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Real Exchange Rates, Income Per Capita, and Sectoral Input Shares

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ABSTRACT

Aggregate price levels are positively related to GDP per capita across countries. We propose a mechanism that rationalizes this observation through sectorial differences in intermediate input shares. As aggregate productivity and income grow, so do wages relative to intermediate input prices, which increases the relative price of non-tradables if tradable sectors use intermediate inputs more intensively. We show that sectorial differences in intermediate input shares can account for two thirds of the observed elasticity of the aggregate price level with respect to GDP per capita. The mechanism has stark implications for industry-level real exchange rates that are strongly supported by the data.

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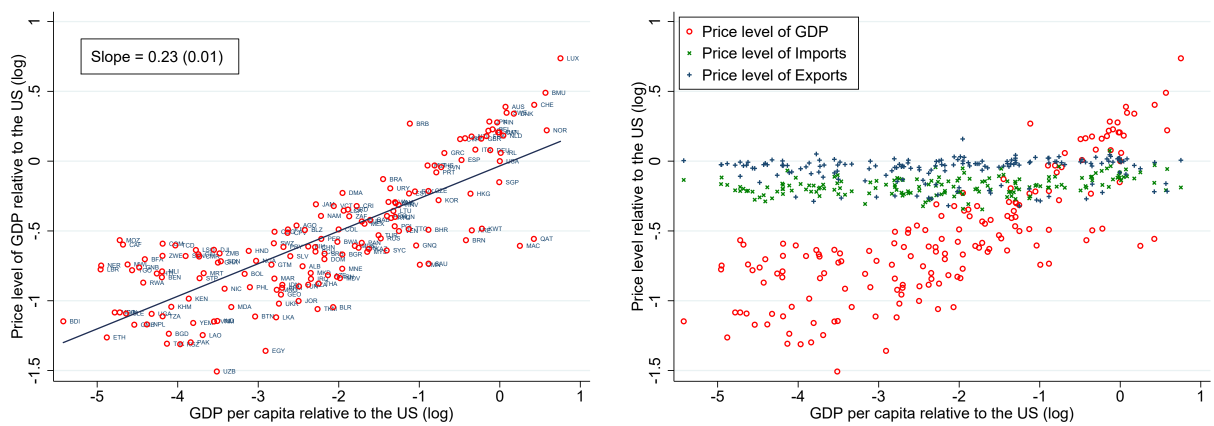
1 Introduction

Aggregate price levels are positively related to income per capita across countries, as illustrated in Figure 1a.[1] The leading explanation for this observation is the Balassa-Samuelson hypothesis, which postulates that productivity in tradable relative to non-tradable sectors increases with income. According to this theory, the price level is determined by the price of non-tradables, and high productivity in tradables leads to high wages and high non-tradable prices. Indeed, Figure 1b shows a strong correlation between GDP per capita and the aggregate price level, but not between GDP per capita and tradable prices.

Figure 1: Real exchange rates and GDP per capita

(a) Price level of GDP

(b) Tradables and non-tradable prices



Notes: Price data is from the Penn World Table 9.0. GDP per capita at market prices is from the World Development Indicators.

In spite of its popularity, empirical evidence supporting the Balassa-Samuelson hypothesis is scarce. An important limitation is that, since sectorial productivities are rarely measured in levels, the model's predictions for relative price levels (i.e. real exchange rate levels) are hard to confront with data.[2] As a result, most of the empirical literature has focused on studying the model's predictions for the growth of the real exchange rate using proxies for sectorial productivity growth, often with mixed results.[3]

[1] See Rogoff (1996) or Feenstra et al. (2015). The positive relation between relative prices and GDP per capita is often referred to as the 'Penn Effect', after Summers and Heston (1991).

[2] Measures of sectorial productivity are typically available in index form only. An important exception is a recent paper by Berka et al. (2014), who find evidence in favor of the Balassa-Samuelson hypothesis in levels using newly constructed indexes on relative productivity levels for 9 Euro-zone countries.

[3] In particular, a large literature finds that the Balassa-Samuelson model does not do well in explaining

This paper proposes an alternative mechanism linking real exchange rates to GDP per capita that relies on sectorial differences in intermediate input shares rather than on cross-country differences in sectorial productivities, and hence can be easily quantified using readily-available input-output data. The mechanism is an extension of that in Bhagwati (1984), who argued that if the tradable sector is capital intensive, the relative price of non-tradables should be higher in rich, capital-abundant countries where capital is relatively cheap. We extend this idea to incorporate sectorial differences in intermediate input shares, which we show are much larger in tradable than in non-tradable sectors. The extended theory indicates that, if the cost of labor relative to the cost of intermediate inputs is higher in rich countries, so should be the relative price of non-tradables and the aggregate price level.

We quantify this mechanism by incorporating differences in input intensities across tradable and non-tradable sectors into a textbook open economy model.[4] In the model, the relationship between real exchange rate levels and GDP per capita is shaped by three mechanisms. First, real exchange rates depend on cross-country differences in sectorial technology, as in the standard Balassa-Samuelson model. As highlighted above, this effect cannot be quantified directly without data on sectorial productivity levels in each country.[5] Second, real exchange rates depend on differences in capital shares across sectors and cross-country differences in the stock of capital per capita, as proposed by Bhagwati. Third, real exchange rates are shaped by differences in intermediate input shares across sectors, coupled with differences in aggregate productivity across countries, as explained above. Crucially, since the last two mechanisms depend only on sectorial factor and input intensities, and not on the relative levels of sectorial productivity, they can be quantified directly using publicly available data.

We show that sectorial differences in intermediate input shares account for about two thirds of the elasticity of the aggregate price level with respect to GDP per capita. In particular, we decompose the real exchange rate of each country relative to the US into three terms capturing the mechanisms described above. Differences in intermediate input shares across tradable and non-tradable sectors imply an elasticity of the real exchange rate to GDP per capita of 0.16, more than two thirds of the elasticity of the 0.23 elasticity in Figure 1a.[6] The elasticity implied by sectorial differences in capital shares is -0.05.

real exchange rates except in the very long run. See for example De Gregorio et al. (1994), Rogoff (1996), Tica and Druzic (2006), Lothian and Taylor (2008) and Chong et al. (2012).

[4] See for example Obstfeld and Rogoff (1996).

[5] In turn, measures of sectorial productivity levels can only be constructed as a residual using data on sectorial relative price levels, as done by Inklaar and Timmer (2014). In contrast, our mechanism can be quantified independently of the sectorial price data.

[6] Feenstra et al. (2015) obtain similar estimates of this elasticity using data from the PWT 8.0.

Contrary to Bhagwati's hypothesis, the share of capital in gross output is actually larger in non-tradable than in tradable sectors.[7] The residual component of the slope coefficient (0.12) can be attributed to differences in sectorial technologies, as in the Balassa-Samuelson model.

Our proposed mechanism has strong implications for the behavior of industry-level real exchange rates. It implies that, as income increases, industry-level prices should increase relative to the aggregate price of non-tradables for industries where the share of intermediate inputs is lower than for the non-tradable sector as a whole. We find strong support for this prediction using detailed industry-level price data from the International Comparison Program (ICP). We also calibrate the model to the industry-level data and show that industry-level variation in input shares accounts for a significant fraction of the observed industry-level real exchange rates. While the Balassa-Samuelson model can rationalize these industry-level predictions, it can only do so through specific assumptions on how industry-level productivities change with income. Instead, our mechanism delivers these predictions from observed intermediate input coefficients for different industries.

We note that in our model, even under the assumption that there are no differences in sectorial technologies across countries, differences in sectorial value-added productivity across countries arise endogenously from sectorial differences in input shares coupled with cross-country differences in aggregate productivity. This distinction between gross-output and value-added productivity does not arise in the textbook Balassa-Samuelson model without intermediate inputs. However, given value-added productivities in each country and each sector, the two models have the same predictions for the level of the real exchange rate. We highlight two advantages of starting from gross-output, rather than from value-added production functions. First, differences in sectorial value-added productivities arise endogenously from observed intermediate input shares, so they can be quantified directly from aggregate data. Second, it facilitates the mapping of the model to the final expenditure price data which is typically used to compute real exchange rates, since final prices capture both the cost of value-added and of intermediate inputs.[8]

Our paper contributes to the long literature that studies the relationship between real exchange rates and GDP per capita.[9] Most of the empirical literature has looked at the re-

[7]In contrast, the share of capital in value-added is indeed slightly larger in tradable sectors. We note, however, that real exchange rates are computed using prices of final expenditures, rather than 'value-added' prices.

[8]Alternatively, one can start from value-added production functions, and work with 'value-added' price data. Herrendorf et al. (2013) and Bems and Johnson (Forthcoming) are two recent examples that compute 'value-added' prices.

[9]See Rogoff (1996) for a summary of the early literature on this topic, and Inklaar and Timmer (2014) for

lationship between productivity and real exchange rate growth, but in most cases has only found evidence of a long-run relationship such as cointegration.[10] In a recent series of papers, Berka et al. (2012) and Berka et al. (2014) use newly-constructed data on Price Level Indices for countries in the Euro area to show evidence supporting the Balassa-Samuelson model. Our paper complements these studies by proposing a mechanism through which differences in sectorial value-added productivities arise endogenously from the differences in input intensities across sectors, in the spirit of Jones (2011). Since the mechanism does not require data on the level of sectorial productivity, we can quantify it both in growth rates and levels for a broad set of countries.[11]

The rest of the paper is organized as follows. Section 2 uses a simple model to illustrate our main results relating real exchange rate levels to GDP per capita. Section 3 describes a more detailed model incorporating capital as a factor of production and a richer input-output structure and that will be used for our quantification. Section 4 describes the data. Section 5 presents the quantitative results, and Section 6 concludes.

2 Intermediate input shares and sectorial relative prices

This section develops a simple model to show how sectorial differences in intermediate input shares can shape the relation between real exchange rates and GDP per capita. Consider a small open economy that produces two goods, tradables and non-tradables, using labor and intermediate inputs. For the moment, assume that production does not use intermediate inputs that are produced in other sectors.[12] The price of tradables is equalized across countries and set as the numeraire, $P^T = 1$. The production function for good j is given by:

$$Y^j = Z\bar{A}^j L^{j\theta^j} M^{j1-\theta^j},$$

recent evidence based on the new ICP data. Bergin et al. (2006) explain why the observed relation between real exchange rate levels and GDP per capita may have changed through time.

[10]See for example Asea and Mendoza (1994), De Gregorio et al. (1994), Canzoneri et al. (1999) and Lee and Tang (2007).

[11]A related literature starting with Engel (1999) has focused on the relative price of tradable goods in accounting for in real exchange rates (see for example Burstein et al. (2003), Betts and Kehoe (2008), Drozd and Nosal (2012) among many others). While a significant part of the measured movement in the relative price of tradables can be attributed to the retail component of tradable prices, Burstein and Gopinath (2015) show that movements in RERs for tradable goods measured using border prices still account for about 30 percent of the movements in real exchange rates. Since our main focuse is on cross-sectional departures from PPP, we concentrate on the relative price of non-tradable goods, a view supported by Berka and Devereux (2013) and Feenstra et al. (2015) among others, and by the evidence in Figure 1b.

[12]That is, non-tradables are not used in the production of tradables, and vice-versa.

where L^j and M^j denote labor and intermediate inputs used in sector j, and $Z \times A^j$ is a productivity term that has an aggregate and a sector-specific component. All markets are perfectly competitive, so the price of good j equals

$$P^j = \left[ZA^j\right]^{\frac{-1}{\theta^j}} W, \tag{1}$$

where $A^j \equiv \bar{A}^j \theta^{j\theta^j} \left[1 - \theta^j\right]^{1-\theta^j}$. We can write the relative price of non-tradables in terms of tradables as a function of the wage as:

$$P^N = \left[A^T W^{\theta^N - \theta^T}\right]^{\frac{1}{\theta^N}},$$

where we normalized $A^N = 1$ without loss of generality.[13]

Let $P \equiv \left[P^N\right]^{\omega}$ denote the aggregate price level of GDP in terms of the tradable good, where ω is the share of non-tradables in GDP. In addition, let the lower case of a variable denote the log of the variable, with $\Delta x \equiv x - x_w$ denoting the log of a variable relative to the rest of the world. Noting that GDP per capita in this economy is given by the wage, we can write the log of the price level relative to the rest of the world, $q \equiv \Delta p$, as:

$$q = \frac{\omega}{\theta^N} \left[\Delta a^T + \left[\theta^N - \theta^T\right] \Delta gdp\right], \tag{2}$$

where we used the equality $\Delta w = \Delta gdp$.

Equation (2) relates relative price levels to cross-country differences in relative sectorial productivities and cross-country differences in GDP per capita.[14] It postulates that the price level should be higher in countries that are relatively more productive in the tradable sector (high a^T). In the Balassa-Samuelson model, it is assumed that a^T is relatively high in rich countries, which leads to a positive correlation between the relative price level and GDP per capita. The equation also shows that, if the share of value-added is larger in non-tradable sectors, $\theta^N > \theta^T$, prices should be higher in countries with a high level of GDP per capita, even if there are no cross-country differences in sectorial productivity $\Delta a^T = 0$.

[13] This equation follows from solving for Z and substituting back using equation (1).

[14] The relation between relative price levels and GDP evaluated at world prices (that is, PPP adjusted GDP), $gdp^{ppp} \equiv gdp - q$, is:

$$q = \frac{\omega}{\bar{\theta}} \left[\Delta a^T + \left[\theta^N - \theta^T\right] \Delta gdp^{ppp}\right],$$

where $\bar{\theta} \equiv \omega\theta^T + \theta^N \left[1 - \omega\right]$. We evaluate this relation in our robustness exercises.

Value-added production functions and mapping to the Balassa-Samuelson model We can write the production functions in this model in value-added, rather than in gross-output terms. Substituting intermediate input demands into the value-added production functions, $V^j \equiv \theta^j Y^j$, we obtain

$$V^j = B^j L^j, \tag{3}$$

where $B^j \equiv \left[ZA^j\right]^{\frac{1}{\theta^j}}$.[15] The equation shows that even if there are no differences in gross-output productivity across sectors, $A^j = 1$, sectorial differences in value-added productivity, B^j, can arise endogenously from differences in the share of intermediate inputs in production, θ^j. The intuition for this result is that, as noted by Jones (2011), intermediate inputs deliver a multiplier similar to the multiplier associated with capital in the neoclassical growth model. If the multiplier is greater in the tradable sector, $\theta^T < \theta^N$, this implies that a given increase in aggregate productivity Z has a larger impact in tradable than in non-tradable output.

This observation makes clear that the theoretical predictions of the model for the real exchange rate are isomorphic to a Balassa-Samuelson model with production functions given by equation (3). We highlight two important advantages of incorporating sectorial differences in intermediate-input shares explicitly in the model. First, while the Balassa-Samuelson model simply assumes how differences in sectorial productivities change with development (i.e. the model assumes a correlation between B^T/B^N and GDP per capita), these differences can also arise endogenously from differences in the intermediate input shares across sectors and differences in aggregate productivity Z across countries. Perhaps more importantly, differences in the relative level of productivity across sectors and countries are not measured by statistical agencies -i.e. neither A^T nor B^T is measured in levels- which makes it virtually impossible to directly quantify the Balassa-Samuelson hypothesis in levels. In contrast, differences in the share of intermediate inputs across sectors are easily quantifiable, so the input multiplier channel can be directly quantified.[16] A back of the envelope calculation using equation (2) reveals that this channel is potentially large: using US values for $\theta^N = 0.61$, $\theta^T = 0.35$, and $\omega = 0.84$, indicates that, given relative sectorial productivities, the elasticity of the relative price level of GDP with respect to relative GDP per capita is 0.38 vs. 0.23 in the data in Figure 1a. The remainder of the

[15]This follows from the input demands that minimize costs, $M^j = \left[\left[1-\theta^j\right] Z\bar{A}^j\right]^{\frac{1}{\theta^j}} L^j$.

[16]Another, often overlooked limitation of specifying the production function in value-added terms is that in the data real exchange rates are typically computed from prices of final expenditures, rather than from 'value-added' prices An important exception is Bems and Johnson (Forthcoming) who estimate of value-added real exchange rates.

paper measures the importance of this channel in a more detailed quantitative framework that incorporates capital as a factor of production, allows for multiple non-tradable sectors and a richer input-output structure, and allows for differences in factor shares across countries.

3 Quantitative framework

We now extend the simple model from Section 2 to incorporate capital as a factor of production and to allow for a more realistic input-output structure and for differences in factor shares across countries. In addition, we incorporate multiple non-tradable industries to derive predictions for industry-level real exchange rates.[17] We thus consider a small open economy that produces $J+1$ of goods, $j = 1, ..., J$ which are non-tradable and $j = J+1$ which is tradable, using labor, capital, and intermediate inputs. We index the tradable good by T, while the remaining J goods can be grouped in a non-tradable sector labeled by N. The price of the tradable good is equalized across countries and taken as the numeraire, $P_t^T = 1$. All markets are perfectly competitive.

Production The production function for good j is given by:

$$Y_i^j = Z_i \bar{A}_i^j \left[L_i^{j^{1-\alpha_i^j}} K_i^{j^{\alpha_i^j}} \right]^{\theta_i^j} \left[\left[M_i^{T,j} \right]^{\sigma_i^{Tj}} \left[M_i^{N,j} \right]^{\sigma_i^{Nj}} \right]^{\left[1-\theta_i^j\right]}, \tag{4}$$

where Y_i^j, L_i^j and K_i^j denote gross output, employment, and capital in country i and sector j, $M_i^{T,j}$ is the quantity of tradable intermediate inputs used in the production of sector j, and $M_i^{N,j}$ is a composite of non-tradable goods used in the production of j. θ_i^j and α_i^j denote the share of value-added in gross output and the share of capital in value-added respectively. Note that production in sector j can potentially use both tradable and non-tradable inputs. The share of tradable and non-tradable inputs used in sector j is given by $\sigma_i^{Tj} \times \left[1-\theta_i^j\right]$ and $\sigma_i^{Nj} \times \left[1-\theta_i^j\right]$ respectively, where $\sigma_i^{Tj} + \sigma_i^{Nj} = 1$. As in the previous section, $Z_i \times \bar{A}_i^j$ is a productivity term that has an aggregate and a sector-specific component.

[17] As it will become apparent below, this will allow us to evaluate which non-tradable industries become more expensive as GDP per capita grows.

Prices Perfect competition implies that the price of good j is given by:

$$P_i^j = \bar{\gamma}_i^j W_i^{\left[1-\alpha_i^j\right]\theta_i^j} R_i^{\alpha_i^j \theta_i^j} \left[\left[P_i^T\right]^{\sigma_i^{Tj}} \left[P_i^N\right]^{\sigma_i^{Nj}} \right]^{\left[1-\theta_i^j\right]} / \left[\bar{A}_i^j Z_i\right],$$

where W_i and R_i denote the wage and the rental rate of capital in country i in units of the tradable good and where $\bar{\gamma}_i^j$ is a constant.[18] Taking logs we can write the log-price of good j as:

$$p_i^j = log\bar{\gamma}_i^j - \bar{a}_i^j + \theta_i^j w_i + \alpha_i^j \theta_i^j \left[r_i - w_i\right] + \sigma_i^{Nj} p_i^N \left[1 - \theta_i^j\right] - z_i, \tag{5}$$

where p_i^j is the (log of the) price for good j, and $p_i^T = 0$ given the choice of the numeraire. Let ω_i^j denote the share of non-tradable good j in the non-tradable sector, so that $\sum_{j=1}^J \omega_i^j = 1$. We can write the log of the non-tradable price index as:

$$p_i^N \equiv \sum_{j=1}^J \omega_i^j p_i^j.$$

In combination with (5) this implies

$$p_i^N = \frac{\bar{\bar{a}}_i^T}{\bar{\theta}_i^N} + \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} w_i + \frac{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T}{\bar{\theta}_i^N} \left[r_i - w_i\right],$$

where $\bar{\bar{a}}_i^T \equiv log\left[\bar{\gamma}_i^N / \bar{\gamma}_i^T\right] + \bar{a}_i^T - \bar{a}_i^N$ and $\bar{\theta}_i^N \equiv \theta_i^N + \sigma_i^{TN}\left[1 - \theta_i^N\right] + \sigma_i^{NT}\left[1 - \theta_i^T\right]$.

Relative prices and GDP per capita We are interested in understanding the relation between the aggregate price level and GDP per capita. Let $1 - \bar{\alpha}_i \equiv W_i L_i / GDP_i$ and $\bar{\alpha}_i \equiv R_i K_i / GDP_i$ denote the aggregate labor share and capital share in country i, where $L_i = \sum_j L_i^j$ and $K_i = \sum_j K_i^j$ are the aggregate labor supply and the aggregate capital stock. Factor prices are related to factor supplies by:

$$\frac{R_i}{W_i} = \frac{\bar{\alpha}_i}{1 - \bar{\alpha}_i} \frac{L_i}{K_i}.$$

[18] The constant is given by $\left[\bar{\gamma}_i^j\right]^{-1} \equiv \left[\left[1-\alpha_i^j\right]^{1-\alpha_i^j} \alpha_i^{j\alpha_i^j}\right]^{\theta_i^j} \theta_i^{j\theta_i^j} \left[1-\theta_i^j\right]^{1-\theta_i^j} \left[\prod_{j'} \sigma_i^{j'j\sigma_i^{j'j}}\right]^{\left[1-\theta_i^j\right]}$.

We can then write the (log) price of non-tradables in terms of tradables as:

$$p_i^N = \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} gdp_i + \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N} k_i + \frac{a_i^T}{\bar{\theta}_i^N}, \tag{6}$$

where gdp_i is the log of GDP per capita measured in units of the tradable good, k_i is the log of the capital-labor ratio in the economy, and a_i^T captures country-specific productivity differences across the two sectors.[19] Equation (6) links the price of non-tradables to GDP per capita and the capital-labor ratio in the economy. The equation shows that, if the share of intermediate inputs in gross output is relatively high in the tradable sector, $\theta_i^N > \theta_i^T$, the price of non-tradables increases with GDP per capita. Intuitively, as productivity grows, labor gets more expensive relative to intermediate inputs, which increases the price in sectors that use labor more intensively. In addition, if the non-tradable sector uses capital more intensively, $\alpha_i^N \theta_i^N > \alpha_i^T \theta_i^T$, the price of non-tradables decreases with the capital-labor ratio in the economy, k_i.

Decomposing real exchange rates We now decompose the determinants of bilateral real exchange rates in the model. To facilitate comparisons with the data in Figure 1a we define the real exchange rate as the price level of GDP in each country relative to the US. The log of the price level of GDP in country i is defined as $p_i = \omega_i^N p_i^N$, where ω_i^N denotes the share of non-tradables in country i's GDP. Letting $\Delta x_i \equiv x_i - x_{us}$ denote the log difference of a variable relative to the US, we can write the log-price of GDP in country i relative to the US, $q_i \equiv \omega_i^N \Delta p_i^N$, as:[20]

$$q_i = \underbrace{\omega_i^N \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\omega_i^N \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N} \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\omega_i^N \Delta \bar{a}_i^T}_{\text{'Balassa-Samuelson'}}, \tag{7}$$

where

$$\Delta \bar{a}_i^T \equiv \Delta \left[\frac{a_i^T}{\bar{\theta}_i^N} \right] + k_{us} \times \Delta \left[\frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N} \right] + gdp_{us} \times \Delta \left[\frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N} \right].$$

[19] That is, $k_i \equiv log \frac{K_i}{L_i}$, $gdp_i \equiv log \frac{GDP_i}{L_i}$, and $a_i^T \equiv \bar{\bar{a}}_i^T + log \left[\bar{\alpha}_i^{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T} \left[1 - \bar{\alpha}_i\right]^{\theta_i^N [1-\alpha_i^N] - [1-\alpha_i^T] \theta_i^T} \right]$.

[20] Note that, in line with the price level index estimates of the ICP, our relative price level focuses on weighted averages of relative price differences ($\sum_j \omega_i^j \left[p_i^j - p_{us}^j \right]$) as opposed to differences in the weighted average or price levels ($\sum_j \omega_i^j p_i^j - \sum_j \omega_{us}^j p_{us}^j$).

Equation (7) decomposes cross-country differences in the price level into three terms. The first term, labeled 'Intermediate Inputs', captures the differences in aggregate price levels that arise from sectorial differences in intermediate input shares coupled with differences in GDP per capita across countries. It states that, if the share of intermediate inputs is larger in the tradable sector, $\theta_i^N > \theta_i^T$, countries with higher GDP per capita should have a higher price level. This effect is the main focus of this paper and is measured in the quantitative section below.

The second term, labeled 'Capital-Deepening', captures how cross-country differences in the capital-labor ratio affect relative price levels, and states that the relative price level should increase with the capital-labor ratio if the production of tradables is more intensive in capital $\alpha_i^T\theta_i^T > \alpha_i^N\theta_i^N$. This mechanism was first highlighted by Bhagwati (1984). Note that if the share of value-added in the tradable sector is low enough, the price level can actually decrease with the capital-labor ratio even if the capital share in value-added is higher in the tradable sector $\alpha_i^T > \alpha_i^N$. Indeed, in contrast to what is postulated in Bhagwati (1984), $\alpha_i^T\theta_i^T < \alpha_i^N\theta_i^N$ for the vast majority of countries for which input-output data are available.

Finally, the 'Balassa-Samuelson' term captures differences in the price level that arise from cross-country differences in sectorial technology, which encompass both cross-country differences in the relative level of sectorial productivity, $\bar{A}_i^T$, and cross-country differences in sectorial factor shares α_i^j, θ_i^j, and $\bar{\theta}_i^N$. Note that this term cannot be measured directly from national accounts data, as it requires not only data on the relative level of sectorial productivity, $\bar{A}_i^T$, but also data on the level of US GDP measured in units of tradables (which requires taking a stand on the level of the dollar price of tradable goods).

3.1 Industry-level real exchange rates

We now derive the model's implications for industry-level real exchange rates. From equations (5) and (6) we can write the price of any non-tradable good j as:

$$p_i^j = \beta_i^{gdp,j} gdp_i + \beta_i^{k,j} k_i + a_i^j,$$

with

$$\beta_i^{gdp,j} \equiv \left[\theta_i^j - \theta_i^N\right] + \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N},$$

and

$$\beta_i^{k,j} \equiv \frac{\theta_i^N - \theta_i^j}{\bar{\theta}_i^N}\left[\alpha_i^N\left[\sigma_i^{TN} + \sigma_i^{NT}\left[1-\theta_i^T\right]\right] + \alpha_i^T\theta_i^T\sigma_i^{NN}\right] + \frac{\alpha_i^T\theta_i^T - \alpha_i^N\theta_i^N}{\bar{\theta}_i^N}.$$

The log price in industry j relative to the US (i.e. the industry-level real exchange rate) is:

$$q_i^j = \underbrace{\beta_i^{gdp,j}\Delta gdp_i}_{'\text{Intermediate Inputs}'} + \underbrace{\beta_i^{k,j}\Delta k_i}_{'\text{Capital-Deepening}'} + \underbrace{\Delta a_i^j}_{'\text{Balassa-Samuelson}'} \tag{8}$$

Equation (8) states that the slope of the industry-level real exchange rate with respect to GDP should increase with the share of value-added in the industry; a prediction we verify in Section (5.2). Finally, we can write the price of non-tradable good j relative to the average price of non-tradables, relative to the US as:

$$\Delta\left[p_i^j - p_i^N\right] = \left[\theta_i^j - \theta_i^N\right]\Delta gdp_i + \bar{\beta}_i^{k,j}\Delta k_i + \Delta\bar{a}_i^j, \tag{9}$$

with $\bar{\beta}_i^{k,j} \equiv \frac{\theta_i^N - \theta_i^j}{\bar{\theta}_i^N}\left[\alpha_i^N\left[\sigma_i^{TN} + \sigma_i^{NT}\left[1-\theta_i^T\right]\right] + \alpha_i^T\theta_i^T\sigma_i^{NN}\right]$. Equation (9) states that, as GDP per capita grows, industry-level prices will rise relative to the price of non-tradables in industries where the share of intermediate inputs is relatively high, $\theta_i^j < \theta_i^N$.

4 Data

To evaluate the relation between relative prices and GDP per capita derived in equations (7), (8), and (9) we need data on relative price levels, GDP per capita, and the stock of capital per capita across countries. We also need to assign values to the share of value-added in gross output for each country and sector, θ_i^j, the labor share in each country and sector, $1-\alpha_i^j$, the intermediate inputs shares, $\sigma_i^{j'j}$, and the share of non-tradables in GDP, ω_i^N.

Relative price levels, GDP per capita and capital-labor ratio: We take GDP per capita at market prices from the World Development Indicators Tables (WDI). Data on relative prices come from the Penn World Table 9.0 (PWT). Our baseline relative price measure is the price level index of GDP relative to the US, which is variable PL_GDP^o in the PWT.[21] We focus on a subsample of 168 countries for which we have data in both the PWT and WDI. We construct GDP per capita at PPP dollars from the PWT by taking the ratio of real

[21] See Feenstra et al. (2015) for a description of the new PWT.

GDP at constant 2011 national prices (variable $RDGP^{NA}$ in the PWT) to population. For the stock of capital per capita, we use the capital stock in PPP dollars (variable RK^{NA}). When looking at growth rates, we compute the growth rates of these per capita variables. We complement these data with the benchmark ICP 2011 data containing sector-specific price level indices and expenditure shares.[22]

Input shares and sectorial weights: Input-output coefficients come from the OECD Inter-Country Input-Output (ICIO) Tables, which provide input-output tables for 61 countries between 1995-2011. We classify sectors in the ICIO and the ICP into tradables and non-tradables following Crucini et al. (2005).[23] We compute θ_i^j as the ratio of value-added to gross output in each sector, and the parameters $\sigma_i^{j'j}$ as the ratio of the value of inputs from sector j' to the total value of inputs used in sector j.

Unfortunately, the shares of labor compensation in value-added, $1-\alpha_i^j$, are not directly observable in the ICIO tables. In particular, I-O tables report the share of compensation to employees relative to value-added for each sector. It is well known that compensation to employees understates labor compensation as it does not include payments to self-employed workers.[24] The PWT adjusts the labor income of employees to account for the income of self-employed workers to obtain an aggregate measure of the labor share. We follow this approach and rescale the sectorial ratios of compensation to employees to value-added that we observe in the ICIO to match the aggregate labor shares reported in the PWT. In particular, for each country in the ICIO we compute

$$1-\alpha_i^j = \frac{\text{Comp. to employees}_i^j}{\text{Value added}_i^j} \times \frac{\text{Labor comp.}_i/\text{Value added}_i}{\text{Comp. to employees}_i/\text{Value added}_i}, \tag{10}$$

where the sectorial and aggregate ratios of compensation to employees to value-added come from the ICIO, and the aggregate ratio of labor compensation to value-added is obtained from the PWT. For countries not available in the ICIO tables, we impute the cross-country average of the observed θ_i^j, $\sigma_i^{j'j}$ and compensation-to-employees-to-value-added ratio, and use equation (10) to obtain sectorial measures of the labor share that are consistent with the PWT. In all cases, we use the shares as measured in 2011. The industries in ICIO are mapped to the industries in the ICP program with the concordance in Appendix Table A1. We compute the share of non-tradables in GDP, ω_i^N, from the

[22]While the benchmark PLIs in the detailed ICP data are defined relative to the world, we divide by the US PLIs to work with price indices of consumption relative to the US.

[23]See Table A1 in the Appendix.

[24]See Gollin (2002) and Feenstra et al. (2015).

expenditure data that underlie the construction of the relative prices levels in the ICP program.

Appendix Table A2 reports the share of value-added in gross output, θ_i^j, for the countries in our sample. Non-tradable sectors are significatively more labor intensive than tradable sectors for every country in the sample. For the average country, the share of value-added in gross output in tradable sectors is about half than in the non-tradable sectors (0.33 vs 0.54).

Finally, we compute the share of non-tradables in GDP, ω_i^N, as the ratio of value-added in the non-tradable sector to total value-added. Appendix Table A3 reports the division of the ICIO industries into tradable and non-tradable sectors. Within the non-tradable sector, industry-specific ω_i^j's are computed as the ratio value-added between industry j to total value-added in the non-tradable sector.

5 Quantitative results

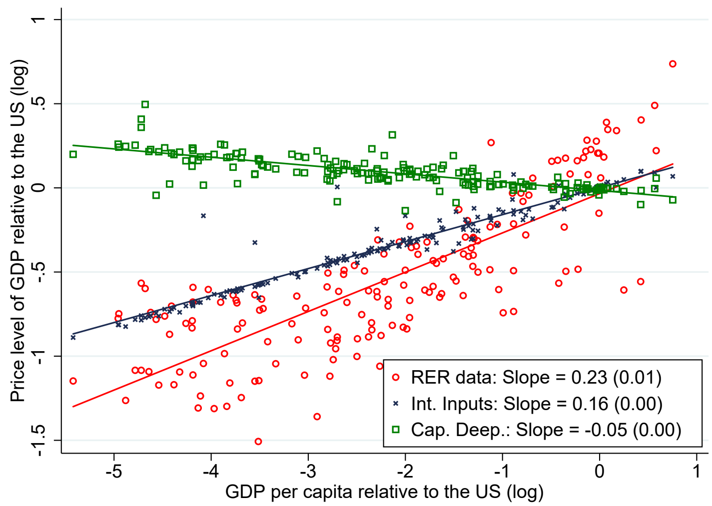
This section uses the framework in Section 3 to disentangle the sources of the cross-country relation between real exchange rate levels and GDP per capita. First, we use equation (7) to evaluate how much of the observed differences in price levels across countries can be accounted for by sectorial differences in intermediate input shares coupled with cross-country differences in GDP per capita. Second, we use equations (8) and (9) to test the industry-level predictions of this mechanism. Third, we show that the results of this section are unchanged if we instead focus on the relation between price levels and GDP per capita measured at PPP prices, the relation between the growth of the price level and real GDP per capita across countries, and in a version of the model where tradable goods are differentiated across countries.

5.1 Price levels and GDP per capita

We first decompose the relation between aggregate price levels and GDP per capita following the decomposition in Section 3. In particular, for each country i, we compute the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (7), given by $\omega_i^N \left[\theta_i^N - \theta_i^T\right] / \bar{\theta}_i^N \Delta gdp_i$ and $\omega_i^N \left[\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N\right] / \bar{\theta}_i^N \Delta k_i$ respectively. Subtracting these two terms from the observed relative price levels we can obtain the 'Balassa-Samuelson' term as a residual.

Figure 2 shows the results of this decomposition by plotting the 'Intermediate Inputs' and 'Capital-Deepening' terms along with the relative price levels observed in the data.[25] The relation between aggregate price levels and GDP per capita can be mostly attributed to sectorial differences in intermediate inputs shares, captured by the term labeled 'Intermediate Inputs'. This term gives an elasticity of the relative price level with respect to GDP per capita of 0.16, more than two thirds of the 0.23 aggregate elasticity observed in the data. In contrast, sectorial differences in the share of capital in gross output, captured by the 'Capital-Deepening' term, generate a small but negative elasticity of the price to GDP per capita of -0.05. This is due to the fact that, in contrast to the postulate of Bhagwati (1984), in the data the share of capital in gross output is higher in non-tradable sectors, that is, $\alpha_i^T \theta_i^T < \alpha_i^N \theta_i^N$, even though $\alpha_i^T > \alpha_i^N$. The residual variation in real exchange rate levels can be attributed to sectorial differences in technology, captured in the 'Balassa-Samuelson' term. Appendix Figure A.1 shows that this term gives an elasticity of the price level to GDP per capita of 0.12.

Figure 2: Real exchange rate decomposition



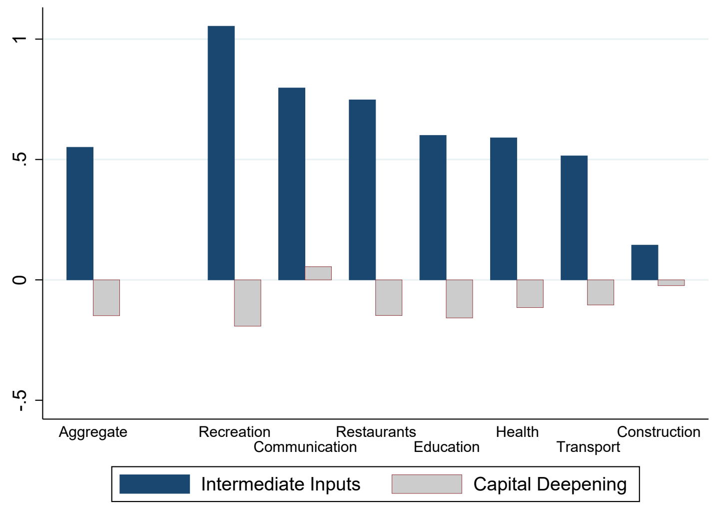
Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT 9.0, already depicted in Figure 1a. 'Int. Inputs' and 'Cap. Deep.' are the relative prices implied by the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (7).

Figure 3 reports the contribution the Intermediate Inputs and the 'Capital-Deepening' terms to the real exchange rate in the median country of our sample. Sectorial differences in input shares account for about half of the level of the real exchange rate relative to the US in the median country. We conclude that sectorial differences in intermediate input

[25] To prevent cluttering figure, the 'Balassa-Samuelson' term is plotted separately in Appendix Figure A.1.

shares are an important source of variation in real exchange rates.

Figure 3: Contribution of sectorial differences in intermediate input shares to real exchange rates: median country



Notes: This figure plots the share of the real exchange rate that is accounted for the 'Intermediate Inputs' and 'Capital-Deepening' terms in equations (7) and (8) for the median country of our sample. 'Aggregate' corresponds to the aggregate real exchange rate and the decomposition correspond to equation (7). The remaining bars correspond to industry-level real exchange rates, and the decomposition correspond to equation (8).

5.2 Industry-level real exchange rates

The mechanism highlighted in this paper makes sharp predictions for the behavior of industry-level relative prices. There is wide variation in the share of intermediate inputs across non-tradable industries. Appendix Table A2 shows the average share of intermediate inputs in gross output for the countries in ICIO for 7 non-tradable sub-sectors for which the ICP reports detailed price indexes.[26] The share of intermediate inputs in Education, Health, and Recreation is lower than for the non-tradable sector as a whole, and is higher in Transport, Communication, and Restaurants. An implication that can be gleaned from equation (8) is that the slope of the price level of an industry with respect to GDP per capita should be higher the higher is the share of value-added in the industry (i.e. the higher is θ_i^j).

We first evaluate this prediction by running a regression of industry-level real-exchange rates on relative GDP per capita and an interaction of GDP per capita with the value-

[26] Appendix Table A2 also reports these shares for each country in our sample.

added share of the sector θ_i^j.[27] We expect the coefficient on the interaction term to be positive: the slope of the of the industry-level real exchange rate should be higher in industries for which the share of value-added is high (and the share of intermediate inputs is low). Table 1 supports this result. The first column shows a significant positive relation between the industry-level real exchange rates and GDP per capita, similar in magnitude to the aggregate slope in Figure 1a. The second column adds the interaction of GDP per capita and the sectorial value-added share. The coefficient on the interaction term is positive and strongly statistically significant, in line with the predictions of our mechanisms. Moreover, the R-squared of the regression increases from 0.266 to 0.476 once we add the interaction term, indicating that sectorial input shares are important for understanding the variation in industry-level prices. Column 3 adds country-level fixed effects, so that the interaction term is identified from the variation in value-added shares across sectors within countries, and shows that the interaction terms is very similar under this specification. Finally, the last column includes industry-level fixed effects.[28] We continue to find a positive and significant coefficient in this specification. We conclude that the reduced form evidence brings strong support for the notion that sectorial differences in intermediate input shares shape the relation between real exchange rates and GDP per capita.

We then decompose industry-level real exchange rates by computing the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (8) for seven expenditure categories for which the ICP reports price data. Figure 3 shows that, in the median country of the sample, the 'Intermediate Inputs' term accounts for a sizable fraction of the industry-level real exchange rate in most industries. Figure 4 shows that industry-level differences in intermediate input shares account for a significant fraction of the relation between industry-level real exchange rates and GDP per capita. This shows that the mechanism is quantitatively important in accounting for the real exchange rates industry-by-industry.

Finally, equation (9) implies that as GDP per capita grows, industry-level prices should increase relative to the aggregate price of non-tradables for industries where the share of intermediate inputs is lower than for the non-tradable sector as a whole, $\theta^j > \theta^N$. Figure 5 evaluates how the price of each industry relative to the aggregate price of non-tradables

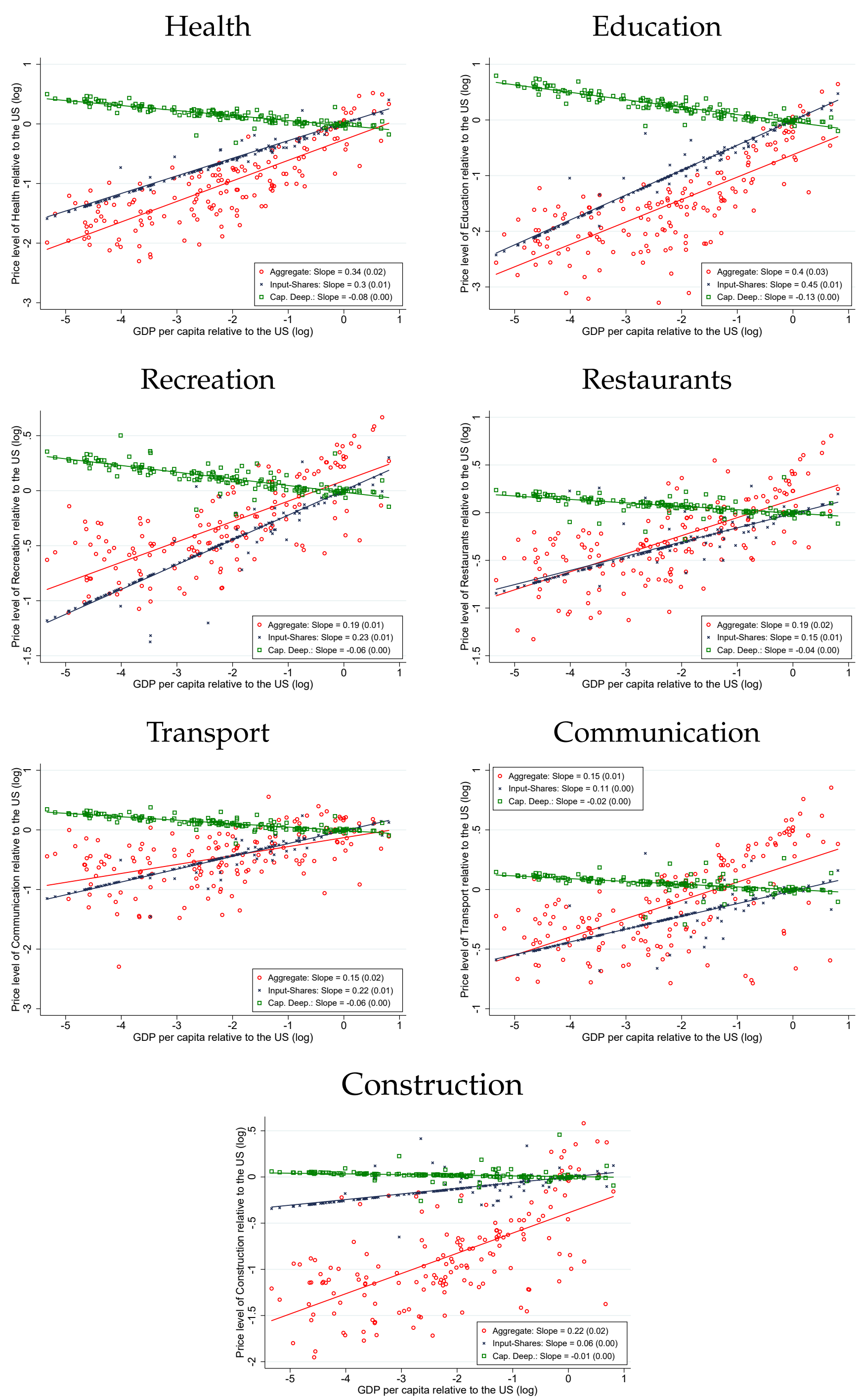
[27] More precisely, in our baseline regression in Column 2 of Table 1 we estimate:

$$q_i^j = \alpha + \beta_1 \Delta gdp_i + \beta_2 \left[\theta_i^j \times \Delta gdp_i\right] + \beta_3 \theta_i^j + \varepsilon_i^j.$$

where we obtain the industry specific value-added shares θ_i^j by matching the expenditure categories in the ICP data from which the q_i^j's are obtained to the industries in the Input-Output Tables manually, as described in Appendix Table A1.

[28] For this specification, we exclude the countries for which we impute θ_i^j, and only include the set of countries for which we can directly observe θ_i^j from the ICIO data.

Figure 4: Industry-level real exchange rate decomposition



Notes: 'RER data' refers to the relative price of the industry relative to the US obtained from the ICP data. 'Int. Inputs' and 'Cap. Deep.' are the relative price implied by the terms labeled 'Intermediate Inputs' and the 'Capital-Deepening' terms in equation (8).

Table 1: Industry level relative prices and sectorial input shares

Dep var: q_i^j	(1)	(2)	(3)	(4)
Δgdp_i	0.235***	0.241***		0.419***
	(0.0163)	(0.0163)		(0.0237)
$\theta_i^j \times \Delta gdp_i$		0.676***	0.667***	0.429***
		(0.0694)	(0.0643)	(0.0859)
θ_i^j		-0.906***	-0.974***	0.615**
		(0.171)	(0.152)	(0.297)
R-squared	0.266	0.476	0.630	0.775
Observations	1,127	1,127	1,127	399
CTY FE	No	No	Yes	No
IND FE	No	No	No	Yes

Notes: Robust standard errors clustered at the country level in parentheses. ***: significant at 1%; **: significant at 5%; *: significant at 10%.

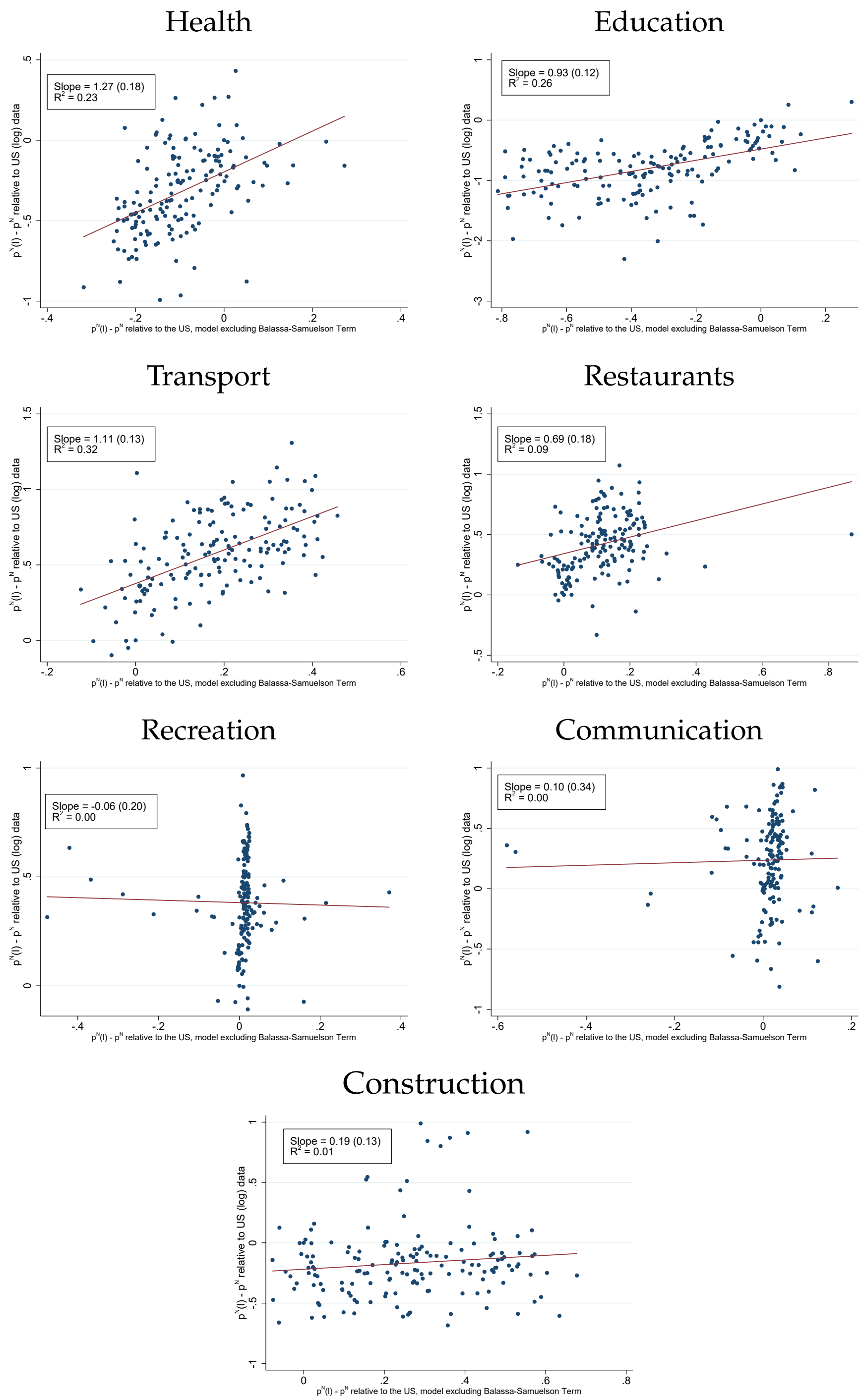
changes across countries in the data and in the model without cross-country differences in industry-level technology. In particular, we compare data on relative prices to the sum of first two terms in equation (9), ignoring the 'Balassa-Samuelson' term. Despite the fact that the mapping between the industry categories in the ICIO and the expenditure categories in the ICP data is imperfect, the figure shows that industry-level differences in input shares generates the observed ranking of the relative price changes for the Health, Education, Transport, Restaurants and Construction. In contrast, the industry-level differences in input shares do not generate much variation across countries in the prices of Recreation and Communication relative to the price of non-tradables. Overall, the mechanism is successful in matching the relation of industry-level real exchange rates and GDP per capita.

5.3 Robustness

5.3.1 Relative prices and GDP per capita evaluated at PPP prices

This section shows that our quantitative results don't change if we focus on the relation between the real exchange rate and GDP measured in PPP dollars. With this in mind, we write differences in the relative price level as a function of the difference in GDP per

Figure 5: Industry-level relative prices: Data vs. model with common sectorial technologies across countries



Notes: This figure plots the price of each industry relative to the price of non-tradables, relative to that relative price in the US from the ICP data (y-axis) and from adding the 'Intermediate Inputs' and 'Capital-Deepening' terms in equation (9) in the model.

capita evaluated as US prices, $gdp_i^{ppp} \equiv gdp_i - q_i$:

$$q_i = \underbrace{\beta_i^{gdp^{ppp}} \Delta gdp_i^{ppp}}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^k \Delta k_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta \bar{\bar{a}}_i}_{\text{'Balassa-Samuelson'}}, \tag{11}$$

where the elasticities are given by:

$$\beta_i^{gdp^{ppp}} = \frac{\omega_i^N \left[\theta_i^N - \theta_i^T\right]}{\bar{\theta}_i^N - \omega_i^N \left[\theta_i^N - \theta_i^T\right]},$$

and

$$\beta_i^k = \frac{\omega_i^N \left[\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N\right]}{\bar{\theta}_i^N - \omega_i^N \left[\theta_i^N - \theta_i^T\right]}.$$

Appendix Figure A.2 evaluates the terms in this decomposition and shows that the sectorial differences in input multipliers account for about eighty percent of the elasticity between the real exchange rate and PPP adjusted GDP per capita seen in the data (0.19 vs. 0.24).

5.3.2 Real exchange rates and GDP growth

We now evaluate the model's prediction for the growth of the real exchange rate. Taking differences across time in equation (11) and using hats to denote log-changes across time, we obtain an expression for the change in the real exchange rate:

$$\hat{q}_i = \underbrace{\beta_i^{gdp^{ppp}} \Delta \widehat{gdp}_i^{ppp}}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^k \Delta \hat{k}_i}_{\text{'Capital-Deepening'}} + \underbrace{\Delta \hat{\bar{a}}_i}_{\text{'Balassa-Samuelson'}} \tag{12}$$

Equation (12) establishes that, if $\theta_i^N > \theta_i^T$, fast growing countries should appreciate . Appendix Figure A.3 compares the terms in equation (12) to the growth of the real exchange rate observed in the data. The figure shows that sectorial differences in input shares account for about three-quarters of the elasticity of the growth of the real exchange rate to the growth or real GDP over the 1997-2014 period.

5.3.3 Alternative classifications of the tradable sector

This section re-evaluates the results of Section 5.1 under an alternative classification of industries into tradables and non-tradables. In particular, we follow the macro-economic database of the European Commission's Directorate General for Economic and Financial Affairs (AMECO) and classify the Wholesale and Retail Trade, Hotels, Restaurants, Transport, Utility, and Storage industries as tradables. Figure A.4 in the appendix plots the decomposition of equation (7) using this classification. The figure shows that differences in intermediate input shares still account for about half the slope of the relation between the real exchange rate and GDP per capita using this alternative classification.

5.3.4 Multiple tradable goods

Finally, we show how to extend our baseline model to allow for differentiated tradable goods. In particular, assume that tradable goods are differentiated by country of origin. Final good producers in each country i aggregate tradable intermediates from different source countries according to the aggregator

$$G_i^T = \left[\sum_{n=1}^{N} \omega_{ni}^{\frac{1}{\rho}} Y_{ni}^{T\,\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \tag{13}$$

where Y_{ni}^T denotes country $i's$ absorption of tradable good from country n, ρ is the elasticity of substitution across tradable goods from different source countries, and the parameters ω_{ni} control the share of goods from country n in total absorption of tradables by country i. The price of the tradable bundle consumed in country i is then given by:

$$P_i^T = \left[\sum_{n=1}^{N} \omega_{ni} \left[\varphi_n^T \right]^{1-\rho} \right]^{\frac{1}{1-\rho}}, \tag{14}$$

where φ_n^T denotes the price of the tradable product produced in country n, and the parameter ω_{ni} controls the trade shares. Sales from country n into country i are given by:

$$\varphi_i^T Y_{ni}^T = \omega_{ni} \left[\frac{\varphi_n^T}{P_i^T} \right]^{1-\rho} P_i^T G_i^T. \tag{15}$$

Appendix A fully describes this version of the model, characterizes the equilibrium, and shows that in this case the real exchange rate can be written as:

$$q_i = \underbrace{\beta_i^{gdp} \Delta gdp_i}_{\text{'Intermediate Inputs'}} + \underbrace{\beta_i^k \Delta k_i^y}_{\text{'Capital-Deepening'}} + \underbrace{\beta_i^p \Delta p_i^T + \beta_i^\varphi \Delta log \varphi_i^T}_{\text{'Relative Price of Tradeables'}} + \underbrace{\Delta a_i,}_{\text{'Balassa-Samuelson'}} \tag{16}$$

with $\beta_i^{gdp} \equiv \omega \frac{\theta_i^N - \theta_i^T}{\bar{\theta}_i^N}$, $\beta_i^k \equiv \omega \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N}$, $\beta_i^p \equiv 1 - \omega \frac{1 - \left[\theta_i^T - \theta_i^N\right]}{\bar{\theta}_i^N}$, $\beta_i^\varphi \equiv \frac{\omega}{\bar{\theta}_i^N}$, and $\Delta a_i \equiv \frac{\gamma}{\bar{\theta}_i^N} \Delta log \left[\frac{\bar{\gamma}_i^N \bar{A}_i^T}{\bar{\gamma}_i^T \bar{A}_i^N}\right]$. Equation (16) states that, in addition to the 'Intermediate Inputs', 'Capital-Deepening', and 'Balassa-Samuelson' terms already present in equation (7), the real exchange rate in this model also depends on the relative price of tradables. To conduct the decomposition in (16), we obtain the relative price of tradables that is consistent with the model and with data on trade flows. In particular, we use equation (15) to write:

$$log \left[\varphi_i^T Y_{ni}^T / \varphi_n^T Y_{nn}^T\right] = s_i + d_n + log \omega_{ni}. \tag{17}$$

Here $s_i \equiv [1-\rho] \, log \varphi_i$ and $d_n \equiv [\rho - 1] \, log \varphi_n$ can be estimated by OLS regression from equation (17) as source and destination dummies under the restriction that $s_i = -d_i$. The bilateral preference term ω_{ni} can be obtained as the residual of this regression. Using the estimates on s_i, we recover the prices φ_i by setting an elasticity of substitution of $\rho = 6$, consistent with a trade elasticity of 5 as obtained from Eaton and Kortum (2002). Finally, using these estimates, P_i^T can be then recovered from equation (14). Appendix A details this estimation and plots the decomposition of equation (16) for countries in the WIOD. It shows that the sectorial differences in input shares are still important in accounring for the elasticity of the real exchange rate with respect to GDP per capita.

6 Conclusion

This paper proposes a mechanism to account for the relation between real exchange rates and GDP per capita. If the share of intermediate inputs in the production of tradables is relatively high and the price of tradables is equalized across countries, the price of non-tradables should increase with GDP per capita. The intuition is that the input multiplier will be larger for tradables in this case. Since this mechanism acts independently of the differences in the level of productivities across sectors, it can be easily evaluated using input-output data. We show that differences in input shares across tradable and non-tradable sectors can account for about a third of the elasticity of the real exchange rates to income per capita.

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Appendix A Armington Model

A.1 Setup

Preliminaries: We consider a world economy with I countries indexed by i and n. Each country produces 2 goods indexed by $j = T, N$. Production uses labor, capital, and intermediate inputs. Tradable goods are differentiated by country of origin. We index the tradable goods by T, while the remaining J goods can be grouped in a non-tradable sector labeled by N. Each country is endowed with K_i and L_i efficiency units of capital and labor, respectively. The final output of each sector can be used for consumption or as an intermediate input in the production of any sector. All factor and goods markets are perfectly competitive.

Preferences: The utility of the representative household in country i is given by

$$C_i = C_i^{T\,1-\gamma_i} C_i^{N\,\gamma_i}, \tag{A.1}$$

where C_i^T is a bundle of tradable goods from different source countries, and C_i^N is a bundle of non-tradables produced in country i. The household's budget constraint is given by

$$W_i L_i + R_i K_i = P_i C_i + P_i I_i + NX_i \equiv GDP_i. \tag{A.2}$$

Here, W_i and R_i denote the wages and the return to capital, and $P_i \equiv \gamma_i^{-\gamma_i} (1-\gamma_i)^{\gamma_i - 1} P_i^{T\,1-\gamma_i} P_i^{N\,\gamma_i}$ is the price level of GDP. I_i denotes total investment. NX_i are net transfers from country i to the rest of the world, which for the purpose of our exercise are an exogenous fraction of GDP_i, that is $NX_i \equiv nx_i GDP_i$. Note that if $nx_i < 0$ the country is running a trade deficit. We can re-write this equation as:

$$[P_i C_i + P_i I_i] = GDP_i \left[1 - nx_i\right]. \tag{A.3}$$

Producers of intermediate goods: The production function for good j is given by:

$$Y_i^j = Z_i \bar{A}_i^j \left[L_i^{j\,1-\alpha_i^j} K_i^{j\,\alpha_i^j} \right]^{\theta_i^j} \left[\left[M_i^{T,j}\right]^{\sigma_i^{Tj}} \left[M_i^{N,j}\right]^{\sigma_i^{Nj}} \right]^{\left[1-\theta_i^j\right]}, \tag{A.4}$$

where Y_i^j, L_i^j and K_i^j denote gross output, employment, and capital in country i and sector j, while $M_i^{T,j}$ and $M_i^{N,j}$ denote tradable and non-tradable intermediate inputs used in the production of sector j.[29] θ_i^j and α_i^j denote the share of value-added in gross output and the share of capital in value-added respectively. Note that production in sector j can potentially use both tradable and non-tradable inputs. The share of tradable and non-

[29] Note that for simplicity, we have assumed that all the sectors use the same non-tradable composite, though the shares of the tradable and non-tradable composites can vary across sectors.

tradable inputs used in sector j is given by $\sigma_i^{Tj} \times \left[1-\theta_i^j\right]$ and $\sigma_i^{Nj} \times \left[1-\theta_i^j\right]$ respectively, where $\sigma_i^{Tj} + \sigma_i^{Nj} = 1$. As in the previous section, $Z_i \times \bar{A}_i^j$ is a productivity term that has an aggregate and a sector-specific component.

Final good producers in each country i aggregate tradable intermediates from different source countries according to the aggregator

$$G_i^T = \left[\sum_{n=1}^{N} \omega_{ni}^{\frac{1}{\rho}} Y_{ni}^{T\,\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}, \tag{A.5}$$

where Y_{ni}^T denotes country $i's$ absorption of tradable good from country n, ρ is the elasticity of substitution across tradable goods from different source countries, and the parameters ω_{ni} control the share of goods from country n in total absorption of tradables by country i.

Intratemporal equilibrium A competitive equilibrium is a set of final and intermediate goods prices $\{P_i^T, P_i^N\}_{\forall_i}$ and $\{\varphi_i^T\}_{\forall_i}$, factor prices $\{W_i, R_i\}_{\forall_i}$, final and intermediate goods quantities, $\{G_i^T, G_i^N, C_i^T, C_i^N, I_i^T, I_i^N\}_{\forall_i}$, and $\{Y_i^T\}_{\forall_i}$ and $\{Y_{in}^T\}_{\forall_{i,n}}$, and factor allocations $\left\{L_i^j, K_i^j, M_i^{T,j}, M_i^{N,j}\right\}_{\forall_{i,j=\mathrm{T,N}}}$, such that, given factor supplies $\{L_i, K_i\}_{\forall_i}$ transfers $\{NX_i\}_{\forall_i}$ and investment $\{I_i\}_{\forall_i}$:

i. **Households maximize utility subject to their budget constraints:** This implies demands given by

$$P_i^T C_i^T = \frac{1-\gamma_i}{\gamma_i} P_i^N C_i^N \tag{A.6}$$

and the budget constraint in (A.2) is satisfied.

ii. **Producers of final investment minimize costs:**

$$P_i^T I_i^T = [1-\gamma_i]\, P_i I_i \tag{A.7}$$

$$P_i^N I_i^N = \gamma_i P_i I_i \tag{A.8}$$

iii. **Final goods producers of tradable goods minimize costs:** Cost minimization implies that demands for intermediate tradable goods are

$$\varphi_i^T Y_{in}^T = \omega_{in} \left[\frac{\varphi_i^T}{P_n^T}\right]^{1-\rho} P_n^T G_n^T, \tag{A.9}$$

and that the price of the aggregate tradable good is given by

$$P_i^T = \left[\sum_{n=1}^{N} \omega_{ni} \varphi_n^{T1-\rho} \right]^{\frac{1}{1-\rho}}. \tag{A.10}$$

iv. **Intermediate producers minimize costs:** Cost minimization implies that intermediate prices are given by:

$$\varphi_i^T = \bar{\gamma}_i^T W_i^{\left[1-\alpha_i^T\right]\theta_i^T} R_i^{\alpha_i^T \theta_i^T} \left[\left[P_i^T\right]^{\sigma_i^{TT}} \left[P_i^N\right]^{\sigma_i^{NT}} \right]^{\left[1-\theta_i^T\right]} / \left[\bar{A}_i^T Z_i\right], \tag{A.11}$$

where $\bar{\gamma}_i^j$ is a constant. Non-tradable prices are given by:

$$P_i^N = \bar{\gamma}_i^N W_i^{\left[1-\alpha_i^N\right]\theta_i^N} R_i^{\alpha_i^N \theta_i^N} \left[\left[P_i^T\right]^{\sigma_i^{TN}} \left[P_i^N\right]^{\sigma_i^{NN}} \right]^{\left[1-\theta_i^N\right]} / \left[\bar{A}_i^N Z_i\right]. \tag{A.12}$$

Factor and input demands satisfy:

$$W_i L_i^T = \theta_i^T \left[1 - \alpha_i^T\right] \varphi_i^T Y_i^T \tag{A.13}$$

$$R_i K_i^T = \theta_i^T \alpha_i^T \varphi_i^T Y_i^T \tag{A.14}$$

$$P_i^T M_i^{T,T} = \left[1 - \theta_i^T\right] \sigma_i^{TT} \varphi_i^T Y_i^T \tag{A.15}$$

$$P_i^N M_i^{N,T} = \left[1 - \theta_i^T\right] \sigma_i^{NT} \varphi_i^T Y_i^T, \tag{A.16}$$

and

$$W_i L_i^N = \theta_i^N \left[1 - \alpha_i^N\right] P_i^N G_i^N \tag{A.17}$$

$$R_i K_i^N = \theta_i^N \alpha_i^N P_i^N G_i^N \tag{A.18}$$

$$P_i^T M_i^{T,N} = \left[1 - \theta_i^N\right] \sigma_i^{TN} P_i^N G_i^N \tag{A.19}$$

$$P_i^N M_i^{N,N} = \left[1 - \theta_i^N\right] \sigma_i^{NN} P_i^N G_i^N \tag{A.20}$$

v. **Markets clear:** Market clearing for intermediate tradable goods implies:

$$Y_i^T = \sum_n Y_{in}^T. \tag{A.21}$$

Market clearing for final goods implies:

$$G_i^T = C_i^T + I_i^T + M_i^{T,T} + M_i^{T,N} \tag{A.22}$$

$$G_i^N = C_i^N + I_i^N + M_i^{N,T} + M_i^{N,N}, \tag{A.23}$$

Factor market clearing implies:

$$L_i = L_i^T + L_i^N \tag{A.24}$$
$$K_i = K_i^T + K_i^N. \tag{A.25}$$

Note that, after choosing the numeraire, $20 \times I - 1 + I^2$ variables must be determined in equilibrium. Equations (A.2) and (A.6)-(A.25) give a system of $20 \times I - 1 + I^2$ independent equations, since the market clearing conditions together with the budget constraints make one budget constraint redundant.

A.2 Relative prices and GDP per capita

We now evaluate the relation between relative prices and GDP per capita in this model. Combining equations (A.11) and (A.12) we can write the relative price of non-tradables to tradables as:

$$\frac{P_i^N}{P_i^T} = \left[\frac{\bar{\gamma}_i^N \bar{A}_i^T}{\bar{\gamma}_i^T \bar{A}_i^N}\right]^{\frac{1}{\bar{\theta}_i^N}} \left[\frac{\varphi_i^T}{P_i^T}\right]^{\frac{1}{\bar{\theta}_i^N}} \left[P_i^T\right]^{\frac{\theta_i^T - \theta_i^N}{\bar{\theta}_i^N}} \left[W_i^{\theta_i^N - \theta_i^T} \left[\frac{R_i}{W_i}\right]^{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T}\right]^{\frac{1}{\bar{\theta}_i^N}}.$$

The aggregate price level is:

$$P_i = \left[P_i^T\right]^{1-\omega_i} \left[P_i^N\right]^{\omega_i}$$

We can then write the (log) real exchange rate as:

$$q_i = \beta_i^{gdp} \Delta gdp_i + \beta_i^k \Delta k_i^y + \beta_i^p \Delta p_i^T + \Delta log \varphi_i^T + \Delta a_i,$$

with $\beta_i^{gdp} \equiv \omega \frac{\theta_i^N[1-\alpha_i^N] - \theta_i^T[1-\alpha_i^T]}{\bar{\theta}_i^N}$, $\beta_i^k \equiv \omega \frac{\alpha_i^T \theta_i^T - \alpha_i^N \theta_i^N}{\bar{\theta}_i^N}$, $\beta_i^p \equiv 1 - \omega \frac{1-[\theta_i^T - \theta_i^N]}{\bar{\theta}_i^N}$, $\beta_i^p \equiv \frac{\omega}{\bar{\theta}_i^N}$, and $\Delta a_i \equiv \frac{\gamma}{\bar{\theta}_i^N} \Delta log \left[\frac{\bar{\gamma}_i^N \bar{A}_i^T}{\bar{\gamma}_i^T \bar{A}_i^N}\right]$.

To conduct the decomposition in equation (16), we need to evaluate the model's predictions of the relative price of tradables across countries. Taking logs and re-arranging equation (A.9), we can write:

$$log \frac{\varphi_i^T Y_{in}^T}{\varphi_n^T Y_{nn}^T} = \underbrace{[1-\rho]\, log \varphi_i^T}_{s_i} \underset{+}{+} \underbrace{[1-\rho]\, log \varphi_n^T}_{d_n} \underset{+}{+} \underbrace{log \omega_{in}}_{\epsilon_{in}}. \tag{A.26}$$

Note that the terms $[1-\rho]\, log \varphi_i^T$ and $[1-\rho]\, log \varphi_n^T$ are constant across source countries and destination countries respectively, and can be estimated by OLS using source and destination country dummies. With this in mind, we obtain the relative price of tradables by estimating equation (A.26) under the restriction $s_i = -d_i$ by OLS. We then recover the price of the tradable good in each country i as

$$\hat{\varphi}_i^T = exp\left[\frac{\hat{s}_i}{1-\rho}\right],$$

and using an elasticity of substitution of $\rho = 6$, consistent with a trade elasticity of 5, as estimated by Eaton and Kortum (2002). We can also estimate the taste parameters ω_{in} from the residuals in the regression. The we can recover the relative price of tradables by plugging $\hat{\varphi}_i^T$ and $\hat{\omega}_{in}$ in equation (A.10). The decomposition in equation (16) is plotted in Figure A.5.

Table A1: ICP-ICIO Concordance

ICP	ICIO	ICIO	Tradable
Health	Health & Social Work	85	N
Transport	Transport & Storage	60t63	N
Communication	Post & Telecommunications	64	N
Recreation & Culture	Other community, Social & Personal Services	90t93	N
Education	Education	80	N
Restaurants & Hotels	Hotels & Restaurants	55	N
Food & Non-Alcohol	Food Products, Beverages & Tobacco	15t16	Y
Alcohol, Tobacco, & Narcotics	Food Products, Beverages & Tobacco	15t16	Y
Clothing & Footwear	Textiles, Textile Products, Leather & Footwear	17t19	Y

Table A2: Intermediate input shares in gross output by sector

Country	Trad.	Non-trad.	ω^N	Health	Trans.	Comm.	Rec.	Educ.	Rest.	Cons.
AUS	0.40	0.52	0.80	0.67	0.44	0.49	0.59	0.75	0.46	0.31
AUT	0.32	0.53	0.79	0.62	0.40	0.44	0.56	0.83	0.61	0.40
BEL	0.21	0.50	0.85	0.60	0.33	0.53	0.41	0.88	0.38	0.28
BGR	0.26	0.47	0.72	0.57	0.31	0.56	0.44	0.78	0.58	0.26
BRA	0.30	0.61	0.76	0.56	0.47	0.50	0.51	0.71	0.42	0.52
BRN	0.77	0.59	0.30	0.66	0.72	0.80	0.52	0.86	0.43	0.21
CAN	0.40	0.60	0.78	0.82	0.56	0.63	0.58	0.78	0.50	0.43
CHE	0.36	0.57	0.79	0.68	0.35	0.52	0.45	0.73	0.51	0.47
CHL	0.42	0.55	0.69	0.61	0.34	0.48	0.69	0.81	0.45	0.53
CHN	0.24	0.43	0.53	0.41	0.47	0.60	0.45	0.58	0.40	0.25
COL	0.48	0.60	0.67	0.40	0.44	0.55	0.57	0.79	0.46	0.50
CRI	0.33	0.60	0.77	0.69	0.48	0.51	0.65	0.85	0.47	0.42
CYP	0.33	0.61	0.91	0.65	0.54	0.63	0.58	0.87	0.49	0.37
CZE	0.23	0.43	0.72	0.59	0.37	0.54	0.40	0.75	0.41	0.29
DEU	0.31	0.57	0.75	0.70	0.36	0.42	0.60	0.77	0.50	0.43
DNK	0.34	0.52	0.83	0.70	0.26	0.43	0.52	0.73	0.38	0.37
ESP	0.30	0.60	0.83	0.64	0.42	0.48	0.55	0.85	0.63	0.50
EST	0.27	0.46	0.77	0.61	0.28	0.42	0.43	0.70	0.34	0.32
FIN	0.26	0.53	0.79	0.65	0.39	0.47	0.53	0.70	0.41	0.35
FRA	0.25	0.58	0.87	0.75	0.46	0.44	0.53	0.82	0.47	0.45
GBR	0.35	0.53	0.85	0.51	0.42	0.52	0.54	0.70	0.47	0.41
GRC	0.33	0.65	0.86	0.70	0.44	0.79	0.57	0.91	0.73	0.29
HKG	0.16	0.56	0.98	0.71	0.40	0.28	0.51	0.74	0.53	0.51
HRV	0.35	0.53	0.76	0.67	0.47	0.55	0.47	0.79	0.57	0.33
HUN	0.23	0.53	0.73	0.58	0.41	0.60	0.51	0.76	0.36	0.41
IDN	0.51	0.51	0.50	0.46	0.40	0.78	0.50	0.60	0.45	0.35
IND	0.35	0.63	0.66	0.60	0.44	0.58	0.74	0.90	0.27	0.35
IRL	0.31	0.46	0.71	0.56	0.31	0.42	0.41	0.76	0.46	0.26
ISL	0.33	0.48	0.78	0.54	0.25	0.35	0.48	0.56	0.38	0.34
ISR	0.34	0.59	0.83	0.49	0.43	0.62	0.48	0.75	0.44	0.46
ITA	0.28	0.54	0.81	0.63	0.39	0.50	0.49	0.85	0.47	0.43
JPN	0.31	0.63	0.80	0.60	0.58	0.56	0.67	0.80	0.45	0.49

Table A2: Intermediate input shares in gross output by sector

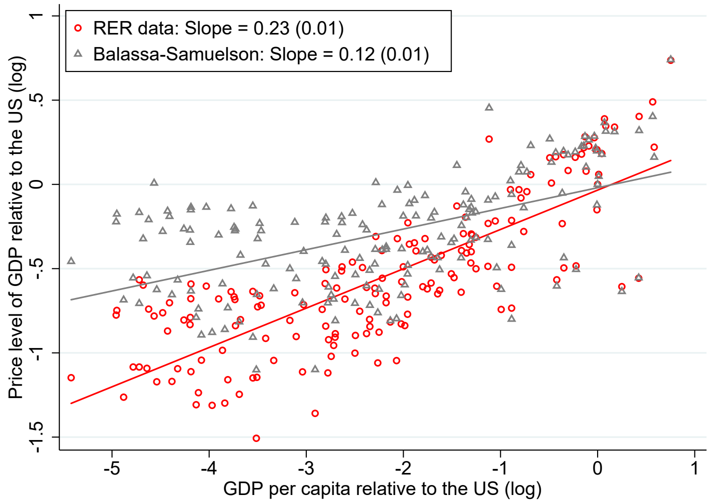
Country	Trad.	Non-trad.	ω^N	Health	Trans.	Comm.	Rec.	Educ.	Rest.	Cons.
KHM	0.45	0.53	0.46	0.62	0.47	0.56	0.70	0.70	0.38	0.48
KOR	0.21	0.51	0.66	0.55	0.33	0.39	0.50	0.76	0.33	0.35
LTU	0.30	0.65	0.75	0.63	0.65	0.66	0.61	0.80	0.72	0.53
LUX	0.28	0.34	0.93	0.75	0.45	0.40	0.62	0.83	0.49	0.40
LVA	0.28	0.43	0.80	0.61	0.36	0.40	0.49	0.74	0.39	0.21
MEX	0.43	0.72	0.69	0.75	0.73	0.61	0.64	0.90	0.74	0.50
MLT	0.34	0.41	0.84	0.68	0.30	0.48	0.26	0.83	0.37	0.35
MYS	0.26	0.46	0.53	0.34	0.27	0.49	0.33	0.64	0.38	0.25
NLD	0.28	0.53	0.81	0.73	0.40	0.47	0.44	0.78	0.51	0.36
NOR	0.53	0.53	0.64	0.78	0.28	0.39	0.52	0.78	0.49	0.38
NZL	0.31	0.51	0.79	0.63	0.42	0.50	0.51	0.71	0.46	0.30
PHL	0.36	0.60	0.66	0.52	0.44	0.61	0.49	0.68	0.37	0.55
POL	0.27	0.52	0.75	0.60	0.38	0.53	0.54	0.81	0.53	0.34
PRT	0.26	0.54	0.83	0.56	0.41	0.49	0.50	0.85	0.49	0.34
ROU	0.39	0.46	0.67	0.53	0.40	0.53	0.53	0.81	0.46	0.35
SAU	0.77	0.58	0.40	0.54	0.52	0.52	0.49	0.80	0.46	0.39
SGP	0.22	0.43	0.79	0.54	0.34	0.44	0.49	0.69	0.46	0.23
SVK	0.23	0.48	0.74	0.57	0.34	0.53	0.62	0.75	0.52	0.39
SVN	0.29	0.51	0.76	0.63	0.34	0.47	0.45	0.76	0.48	0.31
SWE	0.31	0.53	0.80	0.72	0.32	0.41	0.50	0.67	0.37	0.44
THA	0.29	0.52	0.56	0.46	0.33	0.59	0.29	0.78	0.34	0.22
TUN	0.37	0.64	0.67	0.68	0.64	0.77	0.86	0.90	0.58	0.30
TUR	0.26	0.58	0.71	0.51	0.49	0.55	0.53	0.78	0.44	0.43
TWN	0.20	0.60	0.72	0.61	0.35	0.56	0.52	0.80	0.51	0.29
USA	0.35	0.61	0.84	0.61	0.51	0.55	0.61	0.74	0.53	0.53
VNM	0.32	0.49	0.47	0.61	0.49	0.71	0.68	0.68	0.52	0.26
ZAF	0.32	0.54	0.75	0.46	0.53	0.41	0.70	0.51	0.45	0.30
Mean	**0.33**	**0.54**	**0.73**	**0.61**	**0.42**	**0.53**	**0.53**	**0.76**	**0.47**	**0.37**

Table A3: Industry Tradability

Sector	Code	Feenstra	AMECO
C01T05	Agriculture, hunting, forestry and fishing	T	T
C10T14	Mining and quarrying	T	T
C15T16	Food products, beverages and tobacco	T	T
C17T19	Textiles, textile products, leather and footwear	T	T
C20	Wood and products of wood and cork	T	T
C21T22	Pulp, paper, paper products, printing and publishing	T	T
C23	Coke, refined petroleum products and nuclear fuel	T	T
C24	Chemicals and chemical products	T	T
C25	Rubber and plastics products	T	T
C26	Other non-metallic mineral products	T	T
C27	Basic metals	T	T
C28	Fabricated metal products	T	T
C29	Machinery and equipment, nec	T	T
C30T33X	Computer, Electronic and optical equipment	T	T
C31	Electrical machinery and apparatus, nec	T	T
C34	Motor vehicles, trailers and semi-trailers	T	T
C35	Other transport equipment	T	T
C36T37	Manufacturing nec; recycling	T	T
C40T41	Electricity, gas and water supply	N	N
C45	Construction	N	N
C50T52	Wholesale and retail trade; repairs	N	T
C55	Hotels and restaurants	N	T
C60T63	Transport and storage	N	T
C64	Post and telecommunications	N	N
C65T67	Financial intermediation	N	N
C70	Real estate activities	N	N
C71	Renting of machinery and equipment	N	N
C72	Computer and related activities	N	N
C73T74	R&D and other business activities	N	N
C75	Public admin. and defense; compulsory social security	N	N
C80	Education	N	N
C85	Health and social work	N	N
C90T93	Other community, social and personal services	N	N

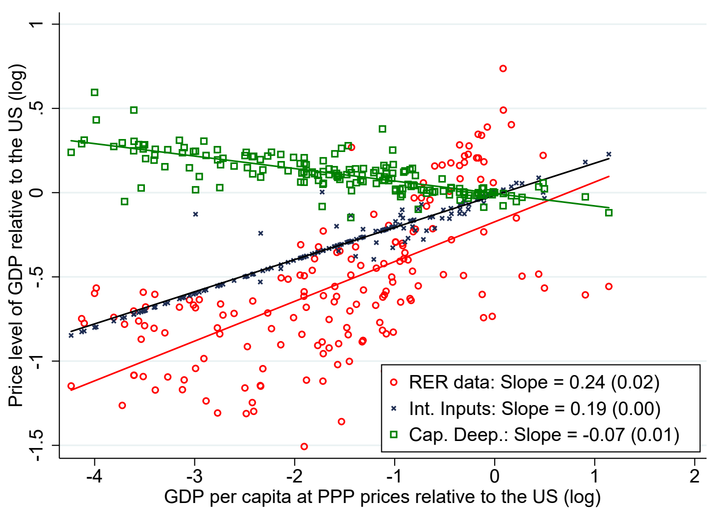
Notes: The Table reports the average and median sectorial labor shares for the countries in our sample Source: Authors calculations based on ICIO Tables and the PWT.

Figure A.1: Real exchange rates and sectorial differences in technologies



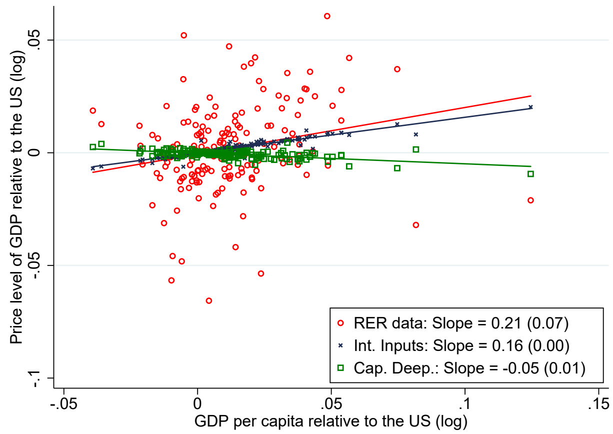
Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT 9.0. 'Balassa-Samuelson' corresponds to the relative prices implied by the term labeled 'Balassa-Samuelson' in equation (7).

Figure A.2: Real exchange rates and GDP per capita at PPP prices



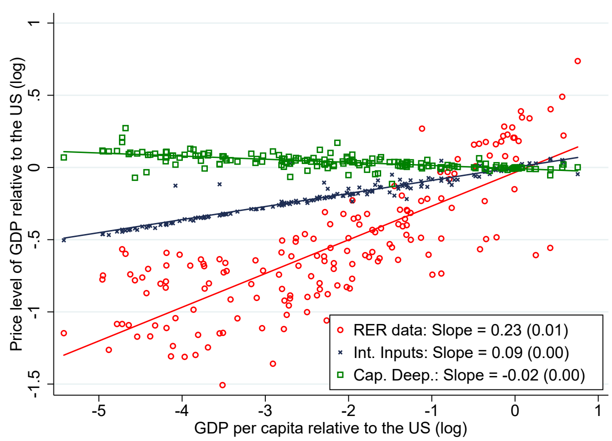
Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US measured at PPP prices. The x-axis measures GDP per capita in PPP dollars, relative to the US, obtained from the PWT 9.0. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT. 'Int. Inputs' and 'Cap. Deep.' are the relative price implied by the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (11).

Figure A.3: Real exchange rates and GDP growth



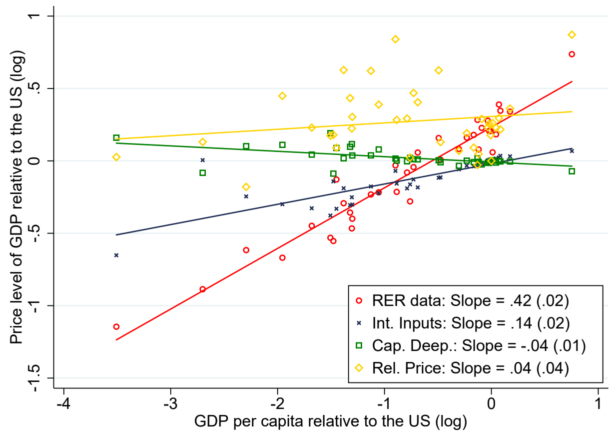
Notes: This figure plots the relation between the log change in the price level of each country relative to the US to the log of change GDP per capita relative to the US. The x-axis measures the 1997-2014 growth of GDP per capita in PPP dollars, relative to the US, obtained from the PWT 9.0. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT. 'Int. Inputs' and 'Cap. Deep.' are the relative price implied by the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' in equation (12).

Figure A.4: Real exchange rates and GDP per capita: Alternative classification of the tradable sector



Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US measured at market prices. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT. 'Int. Inputs' and 'Cap. Deep.' are the relative price implied by the terms labeled 'Intermediate Inputs' and the 'Capital-Deepening' terms in equation (7), where the parameters used to compute these terms are obtained after classifying the Agriculture, Mining, Manufacturing, Wholesale and Retail trade, Hotel & Restaurant, Transport, and Utility and Storage industries as tradables, following AMECO.

Figure A.5: Real exchange rates and GDP per capita: Differentiated Homogeneous goods



Notes: This figure plots the relation between the log of the price level of each country relative to the US and the log of GDP per capita relative to the US. 'RER data' refers to the relative price of GDP relative to the US obtained from the PWT. 'Int. Inputs' and 'Cap. Deep.' and 'Rel. Price' are the relative price implied by the terms labeled 'Intermediate Inputs' and 'Capital-Deepening' and 'Relative Price of Tradables' in equation (16).