REAL EXCHANGE RATES, INCOME PER CAPITA, AND SECTORAL INPUT SHARES

Javier Cravino and Sam Haltenhof*

Abstract—Aggregate price levels are positively related to GDP per capita across countries. We propose a mechanism that rationalizes this observation through sectoral differences in intermediate input shares. As productivity and income grow, so do wages relative to intermediate input prices, which increases the relative price of nontradables if tradable sectors use intermediate inputs more intensively. We show that sectoral differences in input intensities can account for about half 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.

I. 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 nontradable sectors increases with income. According to this theory, the price level is determined by the price of nontradables, and high productivity in tradables leads to high wages and high nontradable 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.

In spite of its popularity, empirical evidence supporting the Balassa-Samuelson hypothesis is scarce. An important limitation is that since sectoral 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 sectoral productivity growth, often with mixed results.3

This paper evaluates an alternative mechanism linking real exchange rates to GDP per capita that relies on sectoral differences in input intensities rather than on cross-country differences in sectoral productivities, and hence can be easily quantified using data on sectoral input shares. The mechanism was first noted by Bhagwati (1984), who argued that if the tradable sector is capital intensive, the relative price of nontradables should be higher in rich, capital-abundant countries where capital is relatively cheap. Our main contribution is to extend this idea to incorporate sectoral differences in intermediate input shares, which we show are much larger in tradable than in nontradable 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 nontradables and the aggregate price level.

We quantify this mechanism by incorporating differences in input intensities across tradable and nontradable sectors into a textbook open economy model.4 In the model, goods and factor markets are competitive, and the price of tradables is equalized across countries. Differences in GDP per capita across countries may arise either from differences in aggregate or sector-specific productivity. The relationship between real exchange rate levels and GDP per capita is shaped by three mechanisms. First, real exchange rates are shaped by sectoral differences in intermediate input shares coupled with cross-country differences in real wages, as explained above. Second, real exchange rates depend on differences in capital shares across sectors and cross-country differences in the stock of capital per capita, as (1984) proposed. Crucially, since these two mechanisms depend only on sectoral factor and input intensities, and not on the relative levels of sectoral productivity, they can be quantified directly using publicly available data. Finally, real exchange rates are also shaped by cross-country differences in sectoral technology, as in the standard Balassa-Samuelson model. As highlighted above, this effect cannot be quantified directly without data on sectoral productivity levels in each country.5

We show that the observed differences in input shares across sectors account for about half of the elasticity of the aggregate price level with respect to GDP per capita. In particular, we write the real exchange rate of each country relative to the United States as the sum of three terms that capture the mechanisms described above. Differences in intermediate input shares across tradable and nontradable sectors imply an elasticity of the real exchange rate to GDP per capita of 0.16, more than two-thirds of the 0.23 elasticity measured

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* Cravino: University of Michigan and NBER; Haltenhof: University of Michigan.

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1 See Rogoff (1996) or Feenstra, Inklaar, and Timmer (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 Sectoral productivity measures are typically available in index form only.

3 In particular, a large literature finds that the Balassa-Samuelson model does not do well in explaining real exchange rates except in the very long run. See, for example, de Gregorio, Giovannini, and Krueger (1994), Rogoff (1996), Taca and Druzie (2006), Lothian and Taylor (2008) and Chong, Jord, and Taylor (2012).

3 See, for example, Obstfeld and Rogoff (1996).

5 In turn, measures of sectoral productivity levels can only be constructed as a residual using data on sectoral relative price levels, as Inklaar and Timmer (2014) did. In contrast, our mechanism can be quantified independently of the sectoral price data.
The elasticity implied by sectoral differences in capital shares is $-0.05$. Contrary to Bhagwati’s hypothesis, the share of capital in gross output is actually larger in nontradable than in tradable sectors. Together, the sectoral differences in input intensities generate an elasticity of 0.11, almost half the elasticity in the data. The residual component of the slope coefficient (0.12) can be attributed to differences in sectoral technologies, as in the Balassa-Samuelson model. We note, however, that this residual could be capturing other factors driving real exchange rates not included in the model, such as differences in the price of tradables across countries. Our main focus is to assess how much of the observed slope between the aggregate price level and income per capita can be accounted for by the observed differences in input shares rather than on measuring the Balassa-Samuelson effect (which is captured in our residual, potentially along with other factors).

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 nontradables for industries where the share of intermediate inputs is lower than for the nontradable 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 do so only 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 sectoral technologies across countries, differences in sectoral value-added productivity across countries arise endogenously from sectoral differences in intermediate 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 sectoral value-added productivities arise endogenously from observed intermediate input shares, so they can be quantified directly from aggregate data. Second, while sectoral differences in intermediate inputs intensities have been ignored in the literature, real exchange rate measures are typically based on data on final prices. Since final prices reflect the costs of all the inputs used in production (and not just the value-added costs), incorporating intermediate inputs in the analysis makes the prices in the theory consistent with the price data.

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

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

7In 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.

8We extend the baseline model to allow for differentiated tradable goods in section VC.

9Alternatively, one can start from value-added production functions and work with “value-added” price data. Herrendorf, Rogerson, and Valentinyi (2013) and Bems and Johnson (2017) are two examples that compute “value-added” prices.

10See Rogoff (1996) for a summary of the early literature on this topic and Inklaar and Timmer (2014) for recent evidence based on the new ICP data. Bergin, Glick, and Taylor (2006) explain why the observed relation...
relationship between productivity and real exchange rate growth, but in most cases has only found evidence of a long-run relationship such as cointegration. In a recent series of papers, Berka, Devereux, and Engel (2012, 2018) 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 sectoral 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 sectoral productivity, we can quantify it in both growth rates and levels for a broad set of countries.

Another related strand of literature uses microdata to study deviations from the law of one price for detailed goods. Boivin, Clark, and Vincent (2012) show that violations of the law of one price arise even for reset prices using data from three online book sellers in Canada and the United States. Cavallo, Neiman, and Rigobon (2014) study deviations of the law of one price (LOOP) for online prices of identical goods sold by four large global retailers and show that LOOP holds very well within currency unions. Crucini and Yilmazkuday (2014) document that trade costs and good-specific markups are an important source of deviations from LOOP for detailed tradable goods and that these deviations tend to average out at the aggregate level. In contrast to this literature, our focus is on understanding the correlation between the aggregate price level and income per capita. To do so, we mostly abstract from deviations of LOOP for tradable goods at the microlevel, which wash out in the aggregate, as Crucini and Yilmazkuday (2014) noted. We instead concentrate on the relative price of nontradable goods since its relation with income per capita is much stronger than for the purely tradable component of prices, a view supported by Berka and Devereux (2013) and Feenstra et al. (2015) among others, and by the PWT data in figure 1b.

The rest of the paper is organized as follows. Section II uses a simple model to illustrate our main mechanisms relating real exchange rate levels to GDP per capita. Section III describes a more detailed model incorporating capital as a factor of production and a richer input-output structure, which we use for our quantification. Section IV describes the data. Section V presents the quantitative results, and section VI concludes.

II. Intermediate Input Shares and Sectoral Relative Prices

This section develops a simple model to show how sectoral 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 nontradables, using labor and intermediate inputs. For the moment, assume that production does not use intermediate inputs that are produced in other sectors. 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

$$Y^j = Z \bar{A} L^{\theta^j} M^{1-\theta^j},$$

where $L^j$ and $M^j$ denote labor and intermediate inputs used in sector $j$, $\theta^j$ is the share of value added in gross output, and $Z \bar{A}^j$ 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

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

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

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

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

Let $P \equiv \left[P^N\right]^{\omega}$ denote the aggregate price level of GDP in terms of the tradable good, where $\omega$ is the share of nontradables in GDP. In addition, let the lowercase of a variable denote the log of the variable, with $\Delta x \equiv x - x_0$ 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

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

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

Equation (2) relates relative price levels to cross-country differences in relative sectoral productivities and cross-country differences in GDP per capita. 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

11That is, nontradables are not used in the production of tradables, and vice versa.
12Section VC shows how to extend our baseline framework to allow for LOOP deviations for tradable goods.
nontradable 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 sectoral productivity $\Delta a^T = 0$.

Of course, cross-country differences in GDP per capita are endogenous, and in this model, they may arise from either cross-country differences in aggregate or in sectoral productivity, $Z$ or $A^j$. In particular, using equation (1) for tradables to and substituting in equation (2), we can write

$$q = \frac{\omega_i}{\theta N} \left[ (\theta N - \theta T) \frac{\Delta a^T + \Delta z^j}{\theta N^T + \Delta a^T} \right],$$

(3)

where the difference in GDP across countries is given by the term in the brace. Given data on $\Delta d^p$, and irrespective of whether it arises from $\Delta a^T$ or $\Delta z$, we can implement equation (4) and ask what the difference is in price levels arising from the difference input shares. The observed differences in input shares alone imply that a log point difference in GDP per capita should result in a $\omega_i (\theta N - \theta T)/\theta N^T$ log point difference in the price level. Clearly, the overall elasticity of $q$ with respect to $\Delta d^p$ will be larger if the differences in GDP per capita arise from $\Delta a^T$. The focus of this paper is to quantify the part of the elasticity that we can directly measure using aggregate data on input intensities (i.e., the part arising from differences in input shares) rather than to estimate the elasticity of the price level arising from $\Delta a^T$ versus $\Delta z$.

A. Value-Added Production Functions and Mapping to the Balassa-Samuelson Model

We can write the production functions in this model in value-added terms 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

$$V^j = B^j L^j,$$

(4)

where $B^j \equiv [Z A^j]^{z^j}$.

The equation shows that even if there are no differences in gross-output productivity across sectors, $A^j = 1$, sectoral differences in value-added productivity, $B^j$, can arise endogenously from differences in the share of intermediate inputs in production, $\theta^j$. The intuition for this result is that as Jones (2011) noted, 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 nontradable 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 (4). We highlight two important advantages of incorporating sectoral differences in intermediate-input shares explicitly in the model. First, while sectoral differences in intermediate-input intensities have been ignored in the literature, real exchange rate measures are typically based on data on final prices. Since final prices reflect the costs of all the inputs used in production (and not just the costs of the value added that go into production), incorporating intermediate inputs in the analysis makes the prices in the theory consistent with the prices that we measure in the data. Second, while the Balassa-Samuelson model simply assumes how differences in sectoral productivities change with development (i.e., the model assumes a correlation between $B^j/B^N$ 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 important, differences in the relative level of productivity across sectors and countries are not measured by statistical agencies—that is, neither $A^j$ nor $B^j$ 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. A back-of-the-envelope calculation using equation (2) reveals that this channel is potentially large. Using U.S. values for $\theta N = 0.61$, $\theta T = 0.35$, and $\omega = 0.84$ indicates that given relative sectoral productivities, the elasticity of the relative price level of GDP with respect to relative GDP per capita is 0.38 versus 0.23 in the data in figure 1a. The remainder of the paper measures the importance of this channel in a more detailed quantitative framework that incorporates capital as a factor of production and allows for multiple nontradable sectors, a richer input-output structure, and differences in factor shares across countries.

III. Quantitative Framework

A. Production

The production function for good $j$ is given by

$$Y^j_i = Z_i A^j_i \left[ L^j_i \theta^{x, j} K_i^{\alpha^{x, j}} \right]^{\theta^j_i} \left[ \left( M_i^{F, j} \right)^{\sigma^T} \left( M_i^{N, j} \right)^{\sigma^N} \right]^{[1- \theta^j_i]},$$

(5)

where $Y^j_i$, $L^j_i$ and $K_i^{j}$ denote gross output, employment, and capital in country $i$ and sector $j$; $M_i^{F, j}$ is the quantity of tradable intermediate inputs used in the production of sector $j$; and $M_i^{N, j}$ is a composite of nontradable goods used in the production of $j$. $\theta^j_i$ and $\alpha^j_i$ 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

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16 This follows from the input demands that minimize costs, $M^j_i = \left[\left(1 - \theta^j_i\right) Z A^j_i\right]^{\sigma^j_i} L^j_i$.

17 An important exception is Bems and Johnson (2017) who estimate value-added real exchange rates.
tradable and nontradable inputs. The share of tradable and nontradable inputs used in sector \( j \) is given by \( \sigma^T_{ij} \times [1 - \theta^T_i] \) and \( \sigma^N_{ij} \times [1 - \theta^N_i] \), respectively, where \( \sigma^T_{ij} + \sigma^N_{ij} = 1 \). As in the previous section, \( Z_i \times \bar{A}_j \) is a productivity term that has an aggregate and a sector-specific component.

**B. Prices**

Perfect competition implies that the price of good \( j \) is given by

\[
P^j_i = \frac{\gamma^j_i W^j_i \left[ 1 - \sigma^j_i \right] / \theta^T_i \left[ \sigma^N_{ij} \theta^T_i \right] \left[ \bar{A}_j / Z_i \right]}{\left[ \bar{A}_j / Z_i \right]},
\]

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 \( \gamma^j_i \) is a constant.\(^{18}\) Taking logs, we can write the log-price of good \( j \) as

\[
p^j_i = \log \gamma^j_i - \tilde{a}_j + \theta^T_i \omega_i + \alpha^T_i \theta^T_i [r_i - w_i]
\]

\[+ \alpha^N_i \theta^N_i \left[ 1 - \theta^T_i \right] - z_i, \tag{6}
\]

where \( p^j_i \) is the (log of the) price for good \( j \) and \( p^T_i \equiv 0 \) given the choice of the numeraire. Let \( \omega^j_i \) denote the share of nontradable good \( j \) in the nontradable sector, so that \( \sum_j \omega^j_i \equiv 1 \). We can write the log of the nontradable price index as

\[
p^N_i \equiv \sum_j \omega^j_i p^j_i.
\]

In combination with equation (6), this implies

\[
p^N_i = \frac{\tilde{a}_T + \theta^N_i - \theta^T_i \omega_i + \alpha^N_i \theta^T_i \omega_i}{\theta^N_i} + \frac{\alpha^T_i \theta^T_i}{\theta^N_i} [r_i - w_i], \tag{7}
\]

where \( \tilde{a}_T \equiv \log \left[ \tilde{\gamma}^N_i / \tilde{\gamma}^T_i \right] + \tilde{a}_N + \tilde{a}_T \equiv \theta^N_i + \alpha^T_i \left[ 1 - \theta^N_i \right] + \alpha^T_i \left[ 1 - \theta^T_i \right]. \(^{19}\)

**C. Relative Prices and GDP per Capita**

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

\[
\frac{R_i}{W_i} = \frac{\bar{a}_i}{1 - \bar{a}_i} \frac{L_i}{K_i}.
\]

We can then write the (log) price of nontradables in terms of tradables as

\[
p^N_i = \frac{\theta^N_i - \theta^T_i}{\theta^N_i} \frac{\alpha^N_i \theta^N_i}{\theta^N_i} [r_i - w_i] + \frac{\theta^T_i - \theta^N_i}{\theta^N_i} \frac{\alpha^N_i \theta^N_i}{\theta^N_i} [r_i - w_i], \tag{8}
\]

where \( \log GDP_i \) 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 \( \tilde{a}_T \) captures country-specific productivity differences across the two sectors.\(^{20}\) Equation (8) links the price of nontradables 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, \( \theta^T_i > \theta^N_i \), the price of nontradables 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 nontradable sector uses capital more intensively, \( \alpha^N_i \theta^N_i > \alpha^T_i \theta^T_i \), the price of nontradables decreases with the capital-labor ratio in the economy, \( k_i \).

**D. 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 United States. The log of the price level of GDP in country \( i \) is defined as \( p_i = \omega^N_i p^N_i \), where \( \omega^N_i \) denotes the share of nontradables in country \( i \)'s GDP. Letting \( \Delta x_i \equiv x_i - x_{us} \) denote the log difference of a variable relative to the United States, we can write the log price of GDP in country \( i \) relative to the United States, \( q_i \equiv \omega^N_i \Delta p^N_i \), as

\[
q_i = \omega^N_i \frac{\theta^N_i - \theta^T_i}{\theta^N_i} \log GDP_i + \omega^N_i \frac{\alpha^N_i \theta^N_i}{\theta^N_i} \Delta k_i + \omega^N_i \Delta \tilde{a}_T,
\]

\[\text{‘Intermediate Inputs’} \quad \text{‘Capital-Deepening’} \quad \text{‘Residual’} \quad \tag{9}\]

\(^{18}\)Note that we have assumed that the price of capital \( R_i \) is country specific. We evaluate the implications of assuming that capital is internationally mobile (and its price is equalized across countries) in section VC.

The constant is given by \( \left[ \gamma_i \right]^{-1} \equiv \left[ 1 - \alpha_i \right]^{-1} \left[ \sigma^T_{ij} \theta^T_i \right]^{-1} \left[ \sigma^N_{ij} \theta^N_i \right]^{-1} \left[ 1 - \theta^T_i \right]^{-1} \left[ 1 - \theta^N_i \right]^{-1} \left[ \Pi_j \sigma^T_{ij} \right]^{-1} \left[ \Pi_j \sigma^N_{ij} \right]^{-1} \].

\(^{19}\)Note that in contrast to the simple model from section II, the elasticity of \( p^N_i \) with respect to \( \omega_i \) now depends on the input-output coefficients \( \sigma^T_{ij} \) and \( \sigma^N_{ij} \).

\(^{20}\)That is, \( k_i \equiv \log \frac{K_i}{L_i}, \quad \log GDP_i \equiv \log \frac{GDP}{L_i}, \quad \text{and} \quad \tilde{a}_T \equiv \log \frac{\alpha^T_i \theta^T_i}{\theta^N_i} \left[ 1 - \tilde{a}_T \right]^{-1} \left[ 1 - \tilde{a}_T \right]. \]

\(^{21}\)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 \( \left( \sum_j \omega_j \left[ p^j_i - p^j_{us} \right] \right) \) as opposed to differences in the weighted average of price levels \( \left( \sum_j \omega_j p^j_i - \sum_j \omega_j p^j_{us} \right) \).
where

\[
\Delta \alpha_i^T \equiv \frac{n_i^T}{\bar{N}_i} - \frac{n_i^T}{\bar{N}_i} + \left( \alpha_i^{Tf} - \alpha_i^{Nf} \right) - \left( \alpha_i^{Tf} - \alpha_i^{Nf} \right). \]

Equation (9) 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 sectoral 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 \( \alpha_i^T \), \( \theta_i^T \) than \( \alpha_i^N \), \( \theta_i^T \). 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 “Residual” captures differences in the price level that arise from cross-country differences in sectoral technology, which encompass both cross-country differences in the relative level of sectoral productivity \( \tilde{A}_i \), as in the Balassa-Samuelson model, and cross-country differences in sectoral factor shares \( \alpha_i^T \), \( \theta_i^T \), and \( \theta_i^N \). These terms cannot be measured directly from national accounts data, as it requires not only data on the relative level of sectoral productivity, \( \tilde{A}_i \), but also data on the level of U.S. GDP measured in units of tradables (which requires taking a stand on the level of the dollar price of tradable goods). Note that the residual also captures differences in the aggregate capital share in the economy \( \tilde{\alpha}_i \). These differences may arise even if the sectoral capital shares are identical across countries, \( \alpha_i^T = \alpha_i^N \), when there are differences in capital intensities across sectors and cross-country differences in the sectoral composition of the economy.

### E. Real Exchange Rates and Productivity Differences

Equation (9) expresses cross-country differences in price levels in terms of differences in observable variables, \( \Delta gdp_i \) and \( \Delta \tilde{k}_i \), and a residual term that captures unobserved differences in sectoral productivity levels, potentially along with other factors omitted from the model. Clearly, the differences \( \Delta gdp_i \) and \( \Delta \tilde{k}_i \), are endogenous and may arise from cross-country differences in aggregate or sectoral productivities, \( Z \) or \( \tilde{A}_i \). This section makes two additional assumptions that allow us to rewrite equation (9) in terms of productivity differences, as we did in section II. In particular, if input shares are common across countries, \( \theta_i^T = \theta_i^T \) and \( \sigma_i^T = \sigma_i^T \), and the share of capital in value-added is common across countries and sectors, \( \alpha_i^T = \alpha_i \), we can rewrite equation (9) as

\[
q_i = \frac{\theta_i^N}{\theta_i} \Delta \bar{z}_i + \frac{\theta_i^N}{\theta_i} \left[ \theta_i^N - \theta_i^T \right].
\]

Balassa-Samuelson.

\[
\times \left[ \frac{\theta_i^N}{\theta_i} \Delta \bar{z}_i + \frac{\theta_i^N}{\theta_i} \left[ \theta_i^N + \sigma_i^T N \left[ 1 - \theta_i^N \right] \Delta \tilde{a}_i \right] \right].
\]

Equation (10) writes cross-country differences in price levels in terms of three terms capturing (a) cross-country differences in sectoral productivity levels (i.e., the Balassa Samuelson effect), (b) differences in aggregate productivity, (labeled “Aggregate”), and (c) the indirect effect of sectoral productivity differences that arise from their interaction with sectoral differences in input shares, (labeled “Interaction”). The input channel highlighted in this paper is given by the sum

\[23]In addition, as mentioned above and highlighted again in section VC, the composition of the residual depends on how the model is closed on the demand side.

\[24]\]If factors are sector specific and preferences are not homothetic, the price of nontraded goods may rise with GDP if the demand for nontraded goods rises with income. This Linder mechanism was studied by Bergstrand (1991) and is reflected here in the fact that the aggregate labor share \( 1 - \tilde{\alpha} \) may increase with income if higher-income countries consume more nontradables and the labor share is higher in the nontradable sector. Such a mechanism would also be part of our residual. Although quantifying this mechanism is outside the scope of this paper, appendix figure A.1 shows no systematic relation between the aggregate labor share and GDP per capita in the PWT data (see also Gollin, 2002).

\[25]See the online appendix for a derivation.
of the last two terms, as the equation also shows that differences in "value-added TFP," \( \Delta \{ gdp_i - \alpha k_i \} \), arise from both differences in aggregate and sectoral productivities, \( \Delta z_i \) and \( \Delta \bar{a}_i^{T} \).

F. Industry-Level Real Exchange Rates

We now derive the model’s implications for industry-level real exchange rates. From equations (6) and (8), we can write the price of any nontradable good \( j \) as

\[
p_i^j = \beta_i^{gdp,j} gdp_i + \beta_i^{k,j} k_i + \alpha_i^j,
\]

with

\[
\beta_i^{gdp,j} = \left[ \theta_i' - \frac{\theta_i' \theta_i^{NN} - \theta_i T}{\theta_i^{NN}} \right] \left[ 1 - \theta_i' \right] \frac{\theta_i^{NN} \theta_i^N - \theta_i^T}{\theta_i^{NN}} - \left[ \sigma_i^{NN} - \sigma_i^{N,j} \right] \left[ 1 - \theta_i' \right] \frac{\theta_i^{NN} \theta_i^N - \theta_i^T}{\theta_i^{NN}} + \frac{\theta_i^{NN} - \theta_i^T}{\theta_i^{NN}},
\]

and

\[
\beta_i^{k,j} = \alpha_i^j \theta_i' + \sigma_i^{N,j} \left[ 1 - \theta_i' \right] \frac{\theta_i^{NN} \theta_i^N - \theta_i^T}{\theta_i^{NN}}.
\]

The log price in industry \( j \) relative to the United States (i.e., the industry-level real exchange rate) is

\[
q_i^j = \beta_i^{gdp,j} \Delta gdp_i + \beta_i^{k,j} \Delta k_i + \Delta \alpha_i^j (11)
\]

‘Intermediate Inputs’ ‘Capital-Deepening’ ‘Residual’

Equation (11) 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 \( \theta_i' \); a prediction we verify in section VB. Finally, we can write the price of nontradable good \( j \) relative to the average price of nontradables, relative to the United States as

\[
\Delta \left[ p_i^j - p_i^{NN} \right] = \left( \beta_i^{gdp,j} - \beta_i^{gdp} \right) \Delta gdp_i + \left( \beta_i^{k,j} - \beta_i^{k} \right) \Delta k_i + \Delta \alpha_i^j (12)
\]

‘Intermediate Inputs’ ‘Capital-Deepening’ ‘Residual’

with \( \beta_i^{k,j} \equiv \alpha_i^j \theta_i' + \sigma_i^{N,j} \left[ 1 - \theta_i' \right] \frac{\theta_i^{NN} \theta_i^N + \sigma_i^{TN} \left[ 1 - \theta_i' \right] + \alpha_i^T \theta_i^T \sigma_i^{NN}}{\theta_i^{NN}} \).

Equation (12) states that as GDP per capita grows, all else equal, industry-level prices will rise relative to the price of nontradables in industries where the share of intermediate inputs is relatively high, \( \theta_i' < \theta_i^{NN} \).

IV. Data

To evaluate the relation between relative prices and GDP per capita derived in equations (9), (11), and (12), 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, \( \theta_i' \); the labor share in each country and sector, \( 1 - \alpha_i^j \); the intermediate inputs shares, \( \sigma_i^{N,j} \); and the share of nontradables in GDP, \( \sigma_i^{NN} \).

A. Relative Price Levels, GDP per Capita, and Capital-Labor Ratios

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 United States, which is variable PL_GDP in the PWT.\(^27\) 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 GDP at constant 2011 national prices (variable RDGPNA in the PWT) to population. For the stock of capital per capita, we use the capital stock in PPP dollars (variable RKNA). When looking at growth, 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.\(^28\)

B. Input Shares and Sectoral Weights

Input-output coefficients come from the OECD Inter-Country Input-Output (ICIO) tables, which provide input-output tables for 61 countries between 1995 and 2011. We classify sectors in the ICIO and the ICP into tradables and nontradables following Crucini, Telmer, and Zachariadis (2005).\(^29\) We compute \( \theta_i' \) as the ratio of value added to gross output in each sector and the parameters \( \sigma_i^{N,j} \) as the ratio of the value of inputs from sector \( j \) to the total value of inputs used in sector \( i \). For the countries for which the ICIO data are not available, we assign the parameter values of the average ICIO country.

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.\(^30\) The PWT adjusts the labor income of

\(27\) See Feenstra et al. (2015) for a description of the new PWT.

\(28\) While the benchmark PLIs in the detailed ICP data are defined relative to the world, we divide by the U.S. PLIs to work with price indices of consumption relative to the United States.

\(29\) See the concordance in the online appendix.

\(30\) See Gollin (2002) and Feenstra et al. (2015).
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 sectoral 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

\[ 1 - \alpha_i^j = \frac{\text{Comp. to employees}_i^j}{\text{Value added}_i^j} \times \frac{\text{Labor comp._}_i^j/\text{Value added}_i^j}{\text{Comp. to employees}_i^j/\text{Value added}_i^j}, \]

where the sectoral 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 \( \theta_i^j \), \( \sigma_i^j \), and compensation-to-employees-to-value-added ratio, and use equation (13) to obtain sectoral 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 reported in the online appendix.

We report the share of value added in gross output, \( \theta_i^j \), for the countries in our sample in the online appendix. There we show the share of tradable intermediate inputs relative to total intermediate inputs used in each sector. Nontradable sectors are significantly more labor intensive than tradable sectors for every country in the sample. They also use relatively fewer tradable intermediate inputs than the tradable sectors. For the average country, the share of value added in gross output in tradable sectors is about half that in the nontradable sectors (0.33 versus 0.54). This is consistent with the finding of Johnson and Noguera (2017), who show that the value-added content of trade has been falling dramatically, especially in manufacturing sectors.

Finally, we compute the share of tradables in GDP, \( 1 - \omega_i^N \), as the ratio of value added in the tradable sectors to total value added. We use value-added data evaluated at producers’ prices from the ICIO tables. As discussed in the online appendix, by evaluating output at producer prices, we do not include distribution margins into the price of tradables and prevent overestimating the true share of tradables on the price index. The online appendix reports the division of the ICIO industries into tradable and nontradable sectors. Within the nontradable sector, industry-specific \( \omega_i^N \)'s are computed as the ratio value added between industry \( j \) to total value added in the nontradable sector.

V. Quantitative Results

This section uses the framework in section III to disentangle the sources of the cross-country relation between real exchange rate levels and GDP per capita. First, we use equation (9) to evaluate how much of the observed differences in price levels across countries can be accounted for by sectoral differences in input shares coupled with cross-country differences in GDP per capita. Second, we use equations (11) and (12) 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, in a version of the model where tradable goods are differentiated across countries, or if we assume that capital is fully mobile across countries.

A. Price Levels and GDP per Capita

We first decompose the relation between aggregate price levels and GDP per capita following the decomposition in section III. In particular, for each country \( i \), we compute the terms labeled “Intermediate Inputs” and “Capital-Deepening” in equation (9), given by \( \omega_i^N [\theta_i^N(1 + \Delta gdp_i) - \theta_i^N] / \theta_i^N \Delta gdp_i \) and \( \omega_i^N [\alpha_i^j(1 + \Delta k_i) - \alpha_i^N] / \theta_i^N \Delta k_i \), respectively. We can obtain the residual by subtracting these two terms from the observed relative price levels.

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. The relation between aggregate price levels and GDP per capita can be mostly attributed to sectoral differences in shares of intermediate inputs, 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

31To prevent cluttering the figure, the residual term is plotted separately in the online appendix.
data. In contrast, sectoral 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 nontradable sectors, that is, $\alpha_i^T \theta_i^T < \alpha_i^N \theta_i^N$, even though $\theta_i^T > \theta_i^N$. Together, these two terms generate a slope of 0.11, about half of the elasticity observed in the data. The residual, which among other factors captures country-specific differences in sectoral productivity as in the “Balassa-Samuelson” model, is plotted in the online appendix and gives an elasticity of the price level to GDP per capita of 0.12.\(^3\)

In our model, differences in price levels across countries arise from cross-country differences in the price of nontradable goods. In the online appendix, we show that decomposition in terms of nontradables is similar to our main decomposition: differences in input intensities (i.e., the combination of the “Intermediates” and “Capital” slopes) account for about half of the slope of the relation between nontradable prices and GDP per capita.

How much of the observed variation in our decomposition arises from cross-country differences in input and factor shares? In the online appendix, we show little correlation between the coefficients $\theta_i^N$, $\theta_i^T$, and $\bar{\theta}_i^N$ and GDP per capita. We also show that the relation between the “Intermediate Inputs” and “Capital-Deepening” terms and GDP per capita is barely affected if we instead recompute the terms in our decomposition from equation (9) under the assumption that all input and factor shares are common across countries and equal in value to that of the median country.

**Price levels and relative productivities.** As noted throughout the paper, the advantage of the decomposition in equation (9) versus that in equation (10) is that cross-country differences in GDP per capita and capital per worker are observable, whereas differences in sectoral productivity levels are not. In fact, cross-country differences in sectoral productivity levels can only be computed using the data on cross-country relative price levels that we are trying to explain. This section uses the stronger assumptions imposed for deriving equation (10) to gauge the importance of cross-country differences in sectoral versus aggregate productivities for aggregate price levels. As noted, these stronger assumptions do not substantially alter the results of our main decomposition.

We calibrate the aggregate and sectoral productivities under two alternative exercises. In the first exercise, we back out cross-country differences in sectoral productivities from data on relative prices. In particular, we calibrate $\Delta \bar{a}_i^{T1}$ and $\Delta \bar{a}_i^{I1}$ to exactly match data on value-added TFP and real exchange rate levels using equations (10) and

$$\Delta [gdp_i - \alpha k_i] = \frac{\bar{\theta}_i^N}{\theta_i^T} \Delta z_i^1 + \left[\theta_i + \alpha_i(1 - \theta_i)\right] \Delta \bar{a}_i^{T1}.$$  

By construction, plugging these values of $\Delta \bar{a}_i^{T1}$ and $\Delta \bar{a}_i^{I1}$ back into equation (10) will exactly reproduce the differences in price levels observed in the data. The goal of this exercise is to decompose these differences into the different terms that compose equation (10).

For our second exercise, we assume that there are no differences in sectoral productivities across countries, $\Delta \bar{a}_i^{T2} = 0$, and calibrate cross-country differences in aggregate productivity to match the observed differences in value-added TFP, $\Delta \bar{a}_i^{I2} \equiv \frac{\bar{\theta}_i^N}{\theta_i^T} \Delta [\text{gdp}_i - \alpha k_i]$. We then evaluate equation (10) under $\Delta \bar{a}_i^{I2}$ and $\Delta \bar{a}_i^{T2} = 0$. This exercise answers how much of the observed relation between prices and GDP per capita can be accounted for in a model where sectors differ only in their input shares, and countries differ only in their aggregate productivities.

Figure 3 plots the results of these two exercises. The first exercise shows that roughly half of the intermediate input channel highlighted in this paper comes from the interaction between aggregate productivity differences and sectoral differences in intermediate input shares (i.e., the term labeled “Aggregate,” which generates a slope of 0.043), while the other half comes from the interaction between sectoral productivity differences and intermediate input shares (i.e., the term labeled “Interaction,” which generates a slope of 0.053). The residual in this exercise is fully attributed to the direct effect of sectoral productivity differences (i.e., the Balassa-Samuelson effect).

The second exercise underscores that a model where sectors differ only in their input shares and countries differ only in their aggregate productivities can account for almost half of the slope between relative prices and relative GDP per capita.

\(^3\)Note that while the “Intermediate Input” term produces a relation between the price level and GDP per capita, the relation between prices and GDP per capita in the data is not perfect, indicating that there are other factors unrelated to differences in GDP per capita that can drive differences in price levels.
capital, provided that the aggregate productivity differences are calibrated to match the observed differences on value-added TFP. Note that by construction, the price differences generated in this exercise are exactly equal to those generated by adding up the “Aggregate” and “Interaction” terms from exercise 1, as both exercises are calibrated to match the data on $\Delta \left[ \text{gdp}_i - \alpha k_i \right]$. This highlights that given data on the differences $\Delta \text{gdp}_i$ and $\Delta k_i$, specifying the source of these differences is inconsequential for the measurement of the intermediate input channel in this paper.

B. 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 nontradable industries. The online appendix reports the share of value added in gross output for the countries in ICIO for seven nontradable subsectors for which the ICP reports detailed price indexes.\textsuperscript{33} The share of intermediate inputs in education, health, and recreation is lower than for the nontradable sector as a whole and is higher in transport, communication, and restaurants. An implication that can be gleaned from equation (11) is that the slope of the price level of an industry with respect to GDP per capita should be larger the higher is the share of value added in the industry (i.e., the higher is $\theta_i^j$).

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-added share of the sector $\theta_i^j$.\textsuperscript{34} We expect the coefficient on the interaction term to be positive: the slope of the price level real exchange rates industry by industry.

Finally, equation (12) implies that as GDP per capita grows, nontradable industry-level prices should not only increase, but should increase faster than the aggregate price of nontradables in industries where the share of intermediate inputs is low (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 rate 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 sectoral 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 $R^2$ of the regression increases from 0.266 to 0.476 once we add the interaction term, indicating that sectoral 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 industries within countries and shows that the interaction term is very similar under this specification. Finally, the last column includes industry-level fixed effects.\textsuperscript{35} We continue to find a positive and significant coefficient in this specification. We conclude that the reduced-form evidence supports the notion that sectoral differences in intermediate input shares shape the relation between real exchange rates and GDP per capita.

An obvious challenge with our estimates in table 1 is that we cannot control for industry-level productivity differences across nontradable sectors. This issue could be problematic if the industries with the higher use of intermediate inputs (lower $\theta_i^j$) happen to be the ones for which the productivity gap between rich and poor countries is the largest. With this in mind, we go back to our model and ask what the relation is between industry-level prices and GDP per capita that is implied solely by the observed differences in input shares.

Figure 4 computes the terms labeled “Intermediate Inputs” and “Capital-Deepening” in equation (11) for seven expenditure categories for which the ICP reports price data. It 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 (12) implies that as GDP per capita grows, nontradable industry-level prices should not only increase, but should increase faster than the aggregate price of nontradables in industries where the share of intermediate inputs is lower than for the nontradable sector as a whole, $\theta_i^j > \theta^N$. Figure 5 evaluates this prediction. It shows the price of each industry relative to the aggregate price of nontradables in the data versus in the observable terms in the model. In particular, we compare data on relative prices to the sum of first two terms in equation (12), ignoring the “Residual”

\textsuperscript{33}See the online appendix for our concordance. The appendix also reports these shares for each country in our sample.

\textsuperscript{34}More precisely, in our baseline regression in column 2 of table 1, we estimate

$$q_i^j = \alpha + \beta_1 \Delta \text{gdp}_i + \beta_2 \left[ \theta_i^j \times \Delta \text{gdp}_i \right] + \beta_3 \theta_i^j + \epsilon_i^j,$$

where we obtain the industry-specific value-added shares $\theta_i^j$ 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 the online appendix.

\textsuperscript{35}For this specification, we exclude the countries for which we impute $\theta_i^j$ and include only the set of countries for which we can directly observe $\theta_i^j$ from the ICIO data.

| Table 1.—Industry-Level Relative Prices and Sectoral Input Shares |
|-------------------------|----------|----------|----------|----------|
| Dependent Variable: $q_i^j$ | (1)      | (2)      | (3)      | (4)      |
| $\Delta \text{gdp}_i$     | 0.235*** | 0.241*** | 0.419*** | 0.349*** |
| ($\text{0.0163}$)         |          | ($\text{0.0163}$) | ($\text{0.0237}$) |          |
| $\theta_i^j \times \Delta \text{gdp}_i$ | 0.676*** | 0.676*** | 0.429*** | 0.0859*** |
| ($\text{0.0694}$)         | ($\text{0.0643}$) | ($\text{0.0859}$) |          |          |
| $\theta_i^j$              | -0.906*** | -0.974*** | 0.615*** | 0.297*** |
| ($\text{0.171}$)          | ($\text{0.152}$) | ($\text{0.297}$) |          |          |
| $R^2$                    | 0.266    | 0.476    | 0.630    | 0.775    |
| Observations             | 1,127    | 1,127    | 1,127    | 1,127    |
| CTY FE                   | No       | No       | Yes      | No       |
| IND FE                   | No       | No       | No       | Yes      |

Robust standard errors clustered at the country level in parentheses. Significant at ***, **, and *10%.
“RER data” refers to the relative price of the industry relative to the United States obtained from the ICP data. “Int. Inputs” and “Cap. Deep.” are the relative price implied by the terms labeled “Intermediate Inputs” and “Capital-Deepening” terms in equation (11).

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 the price of each industry relative to the aggregate nontradable price index in the data is positively correlated to that in the model for the health, education, transport, restaurants, communication, and construction industries, although for construction, this relation is not statistically significant. In contrast, the
industry-level differences in input shares do not generate much variation across countries in the prices of recreation relative to the price of nontradables. Overall, the mechanism is successful in matching the relation of the relative industry level prices and GDP per capita.

C. Robustness

Relative prices and GDP per capita evaluated at PPP prices. This section shows that our quantitative results do not 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 capita evaluated as U.S. prices, \( gdp_{i}^{ppp} = gdp_{i} - q_{i} \).

\[
q_{i} = \frac{\beta_{i}^{pdpp} \Delta gdp_{i}^{ppp} + \beta_{i}^{k} \Delta k_{i} + \Delta \tilde{a}_{i}}{\beta_{i}^{\text{Intermediate Inputs}} \text{ 'Intermediate Inputs'}, \beta_{i}^{\text{Capital-Deepening}} \text{ 'Capital-Deepening'}, \beta_{i}^{\text{Residual}} \text{ 'Residual'}} .
\]

(14)

where the elasticities are given by:

\[
\beta_{i}^{pdpp} = \frac{\omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]}{\theta_{N}^{i} - \omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]},
\]

and

\[
\beta_{i}^{k} = \frac{\omega_{i}^{N} \left[ \alpha_{s}^{N} \theta_{T}^{i} - \alpha_{s}^{N} \theta_{N}^{i} \right]}{\theta_{N}^{i} - \omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]}.
\]

In the online appendix (figure OA.4), we evaluate the terms in this decomposition and show that the sectoral differences in input shares account for about half of the elasticity between the real exchange rate and PPP-adjusted GDP per capita seen in the data (0.12 versus 0.24).

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 (14) and using hats to denote log changes across time, we obtain an expression for the change in the real exchange rate:

\[
\hat{q}_{i} = \frac{\beta_{i}^{pdpp} \Delta gdp_{i}^{ppp} + \beta_{i}^{k} \Delta k_{i} + \Delta \tilde{a}_{i}}{\beta_{i}^{\text{Intermediate Inputs}} \text{ 'Intermediate Inputs'}, \beta_{i}^{\text{Capital-Deepening}} \text{ 'Capital-Deepening'}, \beta_{i}^{\text{Residual}} \text{ 'Residual'}} .
\]

(15)

Equation (15) establishes that if \( \theta_{N}^{i} > \theta_{T}^{i} \), fast-growing countries should appreciate. In the online appendix (figure OA.5), we compare the terms in equation (15) to the growth of the real exchange rate observed in the data and show that sectoral differences in input shares account for about half of the elasticity of the growth of the real exchange rate to the growth of real GDP over the 1997–2014 period.

Alternative classifications of the tradable sector. This section reevaluates the results of section VA under an alternative classification of industries into tradables and nontradables. In particular, we follow the macroeconomic 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. In the online appendix, we plot the decomposition of equation (9) using this classification (figure OA.6) and show 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.

Differentiated tradable goods and deviations from the law of one price. We now show how to extend our baseline model to allow for differentiated tradable goods and deviations from the law of one price. In particular, assume that tradable goods are differentiated by country of origin. We continue to assume the production functions from section III, but assume that trade between countries \( i \) and \( n \) is costly and subject to iceberg trade costs \( \tau_{in} > 0 \) for \( i \neq n \), and \( \tau_{ii} = 1 \).

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

\[
G_{i}^{T} = \left[ \sum_{n=1}^{N} \omega_{ni} \left[ \frac{\theta_{T}^{n} - \theta_{N}^{n}}{\theta_{T}^{n} - \omega_{ni} \left[ \theta_{N}^{n} - \theta_{T}^{n} \right]} \right] \right]^{\frac{1}{\rho_{i}}} ,
\]

(16)

where \( \theta_{T}^{n} \) denotes country \( n \)’s absorption of tradable good from country \( i \), \( \rho_{i} \) is the elasticity of substitution across tradable goods from different source countries, and the parameters \( \omega_{ni} \) 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

\[
P_{i}^{T} = \sum_{n=1}^{N} \omega_{ni} \left[ \frac{\theta_{T}^{n} - \theta_{N}^{n}}{\theta_{T}^{n} - \omega_{ni} \left[ \theta_{N}^{n} - \theta_{T}^{n} \right]} \right]^{\frac{1}{\rho_{i}}} ,
\]

(17)

where \( \theta_{T}^{n} \) denotes the price of the tradable product produced in country \( n \) and consumed in country \( i \), and the parameter \( \omega_{ni} \) controls the trade shares. Note that because of the iceberg trade costs, this price varies across destinations, so that the law of one price does not hold. Sales from country \( n \) into country \( i \) are given by

\[
\frac{\theta_{T}^{n} Y_{ni}^{T}}{\rho_{i}} = \omega_{ni} \left[ \frac{\theta_{T}^{n} - \theta_{N}^{n}}{\theta_{T}^{n} - \omega_{ni} \left[ \theta_{N}^{n} - \theta_{T}^{n} \right]} \right]^{\frac{1}{\rho_{i}}} \cdot \frac{\theta_{T}^{n} G_{i}^{T}}{\rho_{i}} .
\]

(18)

The online appendix fully describes this version of the model, characterizes the equilibrium, and shows that in this case, the real exchange rate can be written as

\[
q_{i} = \frac{\beta_{i}^{pdpp} \Delta gdp_{i} + \beta_{i}^{k} \Delta k_{i} + \Delta \tilde{a}_{i}}{\beta_{i}^{\text{Intermediate Inputs}} \text{ 'Intermediate Inputs'}, \beta_{i}^{\text{Capital-Deepening}} \text{ 'Capital-Deepening'}, \beta_{i}^{\text{Residual}} \text{ 'Residual'}} .
\]

(19)

with \( \beta_{i}^{pdpp} = \frac{\omega_{i}^{N} \theta_{T}^{i} - \omega_{i}^{N} \theta_{N}^{i}}{\theta_{T}^{i} - \omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]}, \beta_{i}^{k} = \frac{\alpha_{s}^{N} \theta_{T}^{i} - \alpha_{s}^{N} \theta_{N}^{i}}{\theta_{T}^{i} - \omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]}, \beta_{i}^{p} = 1 - \frac{\theta_{N}^{i} - \theta_{T}^{i}}{\theta_{T}^{i}}, \beta_{i}^{\text{Residual}} = \frac{\omega_{i}^{N} \theta_{T}^{i} - \omega_{i}^{N} \theta_{N}^{i}}{\theta_{T}^{i} - \omega_{i}^{N} \left[ \theta_{N}^{i} - \theta_{T}^{i} \right]} \cdot \frac{\theta_{T}^{i} \theta_{N}^{i}}{\rho_{i} \rho_{i}} . \)
\[
\Delta a_{i} = \frac{\theta_{T}^{i} \theta_{N}^{i}}{\rho_{i} \rho_{i}} . \]

Equation (19) states that in addition to the “Intermediate Inputs,” “Capital-Deepening,” and \( \Delta a \) terms already present in equation (9), the residual now includes differences in the price of tradable across countries, \( \Delta p_{i}^{T} \) and \( \Delta \log p_{i}^{T} \). Note, however, that the coefficients \( \beta_{i}^{pdpp} \) and \( \beta_{i}^{k} \), have not changed. That is, the part
of the elasticity between GDP per capita and the aggregate price level that can be attributed to sectoral differences in input shares in this model would be the same as would be attributed in our baseline model of section III. Incorporating differentiated tradable inputs affects the interpretation of the residual.

** Tradable capital.** Finally, we evaluate the model’s prediction under the alternative assumption that capital is mobile across countries, as in Obstfeld and Rogoff (1996). In this case, equation (7) can be written as

\[
p_i^N = \frac{\partial p_i}{\partial \theta_i} + \frac{\partial p_i}{\partial \theta_i} \left[ 1 - \alpha_i^N \right] \frac{\partial \theta_i}{\partial \theta_i} \frac{\partial \theta_i}{\partial \theta_i} \omega_i + \frac{\alpha_i^N \theta_i^N - \alpha_i^T \theta_i^T}{\partial \theta_i} r^*,
\]

where \( r^* \) is the international rate of return to capital. Following the steps from section III, we can write the price level in country \( i \) relative to the United States as

\[
q_i = \omega_i \left[ 1 - \alpha_i^N \right] \frac{\partial \theta_i}{\partial \theta_i} \Delta \text{gdp}_i + \omega_i \Delta \text{a}_i^{T}, \tag{20}
\]

where

\[
\Delta \text{a}_i^{T} \equiv \frac{a_i^{T}}{\partial \theta_i} - \frac{a_i^{T}}{\partial \theta_i} \left[ 1 - \alpha_i^N \right] \frac{\partial \theta_i}{\partial \theta_i} \frac{\partial \theta_i}{\partial \theta_i} \omega_i + \left[ \frac{\theta_i^N \left[ 1 - \alpha_i^N \right] - \theta_i^T \left[ 1 - \alpha_i^T \right]}{\partial \theta_i} \right] r^* + \left[ \frac{\theta_i^N \left[ 1 - \alpha_i^N \right] - \theta_i^T \left[ 1 - \alpha_i^T \right]}{\partial \theta_i} \right] \text{gdp}_i.
\]

In this case, the coefficient on \( \Delta \text{gdp}_i \) depends on the sectoral differences in the labor share in gross output, \( \left[ 1 - \alpha_i^N \right] \theta_i^N - \left[ 1 - \alpha_i^T \right] \theta_i^T \) rather than on the sectoral differences in intermediate input shares, \( \theta_i^N - \theta_i^T \). We note that in the data, however, sectoral differences in the share of labor in gross output arise primarily from sectoral differences in the share of value added in gross output, \( \theta_i^T \), rather than from sectoral differences in the labor share in value added, \( \left[ 1 - \alpha_i^T \right] \).

In the online appendix (figure OA.7), we compare the term labeled “Input shares” to the real exchange rate observed in the data and show that sectoral differences in input shares account for almost half of the elasticity of the real exchange rate to GDP per capita.

** VI. 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 nontradables 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 independent 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 nontradable sectors can account for about half of the elasticity of real exchange rates to income per capita.

**REFERENCES**


**Figure Appendix**

**Figure A.1.—Aggregate Labor Share and Income per Capita**

This figure plots the relation between the aggregate labor share and income per capita (PWT and WDI indicators, data for 2011.)