m_{fg}/y_{fg} and m_{mg}/y_{mg} are increasing (decreasing) and m_{fs}/y_{fs} and m_{ms}/y_{ms} are decreasing (increasing) if and only if $\frac{1-\sigma_g}{1-\sigma_s}\frac{dA_s/A_s}{dA_g/A_g}>(<)\ 1$.*

Proof. Appendix. □

Under industry-neutral technical change, for $\sigma_g>\sigma_s$ it is expected that as a countries converges in income, the use of intermediates becomes less intensive in industries producing intermediate goods and more intensive in industries producing intermediate services. The intuition for this result is that following Proposition 1, for $\sigma_g>\sigma_s$, industry-neutral technical change implies a fall in the relative price of final goods. By (10), this also implies a fall in the relative price of intermediate goods relative to services, p_{mg}/p_{ms}. Since the composite intermediate good is a combination of goods and services, it becomes relatively more expensive for the intermediate goods industry and relatively less expensive for the intermediate service industry. The sign of the change is unclear for final goods producers. Notice however that for $dA_m/A_m>dA_f/A_f$ (which is also consistent with the data), the model suggests that at least the production of final services, if not of final goods as well, is likely to become more intensive in intermediate use as the economy converges. This latter point suggests that for dA_m/A_m sufficiently larger than dA_f/A_f all specialization-industry pairs but one are expected to use intermediate inputs more intensively in real terms. This is reminiscent of Hsieh and Klenow (2007) who show how richer countries use investment goods more intensively because they are more efficient at producing them.

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 $P\equiv\left(\omega_g p_g^{1-\rho}+\omega_s p_s^{1-\rho}\right)^{\frac{1}{1-\rho}}$ be the ideal price deflator. Replacing y in VA by the expression

(1) 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:

$$\frac{GDP}{P} = \frac{(1-\sigma_g)\,\sigma_g^{\frac{\sigma_g}{1-\sigma_g}} A_{fg} A_{mg}^{\frac{\sigma_g}{1-\sigma_g}} \left(\gamma_{gg} + \gamma_{sg}\left(\frac{A_{fs}}{A_{fg}}\frac{A_{mg}}{A_{ms}}\frac{p_{fs}}{p_{fg}}\right)^{1-\rho_g}\right)^{\frac{\sigma_g}{(\rho_g-1)(1-\sigma_g)}}}{\left(\omega_g + \omega_s\left(\frac{p_{fs}}{p_{fg}}\right)^{1-\rho}\right)^{\frac{1}{1-\rho}}} \tag{16}$$

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

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 becomes more efficient across the board in the sense that* dA_{fg}, dA_{fs}, dA_{mg}, $dA_{ms} > 0$. *(i) Under industry-neutral technical change a percent increase in intermediate good production efficiency* A_m *increases real theoretical GDP by a factor of* $\frac{\sigma_g(1-\sigma_s)(1-\Omega_s)+\sigma_s(1-\sigma_g)\Omega_s+\sigma_g\sigma_s(2-\Gamma_{gg}-\Gamma_{ss})}{(1-\sigma_g)(1-\sigma_s)+\sigma_g(1-\sigma_s)(1-\Gamma_{gg})+\sigma_s(1-\sigma_g)(1-\Gamma_{ss})}$ *of a percent increase in final good production efficiency* A_f *where* $\Omega_s \equiv \frac{p_{fs}c_s}{p_{fg}c_g+p_{fs}c_s} = \frac{\omega_s\left(\frac{p_{fs}}{p_{fg}}\right)^{1-\rho}}{\omega_g+\omega_s\left(\frac{p_{fs}}{p_{fg}}\right)^{1-\rho}} \in (0,1)$; *(ii) under specialization-neutral technical change a percent increase in goods production efficiency* A_g *increases real theoretical GDP by a factor of* $\frac{(1-\sigma_s)(1-\Omega_s)+\sigma_s(1-\Gamma_{ss})}{(1-\sigma_g)\Omega_s+\sigma_g(1-\Gamma_{gg})}$ *of a percent increase in services production efficiency* A_s.

Proof. Appendix. □

Structural transformation implies that the expenditure share of services Ω_s is increasing with rising income levels. Also, the evidence in Figure (...) suggests that in poorer countries a larger fraction of intermediate inputs used by the goods industry derives from its own sector (relatively large Γ_{gg}) while the opposite is true for the service industry (relatively low Γ_{ss}). As mentioned, it will be shown that industry-neutral technical change is a reasonable description of the data. The numerator in the expression of the first point in Proposition 3 suggests that poorer countries are then expected to benefit more from changes in intermediate good production efficiency (relative to final good production efficiency) than rich countries because they have a rather high value of $\sigma_g(1-\sigma_s)(1-\Omega_s)+\sigma_s(1-\sigma_g)\Omega_s$ (while the value of $2-\Gamma_{gg}-\Gamma_{ss}$ is qualitatively indeterminate). 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 income on goods. The denominator of that expression strengthens this point because by the same argument $\sigma_g(1-\sigma_s)(1-\Gamma_{gg})+\sigma_s(1-\sigma_g)(1-\Gamma_{ss})$ is likely to be lower in poor countries. This reflects the fact that 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. 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.

Specialization-neutral technical change will be shown to be less good of a data description. Note, however, from the expression in the second point in Proposition 3 the effect created by the supply side of the input-output table. If poor countries spend a larger fraction of final income on goods, it is natural that changes in the efficiency of producing goods have, ceteris paribus, a relatively stronger effect (vis-à-vis improvements in producing services) than in rich countries, i.e. $\frac{(1-\sigma_s)(1-\Omega_s)}{(1-\sigma_g)\Omega_s}$ is relatively large in poor countries. The supply side of the input-output table exacerbates this effect ($\frac{\sigma_s(1-\Gamma_{ss})}{\sigma_g(1-\Gamma_{gg})}$ is also likely to be larger in poor countries) since poor countries spend a larger fraction on goods in intermediate consumption as well.

5. Accounting and counterfactuals

In this section I infer the county-specific implied efficiencies A for the sample of countries included in the 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 the relative cost of intermediate goods across countries.[11] Since the construction of the model and the discussion of the theoretical results so far involved arguments based on Figures (1)-(4) that derive from different (and broader) data sources it is in order to check that the EU Klems data have the same stylized features as the ones discusses above.

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 σ_g and σ_s directly and infer γ_{gg} and ρ_g as well as γ_{ss} and ρ_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 ρ and ω from minimizing the discrepancy between the data and model predictions.

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 $\sigma_s = 0.357$. Using $\gamma_{gg} + \gamma_{sg} = 1$ and $\gamma_{gs} + \gamma_{ss} = 1$, the conditions (14) and (15) can be rewritten to give

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

and

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

for each country $k \in \{1, 2, ..., K\}$ where ε_{gk} and ε_{sk} are assumed to be white noise. Using EU Klems data on the observables on the left and right hand side the two separate OLS regression across all countries deliver $\gamma_{gg} = 0.677$ and $\rho_g = 0.178$ as well as $\gamma_{ss} = 0.572$ and

[11]The EU Klems dataset provides two series of prices, output prices and input prices. As described in the Appendix, from this it is possible to construct separate series for intermediate and final good prices.

$\rho_s = 0.223$. 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 is sufficient information to infer the four efficiency values A for each country. The most straightforward way to do this would be to use the productivity data for each specialized industry, y_{ji}/l_{ji}. It can be checked that the optimality conditions imply

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

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

I can construct data on y_{ji}, but because the dataset used only provides information on total hours worked by industry but not by specialization, I need to use supplementary optimality conditions from the model for the purpose of identification. In addition to the above four equations I use (10) for both industries as well as $l_{fg}+l_{mg} = l_g$ and $l_{fs}+l_{ms} = l_s$. Since p_{fs}/p_{fg} is then implicitly defined in the model from (11) the solution is identified. Note, however, that as data on p_{fs}/p_{fg} is readily available, it appears more judicious to use it, and ex post check whether the model's implied final price ratio actually matches the one in the data. The set of data points used for each country are therefore $(p_{fs}/p_{gs})^k$, $(p_{mg}/p_{fg})^k$, $(p_{ms}/p_{fs})^k$, y^k_{fg}, y^k_{fs}, y^k_{mg}, y^k_{ms}, l^k_g and l^k_s. The resulting solution consists of the four efficiency levels A and as a by-product also includes the four levels of hours worked l.

parameter	value	target
σ_g	0.570	$\sum_k \left(\frac{p_{mg}(x_{gfg}+x_{smg})+p_{ms}(x_{sfg}+x_{gmg})}{p_{fg}y_{fg}+p_{mg}y_{mg}}\right)^k/K$
σ_s	0.357	$\sum_k \left(\frac{p_{mg}(x_{gfs}+x_{gms})+p_{ms}(x_{sfs}+x_{gms})}{p_{fs}y_{fs}+p_{ms}y_{ms}}\right)^k/K$
γ_{gg}, ρ_g	0.677, 0.178	$\left(\frac{p_{mg}(x_{gfg}+x_{gmg})}{p_{ms}(x_{sfg}+x_{smg})}\right)^k$, $\left(\frac{p_{ms}}{p_{mg}}\right)^k$
γ_{ss}, ρ_s	0.572, 0.223	$\left(\frac{p_{ms}(x_{sfs}+x_{sms})}{p_{mg}(x_{gfs}+x_{gms})}\right)^k$, $\left(\frac{p_{ms}}{p_{mg}}\right)^k$
ω_g, ρ	0.437, 0.749	$\left(\frac{p_{fg}c_g}{p_{fs}c_s}\right)^k$, $\left(\frac{p_{fs}}{p_{fg}}\right)^k$
A^k_{fg}, A^k_{fs}, A^k_{mg}, A^k_{ms}	-	$(p_{fs}/p_{gs})^k$, $(p_{mg}/p_{fg})^k$, $(p_{ms}/p_{fs})^k$, y^k_{fg}, y^k_{fs},y^k_{mg}, y^k_{ms}, l^k_g, l^k_s

Table 1: Benchmark calibration

Finally, I need to 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

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

where ε_{pk} is assumed to be white noise. I construct the left-hand side of the equation using data on $\frac{p_{fg}c_g}{p_{fs}c_s}$ and perform an OLS regression to obtain values ω_g and ρ that best match the household's first order condition with the data. These are 0.437 and 0.749, so households have stronger preference for services, and less than unitary substitutability between the two goods, the latter being consistent with structural transformation as a result of faster productivity growth in the goods industry.

5.1.2. *Model-data match*

Figure (5) reports the model's deviation from the data for each country in several variables of interest. A perfect match would be such that all the countries lie on the 45 degree line. The upper left panel compares the model's measure of aggregate productivity (which is just GDP/hour) with the data. It is natural that these two measures are not identical because to measure productivity consistently across countries in the model, I evaluate it at US prices, i.e. $(GDP/l)^k_{US\ price} = c^k_g + (p_{fs}/p_{fg})^{US} c^k_s$ while the data are based on international prices.[12] This notwithstanding, there is no apparent bias in the model's predictions vis-à-vis the data, suggesting that the model measure of aggregate productivity can be employed for counterfactual exercises.

As explained above, even though the data price ratio p_{fs}/p_{fg} is used in the calibration, it is not directly targeted. The model therefore predicts another price ratio, based on relative productivities between the final goods sectors. Again, it is apparent that the model's predictions do not depart widely from the data.

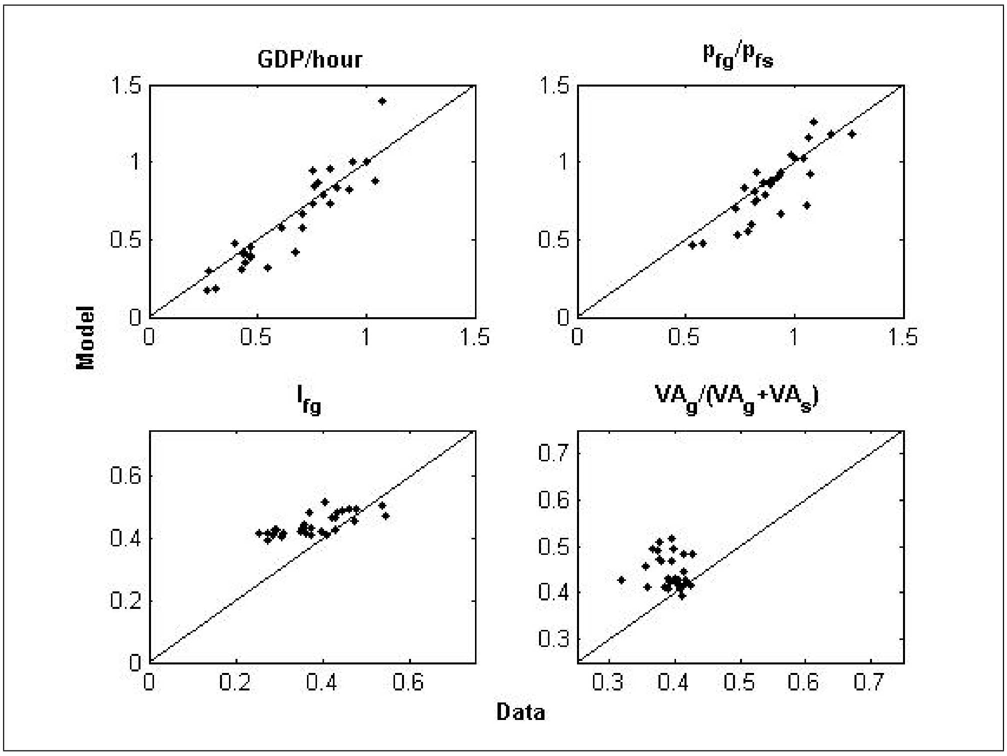

FIGURE 5. Model predictions versus data

What is of more concern is the amount of labor allocated to the goods sector l_g. The model clearly overestimates it. This is presumably because the preference parameters are based on consumption shares, but the relation between consumption shares and labor allocation in the data somewhat departs in the data. For the same reason, the model also over-predicts value-added in the goods industry (lower left panel). These departures should not be viewed with concern as regards the validity of the main result, which is the

[12]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 the prices of large and rich countries (especially the US) are disproportionately represented.

measure of the countries' efficiency levels, since the latter are not affected by preferences. The subsequent counterfactuals, however, must be regarded with some caution.

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 as given by the data. Several things stand out. First, and not surprisingly, rich 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, with richer countries appearing to be only slightly more efficient at producing goods. The more pronounced difference is across specializations: compared to poor countries, rich countries tend to be particularly more efficient at producing intermediate goods.

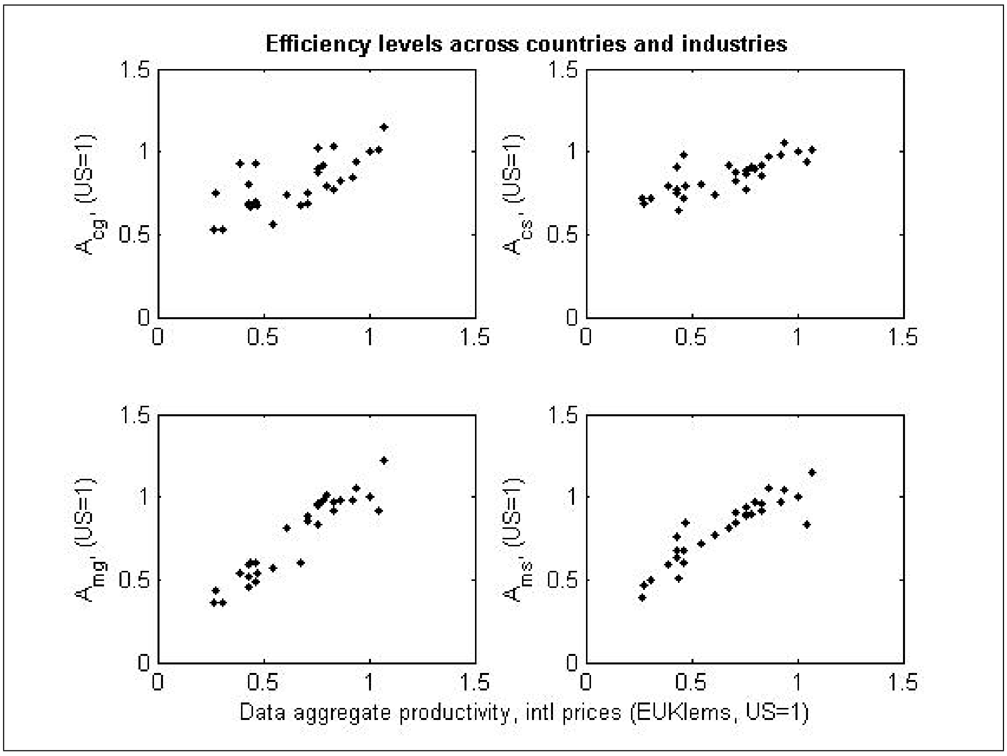

FIGURE 6. Implied efficiency levels

The first column of Table (2) presents an alternative organization of these data. It compares the mean efficiency for each category between the bottom and top quintile sample countries in terms of aggregate productivity.[13] Note that the efficiency gap between the least and most productive countries in the production of final goods is moderate, at about 10-20%, and is only slightly larger for goods than services. The efficiency gap is significantly larger for the production of intermediates at roughly 50%. Besides, the gap is more pronounced for goods compared to services.

[13]The most productive countries in the sample (from top down) are: Sweden, Canada, the US, the UK, Germany and Denmark. The least productive are (from botom up) Lithuania, Estonia, Poland, Latvia, the Czech Republic and the Slovak Republic.

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 3-5 of Table (2) present the effect of closing down any of these variations one at a time by comparing again the resulting efficiency levels between the bottom and top productive countries.

The efficiency levels inferred in column 2 result from repeating the original calibration but ignoring equation (10) and setting $A^k_{mg} = A^k_{fg}$ and $A^k_{ms} = A^k_{fs}$, $\forall k$. Notice that compared to the benchmark, ignoring efficiency differences across specializations implies that the efficiency gap between poor and rich countries in final goods production significantly increases while the one in intermediate goods production only slightly decreases. This also expands the efficiency gap in goods compared to services. Clearly, not allowing for the possibility that poor countries are particularly inefficient at producing intermediates overstates the overall efficiency gap between poor and rich countries to mimic their productivity differences and exaggerates in particular the gap between goods and services to mimic the price ratio differences in final goods.

	benchmark	$A^k_{mg} = A^k_{fg}$, $A^k_{ms} = A^k_{fs}$	$\sigma_g = \sigma_s = 0.5$	$\gamma_{gg} = \gamma_{ss} = 0.5$, $\rho_g = \rho_s \to 1$
A^P_{fg}/A^R_{fg}	0.830	0.520	0.748	0.795
A^P_{fs}/A^R_{fs}	0.855	0.663	1.015	0.866
A^P_{mg}/A^R_{mg}	0.456	0.520	0.410	0.436
A^P_{ms}/A^R_{ms}	0.573	0.663	0.678	0.580

Table 2: Alternative calibrations, average efficiency levels of poorest to richest quintile

The results in column 4 stem from repeating the calibration exercise but setting $\sigma_g = \sigma_s = 0.5$ so that goods and services have the intensity in the composite intermediate input. Evidently, ignoring differences in the intermediate input intensity between goods and services increases the efficiency gap between rich and poor countries in the production of goods, and decreases it in the production of services. Just as argued in the theoretical section, poor countries are likely to appear less productive in producing goods than services to a large extent because goods are more intensive input users.

Finally, column 5 presents the results from the calibration that sets $\gamma_{gg} = \gamma_{ss} = 0.5$ and $\rho_g = \rho_s \to 1$ (i.e. the composite intermediate good is a Cobb-Douglas specification) In this way the composite intermediate good in both industries has the same value composition between goods and services. Compared to the benchmark, the qualitative effect on the implied cross-country efficiency differences of rendering the supply side of the input-output matrix symmetric is the same as the one of rendering the demand side more symmetric (column 4). Quantitatively, however, the effect is much smaller.

5.3.2. *Convergence scenarios*

The second column of Table (3) presents the results on the aggregate productivity gap (which here is the GDP per capita gap) between the poorest and richest quintile from moving all countries in the sample to the US efficiency level for each category at a time. First, notice that according to the model's measure of aggregate productivity the poorest quintile countries are about 46% percent less productive than the richest countries, which is only slightly lower than the gap in the data (40%). Hence, the model's measure is likely to be a good gauge for aggregate productivity differences. Compared to this benchmark, it is obvious that having countries move to the US efficiency level in goods raises their income levels very significantly while the effect is more negligible for services. Also, the effect is negligible for final goods, but is very strong for intermediate goods, attaining about 84%. This is to say that if poor countries were somehow able of grow as efficient as the US, by far the most prominent impact is predicted to come from boosting the efficiency in intermediate input production.

	$\frac{(GDP/l)^P}{(GDP/l)^R}$	$\frac{(p_{fs}/p_{fg})^P}{(p_{fs}/p_{fg})^R}$
data	0.401	0.778
benchmark calibration	0.467	0.683
$A^k_{fg} = A^{US}_{fg}$, $A^k_{mg} = A^{US}_{mg}$	0.728	1.119
$A^k_{fs} = A^{US}_{fs}$, $A^k_{ms} = A^{US}_{ms}$	0.589	0.600
$A^k_{fg} = A^{US}_{fg}$, $A^k_{fs} = A^{US}_{fs}$	0.542	0.695
$A^k_{mg} = A^{US}_{mg}$, $A^k_{ms} = A^{US}_{ms}$	0.843	0.972

Table 3: Scenarios of convergence to US efficiency levels

The third column of Table (3) is analogous to the second one for the final price ratio p_{fs}/p_{fg} rather than aggregate productivity. The model's prediction on the mean final price ratio of the poorest compared to the richest countries comes reasonably close to the one in the data. In light of the theoretical results on the price ratio, it is interesting to observe that poor countries are predicted to have a similar final price ratio to rich countries if they were as efficient in producing intermediates as rich countries. It confirms the intuition that the cross-country final price ratio depends as much on efficiency differences across specializations as on efficiency differences across industries.

6. Concluding remarks

This paper identifies that the main driving factor behind aggregate and sectoral relative 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, Antràs and Helpman (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.

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8. Appendix

8.1. *Data*

8.1.1. *Figures*

Figure (1) is based on the World Bank's International Comparisons Program 2005 benchmark data. The sample includes 147 countries. Commodity agriculture is simply Food and non-alcoholic beverages (1101). Commodity Industrial consumption good includes Alcoholic beverages and tobacco (1102), Clothing and footwear (1103), Housing, water, electricity, gas and other fuels (1104), Furnishings, household equipment and household maintenance (1105). Commodity Investment corresponds to Gross capital formation (15). Commodity Services includes Health (1106), Transport (1107), Communication (1108), Recreation and culture (1109), Education (1110) and Restaurants and hotels (1111). The constructed series are geometric averages with weights based on expenditure shares on the subsectors. GDP per capita is taken from the Penn World Tables.

Figure (2) computes relative prices from the EU Klems 1997 benchmark data in the following way. Notice 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 the all the two-digit subsectors in the dataset, the weights being the supply shares (IIS and IIE+IIM, respectively) to each subsector. The intermediate input price is hence simply the mean over the prices that all the sectors in the economy pay for that particular intermediate input. The series for the final price is subsequently computed via the construction of the aggregate output price, based on the output deflator (PPP_SO). The output price for goods is a weighted average over the output prices of the subsectors composing goods: agriculture, hunting, forestry and fishing (AtB); Consumer manufacturing (Mcons), Intermediate manufacturing (Minter), Mining and quarrying (C) and Electricity, gas and water supply (E); Investment goods, excluding hightech (Minves), Electrical and optical equipment (30t33) and Construction (F). The composite for the service output price consists of market services, excluding post and telecommunications (MSERV), Post and telecommunication (64) and Non-market services (NONMAR). The output and intermediate price for goods and services in hand, I compute the final good and final service price simply by noting that the output price is the geometric average 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). Finally, note that aggregate productivity in the data equals the ratio between total LP_VADD to total HOURS.

The data underlying Figures (3) and (4) are country-year pairs from the OECD 2005 international input-output data. The years are 1995, 2000 and 2005.[14] The sample includes OECD as well a number of poorer countries.[15] Intermediate consumption ratios are computed by adding the intermediate consumption of all the subsectors and dividing them by their total output. Similarly, own intermediate shares are computed by adding each subsector's intermediate consumption deriving from related subsectors and dividing by the composite sector's total intermediate consumption. The Goods and Service sectors are based on the following subsectors, respectively: 1-30 and 31-48. GDP per capita is taken from the Penn World Tables. Since these data report GDP per capita levels for each year as a ratio to the US, country-year pairs are constructed by using US GDP/capita growth between 1995 and 2005, also taken from the Penn World Tables.

8.1.2. *Calibration*

All the series are based on 1997 EU Klems dataset. For the construction of final and intermediate good price data, please refer to the above description of the data underlying Figure (2). Also, note that the definition of the subsectors composing the goods and the service industry, respectively, is of course identical to the one used in the construction of prices. Hours worked are based on the series HOURS. The series l_g and l_s are constructed by adding the hours worked in all subsectors defined to as goods and services, respectively. The series y_{fg}, y_{fs}, y_{mg} and y_{ms} are built as follows. Aggregate nominal intermediate production is the aggregate value (i.e. the addition across subsectors) of IIS for services and IIE+IIM for goods. These series are then deflated by their respective intermediate good price to arrive at y_{ms} and y_{mg}. I then construct aggregate output for goods and services by adding the relevant series (SO) across the subsectors composing each of the two industries. From the resulting value I subtract IIS for services and IIE+IIM for goods to arrive at aggregate nominal consumption. Deflating the resulting series by the relevant final good price consequently gives y_{fs} and y_{fg}.

The normalization employed is the following. I set $(p_{fs}/p_{fg})^{US} = (p_{mg}/p_{fg})^{US} = (p_{ms}/p_{fs})^{US} = 1$, so that the price ratios of all the other countries are multiples of the US price ratio. The physical quantities allow for one normalization, which is $y_{fg}^{US} = 1$.

Luxembourg is excluded from the analysis because of lack of data on intermediate goods.

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

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

[14]Some countries report for dates other than the three, for instance 1997 instead of 1995.

[15]Amongst others Argentina, Brazil, China, India, Indonesia, and Russia.

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, $\forall j \in \{f,m\}, i \in \{s,g\}$,

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

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

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

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

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

The household's maximization problem implies:

$$\frac{p_{fs}}{p_{fg}} = \frac{u_{c_s}}{u_{c_g}} = \left[\frac{\omega_s}{\omega_g}\frac{c_g}{c_s}\right]^{\frac{1}{\rho}}. \tag{25}$$

These last five formulations, coupled with the clearing conditions (1), $\forall i \in \{g,s\}$, (3), (5), (6) and (9) 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

$$\frac{d\left(p_{fs}/p_{fg}\right)}{p_{fs}/p_{fg}} = \Lambda\left(1+\frac{\sigma_g}{1-\sigma_g}\left(1-\Gamma_{gg}\right)+\frac{\sigma_s}{1-\sigma_s}\left(1-\Gamma_{ss}\right)\right)\frac{dA_{fg}}{A_{fg}} \tag{26}$$
$$-\Lambda\left(1+\frac{\sigma_g}{1-\sigma_g}\left(1-\Gamma_{gg}\right)+\frac{\sigma_s}{1-\sigma_s}\left(1-\Gamma_{ss}\right)\right)\frac{dA_{fs}}{A_{fs}}$$
$$+\Lambda\left(\frac{\sigma_g}{1-\sigma_g}-\frac{\sigma_g}{1-\sigma_g}\left(1-\Gamma_{gg}\right)-\frac{\sigma_s}{1-\sigma_s}\left(1-\Gamma_{ss}\right)\right)\frac{dA_{mg}}{A_{mg}}$$
$$-\Lambda\left(\frac{\sigma_s}{1-\sigma_s}-\frac{\sigma_g}{1-\sigma_g}\left(1-\Gamma_{gg}\right)-\frac{\sigma_s}{1-\sigma_s}\left(1-\Gamma_{ss}\right)\right)\frac{dA_{ms}}{A_{ms}}$$

where

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

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

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

Industry-neutral technical change ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{fs}}{A_{fs}} \equiv \frac{dA_f}{A_f}$ and $\frac{dA_{mg}}{A_{mg}} = \frac{dA_{ms}}{A_{ms}} \equiv \frac{dA_m}{A_m}$) gives

$$\frac{d\left(p_{fs}/p_{fg}\right)}{p_{fs}/p_{fg}} = \frac{\sigma_g-\sigma_s}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)}\frac{dA_m}{A_m},$$

while specialization-neutral technical change ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{mg}}{A_{mg}} \equiv \frac{dA_g}{A_g}$ and $\frac{dA_{fs}}{A_{fs}} = \frac{dA_{ms}}{A_{ms}} \equiv \frac{dA_s}{A_s}$) gives:

$$\frac{d\left(p_{fs}/p_{fg}\right)}{p_{fs}/p_{fg}} = \frac{\left(1-\sigma_s\right)\frac{dA_g}{A_g}-\left(1-\sigma_g\right)\frac{dA_s}{A_s}}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)}$$

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

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

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

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

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

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

Industry-neutral growth ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{fs}}{A_{fs}} \equiv \frac{dA_f}{A_f}$ and $\frac{dA_{mg}}{A_{mg}} = \frac{dA_{ms}}{A_{ms}} \equiv \frac{dA_m}{A_m}$) delivers:

$$\frac{d\left(m_{mg}/y_{mg}\right)}{m_{mg}/y_{mg}} = \frac{\left(\sigma_s-\sigma_g\right)\left(1-\Gamma_{gg}\right)}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)}\frac{dA_m}{A_m},$$

$$\frac{d\left(m_{fg}/y_{fg}\right)}{m_{fg}/y_{fg}} = \frac{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{gg}\right)}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)}\frac{dA_m}{A_m}-\frac{dA_f}{A_f},$$

$$\frac{d\left(m_{ms}/y_{ms}\right)}{m_{ms}/y_{ms}} = \frac{\left(\sigma_g-\sigma_s\right)\left(1-\Gamma_{ss}\right)}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)}\frac{dA_m}{A_m},$$

$$\frac{d\left(m_{fs}/y_{fs}\right)}{m_{fs}/y_{fs}} = \frac{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{ss}\right)}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)}\frac{dA_m}{A_m}-\frac{dA_f}{A_f}.$$

while specialization-neutral growth ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{mg}}{A_{mg}}$ and $\frac{dA_{fs}}{A_{fs}} = \frac{dA_{ms}}{A_{ms}}$) is given by:

$$\begin{aligned}
\frac{d\left(m_{fg}/y_{fg}\right)}{m_{fg}/y_{fg}} &= \frac{d\left(m_{mg}/y_{mg}\right)}{m_{mg}/y_{mg}} \\
&= \frac{\left(1-\Gamma_{gg}\right)\left[\left(1-\sigma_g\right)\frac{dA_s}{A_s}-\left(1-\sigma_s\right)\frac{dA_g}{A_g}\right]}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)},
\end{aligned}$$

$$\begin{aligned}
\frac{d\left(m_{fs}/y_{fs}\right)}{m_{fs}/y_{fs}} &= \frac{d\left(m_{ms}/y_{ms}\right)}{m_{ms}/y_{ms}} \\
&= \frac{\left(1-\Gamma_{ss}\right)\left[\left(1-\sigma_s\right)\frac{dA_g}{A_g}-\left(1-\sigma_g\right)\frac{dA_s}{A_s}\right]}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)}.
\end{aligned}$$

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

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

where $\Omega_s \equiv \frac{\omega_s\left(\frac{p_{fs}}{p_{fg}}\right)^{1-\rho}}{\omega_g+\omega_s\left(\frac{p_{fs}}{p_{fg}}\right)^{1-\rho}}$. Industry-neutral technical change ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{fs}}{A_{fs}} \equiv \frac{dA_f}{A_f}$ and $\frac{dA_{mg}}{A_{mg}} = \frac{dA_{ms}}{A_{ms}} \equiv \frac{dA_m}{A_m}$) gives:

$$\frac{d\left(GDP/P\right)}{GDP/P}=\frac{\Lambda\left\{\begin{array}{c}\left[\left(1-\sigma_g\right)\left(1-\sigma_s\right)+\sigma_g\left(1-\sigma_s\right)\left(1-\Gamma_{gg}\right)+\sigma_s\left(1-\sigma_g\right)\left(1-\Gamma_{ss}\right)\right]\frac{dA_f}{A_f} \\ +\left[\sigma_g\left(1-\sigma_s\right)\left(1-\Omega_s\right)+\sigma_s\left(1-\sigma_g\right)\Omega_s+\sigma_g\sigma_s\left(2-\Gamma_{gg}-\Gamma_{ss}\right)\right]\frac{dA_m}{A_m}\end{array}\right\}}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)},$$

while specialization-neutral technical change ($\frac{dA_{fg}}{A_{fg}} = \frac{dA_{mg}}{A_{mg}} \equiv \frac{dA_g}{A_g}$ and $\frac{dA_{fs}}{A_{fs}} = \frac{dA_{ms}}{A_{ms}} \equiv \frac{dA_s}{A_s}$) gives:

$$\frac{d\left(GDP/P\right)}{GDP/P}=\frac{\Lambda\left\{\left[\left(1-\sigma_s\right)\left(1-\Omega_s\right)+\sigma_s\left(1-\Gamma_{ss}\right)\right]\frac{dA_g}{A_g}+\left[\left(1-\sigma_g\right)\Omega_s+\sigma_g\left(1-\Gamma_{gg}\right)\right]\frac{dA_s}{A_s}\right\}}{\left(1-\sigma_g\right)\left(1-\sigma_s\right)}.$$