Which Sectors Make the Poor Countries so Unproductive?*

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Abstract

Standard growth accounting exercises find large cross–country differences in aggregate TFP. Here we ask whether specific sectors are driving these differences, and, if this is the case, which these problem sectors are. We argue that to answer these questions we need to consider four sectors. In contrast, the literature typically considers only two sectors. Our four sectors produce services (nontradable consumption), consumption goods (tradable consumption), construction (nontradable investment), and machinery and equipment (tradable investment). Interacting the data from the 1996 benchmark study of the Penn World Tables with economic theory, we find that the TFP differences across countries are much larger in the two tradable sectors than in the two nontradable sectors. This is consistent with the Balassa–Samuelson hypothesis. We also find that within the tradable sectors the TFP differences are much larger in machinery and equipment than in consumption goods. We illustrate the usefulness of our findings by accounting for the conflicting results of the existing two–sector analyses and by developing criteria for a successful theory of aggregate TFP.

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1 Introduction

One of the major challenges in economics is to account for the huge international disparity in income. Standard growth accounting exercises find that cross–country differences in aggregate total factor productivity (TFP henceforth) cause a sizeable part of the differences in GDP per capita.[1] This suggests that we need to understand where the TFP differences come from. A growing literature addresses this issue and shows that cross–country differences in the institutional environment or in policies can cause differences in TFP.[2] In this paper, we argue that information about the sectoral patterns of TFP differences can help to discriminate among the existing theories. We therefore ask whether specific sectors are driving the aggregate TFP differences, and, if this is the case, which these problem sectors are.

A key challenge in measuring sector TFPs comes from the limited available data. Unfortunately, disaggregate and comparable data on sector inputs and outputs does not exist for a wide range of rich and poor countries.[3] The only broad source of comparable and disaggregate cross–country data is the Penn World Tables as provided by Heston et al. (2002). We will work with the largest and most recent benchmark study from 1996 (PWT96 henceforth), which provides information about expenditures, purchase prices, and quantities. We will interact this information with economic theory so as to infer the sector inputs and outputs needed to calculate sector TFPs. Our approach follows Hsieh and Klenow (2003) in that it utilizes that differences between sector TFPs lead to differences in the observable corresponding relative prices. Our approach extends Hsieh and Klenow (2003) in that we disaggregate further and pay closer attention to factors other than TFP differences that can cause observable relative prices to differ. Moreover, Hsieh and Klenow (2003) asked the different question what can account for the fact that

[1] See, for example, Klenow and Rodriguez-Clare (1997), Prescott (1998), Hall and Jones (1999), Hendricks (2002), and Caselli (2004).

[2] See, for example, Holmes and Schmitz (1995), Parente and Prescott (1999), Acemoglu et al. (2001), Amaral and Quintin (2004), Erosa and Hidalgo (2004), Caselli and Coleman (2005), Herrendorf and Teixeira (2005a,b) and Cole et al. (2005).

[3] The McKinsey Global Institute collected firm level data for a small number of countries, but that data is not publicly available. The OECD has sector data for many of its members, but poorer countries are not OECD members.

across countries investment quantities are strongly positively correlated with income.[4]

We argue that in order to understand sectoral TFP patterns, it is important to disaggregate to four sectors. In contrast, the literature typically considers only two sectors: growth theorists distinguish between consumption and investment while trade theorists distinguish between tradables and nontradables. We come to our view because both consumption and investment have sizeable tradable and nontradable components and the prices of the tradable relative to the nontradable components vary systematically with GDP. To the extent that these price variations reflect variations in sector TFPs, we can gain important information from disaggregating consumption and investment into their nontradable and tradable components. We therefore build a model with the following four sectors: services (nontradable consumption), consumption goods (tradable consumption), construction (nontradable investment), and equipment investment (tradable investment). Since we consider construction and equipment investment separately, another novelty of our model is that it has two different capital stocks, namely the stocks of buildings and equipment. Our model also pays close attention to two factors other than sector TFP differences that can cause relative purchase prices to differ across countries: "taxes" broadly defined and distribution services. Examples of "taxes" include value–added taxes, tariffs, bribes, and rents from monopoly power. Distribution services are retail, wholesale, and transport services. Both affect the purchases price but not the producer prices.

Our main finding is that there are huge cross-country differences in the TFPs of the two tradable sectors and considerably smaller cross-country differences in the TFPs of the two nontradable sectors. We also find that within the tradable sectors, the international TFP disparities are larger in machinery and equipment investment than in consumption goods. A successful theory of aggregate TFP ought to be consistent with these findings. At this stage, it is not clear to us how well the existing theories do in this respect. They attribute the cross–country differences in TFP to exogenous cross–country differences in institutions or policies. This raises the question why these exogenous differences do so

[4]Caselli and Coleman (2005) is also related to our approach in that they use information about relative wages to learn about the elasticity of substitution between skilled and unskilled labor.

much more damage in the tradable sectors than in the nontradable ones.

Here we have abstracted from human capital. It is well known that unmeasured cross–country differences in human capital show up as cross–country differences in TFP, but it is still hotly debated for how much human capital can account.[5] Be that as it may, our disaggregate four–sector analysis has the testable implication that unmeasured differences in human capital should cause the largest TFP differences in the sectors that have the largest labor shares. Carefully measuring the capital shares of our four sectors for the U.S., it turns out that the labor share in the nontradables is larger than in tradables. While this speaks against simple theories of human capital, it still leaves room for more sophisticated ones. For example, Acemoglu and Zilibotti (2001) argued that poorer countries find it hard to adopt new technologies because skilled workers that can operate them are scarce.[6] If this matters more in the tradable than in the nontradable sectors (for example because the technologies there are more skill intensive), then unmeasured differences in human capital can cause sector TFP differences that line up with our findings. Another possibility is that bad institutions in poorer countries allow rent extraction mainly in the nontradable sectors, as international competition limits it in the tradable ones. This could distort the allocation of skilled workers towards the nontradable sectors, in which case unmeasured differences in human capital would lead to larger sector TFP differences in the tradables. We leave exploring these ideas to future research.

The importance of our four–sector approach is illustrated by comparing our results to the existing ones. While the literature has produced sound evidence suggesting that there are problem sectors, it has not produced conclusive evidence as to which these problem sectors are. For example, many years ago Balassa (1964) and Samuelson (1964) conjectured that the cross–country differences in labor productivity are much larger in the tradable sectors than in the nontradable ones.[7] In sharp contrast, Lewis (2004) has argued recently that the firm–level evidence collected by the McKinsey Global Institute

[5]See for example Barro (1991), Barro and Lee (1994) Mankiw et al. (1992), Blis and Klenow (2000), Hendricks (2002), Erosa et al. (2005), and Manuelli and Seshadri (2005).

[6]This is a version of the appropriate–technology hypothesis; see also Basu and Weil (1998).

[7]Rogoff (1996) offers a review of the literature on the Balassa–Samuelson hypothesis. He concludes that the supporting evidence is surprisingly scant and mostly indirect.

points to the nontradable sectors as the problem sectors.[8] If we use our results and compute the labor productivities of the aggregate tradables and nontradables categories, then we confirm the conjecture of Balassa (1964) and Samuelson (1964). This suggests that the results of the McKinsey Studies, which comprise only a relatively small number of countries, do not generalize to a broad cross section.[9]

A second group of two–sector analyses identified completely different problem sectors. On the one hand, Kuznets (1971) found that cross–country differences in labor productivity are much larger in agriculture than in the aggregate of the other goods.[10] On the other hand, Hsieh and Klenow (2003) found that cross–country differences in TFP are much larger in investment than in consumption. Since agriculture is a part of consumption, these two findings seem opposite of each other. Our more disaggregate four–sector explains why they coexist nonetheless. If we aggregate the nontradable consumption and tradable and nontradable investment and compute the labor productivities of consumption goods and the other goods, we find that consumption goods are the problem sector. In contrast, if we aggregate nontradable and tradable components and compute the sector TFPs of aggregate consumption and investment, we find that investment is the problem sector. In other words, the explanation for the very different results from two–sector analyses is that sector TFPs differ across countries at a more disaggregate level.

The next section lays out the economic environment. Section 3 defines the competitive equilibrium. Section 4 describes our measurement and the calibration of our model. We report our findings in Section 5 and conclude in Section 6. An appendix contains all proofs and a detailed description of our data work.

[8]See also Bailey and Solow (2001).

[9]To be precise, McKinsey have firm–level data on 10 countries. The only developing countries in this data set are India and Brazil.

[10]More recent related studies include Restuccia et al. (2003), Córdoba and Ripoll (2004), and Gollin et al. (2004).

2 Environment

There is a finite set $\mathcal{J}$ of small open economies. Time is discrete and runs forever. All final goods are tradable within each country, but they may or may not be tradable across countries. We call a final good tradable if it is tradable across countries and nontradable if it is not. In each period, there are four final goods: nontradable and tradable consumption and nontradable and tradable investment. For concreteness we call them services x_s, construction of building x_b, consumption goods x_g, and equipment investment x_e. We denote the set of goods indices by $\mathcal{I} \equiv \{s, b, g, e\}$. Construction and equipment investment augment the stocks of buildings k_b and equipment k_e, which depreciate at the rates $\delta_b, \delta_e \in (0, 1)$.[11]

Each economy $j \in \mathcal{J}$ is populated by a representative household, whose preferences are described by the utility function:[12]

$$\sum_{t=0}^{\infty} \beta^t u\left(x_{st}^j, x_{gt}^j\right). \tag{1}$$

$\beta \in (0, 1)$ is the discount factor and u has the standard regularity properties. The representative household is endowed with one unit of labor in each period and with positive stocks of buildings k_{b0}^j and equipment k_{e0}^j in the initial period.

All technologies have constant returns to scale. There is no technological progress. This is without loss of generality here, as we are interested in ratios that along balanced growth paths are constant and independent of growth rates. Country $j \in \mathcal{J}$ produces final good $i \in \mathcal{I}$ according to

$$y_i^j = F_i^j(k_{bi}^j, k_{ei}^j, l_i^j). \tag{2}$$

k_{bi} and k_{ei} are the stocks of buildings and equipment and l_i is the labor allocated to the production of y_i. F_i^j has the usual regularity properties. Note that F_i^j differs across goods and countries. We will be more specific on the nature of these differences in Subsection

[11]Note that some authors use the terms "structures and residential housing" and "machinery and equipment" instead.

[12]We will specify functional forms below when we do our quantitative exercise.

4.1 below when we specify functional forms.

Tradable output is sold in the world market and delivering it from there to household requires distribution services. Burstein et al. (2003, 2004) document that the share of distribution services in the purchase price of tradable goods (the so called distribution margin) can be large quantitatively.[13] To capture this, we assume that the production function for delivering x_i units of tradable good $i \in \{g, e\}$ to the representative household in country j is given by

$$x_i^j = G_i(y_i^{*j}, y_{si}^j), \tag{3}$$

where y_i^{*j} is the quantity of good i that is purchased in the world market and y_{si}^j are the distribution services. G_i has the standard regularity properties of a production function. Again we will be more specific Subsection 4.1 below.

3 Competitive Equilibrium

We abstract from the possibility that assets are traded across countries. This is without loss of generality because we will restrict our attention to balanced–growth–path comparisons.

In each period there are markets for each final good and each factor of production. The market clearing conditions are:

$$p_g^*(y_g^{*j} - y_g^j) + (y_e^{*j} - y_e^j) = 0 \tag{4a}$$

$$x_s^j + y_{sg}^j + y_{se}^j = y_s^j, \qquad x_b^j = y_b^j, \tag{4b}$$

$$k_b^j = \sum_{i \in \mathcal{I}} k_{bi}^j, \qquad k_e^j = \sum_{i \in \mathcal{I}} k_{ei}^j, \qquad 1 = \sum_{i \in \mathcal{I}} l_i^j, \qquad j \in \mathcal{J}. \tag{4c}$$

The first condition says that trade must be balanced in each country.[14] The second

[13] We do not consider a distribution margin for construction because the IO tables do not report it. We do not consider a distribution margin for services because distribution services are services.

[14] Recall that we don't have borrowing and lending across countries. Recall too that we consider small open economies, so we do not need to impose world market clearing for the tradable goods.

condition says that the purchases of services by the household and the distribution sector must equal the production of services. Note that this implicitly assumes that consumed services and distribution services are perfect substitutes. The reason for this assumption is that we do not have information about the relative prices of the two in our data set. The third condition says that the purchases of new buildings must equal the construction of buildings. The last three conditions say that the three factors owned by the household must equal the sums of the quantities rented by the four sectors.

We take into account that "taxes" can be a source of cross-country differences in observable relative prices, as suggested by Chari et al. (1996) and Restuccia and Urrutia (2001). We define "taxes" broadly as any distortion that increases the purchase price and gets rebated to the households. Examples include value–added taxes, tariffs, bribes, and monopoly rents. The tax rates are denoted by τ_{it}^{j} where $i \in \mathcal{I}$ and $j \in \mathcal{J}$. The tax revenues are rebated to the households through lump-sum transfers Λ_t^j. The fact that they are rebated distinguish taxes from sector TFPs: a decrease in a sector's TFP has the same effect on the relative price as an increase in the "tax", but only the tax revenue gets rebated to the representative household.

We choose equipment in the world market as the numeraire: $p_e^* = 1$. We denote the relative world–market price of consumption goods before delivery by p_g^*, the relative producer prices by p_i^j, the relative purchase prices after delivery and taxes by P_i^j, and the rental rates by r_b^j, r_e^j, and w^j where $(i,j) \in \mathcal{I} \times \mathcal{J}$.

For convenience, we define the following column vectors:

$$\boldsymbol{\tau} \equiv (\tau_s, \tau_b, \tau_g, \tau_e)', \qquad \boldsymbol{r} \equiv (r_b, r_e)', \qquad \boldsymbol{x} \equiv (x_s, x_b, x_g, x_e)', \tag{5a}$$

$$\boldsymbol{P} \equiv (P_s, P_b, P_g, P_e)', \qquad \boldsymbol{p} \equiv (p_s, p_b, p_g, p_e)', \tag{5b}$$

$$\boldsymbol{k} \equiv (k_b, k_e)', \qquad \boldsymbol{k}_i \equiv (k_{bi}, k_{ei})', \tag{5c}$$

$$\boldsymbol{k_b} \equiv (k_{bs}, k_{bb}, k_{bg}, k_{be})', \qquad \boldsymbol{k_e} \equiv (k_{es}, k_{eb}, k_{eg}, k_{ee})', \tag{5d}$$

$$\boldsymbol{y} \equiv (y_s, y_b, y_g, y_e)', \qquad \boldsymbol{l} \equiv (l_s, l_b, l_g, l_e)'. \tag{5e}$$

Definition 1 (Competitive Equilibrium)

Given sequences of taxes and rebates $\{\boldsymbol{\tau}_t^j, \Lambda_t^j\}_{t=0}^{\infty}$ *where* $j \in \mathcal{J}$*, a competitive equilibrium consists of sequences of relative prices* $\{\boldsymbol{P}_t^j, p_g^*, \boldsymbol{p}_t^j, \boldsymbol{r}_t^j, w_t^j\}_{t=0}^{\infty}$*, household allocations* $\{\boldsymbol{x}_t^j, \boldsymbol{k}_{t+1}^j\}_{t=0}^{\infty}$*, firm allocations* $\{\boldsymbol{y}_t^j, \boldsymbol{k}_t^j, \boldsymbol{l}_t^j\}_{t=0}^{\infty}$*,* $\{x_{it}^j, y_{it}^{*j}, y_{sit}^j\}_{t=0}^{\infty}$ *for* $i \in \{g, e\}$ *such that:*

1. $p_g^j = p_g^*$ *and* $p_e^j = 1$*;*

2. *given prices,* $\{\boldsymbol{x}_t^j, \boldsymbol{k}_{t+1}^j\}_{t=0}^{\infty}$ *solve the problem of the household in country* j*:*[15]

$$\max_{\{\boldsymbol{x}_t^j, \boldsymbol{k}_{t+1}^j\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t u(x_{st}^j, x_{gt}^j) \tag{6a}$$

$$\begin{aligned} s.t. \quad & (\boldsymbol{p}_t^j)' \cdot \boldsymbol{x}_t^j = (\boldsymbol{r}_t^j)' \cdot \boldsymbol{k}_t^j + w_t^j + \Lambda_t^j, \\ & k_{it+1}^j = (1 - \delta_i) k_{it}^j + x_{it}^j \quad i \in \{b, e\}, \\ & \boldsymbol{x}_t^j, \boldsymbol{k}_{t+1}^j \geq 0, \qquad \boldsymbol{k}_0^j > 0 \text{ given}; \end{aligned}$$

3. *given prices,* $\{y_{it}^j, \boldsymbol{k}_{it}^j, l_{it}^j\}_{t=0}^{\infty}$ *solve the problem of the firm in sector* $i \in \mathcal{I}$*:*

$$\max_{\{y_{it}^j, \boldsymbol{k}_{it}^j, l_{it}^j\}} p_{it}^j y_{it}^j - (\boldsymbol{r}_t^j)' \cdot \boldsymbol{k}_{it}^j - w_t^j l_{it}^j \quad s.t. \quad (2); \tag{6b}$$

4. *given prices,* $\{x_{it}^j, y_{it}^{*j}, y_{sit}^j\}_{t=0}^{\infty}$ *for* $i \in \{g, e\}$ *solve the problems of the firms in the distribution sector:*

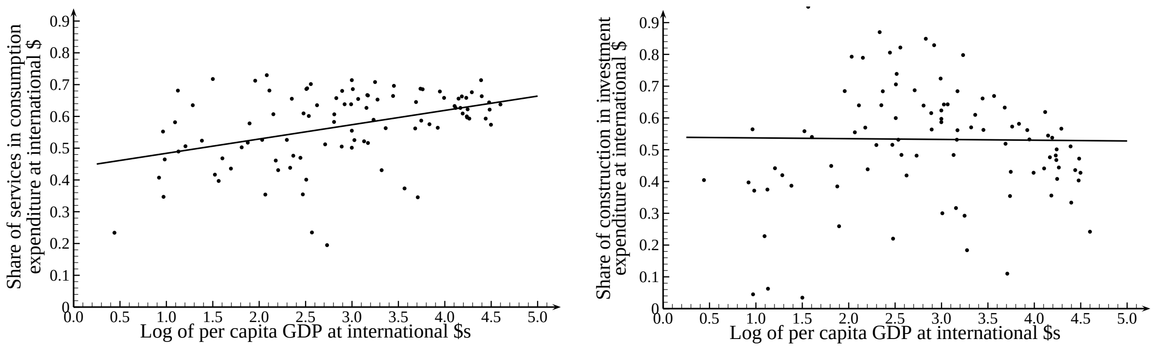
$$\max_{\{x_{gt}^j, y_{gt}^{*j}, y_{sgt}^j\}} \frac{P_{gt}^j}{1 + \tau_{gt}^j} x_{gt}^j - (p_{gt}^* y_{gt}^{*j} + p_{st}^j y_{sgt}^j) \ \ s.t. \ (3), \tag{6c}$$

$$\max_{\{x_{et}^j, y_{et}^{*j}, y_{set}^j\}} \frac{P_{et}^j}{1 + \tau_{et}^j} x_{et}^j - (y_{et}^{*j} + p_{st}^j y_{set}^j) \ \ s.t. \ (3); \tag{6d}$$

5. *markets clear, that is,* (4) *hold.*

[15] Note that profits are zero in competitive equilibrium, so we suppress them.

Figure 1: The composition of consumption and investment



4 Data and Measurement

4.1 Definitions

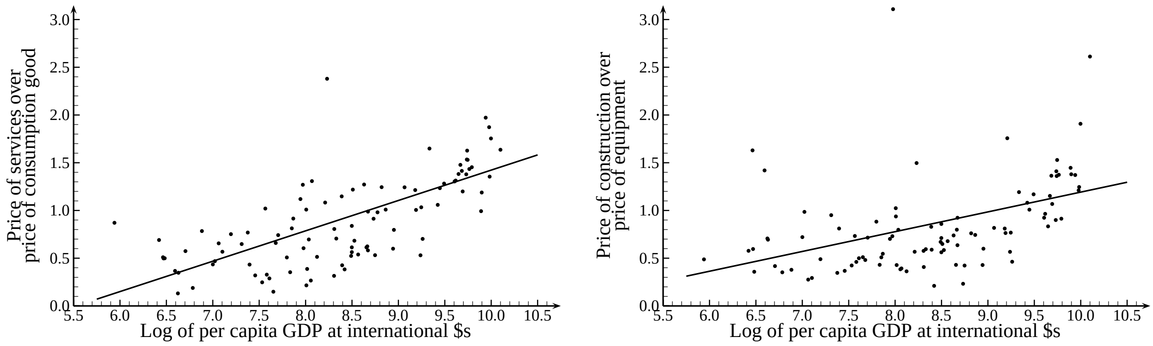
We work with the PWT96, that is, the 1996 Benchmark Study of the Penn World Tables. The PWT96 is a fairly disaggregate cross section for 1996, which is collected within the International Comparisons Program. It contains information about expenditures, purchased quantities, and purchase prices for 30 categories in 98 countries with more than 1 million inhabitants.[16]

We are going to apply our model to three economies: the U.S., Latin America, and the 20 poorest countries in our sample.[17] We represent them by the superscripts US, LA, and PC, so $j \in \mathcal{J} \equiv \{US, LA, PC\}$. Two remarks about our choice of countries are at order. First, our small–economy assumption is somewhat questionable for the U.S. We make it nonetheless because the alternative would be to assume that the world market clears among our three economies. This is more questionable, as most of U.S. trade is with countries outside of the set considered here. Second, we calculate the relevant statistics for Latin America and the Poorest Countries as the averages of the member countries' statistics. Since we have data only for 1996, we hope that taking averages across broad sets of countries will eliminate the deviations that individual countries may experience

[16] We restrict our attention to benchmark years and countries, because only for those the International Comparisons Program actually collects the data.

[17] The identity of the Latin American countries and the twenty poorest countries of our sample can be found in Appendix B.1.

Figure 2: Prices of nontradables relative to tradables



from their balanced growth paths. Because of this concern, we do not consider countries such as India and China, who are typically viewed as being in a transition.

We now aggregate the 30 expenditure categories of the PWT96 to our four sectors. To do this, we make a judgment about each categories as to whether it is mainly nontradable or tradable and mainly investment or consumption. The details are described in Appendix B.1.1. The resulting assignment is very similar to that typically used in other studies; see for example de Gregorio et al. (1994). Having formed our four sectors, we can provide the evidence that made us disaggregate to our four, instead of two, sectors.[18] Figure 1 shows that both consumption and investment have large nontradable and tradable parts. Figure 2 shows that for both consumption and investment the prices of the tradable relative to the nontradable component increase systematically with income. To the extent that relative prices reflect relative sector TFPs, important information should be obtained from disaggregating consumption and investment into their nontradable and tradable components. For completeness, Figure 3 in Appendix C also shows the usual way of reporting relative price variations across countries, namely by looking at the price of nontradables relative to tradables or by looking at the price of consumption relative to investment. Both increase systematically with income too.

Next, we need to discuss what happens when countries specialize. A country that specializes produces only one of the two tradable goods and replaces the domestic technology

[18]Appendix B.1 explains in detail how to compute the prices and quantities of our four categories.

for the other tradable good by the world–market technology, so it can obtain the other tradable good at the world market price. We can avoid dealing with the different possible specialization patterns if we endow each country with the world–market technology of exchanging the two tradable goods, that is, if we restrict the domestic technologies such that the marginal rate of transformation between the two tradables equals p_g^* in all countries. Given this restriction, we can without loss of generality restrict our attention to the equilibrium in which all countries produce everything themselves, so exports and imports are zero. While this may seem restrictive, it is easy to show that in any equilibrium (with or without specialization) the marginal rates of transformation for the operated technologies equal p_g^* anyways and the following variables are the same: the relative prices, the consumed and produced quantities of nontradables, the consumed quantities of tradables and the world productions of tradables, and welfare. In other words, equilibria with different specialization patters only differ with respect to the quantities of tradables that the different countries produce. Since we the PWT96 has no information about the quantities produced, we do not have nothing to say about them here anyways.

To compute our model, we also need to adopt functional forms. We work with the following ones:

$$u(x_s^j, x_g^j) \equiv \log\left((x_s^j)^{\alpha}(x_g^j - \bar{x}_g)^{1-\alpha}\right) \qquad j \in \mathcal{J},\ i \in \mathcal{I}, \tag{7a}$$

$$F_i^j(k_{bi}^j, k_{ei}^j, l_i^j) \equiv A_i^j (k_i^j)^{\theta_i} (l_i^j)^{1-\theta_i}, \tag{7b}$$

$$k_i^j \equiv \left[\mu^{\frac{1}{\sigma}}(k_{bi}^j)^{\frac{\sigma-1}{\sigma}} + (1-\mu)^{\frac{1}{\sigma}}(k_{ei}^j)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \qquad j \in \mathcal{J},\ i \in \mathcal{I}, \tag{7c}$$

$$G_i(y_i^{*j}, y_{si}^j) \equiv \min\left\{y_i^{*j}, \psi_i y_{si}^j\right\} \qquad j \in \mathcal{J},\ i \in \{g, e\}. \tag{7d}$$

$\alpha \in (0,1)$ and $\bar{x}_g \in (0,\infty)$ are constants that determine the expenditure share of services. Since our consumption goods include food and beverages, we interpret $\bar{x}_g$ as the subsistence level of consumption goods. Having $\bar{x}_g > 0$ allows us to match the fact that both the relative price of services and the expenditure share of service are much lower in the poorer countries than in the U.S.. For the same reason, several recent studies, including Kongsamut et al. (2001) and Gollin et al. (2004), assumed subsistence terms. The production function has the standard Cobb–Douglas form in capital and labor, but here capital is a CES aggregator of the stocks of buildings and equipment. Specifically, A_i^j is the TFP of producing y_i in country j, $\theta_i \in (0,1)$ is the capital share (which possibly differs across sectors but is restricted to be the same across countries), $\sigma \in [0,\infty)$ is the elasticity of substitution between buildings and equipment, $\mu \in (0,1)$ determines the share of buildings in output. The production function of the distribution sector is Leontief. $\psi_i \in (0,\infty)$ determines the distribution services required to deliver one unit of x_i, $i \in \{g, e\}$.

4.2 Measurement

We now explain how we choose the model parameters and how we measure the "taxes" and the sector TFPs. We normalize $A_e^{US} = 1$. We assume that all "taxes" are zero in the U.S.: $\tau_i^{US} = 0$ for $i \in \mathcal{I}$. This leaves us with 32 parameters. Specifically, there are 21 technology parameters: the 11 remaining sectoral TFPs; the 4 capital shares; the 2 parameters in the CES–aggregator of buildings and equipment; the 2 parameters of the distribution technologies; the 2 depreciation rates. Moreover, we have the 3 preference parameters (namely β, α, and $\bar{x}_g$ and 8 "taxes" for Latin America and the Poorest Countries.

We will calibrate 8 of these parameter values to the U.S. economy. These are the two depreciation rates, the four sector capital shares, and the two parameters of the distribution technology. Given these 8 values, we will choose the remaining 24 parameter values so as to match as closely as possible 28 different statistics from the PWT96. Among these 24 parameters are the 11 sectoral TFPs, so what we are doing here really is an exercise in measurement.

We start by explaining how we calibrate to the U.S. economy. We calculate the sector capital shares from the U.S. input–output tables of 1997 as reported by the Bureau of

Economic Analysis (4 statistics).[19] This is less straightforward than it might seem at first sight. To begin with, proprietor's income contains a labor component which needs to be included in the labor share. Moreover, since our data has no information about intermediate inputs, we have not modeled them here. This implies that the capital shares in the model contain the payments to capital that accrue when intermediate inputs are produced whereas the capital shares in the data shares do not contain these. Appendix B.1 reports the detailed steps required to take care of this. Following these steps, we find the following capital shares: 0.32 for services, 0.20 for construction, 0.39 for consumption goods, and 0.31 for equipment. Once we have our methodology in place, it is straightforward to calculate the capital shares for larger aggregates. This gives: 0.35 for tradables, 0.30 for nontradables, 0.33 for consumption, 0.27 for investment and 0.31 for the whole economy. Note that we find that tradables are more capital intensive than nontradables. While Bhagwati (1982) and Kravis and Lispsey (1988) suggested that this is the case, there has been quite some confusion about this. For example, Stockman and Tesar (1995) claimed that the capital share in non–tradables is higher than in tradables.

We calculate the depreciation rates from the fixed asset and investment data from the Bureau of Economic Analysis by setting the depreciation rate equal to the average of $[x_{it}+k_{it}-k_{it+1}]/k_{it}$ between 1987-2003 (2 statistics). We find that the average depreciation rates were $\delta_b = 0.02$ and $\delta_e = 0.14$. These numbers are somewhat different from those of Greenwood et al. (1997), who had $\delta_b = 0.06$ and $\delta_e = 0.12$. The likely reasons for the differences are that these authors considered structures but not buildings and that during the 1990s the BEA changed its way of calculating capital stocks.

We calculate the two distribution margins using the 1997 benchmark IO–tables at

[19]The data of BEA do not allow us to compute the capital shares for 1996, the year of our cross section in the PWTs. 1997 is the closest year for which data is available. Note that for each sector in the PWT96 we needed to make a call as to which of our four model sectors it should go. In contrast, we do not need to make that call in the input–output tables, as they provide more detailed information. In particular, the counterparts of our four sectors in the input–output tables are as follows: services equal the sale to final expenditure by all sectors except agriculture, mining, manufacturing, personal transportation equipment, and construction; construction equals the construction commodities delivered to final expenditure fixed investment; consumption goods equal the agriculture, mining, and manufacturing commodities not delivered to final expenditure fixed investment; equipment investment equals the agriculture, mining, and manufacturing commodities delivered to final expenditure fixed investment plus the final expenditure on personal transportation equipment.

producer prices and at purchase prices. One difference between these two tables is that the output of the distribution industries (retail and wholesale trade and transportation) is reported at producer prices whereas at purchase prices it is included in the output of industries that use them. Using this, we calculate the distribution margins as follows: we divide the difference between the shares of final expenditures at purchase prices and at producer prices by final expenditure at purchase prices. We find that the distribution margin for consumption goods is 0.46 and for equipment 0.05.[20] In equilibrium the two distribution margins equal $P_s^{US}/(P_g^{US}\psi_g)$ and $P_s^{US}/(P_e^{US}\psi_g)$. Using the values for the distribution margins just calculated and the observed values for P_s^{US}/P_g^{US} and P_s^{US}/P_e^{US}, we can solve for ψ_g, ψ_e.

Given these eight parameter values, we choose the remaining 24 parameter values so as to match 28 statistics from the PWT96.[21] These are: the ratios of U.S. per–capita GDP in international prices over Latin American and the Poorest Countries per–capita GDP in international prices (2 statistics); the three relative prices in each country (9 statistics); the expenditure shares of services in each country, which we have plotted against income in Figure 6 in Appendix C (3 statistics); the investment shares of buildings and equipment in domestic and international prices in each country, which we have plotted against income in Figures 4–5 in Appendix C (12 statistics). We also use the fact that when multiplied with the $–market exchange rate as reported by the IMF, the prices of equipment across countries are unrelated to income. This has been noted by Eaton and Kortum (2001) and used by Hsieh and Klenow (2003). It can be seen in Figure 7 in Appendix C. Given $P_e^{US} = 1$ we therefore impose $P_e^{LA} = P_e^{PC} = 1$ (2 statistics).

Table 1 summarizes our target statistics in the data and the model. We match all relative prices by construction. We do a reasonable job at matching the other target statistics. The only exception are the shares of services in total consumption, which we

[20]To put these numbers into perspective, Burstein et al. (2003) calculated 0.42 and 0.17. Our distribution margin for equipment investment is significantly lower than their number. This is due to the fact that they focus on the most tradable part of equipment investment (agriculture, mining, and manufacturing). To be consistent with the way in which we construct equipment investment in the PWT96, our equipment investment is all investment other than construction.

[21]Appendix B.1.2 explains how we compute these statistics. Appendix B.3 explains our minimization procedure.

Table 1: Statistics in the Data and the Model

	US		LA		PC	
	Data	Model	Data	Model	Data	Model
Income relative to the US	1.00	1.00	3.77	3.82	19.76	19.54
Equip invest share (dom prices)	0.11	0.11	0.09	0.09	0.10	0.09
Constr invest share (dom prices)	0.09	0.09	0.12	0.09	0.10	0.10
Equip invest share (int $s)	0.15	0.14	0.12	0.07	0.06	0.05
Constr invest share (int $s)	0.10	0.11	0.12	0.10	0.07	0.08
Services expenditure share	0.77	0.62	0.51	0.58	0.34	0.25
Relative price services	1.92	1.92	0.90	0.90	0.36	0.36
Relative price construction	1.21	1.21	0.90	0.90	0.70	0.70
Relative price consumption goods	1.03	1.03	0.82	0.82	0.64	0.64
Distribution margin cons goods	0.46	0.46	–	–	–	–
Distribution margin equipment	0.05	0.05	–	–	–	–

miss by as much as 27%. The reason is that as countries develop the share of consumption goods remains roughly constant while the shares of services increase and of agricultural goods decrease. Our model with just two consumption goods is not disaggregate enough to capture this. To be sure that this does not critically affect our measurement of sector TFPs, we have also experimented with more complicated utility functions that allow us to match the three service shares much more closely. It turns out that this does not importantly change our measurement of the sector TFPs. Since our current utility function is simpler and commonly used in the development literature, we stick to it.

Table 2: Parameter values

$\theta_s = 0.32$	$\theta_b = 0.20$	$\theta_g = 0.39$	$\theta_e = 0.31$	$\delta_b = 0.02$	$\delta_e = 0.14$
$\psi_g = 36.30$	$\psi_e = 4.07$	$\sigma = 1.55$	$\mu = 0.46$		
$\beta = 0.98$	$\alpha = 0.79$	$\bar{x}_g = 0.02$			

Table 2 summarizes the resulting parameter values. They are fairly standard. Note that $\bar{x}_g = 0.02$ implies that in the U.S. 4% the consumed quantities of goods are for subsistence, while in Latin America and the Poorest Countries these numbers are 17% and 70%, respectively. There is one somewhat unexpected problem left: our procedure does not allow us to identify $(\tau_s^j, \tau_b^j, A_s^j, A_b^j)$. More precisely, for each country $j \in \{LA, PC\}$, we can match all targets equally well for a one–dimensional set of linear combinations of the four parameters $(\tau_s^j, \tau_b^j, A_s^j, A_b^j)$. We will therefore write $(\tau_b^j(\tau_s^j), A_s^j(\tau_s^j), A_b^j(\tau_s^j))$, vary τ_s^j, and report the results under the constraint that both τ_s^j and τ_b^j be non–negative.[22]

5 Findings

Table 3: Relative aggregate, tradable, and nontradable TFPs for different service taxes

τ_s^{LA}	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18
A^{US}/A^{LA}	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
A_T^{US}/A_T^{LA}	3.57	3.54	3.52	3.50	3.48	3.46	3.44	3.43	3.41
A_N^{US}/A_N^{LA}	1.67	1.68	1.68	1.69	1.69	1.70	1.71	1.71	1.71
τ_s^{PC}	0.02	0.04	0.06	0.08	0.10	0.12			
A^{US}/A^{PC}	6.00	6.02	6.04	6.06	6.08	6.10			
A_T^{US}/A_T^{PC}	13.14	13.08	13.04	13.00	12.95	12.90			
A_N^{US}/A_N^{PC}	3.23	3.28	3.32	3.36	3.40	3.44			

Our main findings are summarized in Table 3. To calculate the TFPs of tradables and nontradables, we aggregate our two tradable goods and our two nontradable goods using international prices.[23] We then find that there are much larger differences in the TFPs of tradables than of the nontradables. Specifically, between the U.S. and Latin

[22]Note that related studies do not experience this indeterminacy because they impose additional restriction. For example, Hsieh and Klenow (2003) study consumption versus investment and set the tax on consumption goods to zero.

[23]For example, given $\boldsymbol{\pi} = (1, 1, 1, 1)$ the TFP of tradables is:

$$A_T^j \equiv \frac{A_g^j (k_g^j)^{\theta_g} (l_g^j)^{1-\theta_g} + A_e^j (k_e^j)^{\theta_e} (l_e^j)^{1-\theta_e}}{(k_g^j)^{\theta_g} (l_g^j)^{1-\theta_g} + (k_e^j)^{\theta_e} (l_e^j)^{1-\theta_e}}. \tag{8a}$$

America the TFP differences in the tradables are roughly twice the TFP differences in the nontradables. Between the U.S. and the Poorest Countries this number goes up to four. Table 4 breaks the tradables and nontradables into consumption and investment. We can see that within the tradables the TFP differences in equipment are larger than the TFP differences in consumption goods. The results for nontradables are too sensitive to the choice of τ_s to be able to make robust statements.

To understand why for different values of τ_s, we match all observable statistics equally well, consider how the other parameters adjust when τ_s^j increases. Table 4 reports that τ_b^j and A_s^{US}/A_s^j go down while A_b^{US}/A_b^j goes up. The intuition is as follows. As τ_s^j increases, purchase prices and produced quantities need to remain the same if no observable statistics are to change. For the relative price of service to remain the same, the price effect of the increase in τ_s^j must be neutralized by a decrease in A_s^j. For the service production to remain the same, the output effect of the decrease in A_s^j must be neutralized by reallocating capital and labor from the construction sector to the service sector. For the output of the construction sector to remain the same, the output effect of this reallocation must be neutralized by an increase in A_b^j. For the relative price of construction to remain the same, the price effect of the change in A_b^j must be neutralized by an increase τ_b^j. In sum, as the taxes change, the TFP of one the two nontradables decreases while the other one increases. Consequently, there is a lot of action within the nontradables and little action at aggregate nontradables. We should also mention why the taxes on our two tradable goods are determinate. The reason is that the producer prices of our two tradables are equalized across countries. Thus, there is an additional constraint that pins down the taxes as the differences between the purchases prices after taking out the distribution margins and the producer prices in the world market.

At this point it is useful to come back to the possibility that countries specialize.

We compute labor productivity in a similar way. For example, the labor productivity of nontradables is:

$$LP_N^j \equiv \frac{A_s^j(k_s^j)^{\theta_s}(l_s^j)^{1-\theta_s} + A_b^j(k_b^j)^{\theta_b}(l_b^j)^{1-\theta_b}}{l_s^j + l_b^j}. \tag{8b}$$

.

Table 4: Relative taxes and sector TFPs for different values of τ_s

τ_s^{LA}	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18
τ_b^{LA}	7.51	3.63	2.21	1.48	1.04	0.74	0.52	0.36	0.23
A_s^{US}/A_s^{LA}	1.86	1.81	1.76	1.72	1.68	1.64	1.60	1.56	1.53
A_b^{US}/A_b^{LA}	0.37	1.01	1.56	2.09	2.59	3.07	3.53	3.97	4.38
A_g^{US}/A_g^{LA}	3.58	3.55	3.53	3.51	3.49	3.47	3.45	3.43	3.42
A_e^{US}/A_e^{LA}	4.14	4.11	4.08	4.05	4.03	4.00	3.98	3.96	3.94
τ_s^{PC}	0.02	0.04	0.06	0.08	0.10	0.12			
τ_b^{PC}	10.09	2.68	1.24	0.63	0.29	0.07			
A_s^{US}/A_s^{PC}	3.22	3.15	3.08	3.01	2.94	2.88			
A_b^{US}/A_b^{PC}	2.06	3.64	4.96	6.35	7.69	8.96			
A_g^{US}/A_g^{PC}	13.41	13.36	13.32	13.27	13.22	13.18			
A_e^{US}/A_e^{PC}	18.52	18.44	18.37	18.30	18.23	18.16			

To avoid dealing with it, we endowed all countries with the world–market technology of exchanging the two tradable goods for each other. To understand the implications, suppose for a moment that the poorest countries specialize in consumption goods and import their equipment from the world market.[24] If this is the case, then our measured sector TFP in equipment is not the TFP which the poor countries produce equipment, simply because they do not produce any at all. Instead, our measured sector TFP in equipment is the TFP with which the poor countries obtain equipment in the world market. This is determined by the TFP of their exports and the price of their imports relative to their exports. While the poor countries could not possibly have a higher TFP if they produced equipment themselves (otherwise they would not specialize), they could well have a lower one. Given the limitations of our data, we cannot say anything about this.

The importance of our four–sector approach is illustrated by comparing our results to the existing ones. While the literature has produced sound evidence suggesting that there are problem sectors, it has not produced conclusive evidence as to which these problem

[24]Eaton and Kortum (2001) suggest that this may not be a bad approximation.

Table 5: Relative labor productivities in tradables and nontradables for different τ_s

τ_s^{LA}	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18
LP_N^{LA}/LP_N^{LA}	2.73	2.75	2.76	2.77	2.78	2.80	2.81	2.82	2.83
LP_T^{LA}/LP_T^{LA}	6.43	6.35	6.29	6.23	6.18	6.12	6.07	6.02	5.97
τ_s^{PC}	0.02	0.04	0.06	0.08	0.10	0.12			
LP_N^{PC}/LP_N^{PC}	9.91	10.01	10.07	10.15	10.23	10.31			
LP_T^{PC}/LP_g^{T}	49.72	49.38	49.14	48.84	48.57	48.30			

sectors are. Many years ago, Balassa (1964) and Samuelson (1964) conjectured that the cross–country differences in the labor productivity are much larger in the tradable sectors than in the nontradable ones. They came to that conjecture because of the systematic variations of relative prices and real exchange rates with income.[25] In sharp contrast, Lewis (2004) hasa recently argued that the direct firm–level evidence from McKinsey studies points to the opposite: the nontradable sectors are the problem sectors.[26] What is more, a group of two–sector analyses identified completely different problem sectors. On the one hand, Kuznets (1971), Restuccia et al. (2003), Gollin et al. (2004), and Córdoba and Ripoll (2004) documented that cross–country differences in labor productivity are much larger in agriculture than in the remaining sectors. To the extent that agricultural goods are tradable, this is consistent with Balassa and Samuelson and inconsistent with McKinsey. On the other hand, Hsieh and Klenow (2003) found that cross–country differences in sector TFP are much larger in investment than in consumption. As our evidence, their evidence comes from the benchmark studies of Penn World Tables. Since both investment and consumption contain large tradable and nontradable components, this is hard to relate to Balassa and Samuelson and McKinsey. Since agriculture is part of consumption, this seems to opposite to the finding that agriculture is the problem sector.

To understand the reason for these different findings, we need to aggregate our four

[25] Rogoff (1996) offers a review of the more recent (indirect) evidence on the Balassa–Samuelson hypothesis.

[26] See also Bailey and Solow (2001).

Table 6: Relative labor productivities in consumption goods and the rest for different τ_s

τ_s^{LA}	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18
LP_g^{US}/LP_g^{LA}	6.92	6.83	6.77	6.70	6.64	6.58	6.53	6.48	6.43
LP_R^{US}/LP_R^{LA}	3.20	3.22	3.23	3.24	3.26	3.27	3.28	3.29	3.30
τ_s^{PC}	0.02	0.04	0.06	0.08	0.10	0.12			
LP_g^{US}/LP_g^{PC}	57.09	56.70	56.42	56.09	55.77	55.46			
LP_R^{US}/LP_R^{PC}	19.60	21.38	22.90	24.52	26.09	27.62			

sectors to the different two–sectors splits considered by the literature. Table 5 reports the results if we compute the labor productivities for tradables and nontradables.[27] The table confirms the hypothesis of Balassa (1964) and Samuelson (1964). This suggests that the results of the McKinsey Studies, which comprise only a relatively small number of countries, do not generalize to a broader cross section.[28] Table 6 reports the results if we aggregate nontradable consumption and tradable and nontradable investment into "the rest" and compute the labor productivities of consumption goods and "the rest". We then find that the variation is much larger in consumption goods than in the rest. To the extend that agricultural goods are an important component of tradable consumption goods, particularly in poorer countries, this is consistent with the view that agriculture is the problem sector. Finally, Table 7 reports the results if we aggregate into consumption and investment. We then find that the larger variation in sector TFPs lies in investment. This is consistent with the finding of Hsieh and Klenow. In sum, the explanation for the very different results from two–sector analyses is that the TFP patterns at our four–sector level of disaggregation differ widely across countries.

[27]Again Appendix B.1 explains the details of how to compute aggregate labor productivities.

[28]To be precise, McKinsey has firm–level data on 10 countries. The only developing countries in this set are India and Brazil.

Table 7: Relative consumption and investment TFPs for different τ_s

τ_s^{LA}	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18
A_C^{US}/A_C^{LA}	2.11	2.05	2.00	1.96	1.91	1.87	1.83	1.80	1.76
A_I^{US}/A_I^{LA}	1.91	2.32	2.66	3.00	3.32	3.62	3.90	4.17	4.43
τ_s^{PC}	0.02	0.04	0.06	0.08	0.10	0.12			
A_C^{US}/A_C^{PC}	18.87	18.58	18.33	18.08	17.83	17.60			
A_I^{US}/A_I^{PC}	20.90	23.33	25.37	27.51	29.55	31.50			

6 Conclusion

In this paper, we have interacted the 1996 benchmark study of the PWTs with economic theory in order to measure the cross–country differences in sector TFPs. We have found that the cross–country TFP differences in tradables are much larger than in nontradables. Since these sector TFP differences translate into labor productivity differences, these findings support the Balassa and Samuelson hypothesis. We have shown that our findings can shed light on the different, and often conflicting, results that the literature has found using two–sector analysis.

We think that a successful theory of aggregate TFP ought to be consistent with the finding that the tradable sectors are the problem sectors. At this stage, it not clear to us how well the existing theories do in this respect. For example, one hypothesis is that poor countries have low TFPs because they have bad institutions [Acemoglu et al. (2001), Easterly and Levine (2003)]. But this raises the question why these bad institutions do so much more damage in the tradable sectors. A different hypothesis is that poorer countries are plagued by entry barriers and monopoly rights [Parente and Prescott (1999) and Herrendorf and Teixeira (2005a)]. Again, this raises the question why monopoly rights are more prevalent in the tradable sectors. Resolving these important issues is beyond the scope of the present paper. We suggest it as a fruitful and important area of future research.

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Appendix A. Proofs

A.1 Household first–order conditions

Given there are no government expenditure, rebating taxes implies that lump–sum transfers are:

$$\Lambda_t = \frac{\tau_{st}}{1+\tau_{st}} P_{st}\left(x_{st} + \frac{x_{gt}}{\psi_g} + \frac{x_{et}}{\psi_e}\right) + \frac{\tau_{gt}}{1+\tau_{gt}} P_{gt} x_{gt} + \frac{\tau_{bt}}{1+\tau_{bt}} P_{bt} x_{bt} + \frac{\tau_{et}}{1+\tau_{et}} P_{et} x_{et}. \quad (9)$$

The total expenditure on consumption net of taxes are therefore equal to total income minus the expenditures on the investment goods:

$$\Omega_t \equiv \frac{1}{1+\tau_{st}} P_{st} x_{st} + \left(\frac{1}{1+\tau_{gt}} - \frac{\tau_s}{1+\tau_{st}} \frac{P_{st}}{P_{gt}\psi_g}\right) P_{gt} x_{gt} \quad (10a)$$

$$= r_{bt} k_{bt} + r_{et} k_{et} + w_t - \frac{1}{1+\tau_{bt}} P_{bt} x_{bt} - \left(\frac{1}{1+\tau_{et}} - \frac{\tau_s}{1+\tau_{st}} \frac{P_{st}}{P_{et}\psi_e}\right) P_{et} x_{et}. \quad (10b)$$

The first–order conditions to problem (6a) imply:

$$\frac{P_{st}}{P_{gt}} = \frac{\alpha}{1-\alpha}\frac{x_{gt}-\bar{x}_g}{x_{st}}, \tag{11a}$$

$$\frac{1}{P_{st}}\left(\frac{x_{gt}-\bar{x}_g}{x_{st}}\right)^{1-\alpha} = \beta\frac{1}{P_{st+1}}\left(\frac{x_{gt+1}-\bar{x}_g}{x_{st+1}}\right)^{1-\alpha}\frac{(1-\delta_e)P_{et+1}+r_{et+1}}{P_{et}}, \tag{11b}$$

$$\frac{(1-\delta_e)P_{et+1}+r_{et+1}}{P_{et}} = \frac{(1-\delta_b)P_{bt+1}+r_{bt+1}}{P_{bt}}. \tag{11c}$$

Solving (11a) for $P_{st}s_t$ yields

$$P_{st}x_{st} = \frac{\alpha}{1-\alpha}[P_{gt}x_{gt} - P_{gt}\bar{x}_g]$$

Substituting this into (10a) and rearranging, we get expressions that will prove useful when we compute the model:

$$P_{gt}x_{gt} = \frac{1-\alpha}{\frac{1-\alpha}{1+\tau_{gt}} + \frac{1}{1+\tau_{st}}\left(\alpha - (1-\alpha)\frac{P_{st}\tau_{st}}{P_{gt}\psi_g}\right)}\left(\Omega_t + P_{gt}\bar{x}_g\frac{\alpha}{1-\alpha}\frac{1}{1+\tau_{st}}\right), \tag{12a}$$

$$P_{st}x_{st} = \frac{\alpha}{\frac{1-\alpha}{1+\tau_{gt}} + \frac{1}{1+\tau_{st}}\left(\alpha - (1-\alpha)\frac{P_{st}\tau_{st}}{P_{gt}\psi_g}\right)}\left(\Omega_t + P_{gt}\bar{x}_g\left(\frac{1}{1+\tau_{st}}\frac{P_{st}\tau_{st}}{P_{gt}\psi_g} - \frac{1}{1+\tau_{gt}}\right)\right). \tag{12b}$$

A.2 Steady state prices and quantities

Step 1. Firms take *producer prices* p_i as given. Solving their maximization problems with respect to labor, buildings and equipment gives:

$$w = (1-\theta_i)p_iA_i\left(\frac{k_i}{l_i}\right)^{\theta_i}, \tag{13a}$$

$$r_b = \theta_i p_i A_i\left(\frac{k_i}{l_i}\right)^{\theta_i-1}\mu^{\frac{1}{\sigma}}\left(\frac{k_i}{k_{bi}}\right)^{\frac{1}{\sigma}}, \tag{13b}$$

$$r_e = \theta_i p_i A_i\left(\frac{k_i}{l_i}\right)^{\theta_i-1}(1-\mu)^{\frac{1}{\sigma}}\left(\frac{k_i}{k_{ei}}\right)^{\frac{1}{\sigma}}. \tag{13c}$$

Step 2. We express the two capital–labor ratios and the composite–capital–labor ratio as functions of the interest rates, which in steady state are readily computed from the

Euler equations. (13b) and (13c) imply

$$\frac{k_{ei}}{k_{bi}} = \left(\frac{r_b}{r_e}\right)^{\sigma} \frac{1-\mu}{\mu}.$$

Substituting this into (7c) and rearranging leads to

$$\frac{r_b}{r} = \left(\mu \frac{k_i}{k_{bi}}\right)^{\frac{1}{\sigma}}, \tag{14a}$$

$$\frac{r_e}{r} = \left((1-\mu)\frac{k_i}{k_{ei}}\right)^{\frac{1}{\sigma}}, \tag{14b}$$

where

$$r \equiv \left[\mu r_b^{1-\sigma} + (1-\mu) r_e^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{15}$$

Plugging (14a) into (13b), we obtain:

$$\frac{k_i}{l_i} = \left(\frac{\theta_i p_i A_i}{r}\right)^{\frac{1}{1-\theta_i}}. \tag{16a}$$

Substituting (16a) into (14a) and (14b) and rearranging leads to:

$$\frac{k_{bi}}{l_i} = \mu \left(\frac{r}{r_b}\right)^{\sigma} \left(\frac{\theta_i p_i A_i}{r}\right)^{\frac{1}{1-\theta_i}}, \tag{16b}$$

$$\frac{k_{ei}}{l_i} = (1-\mu) \left(\frac{r}{r_e}\right)^{\sigma} \left(\frac{\theta_i p_i A_i}{r}\right)^{\frac{1}{1-\theta_i}}. \tag{16c}$$

Step 3. We now derive the producer prices. Equation (13a) and (13b) together with (14a) imply that

$$\frac{1-\theta_e}{\theta_e}\frac{k_e}{l_e} = \frac{1-\theta_i}{\theta_i}\frac{k_i}{l_i}. \tag{17}$$

Plugging (16a) into (17) and using that $p_e = 1$, we obtain:

$$p_i = \frac{r}{\theta_i A_i} \left(\frac{\theta_e A_e}{r}\right)^{\frac{1-\theta_i}{1-\theta_e}} \left(\frac{1-\theta_e}{\theta_e}\frac{\theta_i}{1-\theta_i}\right)^{1-\theta_i} \tag{18}$$

for $i \in \mathcal{I}$.

This allows us to rewrite (16a)–(16c) into:

$$\frac{k_i}{l_i} = \frac{1-\theta_e}{\theta_e}\frac{\theta_i}{1-\theta_i}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1}{1-\theta_e}}, \tag{19a}$$

$$\frac{k_{bi}}{l_i} = \mu\frac{1-\theta_e}{\theta_e}\frac{\theta_i}{1-\theta_i}\left(\frac{r}{r_b}\right)^{\sigma}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1}{1-\theta_e}}, \tag{19b}$$

$$\frac{k_{ei}}{l_i} = (1-\mu)\frac{1-\theta_e}{\theta_e}\frac{\theta_i}{1-\theta_i}\left(\frac{r}{r_e}\right)^{\sigma}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1}{1-\theta_e}}. \tag{19c}$$

It is important to point out that with this we expressed the capital-labor ratios as a function of parameters and purchase prices because (12a) and (12b) imply in the steady state that

$$r_e = \frac{1-\beta(1-\delta_e)}{\beta}P_e \tag{20a}$$

$$r_b = \frac{1-\beta(1-\delta_b)}{\beta}P_b, \tag{20b}$$

and (15) states that r depends on r_e and r_b.

Step 4. We now derive the purchase prices, which we denote by capital letters. They satisfy

$$P_s = p_s(1+\tau_s), \tag{21a}$$

$$P_b = p_b(1+\tau_b), \tag{21b}$$

$$P_g = \left(p_g + \frac{P_s}{\psi_g}\right)(1+\tau_g), \tag{21c}$$

$$P_e = \left(1 + \frac{P_s}{\psi_e}\right)(1+\tau_e). \tag{21d}$$

Combining these with (18) leads to

$$\frac{P_s}{1+\tau_s} = \frac{r}{\theta_s A_s}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1-\theta_s}{1-\theta_e}}\left(\frac{1-\theta_e}{\theta_e}\frac{\theta_s}{1-\theta_s}\right)^{1-\theta_s}, \tag{22a}$$

$$\frac{P_b}{1+\tau_b} = \frac{r}{\theta_b A_b}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1-\theta_b}{1-\theta_e}}\left(\frac{1-\theta_e}{\theta_e}\frac{\theta_b}{1-\theta_b}\right)^{1-\theta_b}, \tag{22b}$$

$$\frac{P_g}{1+\tau_g} = \frac{r}{\theta_g A_g}\left(\frac{\theta_e A_e}{r}\right)^{\frac{1-\theta_g}{1-\theta_e}}\left(\frac{1-\theta_e}{\theta_e}\frac{\theta_g}{1-\theta_g}\right)^{1-\theta_g} + \frac{P_s}{\psi_g}, \tag{22c}$$

$$\frac{P_e}{1+\tau_e} = 1 + \frac{P_s}{\psi_e}. \tag{22d}$$

Step 5. Next, we determine l_i by using market clearing. Note that so far we did not use any steady state conditions, but we will now. The market clearing conditions in steady state are

$$\sum_{i\in\mathcal{I}} l_i = 1,$$

$$\delta_e \sum_{i\in\mathcal{I}}\left(\frac{k_{ei}}{l_i}\right) l_i = A_e\left(\frac{k_e}{l_e}\right)^{\theta_e} l_e,$$

$$\delta_b \sum_{i\in\mathcal{I}}\left(\frac{k_{bi}}{l_i}\right) l_i = A_b\left(\frac{k_b}{l_b}\right)^{\theta_b} l_b,$$

$$\frac{1}{P_{gt}}\frac{(1-\alpha)\left(\Omega_t + \frac{\alpha}{1-\alpha}\frac{P_{gt}\bar{x}_g}{1+\tau_{st}}\right)}{\frac{1-\alpha}{1+\tau_{gt}} + \frac{1}{1+\tau_{st}}\left(\alpha - (1-\alpha)\frac{P_{st}\tau_{st}}{P_{gt}\psi_g}\right)} = A_g\left(\frac{k_g}{l_g}\right)^{\theta_g} l_g.$$

where Ω is the steady state version of (10b)

$$\Omega = \left(r_b - \frac{P_b\delta_b}{1+\tau_b}\right)\sum_{i\in\mathcal{I}} k_{bi} + \left(r_e - \frac{P_e\delta_e}{1+\tau_e} + \frac{\tau_s P_s\delta_e}{(1+\tau_s)\psi_e}\right)\sum_{i\in\mathcal{I}} k_{ei} + w$$

with

$$\sum_{i\in\mathcal{I}} k_{ei} = \frac{A_e}{\delta_e}\left(\frac{k_e}{l_e}\right)^{\theta_e} l_e,$$

$$\sum_{i\in\mathcal{I}} k_{bi} = \frac{A_b}{\delta_b}\left(\frac{k_b}{l_b}\right)^{\theta_b} l_b.$$

The equilibrium conditions can be turned into a linear system of equations.

$$\begin{aligned}
&1 = l_e + l_b + l_g + l_s, \\
&A_e \left(\frac{k_e}{l_e}\right)^{\theta_e} l_e = \delta_e \left(\frac{k_{ee}}{l_e}\right) l_e + \delta_e \left(\frac{k_{eb}}{l_b}\right) l_b + \delta_e \left(\frac{k_{eg}}{l_g}\right) l_g + \delta_e \left(\frac{k_{es}}{l_s}\right) l_s, \\
&A_b \left(\frac{k_b}{l_b}\right)^{\theta_b} l_b = \delta_b \left(\frac{k_{be}}{l_e}\right) l_e + \delta_b \left(\frac{k_{bb}}{l_b}\right) l_b + \delta_b \left(\frac{k_{bg}}{l_g}\right) l_g + \delta_b \left(\frac{k_{bs}}{l_s}\right) l_s, \\
&A_g \left(\frac{k_g}{l_g}\right)^{\theta_g} l_g = \frac{1}{P_g} \frac{1-\alpha}{\frac{1-\alpha}{1+\tau_{gt}} + \frac{1}{1+\tau_{st}} \left(\alpha - (1-\alpha)\frac{P_{st}\tau_{st}}{P_{gt}\psi_g}\right)} \left[\left(r_b - \frac{P_b\delta_b}{1+\tau_b}\right) \frac{A_b}{\delta_b} \left(\frac{k_b}{l_b}\right)^{\theta_b} l_b\right. \\
&\left. + \left(r_e - \frac{P_e\delta_e}{1+\tau_e} + \frac{\tau_s P_s \delta_e}{(1+\tau_s)\psi_e}\right) \frac{A_e}{\delta_e} \left(\frac{k_e}{l_e}\right)^{\theta_e} l_e + (1-\theta_e) A_e \left(\frac{k_e}{l_e}\right)^{\theta_e} + \frac{\alpha}{1-\alpha} \frac{P_g \bar{x}_g}{1+\tau_{st}}\right].
\end{aligned}$$

We can solve this system of linar equation for the allocation of labor. Since the capital-labor ratios are the functions of the real interest are, purchase prices and parameters, the labor allocation is a function of real interest are, purchase prices and parameters, and taxes. We use this to express the quantities consumed and invested as the function of the same variables. We use these functions in the calibration where for the purchase prices we substitute the observed once.

Appendix B. Data

Appendix B.1 Data description and measurement

The benchmark study of the Penn World Tables 1996 (PWT96) has 115 countries and 31 goods categories. We exclude all countries with less one million inhabitants, namely Antigua and Barbuda, Bahamas, Bahrain, Barbados, Belize, Bermuda, Dominica, Fiji, Grenada, Iceland, Luxembourg, Qatar, Swaziland, St. Kitts and Nevis, St. Lucia, St. Vincent and Grenadines. Moreover, we exclude Mongolia because it reports zero equipment investment. This leaves 98 countries, which in this appendix we index by $j \in \{1, ..., 98\}$.

Appendix B.1.1 Goods categories and countries

We aggregate the 30 goods categories into four aggregate categories: services, construction, consumption goods, and equipment investment. We denote the sets of goods in each of these four aggregate categories by $(\mathcal{G}_s, \mathcal{G}_b, \mathcal{G}_g, \mathcal{G}_e)$, the quantities by $x^j = (x^j_s, x^j_b, x^j_g, x^j_e)$, and the prices in domestic currency by $\widetilde{p}^j = (\widetilde{p}^j_s, \widetilde{p}^j_b, \widetilde{p}^j_g, \widetilde{p}^j_e)$.[29] Quantities are in international prices, as reported by the PWT96 in Input–Table 4.5. They are aggregated by adding them up. Put differently, expressing quantities in international prices is a transformation of units such that the new international prices are ones: $\pi = (1, 1, 1, 1)$.

We now describe how we aggregate the 30 data categories into our four model categories. We set the model–category nontradable investment equal to the data–category construction. We set the model–category tradable investments equal to the data–categories personal transportation equipment and machinery and equipment. Changes in stocks contain both tradable and nontradable parts. We split this category by assuming that its nontradable share equals the share of construction in investment without changes of stocks.

We continue with the model categories tradable and nontradable consumption. We set the model–category nontradable consumption equal to the data categories gross rent and water charges, medical and health services, transportation, communication, recreation and culture, education, restaurants/cafes and hotels. We set the model–category tradable consumption equal to the data–categories food, beverages, tobacco, clothing and footwear, fuel and power, furniture and floor coverings, other household goods, household appliances and repairs. The data–category other goods and services contains both tradable and nontradable parts. We split it by assuming that its nontradable share equals the share of the nontradable consumption goods assigned thus far in all consumption goods assigned thus far.

We use average statistics from the Latin American and the twenty poorest countries in the PWT96. The Latin American countries of our sample are Bolivia, Ecuador, Peru,

[29]Note that we normalize $\widetilde{p}^j_e = 1$ in the model. It is convenient not to do this yet at this point.

Panama, Venezuela, Mexico, Brazil, Chile, Uruguay, and Argentina. The twenty poorest countries of our sample are Tanzania, Malawi, Yemen, Madagascar, Zambia, Mali, Tajikistan, Nigeria, Benin, Sierra Leone, Kenya, Congo, Bangladesh, Nepal, Senegal, Vietnam, Pakistan, Cote d'Ivoire, Cameroon, and Moldova. Both sets of countries are reported here in the order of increasing real GDPs per capita.

Appendix B.1.2 Definitions of statistics used

We first describe how to aggregate within a country. Total expenditures on all 30 categories in country $j \in \{1, ..., 98\}$ can be expressed either in domestic or in international prices:

$$\widetilde{\boldsymbol{p}}^j \cdot \boldsymbol{x}^j \equiv \sum_{i=1}^{30} \widetilde{p}_i^j x_i^j,$$
$$\boldsymbol{\pi} \cdot \boldsymbol{x}^j \equiv \sum_{i=1}^{30} \pi_i x_i^j.$$

The PWT96 refer to $\widetilde{p}_i^j x_i^j$ as expenditure in national currency (Input–data 4.1) and to $\pi_i x_i^j$ as quantities in international dollars (Input–data 4.5).

Since our model economy does not have borrowing and lending, in the model these expenditure must equal GDP. This is not the case in the PWT96 where GDP in domestic and in international prices are defined as:

$$GDP^j(\widetilde{\boldsymbol{p}}^j) \equiv \widetilde{\boldsymbol{p}}^j \cdot \boldsymbol{x}^j + NFB^j(\widetilde{\boldsymbol{p}}^j),$$
$$GDP^j(\boldsymbol{\pi}) \equiv \boldsymbol{\pi} \cdot \boldsymbol{x}^j + NFB^j(\boldsymbol{\pi}).$$

NFB^j stands for net foreign balance.

Within country j, the prices of each of the four model categories $i \in \{s, g, b, e\}$ are the ratios of the expenditures in domestic currency and quantities in international prices in that category:

$$\widetilde{p}_i^j = \frac{\sum_{\iota \in \mathcal{G}_i} \widetilde{p}_\iota^j x_\iota^j}{\sum_{\iota \in \mathcal{G}_i} \pi_\iota x_\iota^j}.$$

Note that given quantities in international \$s, the price can also be written as the weighted average of the prices of all elements in that category where the relative weights are the relative quantities in international \$s:

$$\widetilde{p}_i^j = \sum_{\iota \in \mathcal{G}_i} \left(\frac{\pi_\iota x_\iota^j}{\sum_{\nu \in \mathcal{G}_i} \pi_\nu x_\nu^j} \right) \frac{\widetilde{p}_\iota^j}{\pi_\iota}.$$

The relative prices are:

$$p_i^j \equiv \frac{\widetilde{p}_i^j}{\widetilde{p}_e^j}.$$

We now explain how we aggregate across countries. Let $\mathcal{C}^{LA}$ and $\mathcal{C}^{PC}$ denote the individual countries in the two subgroups. The average construction and equipment investment shares in international prices in one of the two subgroups of countries are easy to find because we can still add quantities in international prices from different countries. So, for $i \in \{b, e\}$ and $j \in \{LA, PC\}$:

$$\frac{\pi_i^j x_i^j}{\boldsymbol{\pi}^j \cdot \boldsymbol{x}^j} \equiv \frac{\sum_{\iota \in \mathcal{C}^j} \pi_i x_i^\iota}{\sum_{\iota \in \mathcal{C}^j} \boldsymbol{\pi} \cdot \boldsymbol{x}^\iota}.$$

The methodology underlying the PWT96 does not imply how to aggregate variables across countries when the variables are in domestic prices. Since we cannot add up variables that are in different units, we aggregate only unit–free variables such as ratios or relative prices. For quantity ratios we use arithmetic averages because they add up to one (but are not transitive), whereas for relative prices we use geometric averages because they are transitive. For $i \in \{b, e\}$ and $j \in \{LA, PC\}$ the average construction and equipment shares in domestic prices are:

$$\frac{p_i^j x_i^j}{\boldsymbol{p}^j \cdot \boldsymbol{x}^j} \equiv \sum_{\iota \in \mathcal{C}^j} \left(\frac{\boldsymbol{\pi}^\iota \cdot \boldsymbol{x}^\iota}{\sum_{\nu \in \mathcal{C}^j} \boldsymbol{\pi}^\nu \cdot \boldsymbol{x}^\nu} \right) \frac{p_i^\iota x_i^\iota}{\boldsymbol{p}^\iota \cdot \boldsymbol{x}^\iota}.$$

The average service share in consumption expenditure in domestic prices is:

$$\frac{p_s^j x_s^j}{p_s^j x_s^j + p_g^j x_g^j} \equiv \sum_{\iota \in \mathcal{C}^j} \left(\frac{\pi_s x_s^\iota + \pi_g x_g^\iota}{\sum_{\nu \in \mathcal{C}^j} \pi_s x_s^\nu + \pi_g x_g^\nu} \right) \frac{p_s^\iota x_s^\iota}{p_s^\iota x_s^\iota + p_g^\iota x_g^\iota}.$$

The average relative price for good $i \in \{s, g, b\}$ is:

$$p_i^j \equiv \exp \left(\sum_{\iota \in \mathcal{C}^j} \left(\frac{\pi^\iota \cdot x^\iota}{\sum_{\nu \in \mathcal{C}} \boldsymbol{\pi}^\nu \cdot \boldsymbol{x}^\nu} \right) \ln(p_i^\iota) \right).$$

Here, we use relative GDPs (and not relative expenditure on category i) as the weights because that preserves transitivity.

Appendix B.2 Calculating sector capital shares

Appendix B.2.1 Capital shares for each industry

To calculate the capital shares for the sectors of our model, we first determine how to split the value added in each industries into capital and labor income. Then we aggregate the industries to the four sectors of our model. Finally, we calculate the capital shares of the four sectors.

We use the 1997 benchmark Input–Output Tables (IO Tables) for the U.S. from the Bureau of Economic Analysis (BEA). They report the value added of each industry as the sum of the compensation of employees, indirect business tax and nontax liabilities, and other value added. Other value added is also called gross operating surplus. It mostly contains capital income, but one of its components, "Other gross operating surplus – noncorporate" (or "proprietors' income"), contains also labor income. Since we do not have information about how much labor income is contained in proprietors' income, we assume that its share equals the industry–wide average share of labor income. Thus, we calculate the payments to capital and labor in industry i as:

$$V_{il} \equiv COMP_i + \frac{COMP_i}{COMP_i + GOS_i - OGOSN_i} OGOSN_i, \tag{26a}$$

$$V_{ik} \equiv GOS_i - \frac{COMP_i}{COMP_i + GOS_i - OGOSN_i} OGOSN_i. \tag{26b}$$

$COMP_i$ stands for compensation of employees, GOS_i for operating surplus (or other value added), and $OGOSN_i$ for other gross operating surplus – noncorporate.

The IO–tables report $COMP_i$ and GOS_i but not $OGOSN_i$. We use the BEA's "GDP–by–Industry" data to estimate $OGOSN_i$, which is available for 1998–2003. A minor complication is that the "GDP–by–Industry" Data is at the three–digit level whereas the benchmark IO Tables are at the four–digit level. We deal with this as follows. Let j be an industry index at the three digit level and i_j be an industry index at the four digit level such that the four–digit industry i is part of the three–digit industry j. First, we calculate the time average of $(OGOSN/GOS)_j$ for each industry j. Then, we assume that $OGOSN_{i_j}/GOS_{i_j} = (OGOSN/GOS)_j$ for each i_j and estimate $OGOSN_{i_j}$ as

$$OGOSN_{i_j} = GOS_{i_j} \left(\frac{OGOSN}{GOS} \right)_j.$$

Appendix B.2.2 Capital shares for model sectors

We now explain our aggregation procedure in two steps. We first describe how one can calculate the capital and labor share of a particular type of final expenditure. We then explain how to construct the four final expenditure categories that corresponds to the four sector of our model.

The IO–tables of BEA comes with a "use" and a "make" matrix. Let $\boldsymbol{B}$ be the $(m \times n)$ "use" matrix. Entries in each column show the amount of a commodity used by an industry per unit of output of that industry. Let $\boldsymbol{D}$ be the $(n \times m)$ "make" matrix. Entries in each column show, for a given commodity, the proportion of the total output of that commodity produced in each industry.[30]

[30] We use the notation of the BEA.

Let $\mathbf{1}$ be a column vector with all of its elements equal 1. Its size may vary from formula to formula so as to ensure that the matrix operation is well defined. Now we have the following identities:

$$\boldsymbol{q} = \boldsymbol{B}\boldsymbol{g} + \boldsymbol{E}\mathbf{1}, \tag{27a}$$

$$\boldsymbol{g} = \boldsymbol{D}\boldsymbol{q}, \tag{27b}$$

where $\boldsymbol{q}$ is the $(m \times 1)$ commodity output vector, $\boldsymbol{g}$ is the $(n \times 1)$ industry output vector, and $\boldsymbol{E}$ is the $(m \times k)$ vector of final expenditures where k is the number of different types of final expenditures. We can write $\boldsymbol{e} = \boldsymbol{E}\mathbf{1}$ for the GDP vector.

Combining the first and the second identity leads to:

$$\boldsymbol{g} = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{B}\boldsymbol{D})^{-1}\boldsymbol{e}, \tag{28}$$

where $\boldsymbol{I}$ is the identity matrix. The BEA calls $\boldsymbol{D}(\boldsymbol{I} - \boldsymbol{B}\boldsymbol{D})^{-1}$ the *industry–by–commodity total requirements* matrix. It shows the industry output required per unit delivered to final users. In particular, element z_{ij} of the total requirements matrix shows how much output of industry j is required to deliver one unit of commodity i to final users. Note that z_{ij} does not only include the direct effect of final expenditure on industry output, but also all direct and indirect effects from other industries. Hence the name total requirement matrix. Consequently, vector $\boldsymbol{z}_i$ shows how much industry output has to be produced so that one unit of commodity i can be sold to final expenditure.

Let g_i be the i–th element of $\boldsymbol{g}$, thus the output of industry i. Moreover, let $\boldsymbol{v}_l' = (V_{il}/g_i)$ and $\boldsymbol{v}_k' = (V_{ik}/g_i)$ be the $(1 \times m)$ row vectors of labor and capital income shares in industry output where V_{il} and V_{ik} have been calculated according to (26). Then the labor and capital incomes associated with GDP vector $\boldsymbol{e}$ are defined as

$$\begin{bmatrix} v_l \\ v_k \end{bmatrix} = \begin{bmatrix} \boldsymbol{v}_l' \\ \boldsymbol{v}_k' \end{bmatrix} \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{B}\boldsymbol{D})^{-1}\boldsymbol{e}.$$

This can be used to calculate the capital share for GDP.

The same principle can be used to calculate the capital and labor incomes associated with any final expenditure vector. This is because the total requirements matrix can be multiplied by any expenditure vector to calculate the industry output requirement to sell that final expenditure vector. Note the we do not need to calculate $\boldsymbol{D}(\boldsymbol{I} - \boldsymbol{BD})^{-1}$ because the BEA publishes all total requirements matrices. In our calculations we used the industry-by-commodity total requirements matrix.

Now we describe how we construct the four sectors corresponding to our model. We first aggregate final expenditures excluding net exports into consumption and investment. The sale of commodity i to final consumption is made up by personal and government consumption expenditures. The sale of commodity i to final investment expenditures is made up by private and government fixed investment expenditures plus changes in private inventories. In addition, we classify the sale of transportation equipment (three digit NAICS code 336) and the sale of commodities in construction (two digit NAICS code 23) as investments. Finally, we assume that the consumption and investment shares in net exports equal the industry wide average. This procedure leads to consumption and investment commodity vectors $\boldsymbol{x}_C$ and $\boldsymbol{x}_I$ that add up to the GDP vector.

Next, we classify each commodity as tradable or non-tradable. We classify all commodities sold to investment as tradable except for construction commodities, which we classify as non-tradable investment. We classify all commodities sold to consumption with a three digit NAICS code higher or equal to 420 as non-tradable. This includes all industries which are producing commodities traditionally viewed as services. In addition, we classify all commodities with the two–digit NAICS code 22 sold to consumption as non-tradable. These are the utilities (distribution of electric power, natural gas and water). Finally, we classify government services as non-tradables.

This procedure defines four final expenditure vectors nontradable services $\boldsymbol{x}_s$, non-tradable construction $\boldsymbol{x}_b$, tradable goods $\boldsymbol{x}_g$, and tradable equipment $\boldsymbol{x}_e$. These vectors satisfy $\boldsymbol{x}_C = \boldsymbol{x}_s + \boldsymbol{x}_g$, $\boldsymbol{x}_I = \boldsymbol{x}_e + \boldsymbol{x}_b$, and $\boldsymbol{x}_C + \boldsymbol{x}_I = \boldsymbol{e}$ with $\mathbf{1}'\boldsymbol{e} = GDP$ where $\mathbf{1}'$ is a row vector. The capital and labor incomes of the four final expenditure vectors are now easily calculated:

$$\begin{bmatrix} v_{ls} & v_{lb} & v_{lg} & v_{le} \\ v_{ks} & v_{kb} & v_{kg} & v_{ke} \end{bmatrix} = \begin{bmatrix} \boldsymbol{v}_l' \\ \boldsymbol{v}_k' \end{bmatrix} \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{BD})^{-1}[\boldsymbol{x}_s, \boldsymbol{x}_b, \boldsymbol{x}_g, \boldsymbol{x}_e]. \tag{29}$$

Given this, we can calculate the capital share for final expenditure category i as $v_{ki}/(v_{ki} + v_{li})$.

Appendix B.3 Computing the model

We can calibrate some parameters directly. We start with the sector TFPs in the U.S. To calculate them, we use that without taxes the equilibrium purchase price of equipment must satisfy:

$$P_e^{US} = 1 + \frac{P_s^{US}}{\psi_e}.$$

Rearranging this, we obtain:

$$P_e^{US} = \frac{\psi_e}{\psi_e - (P_s^{US}/P_e^{US})}.$$

Since we have already calculated ψ_e and since P_s^{US}/P_e^{US} is observable, this uniquely pins down P_e^{US}. Given we observe P_i^{US}/P_e^{US} for $i \in \{s, b, g\}$, we can now calculate the other three purchase prices. Moreover, in equilibrium the purchase price of consumption goods must satisfy:

$$P_g^{US} = p_g^* + \frac{P_s^{US}}{\psi_g}.$$

Using the purchase prices just calculated and the value of ψ_g, this implies the value of p_g^*. Since $A_e^{US}/A_g^{US} = 1/A_g^{US} = p_g^*$ and $A_i^{US}/A_g^{US} = P_i^{US}/p_g^*$ for $i \in \{s, b\}$, this also pins down A_g^{US} and A_s^{US}, A_b^{US} (3 parameters and 3 statistics).

We continue with Latin America and the Poorest Countries, so $j \in \{LA, PC\}$. We know that $A_e^j/A_g^j = p_g^*$ (2 parameters). Using the restriction $P_e^{US} = P_e^j$ and the observed relative purchase prices, we can calculate the purchase prices. Since

$$P_e^j = (1+\tau_e^j)\left(1+\frac{P_s^j}{\psi_e}\right), \tag{30a}$$

$$P_g^j = (1+\tau_g^j)\left(p_g^* + \frac{P_s^j}{\psi_g}\right), \tag{30b}$$

this pins down the values of τ_g^j, τ_e^j (6 parameters and 8 statistics).

At this point, we are left with 15 parameters. We calibrate them jointly by minimizing the squared percentage deviations of the model statistics from the following 17 observed statistics of the PWT96: the U.S. over the other two per–capita GDPs in international prices (2 statistics), the 4 investment shares of buildings and equipment in domestic prices and international prices in each country (12 statistics), and the shares of services in consumption expenditure in each country (3 statistics).

Appendix C. Figures

Figure 3: Relative Purchase Prices

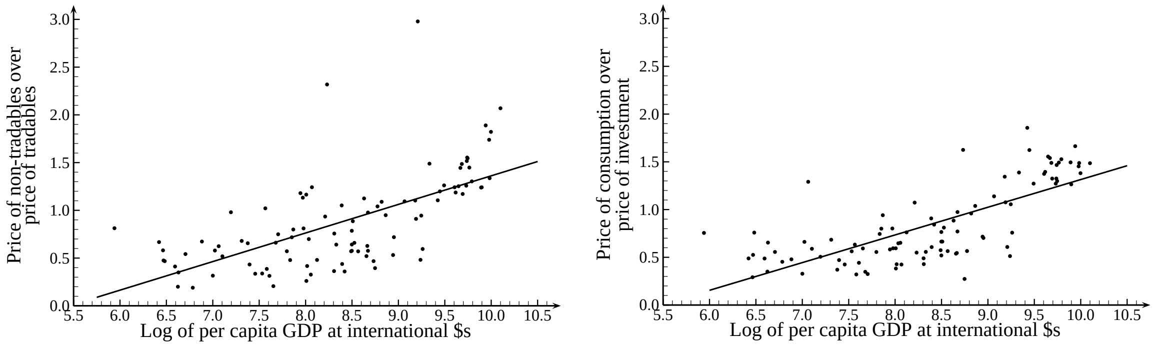

Figure 4: Construction–investment shares

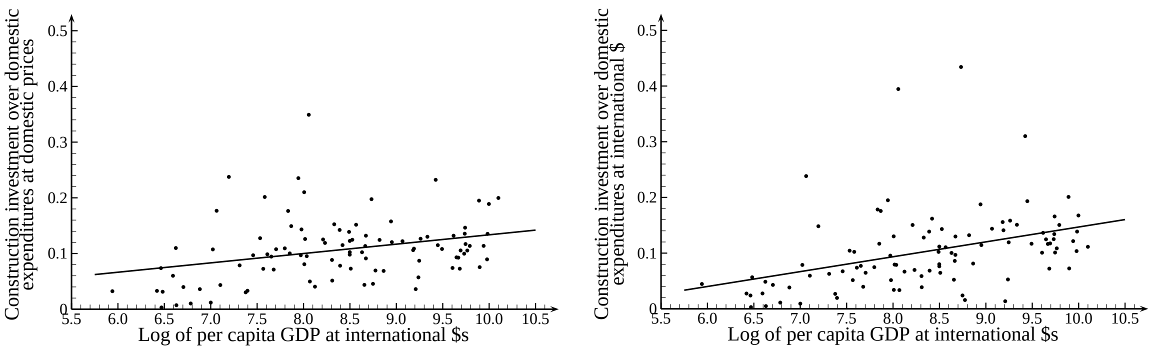

Figure 5: Equipment–investment shares

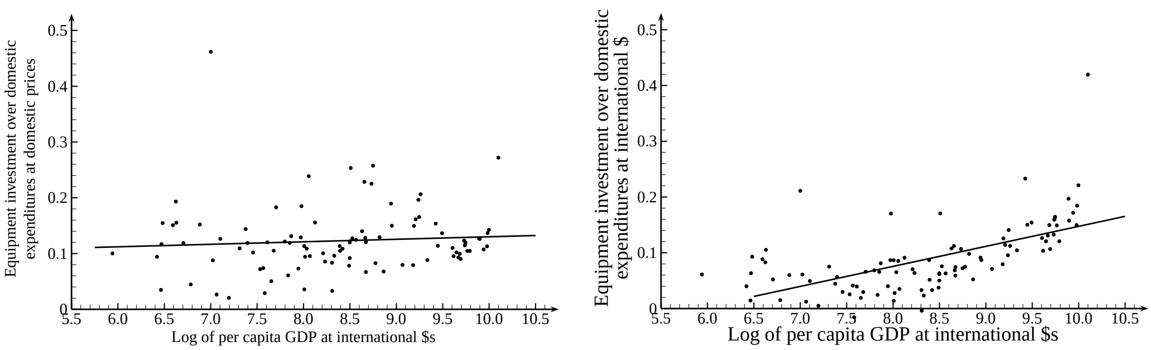

Figure 6: Services shares in consumption expenditure at domestic prices

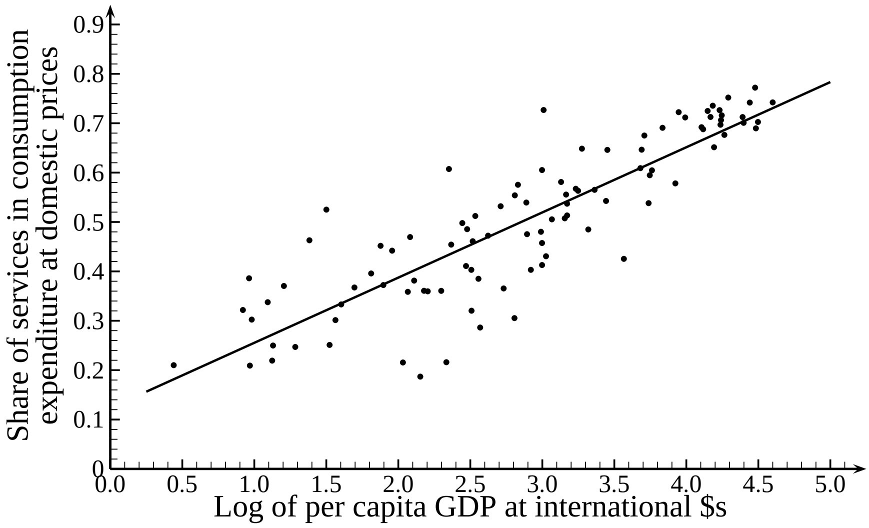

Figure 7: Purchase Prices of Equipment in U.S. $s