The Law of One Price, Patterns of Deviation and Trade

The Case for a Group of Latin American Countries[*]

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Abstract: The Law of One Price (LOP) hypothesis has been the object of plenty of research effort with conclusions going from total rejection to a long-run mean-reverting tendency. However, little research has been conducted to explore the reasons behind such deviations. This study analyzes whether certain technological issues, like differences in countries' production technologies, could explain not only the observed LOP deviations but also its systematic and biased patterns. From a sample of 9 Latin American countries, deviations for 144 products were calculated from the ICP-2011 round. The results obtained are quite appealing: 88% of deviations coincided with differences in production technologies. Two public policy consequences could derive from it: First, free-trade agreements among Latin-American countries might not be enough to boost intraregional trade when different production technologies are applied. Second, adopting sectoral-specific exchange rates instead of an economy-wide average would reduce the loss of a country's competitiveness.

Keywords: Law of One Price, production functions, competitiveness, trade.

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1. Introduction

A *maximum* in economics establishes that, under perfect competition, prices of the same good in different markets will be equalized. Through arbitrage, that is buying the good where it is cheaper and selling it where is costlier, *eventually,* it will be priced the same in all markets. In terms of international trade it means that, under perfectly competitive markets and without obstacles to trade, the price of the same good should be equal in any market once expressed in a common currency. This theoretical conclusion is known as the *Law of One Price* (*LOP*) and, although the stringent conditions to be met, it has been the object of quite an effort in academic research for its relevance in measuring economic variables. For instance, when the LOP holds, relative price indexes between two countries expressed in a common currency (divided by the nominal exchange rate) become their *Purchasing Power Parity* (*PPP*): it can be used to measure their economic sizes in a "comparable" way since it controls for the influence of prices and just keeps the difference in volumes.

There is a clear-cut way for testing the LOP: if an identical good is sold for the same common-currency price in two markets, then the domestic price should respond one-for-one to the domestic nominal exchange rate so currency values would play no role in the structure of relative prices. This total pass-through of the nominal exchange rate on domestic prices is known as the "strict" version of the LOP[1]. A pioneer work by Isard (1977) shedded some serious doubts on the sustainability of the LOP hypothesis when found evidence that disparities between common-currency relative prices in different countries were systematically correlated with exchange rates, rather than randomly fluctuating over time. In the same line, Rogoff (1996) concluded that nominal exchange rates moved much more than the ratio of real prices; what came to be known as the *Real Exchange Rate Puzzle*.

Other authors have concluded that, although the strict version of the LOP might not hold in the short run, the deviations observed are transitory and revert towards equilibrium in the long run. For instance and in line with Balassa's (1964) and

[1] In opposition to the "weak" version of the LOP in which, although a permanent deviation exists between relative prices and the nominal exchange rates, they present a proportional rate of change.

Samuelson's (1964) argument that PPP deviations resulted from labor productivity differences between traded and non-traded sectors, Crucini, Telmer, and Zachariadis (2005) report that much of the deviations can be ascribed to how tradable the goods are, as well as to how tradable are the inputs required to produce them. Crucini and Shintani (2008) found that nontradable goods produce more deviations from the LOP than traded goods. Along these lines, an important work, because of its extensive micro-data, is the one by Clements *et al.* (2017). Using surveyed prices from the 2011 round of the World Bank's International Comparisons Program (ICP) [2] on 198 food items in 175 countries, they found that the LOP was rejected more often than not, but "in many cases the violations did not seem particularly large" (p.2). Furthermore, analyzing the evolution of the deviations using FAO data on agricultural prices, they found them to be stationary. This mean-reverting behavior, concluded the authors, was considered favorable to the LOP hypothesis. On the other hand, however, Ardeni (1989) found that commodity (agricultural) prices failed to cointegrate with nominal exchange rates and that deviation patterns were permanent.

As stressed in Marsh *et al.* (2012), though, these studies have focused on determining whether a deviation from the LOP is small or large and whether it will be short- or long-lived. But even if a mean-reversion process is observed[3], the reasons given so far to justify it are debatable. Trade obstacles, a repeatedly mentioned cause, can hardly be sustained today. Globalization became a real boost to free-trade policies and agreements, limiting all types of tariff and non-tariff barriers and regulating non-competitive market structures (Dornbush 1985, Krugman 1987). Transport expenses, a further often cited factor of price deviations, are usually offset by discounts in export prices. All in all, however, deviations from the LOP are still observed.

[2] This is confidential data only available upon request from the World Bank-ICP.

[3] Some authors like Obstfeld and Rogoff (2000) or Chari, Kehoe, and McGrattan (2002) justify it by the "sticky-price approach" while authors like Gavin (1990, 1992) and Morshed and Turnovsky (2004) propose the "adjustment cost approach".

An unexplored element that could explain the observed price deviations is the difference in countries' production processes: different production technologies that produce the same good at different costs will generate temporary deviations in the real exchange rate which mean-reverts through changes in relative prices and nominal exchange rates[4]. In this paper, I specifically investigate this alternative explanation.

Two lines of independent research support my view: in Clemens *et al.* (2017) the authors observed that poorer countries registered *higher* levels of relative price dispersions while, on the other hand, researchers like Hsieh and Klenow (2009) or Bartlesman *et al.* (2013) have generally found *greater variation* in factor intensity and productivity in less developed countries. That is, less developed countries tend to present a larger variation in factor intensity *and* price dispersion than detected in developed ones. Moreover, Krugman et al. (2017, Ch. 5) observed that developed countries do have *similar* production technologies so their trade is rather intra-industries with large economies of scale, while developing countries' *dissimilar* production technologies result from differences in factors abundance and so their trade is inter-industries and based on each country's comparative advantage; i.e. the Heckscher-Ohlin model. Therefore, I will work with the hypothesis that relatively larger price deviations observed for poorer countries could result from their dissimilar production technologies. The fact is that factor endowment very much conditions the type of production technology a country employs. For instance, a country with a relatively higher endowment of capital very probably will invest in relatively capital-intensive production technology compared to other countries. Production technologies imply different factors and input intensities as well as different elasticities of substitution. Then, it is reasonable to expect that two countries with different production technologies will produce the same good at different prices, and nothing guarantees equality with an economy-wide average nominal exchange rate.

[4] Cumby (1996), analyzing the Big Mac parity, found that the adjustment toward PPP tends to take place through changes in nominal exchange rates and relative prices.

Using surveyed prices from the ICP 2011 round, 9 Latin-American countries were chosen for the study: Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Paraguay, Peru, Uruguay, and Venezuela[5]. Comparing country-pairs relative prices for 144 goods with their market average 2011 nominal exchange rates, deviations were calculated. As expected and for most of the goods, the strict version of the LOP did not hold. To explain such deviations, I develop a partial-equilibrium model with 3-nested Constant Elasticity of Substitution (CES) production functions[6] from which LOP's equilibrium conditions are derived. Using EORA Input-Output matrices for the sampled countries (Lenzen et al.), production function parameters are then obtained, and equilibrium conditions are calculated. The result is quite appealing: 88% of deviation patterns coincided with differences in production technologies.

The relevance of such results is clear-cut: systematic deviations from the LOP might not necessarily result from failures in free-market conditions, but the very natural consequence of applying different production technologies. It also calls on evaluating how convenient would result to apply country-pairs sectoral-specific nominal exchange rates: it would certainly reduce the loss of a country's competitiveness that results from adopting an economy-wide average nominal exchange rate. On the other hand, free-trade agreements among Latin-American countries might not be enough to boost trade among them when different production technologies are applied: trade will be based on each country's comparative advantages and if a region's countries do not have many things to complement one another, trade will not be the growth-enhancing factor it is in industrialized nations.

To the best of my knowledge, a study on technology as a potential cause for deviations from the LOP theory has not been presented. It is hence its primary contribution.

[5]These countries were selected without any particular reason. Argentine, a large South American economy, was not part of the sample since it did not participate in the 2011 ICP round.

[6] As explained in Duffy and Papageorgiou (2004), Cobb-Douglas aggregate production function specification is incorrect since factor's elasticity of substitution goes from values lower than 1 to higher than 1.

In section 2 a description of the facts observed and the data used are presented. In section 3 the partial-equilibrium model is derived, while section 4 presents the results. Conclusions follow in section 5.

2. Facts and Data: Deviations with a pattern?

In a panel data study that covered 157 nations and 208 food and agricultural products over a 24-year period, Clements et al. (2017) examined the long-run features of the deviations. They found that deviations mean-reverted (towards zero) which was considered in support of the LOP in the long run. However, they mentioned nothing about whether a particular distribution of the deviations was identifiable or expected. It is not a trivial issue though because if a pattern is observed, a particular and common cause(s) must explain it. For instance, a certain trade (or nontrade) barrier, a particular cost, or, more important, certain differences in technological issues like the shares of inputs/factors used in each country's production function or its elasticities of substitution.

Using the 2011 International Comparison Project (ICP) round for a random selection of 9 Latin-American countries (Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Paraguay, Peru, Uruguay, and Venezuela), country pairs for 144 items will be formed with prices quoted per country pair[7].

Comparing each good´s relative price per country-pair to their nominal exchange rate, LOP stringent version could be assessed:

$$\frac{P}{P^{*}} = S_c \tag{1}$$

where P and P^{*} stand for domestic and foreign prices and S_c stands for the domestic nominal exchange rate. The left-hand side of this familiar expression, the relative price, represents the purchasing power of the domestic currency (the amount of the domestic currency required to buy in the domestic market the same amount of goods and services a unit of foreign currency buys in the foreign market), while the right-hand side, the nominal exchange rate, represents the amount of domestic currency

[7] Since the 144 items are not quoted for all countries, the price sample country-pair varies.

required to buy one unit of the foreign currency in the exchange market. When equality holds, there is no chance for arbitrage in permuting goods between two countries or converting currencies first; the real exchange rate (expressed in common currency) is in equilibrium and equals 1. When relative prices exceed the nominal exchange rate, for instance, the domestic good is permuted for less of the foreign good (an increase in domestic prices or a decrease in foreign ones), and an opportunity for arbitrage results in exchanging currencies instead. To re-establish equilibrium, the nominal exchange rate must depreciate (increase). The opposite goes alone.

To determine how relative prices relate to a country-pair nominal exchange rate, equation (2) gives the percentage *deviation* (D_{fi}^{c}) between the relative price of a good and the nominal exchange rate of the domestic country. That is:

$$D_{fi}^{c} = \frac{\frac{P_i^c}{P_i^f} - S_c}{S_c} \tag{2}$$

where P_i^c is the price of item *i* in country *c*, P_i^f is the foreign price of item *i* expressed in foreign currency, S_c is the nominal exchange rate of country *c,* and when D_{fi}^{c} = 0 the LOP holds, while any departure from zero will mean an off-alignment of the currencies' real value. For instance, if D_{fi}^{c} > 0, it means that the domestic currency is overvalued (only country *f* will export) and the nominal exchange rate of country *c* in terms of country *f* should depreciate (increase) to restore the equilibrium.

In this study, with just cross-section data, I will analyze whether such deviations are simply random observations or rather follow a pattern by country. Such information results utterly relevant since deviations affect the degree of competitiveness of a country relative to its trading partners. For instance, a country whose manufacturing sector is relatively overvalued with respect to its nominal exchange rate (net positive deviations), has an export-negative bias and thus faces a tendency (mean-reverting) to the depreciation of its relative price or its nominal exchange rate to reestablish its LOP equilibrium.

A particular example of a deviation pattern is the case of Brazil in which 7 out of 8 country-pairs deviation contrasts were mainly positive (relative prices above nominal exchange rates) except with Uruguay. Figure 1 shows the country-pairs deviations for the 144 items of our sample with Brazil as the domestic country and with the nominal exchange rate in the red line.

Figure 1 LOP for Brazil/other countries

An opposite situation occurs with Guatemala where all deviations were negative (not shown). Except for Uruguay with only positive deviations but with Brazil, all other countries showed a specific pattern of deviations per country pair but with mixed patterns among country pairs. Then, what is noteworthy is not the deviations *per se*, which can have various causes, but the consistent bias of such deviations. The **Net** deviation in Table V below is simply the deviation (sign) that dominates (total country-pair deviations are presented in Table A1 in the Appendix).

As stated before, the fact that deviations exist is not necessarily proof against the LOP as long as such deviations do not present a specific pattern (Isard 1975). From equation (1), deviations can be represented as:

$$P = e^{K} P^{*} S_{c} \tag{3}$$

in which *K* represents the deviation parameter. In log form:

$$\log P = K + \log P^{*} + \log S$$

The dynamics of *K*, whether mean-reversing (auto-regressive) or not, should be the object of further research. Besides the debatable arguments mentioned before, other issues, like technological ones, can explain such deviations. In particular, differences in factor endowments, factor and input intensities, and in the elasticity of substitutions between factors and between factors and inputs will affect relative prices and prevent the LOP from holding. In the following section, a partial-equilibrium model is derived, in which differences in countries' production functions alter real exchange rates.

3. The Model

Following Kravis and Lipsey (1988), price levels can be substituted by relative nontradable prices, since such prices are found to be the principal component in the evolution of inflation. Therefore, equation (1) is re-expressed in terms of relative nontradable prices:

$$\left(\frac{\frac{P_N}{P_T}}{\frac{P_N^*}{P_T^*}}\right) = S_c \tag{4}$$

The numerator of the left-hand side of equation (4) represents the relative nontradable price index of the domestic country while the denominator represents it for the foreign (*) country[8]. Aside from the already mentioned causes that prevent the strong version of the LOP to hold, expressing relative prices in terms of nontradables adds a new element of distortion since nontradables are not subdued to competition. In any case, we will not assume the preexistence of a "distortion" parameter but rather evaluate the possibility that if the LOP does not hold it is rather due, at least in the short-run, to technological issues[9].

Let's begin by assuming that the LOP holds in its strict form. Relative nontradable prices are equilibrium prices that result from a partial equilibrium model. For such reason, I present a 3-nested Constant Elasticity of Substitution (CES) production function in which shares and elasticities of substitution play a major role. In equation (5), the first nest, total production Υ is composed of tradable Y_T and nontradable Y_N goods with shares ω and $(1-\omega)$ respectively, and with a tradable-nontradable elasticity of substitution of θ. Equation (6) represents its respective price index equation.

$$\Upsilon = A\left[\omega^{\frac{1}{\theta}}\, Y_T^{1-\frac{1}{\theta}} + (1-\omega)^{\frac{1}{\theta}}\, Y_N^{1-\frac{1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{5}$$

$$P = \left(\gamma\, P_T^{1-\theta} + \,(1-\gamma)\, P_N^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{6}$$

After maximizing the production function (5) with respect to Y_T and Y_N, the classic first-order conditions for the equilibrium prices of nontradable and tradable goods are obtained, in which the effect on such prices from each good's share and how they are combined (elasticity of substitution) becomes clear:

$$P_N = (1-\omega)^{\frac{1}{\theta}} \left(\frac{\Upsilon}{Y_N}\right)^{\frac{1}{\theta}} P \tag{7}$$

[8] Obviously, when relative nontradable prices between two countries are expressed in a common currency, becomes the Real Exchange Rate

[9] As mentioned before, in a globalized world it is rather less probable that market imperfections would be the reason for preventing the LOP from holding.

$$P_T = \omega^{\frac{1}{\theta}} \left(\frac{\Upsilon}{Y_T}\right)^{\frac{1}{\theta}} P \tag{8}$$

Thus the relative nontradable price for a country *i* is:

$$\frac{P_N^i}{P_T^i} = \left[\frac{(1-\omega)}{\omega}\ \frac{Y_T^i}{Y_N^i}\right]^{\frac{1}{\theta^i}} \tag{9}$$

and the (common currency) Real Exchange Rate (RER) for countries *i, j* is:

$$\frac{P_N^i/P_T^i}{P_N^j/P_T^j} = \left[\frac{\left(1-\omega^i\right)}{\omega^i}\ \frac{Y_T^i}{Y_N^i}\right]^{\frac{1}{\theta^i}} \Bigg/ \left[\frac{(1-\omega^j)}{\omega^j}\ \frac{Y_T^j}{Y_N^j}\right]^{\frac{1}{\theta^j}} \tag{10}$$

Next, in the second nest, we need to define the equations for the production functions of tradables and nontradables for countries *i* and *j*, where M represents *inputs* and Q_T and Q_N, the third nest, are "composed" functions of the factors (capital and labor) used in the productions of tradables and nontradables: The functions for country *i* are:

$$Y_{iT} = \left(\alpha_i\, M_{iT}^{\rho_{i_T}} + (1-\alpha_i)\, Q_{iT}^{\rho_{i_T}}\right)^{\frac{1}{\rho_{i_T}}} \tag{11}$$

$$Y_{iN} = \left((1-\alpha_i)\, M_{iN}^{\rho_{i_N}} + \alpha_i\, Q_{iN}^{\rho_{i_N}}\right)^{\frac{1}{\rho_{i_N}}} \tag{12}$$

$$Q_{iT} = \left(\beta_i\, K_{iT}^{\lambda_{i_T}} + (1-\beta_i)\, L_{iT}^{\lambda_{i_T}}\right)^{\frac{1}{\lambda_{i_T}}} \tag{13}$$

$$Q_{iN} = \left((1-\beta_i)\, K_{iN}^{\lambda_{i_N}} + \beta_i\, L_{iN}^{\lambda_{i_N}}\right)^{\frac{1}{\lambda_{i_N}}} \tag{14}$$

And for country *j*:

$$Y_{jT} = \left(\left(1-\alpha_j\right) M_{jT}^{\rho_{j_T}} + \alpha_j\, Q_{jT}^{\rho_{j_T}}\right)^{\frac{1}{\rho_{j_T}}} \tag{15}$$

$$Y_{jN} = \left(\alpha_j\, M_{jN}^{\rho_{j_N}} + \left(1 - \alpha_j\right) Q_{jN}^{\rho_{j_N}}\right)^{\frac{1}{\rho_{j_N}}} \tag{16}$$

$$Q_{jT} = \left(\left(1 - \beta_j\right) K_{jT}^{\lambda_{j_T}} + \beta_j\, L_{jT}^{\lambda_{j_T}}\right)^{\frac{1}{\lambda_{j_T}}} \tag{17}$$

$$Q_{jN} = \left(\beta_j\, K_{jN}^{\lambda_{j_N}} + \left(1 - \beta_j\right) L_{jN}^{\lambda_{j_N}}\right)^{\frac{1}{\lambda_{j_N}}} \tag{18}$$

where ρ_T, ρ_N, λ_T, and λ_N are the substitution coefficients between inputs and factors, and between capital and labor in the production of tradables and nontradables; while α and β are the intensity parameters between inputs and factors, and between capital and labor respectively.

To determine what might alter a country's relative nontradable price, equation (9) is evaluated at a stationary equilibrium state when changes in relative prices equal zero. That is:

$$\partial log\left(\frac{P_N^i}{P_T^i}\right) = \frac{1}{\theta_i}\partial\left[log\frac{(1-\omega)}{\omega} + log\left(\frac{Y_T^i}{Y_N^i}\right)\right] = 0 \tag{19a}$$

or

$$\frac{\hat{Y}_T^i}{Y_T^i} = \frac{\hat{Y}_N^i}{Y_N^i} \tag{19b}$$

Where the caret (hat) stands for the first difference of the variable. That is, for the relative price in country *i* to maintain a stationary state, the rate of change in the production of tradables must equal that in the production of nontradables; a quite intuitive result. The following step would be to totally differentiate the production functions of equation (19b) and then solve for the equilibrium condition. It would be rather convenient to evaluate equation (19b) but for the condition that might differ the most among the sampled countries. It is clear that Latin-American economies are labor-abundant (although with different levels of skills), but highly unequal in their capital endowments. Countries like Brazil or Venezuela, for instance, have larger capital endowments than Uruguay or Ecuador. Therefore, although the relevance of factor intensities and substitution elasticities, differences in capital endowments could be the main technical source of disparity that would alter the RER between two countries. Then, the equilibrium condition expressed in equation (19b) is evaluated only with respect to changes in capital. After plugging equations 11-18 into (19b) and solving, equation (20) gives the partial derivatives of Y_T and Y_N with respect to capital (k) for country *i*. The same result applies to country *j*.

$$\frac{\partial_{k_T} Y_{i_T}}{\partial_{k_N} Y_{i_N}} = \frac{\frac{(1-\alpha_i)\beta_i Y_{i_T}^{\left(1-\rho_{i_T}\right)} Q_{i_T}^{\left(\rho_{i_T}-\tau_{i_T}\right)} K_{i_T}^{\left(\tau_{i_T}-1\right)}}{Y_{i_T}}}{\frac{\alpha_i(1-\beta_i) Y_{i_N}^{\left(1-\rho_{i_N}\right)} Q_{i_N}^{\left(\rho_{i_N}-\tau_{i_N}\right)} K_{i_N}^{\left(\tau_{i_N}-1\right)}}{Y_{i_N}}} = 1 \qquad (20)$$

At this point, some simplifying assumptions are adopted. In particular, it will be assumed that the two countries, *i* and *j*, have the same economic size $\left(Y^i = Y^j\right)$ and that each one produces the same quantities of tradables and nontradables ($Y_T^i = Y_N^i;\ Y_T^j = Y_N^j$)[10]. Also, a common and constant inputs/factors elasticity of substitution applies for each country's sectors ($\rho_T = \rho_N$), and uses the same quantity of total factors ($Q_T = Q_N$), but with different capital/labor technology (different factor amounts and intensities)[11]. Under such assumptions equation (20) can be rewritten as:

$$\frac{\partial_{k_T} Y_{i_T}}{\partial_{k_N} Y_{i_N}} = \frac{(1-\alpha_i)\beta_i K_{i_T}^{\left(\tau_{i_T}-1\right)}}{\alpha_i(1-\beta_i) K_{i_N}^{\left(\tau_{i_N}-1\right)}} = 1$$

or

[10] Obviously, it is not necessarily true since tradable/nontradable sizes go from 46% to 58% in our sample. However, besides being a highly useful simplification, we still maintain differences in capital endowments per sector and country which is really the interest of this research.

[11] This is a clear consequence for assuming the two countries with the same economic and sectoral sizes. The fact that *Q's* are assumed the same, though, does not imply that each country would use the same amount of factors per sector. On the contrary, each country will employ factors depending on its endowments and with different intensities; but different factor combinations will "produce" the same amount of *Q.*

$$\frac{\partial_{k_T} Y_{i_T}}{\partial_{k_N} Y_{i_N}} = \frac{(1-\alpha_i)\beta_i}{\alpha_i(1-\beta_i)} \left(\frac{K_{i_T}}{K_{i_N}}\right)^{\frac{\sigma_i}{1-\sigma_i}} = 1 \tag{21}$$

where the country's *i* capital-labor elasticity of substitution σ_i is given by:

$$\sigma_i = \frac{\tau_i - 1}{\tau_i} \tag{22}$$

Then, the variation in the RER between countries *i* and *j* after a marginal change in each country's capital is given by:

$$\partial_k RER_{i,j} = \frac{\dfrac{\partial_{k_T} Y_{i_T}}{\partial_{k_N} Y_{i_N}}}{\dfrac{\partial_{k_T} Y_{j_T}}{\partial_{k_N} Y_{j_N}}} = \frac{\dfrac{(1-\alpha_i)\beta_i}{\alpha_i(1-\beta_i)} \left(\dfrac{K_{i_T}}{K_{i_N}}\right)^{\frac{\sigma_i}{1-\sigma_i}}}{\dfrac{\alpha_j(1-\beta_j)}{\beta_j(1-\alpha_j)} \left(\dfrac{K_{j_T}}{K_{j_N}}\right)^{\frac{\sigma_j}{1-\sigma_j}}} = 1$$

or

$$\partial_k RER_{i,j} = \frac{(1-\alpha_i)(1-\alpha_j)\beta_i\beta_j}{\alpha_i\alpha_j(1-\beta_i)(1-\beta_j)} \left(\frac{K_{i_T}}{K_{i_N}}\right)^{\frac{\sigma_i}{1-\sigma_i}} \left(\frac{K_{j_N}}{K_{j_T}}\right)^{\frac{\sigma_j}{1-\sigma_j}} \gtreqless 1 \tag{23}$$

Equation (23) indicates that changes in the RER between two countries could result from adopting different capital-prone production technologies, in which capital and factors intensities, sectoral capital endowments, and capital-labor elasticities of substitution will define whether the RER maintains its stationary state (equal 1) or "drift", above (net effect positive) or below 1 (net effect negative)[12]. That is, $RER_{i,j}$ will be above 1 (depreciate) when country *i*'s capital productivity is larger than country *j*'s. A ***coincidence*** occurs when countries with higher capital productivity (net effect positive in eq. 23) also present positive deviations from the LOP (eq.1) due to an appreciated nominal exchange rate (in line with the Balassa-Samuelson Hypothesis): to restore equilibrium, mean-reversion (depreciation) in relative prices and/or nominal exchange rate is required. This result permits reexamining the deviation pattern from equation (2) that impedes the LOP in its strict version to hold:

[12] Since a stationary state is being evaluated, the Net Effect = $\partial_k RER_{i,j} - 1$ which could be positive or negative.

a positive drift in equation (23) is equivalent to a positive deviation in equation (3) (relative prices larger than the nominal exchange rate) and depreciation should follow to re-establish equilibrium. The same follows for a negative drift. This result highlights the approach proposed in this research: not only imperfect market structures or trade barriers but also technological issues could explain a systematic pattern of deviations between relative prices and the nominal exchange rate. In the following section the rate of ***coincidence*** between the *net effect* and the *prices deviations* is explored. If technological issues do explain LOP deviations, a high rate of coincidence must be obtained.

4. The Results

Before applying the data to equation (23), the capital-labor elasticity of substitution (σ) must be derived. Following Oberfield and Raval (2014) and Baqaee and Farhi (2019) the aggregate and per industry elasticities of substitution are derived[13]. Table II shows each's country aggregate elasticity of substitution:

Table II Capital-Labor Elasticity of Substitution

	Brazil	Colombia	Costa Rica	Ecuador	Guatemala	Paraguay	Peru	Uruguay	Venezuela
σ	0.31	0.599	1.29	1.15	0.53	0.51	0.41	0.64	0.63

The ample distribution of σ values is evident with Brazil registering the lowest and Costa Rica the highest[14]. From the I-O tables the values for relative sectoral capital sizes and factor and input intensities are obtained. Table III shows the values of the variables required to estimate equation (21):

[13] The derivation is shown in the Supplementary Material available at DOI 10.17605/OSF.IO/AQ5FJ

[14] Oberfield and Raval (2014) estimate the capital-labor elasticity of substitution for certain developing countries (Chile (0.84), Colombia (0.84) and India (1.11)), but just for the manufacturing (tradable) sector.

Table III Components of the Production Functions

	TRADABLES			NON TRADABLES				
		β_T	$(1-\alpha_T)$		$(1-\beta_N)$	α_N		
	K	$\frac{K}{K+L}$	$\frac{K+L}{K+L+M}$	K	$\frac{K}{K+L}$	$\frac{K+L}{K+L+M}$	$\sigma_{k,L}$	$\left(\frac{\delta Y_T}{\delta K_T}\right)/\frac{\delta Y_N}{\delta K_N}$
BRASIL	4.11E+15	0.61	0.005	7.67E+14	0.999	0.001	**0.31**	**8.24**
COLOMBIA	4.36E+15	0.37	0.31	3.70E+15	0.56	0.30	**0.59**	**0.85**
COSTA RICA	5.02E+14	0.23	0.11	6.89E+14	0.21	0.16	**1.29**	**3.15**
ECUADOR	1.56E+15	0.27	0.17	1.44E+15	0.35	0.19	**1.15**	**0.36**
GUATEMALA	1.01E+15	0.32	0.17	1.78E+15	0.62	0.13	**0.53**	**0.35**
PARAGUAY	4.91E+14	0.22	0.09	5.94E+14	0.24	0.17	**0.50**	**0.38**
PERU	2.80E+15	0.39	0.17	2.52E+15	0.50	0.16	**0.43**	**0.90**
URUGUAY	1.00E+15	0.24	0.22	1.19E+15	0.19	0.22	**0.64**	**0.95**
VENEZUELA	4.36E+15	0.37	0.31	3.70E+15	0.56	0.30	**0.63**	**0.89**

Note. Factors and input shares are derived from each country's I-O tables. The aggregate capital-labor elasticity of substitution (σ) is obtained following Oberfield and Raval (2014), while deriving such elasticity for sectors (tradables/non tradables) follows Baqaee and Farhi (2019).

Note that Brazil is the country with the highest level of sectoral capital intensities, besides registering the lowest elasticity of substitution[15]. Finally, Table IV presents the results for equation (23) where drifts from country pairs are estimated:

Table IV Impact on Real Exchange Rates due to Changes in Capital

	BRA	COL	CRI	ECU	GTM	PRY	PER	URY	VEN
BRA		9.7	2.6	22.6	23.2	22.0	9.2	8.7	9.3
COL	0.1		0.3	2.3	2.4	2.3	1.0	0.9	1.0
CRI	0.4	3.7		8.6	8.9	8.4	3.5	3.3	3.5
ECU	0.0	0.4	0.1		1.0	1.0	0.4	0.4	0.4
GTM	0.0	0.4	0.1	1.0		0.9	0.4	0.4	0.4
PRY	0.0	0.4	0.1	1.0	1.1		0.4	0.4	0.4
PER	0.1	1.1	0.3	2.5	2.5	2.4		0.9	1.0
URY	0.1	1.1	0.3	2.6	2.7	2.5	1.1		1.1
VEN	0.1	1.0	0.3	2.4	2.5	2.4	1.0	0.9	

Abbreviations: BRA (Brazil), COL (Colombia), CRI (Costa Rica), ECU (Ecuador), GTM (Guatemala), PRY (Paraguay), PER (Peru), URY (Uruguay), VEN (Venezuela)

[15]Morshed and Turnovsky (2004) suggest that the capital-labor elasticity of substitution tends to increase from below unity for less developed economies to above one for more advanced economies. Other authors like Griliches (1969), Fallon *et al.* (1975) or Krusell *et al.* (2000), however, suggest the opposite: elasticity of substitution below unity indicates a higher complementarity between capital and labor, which can only occurs with high-skilled labor -proper of advanced economies. Nevertheless, both results are incomparable since Morshed and Turnovsky (2004) employed total rather than skilled/raw labor.

Certain country-pair values in Table IV like Colombia-Peru, Colombia-Venezuela, Venezuela-Peru, or Uruguay-Peru equal 1 (or very close to 1) which means that different production technologies produce no drift even though each of such countries presents differences in factor intensities, sectoral capital endowments and capital-labor elasticity of substitution. The rest of the values are above or below 1 as expected. From Table IV it is also clear that the two most productive countries (in terms of capital) are Brazil and Costa Rica, in that order; and the two less productive countries (in terms of capital) are Guatemala and Ecuador in that order.

Finally, in Table V results from equation (3) (shown as Deviation (net) in Table V) are contrasted with results from equation (23) (shown as Drift -sign- in Table V). The objective is to find out whether deviations and drifts patterns (signs) match. If, for instance, a positive deviation (relative prices larger than the nominal exchange rate) ***coincides*** with a positive drift (positive net effect on the RER from differences in capital-intensive technologies) between two countries, it suggests that a positive correlation might exist between production technologies and the LOP hypothesis. Table A1 in Appendix 1 shows the positive/negative deviations per country pair.

Table V Deviations and Drifts of Relative Prices from Nominal Exchange Rates

FOREIGN	BRASIL					COLOMBIA					COSTA RICA					ECUADOR					GUATEMALA				
DOMESTIC	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)
BRASIL						39%	61%	+	+	9.66	46%	54%	+	+	2.62	24%	76%	+	+	22.58	24%	76%	+	+	23.24
COLOMBIA	61%	39%	-	-	0.10						58%	42%	-	-	0.27	24%	76%	+	+	2.34	21%	79%	+	+	2.41
COSTA RICA	52%	48%	-	-	0.38	40%	60%	+	+	3.69						25%	75%	+	+	8.64	19%	81%	+	+	8.89
ECUADOR	77%	23%	-	-	0.04	67%	33%	-	-	0.43	75%	25%	-	-	0.12						39%	61%	+	+	1.03
GUATEMALA	76%	24%	-	-	0.04	79%	21%	-	-	0.42	81%	19%	-	-	0.11	61%	39%	-	-	0.97					
PARAGUAY	71%	29%	-	-	0.05	55%	45%	-	-	0.44	59%	41%	-	-	0.12	52%	48%	-	+	1.03	40%	60%	+	+	1.06
PERU	68%	32%	-	-	0.11	67%	33%	-	+	1.05	64%	36%	-	-	0.29	48%	52%	+	+	2.46	25%	75%	+	+	2.54
URUGUAY	45%	55%	+	-	0.12	37%	63%	+	+	1.12	36%	64%	+	-	0.30	15%	85%	+	+	2.61	16%	84%	+	+	2.68
VENEZUELA	68%	32%	-	-	0.11	59%	41%	-	-	0.96	65%	35%	-	-	0.28	40%	60%	+	+	2.44	37%	63%	+	+	2.51

FOREIGN	PARAGUAY					PERU					URUGUAY					VENEZUELA				
DOMESTIC	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)	-	+	Deviation (net)	Drift (sign)	Drift (value)
BRASIL	27%	73%	+	+	21.95	31%	69%	+	+	9.16	55%	45%	-	+	8.66	32%	68%	+	+	9.27
COLOMBIA	45%	55%	+	+	2.27	33%	67%	+	+	0.95	63%	37%	-	-	0.90	41%	59%	+	+	0.96
COSTA RICA	39%	61%	+	+	8.39	34%	66%	+	+	3.50	64%	36%	-	+	3.31	35%	65%	+	+	3.54
ECUADOR	48%	52%	+	+	1.0	51%	49%	-	-	0.41	85%	15%	-	-	0.38	60%	40%	-	-	0.41
GUATEMALA	60%	40%	-	-	0.94	75%	25%	-	-	0.39	84%	16%	-	-	0.37	63%	37%	-	-	0.40
PARAGUAY						48%	52%	+	-	0.42	78%	22%	-	-	0.39	56%	44%	-	-	0.42
PERU	52%	48%	-	+	2.40						25%	75%	-	-	0.94	57%	43%	-	+	1.01
URUGUAY	22%	78%	+	+	2.53	25%	75%	+	+	1.06						25%	75%	+	+	1.07
VENEZUELA	44%	56%	+	+	2.37	43%	57%	+	+	0.99	75%	25%	-	-	0.93					

Deviations and drifts coincide in 88% of the cases, while only in 12% do not (cells highlighted represent the cases where no matches were found). An important consequence of the results shown in Table IV is that, if mean-reversion towards equilibrium were to happen, countries like Brazil and Uruguay should experience a depreciation of their respective relative prices and/or nominal exchange rates (except with each other), and Guatemala an appreciation. Country pairs with mixed results deviations-drifts, on the other hand, should experience a mixed dynamics depreciation/appreciation. For instance, Venezuela should experience an appreciation of its relative price and/or domestic currency (the bolivar) with respect to Colombia (its major trading partner), Brazil, Costa Rica, and Uruguay, but a depreciation with the rest; and depending on the evolution of the Venezuelan nationwide-average nominal exchange rate, its real exchange rate will be *closer to* ***and*** *farther from* equilibrium[16].

Two issues that demand further investigation due to their consequences on public policy are the effects of the above outcomes on trade and on exchange policies. On the former, trade agreements to lower trade barriers would not provide any trade advantages to those countries that are not technologically competitive. Trade will be based on comparative advantages and if countries in a region do not have many things to complement one another, trade will not be the growth-enhancing factor expected to be. This could be a reason why trade levels among Latin-American countries have been quite lower than expected. On the other hand, differences in sectoral (or industrial) production technology would require a “sectoral” nominal exchange rate rather than a nationwide-average one if RER equilibrium is to be reached. Using nationwide-average nominal exchange rates will benefit certain industries but will hurt others, independently of each country’s real competitive advantage.

[16] Although there exists the 2017 ICP round, unfortunately it was not possible to check on the mean-reversion dynamics of the 2011 deviations since there was a change in the quoted items that are needed for this analysis.

5. Conclusion

Numerous studies have examined the Law of One Price (LOP) hypothesis and how it affects real exchange rates, with results ranging from absolute rejection to temporary deviations with a mean-reverting tendency to long-run equilibrium. However, little and contentious research has been conducted to analyze what might cause these deviations in the first place. In this study, I analyze whether certain technological issues, like differences in countries' production technologies, could explain the observed LOP deviations. From a sample of 9 Latin American countries (Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Paraguay, Peru, Uruguay, and Venezuela), deviations for 144 products were calculated from the ICP 2011 round for country-pairs relative prices with respect to their market average 2011 nominal exchange rates. As expected and for most of the goods, the strict version of the LOP did not hold. To explain such deviations, I developed a partial-equilibrium model with 3-nested Constant Elasticity of Substitution (CES) production functions from which LOP's equilibrium conditions were derived. The results obtained are quite appealing: 88% of deviations coincided with differences in production technologies.

How relevant could it be to know that different production technologies can produce a drift in the RER? First, the discussion would no longer be about the soundness of the LOP hypothesis since its failure to hold could be the result of technical issues rather than its stringent market-related conditions. Second, the real effects of trade agreements among countries with different production technologies would be quite limited: countries' competitiveness would result from technological issues rather than from trade barriers or market structures. Therefore, trade volume between two countries with different factor intensities would be based mostly on comparative advantages, independently of trade agreements. This could probably be a reason for the lower-than-expected effect of trade agreements in Latin America compared to trade volumes among developed nations. Third, nominal exchange rate depreciation becomes a natural compensatory mechanism in capital-intensive countries, boosting further technological competitiveness. Finally, if RER equilibrium is to be achieved, disparities in sectoral (or industrial) production technology would require a "sectoral" nominal exchange rate rather than a nationwide average one. Independent of each country's true comparative advantage, using nominal average exchange rates will benefit some industries while hurting others.

Then, two consequences on public policy from the results presented above could be highly relevant and call for further study: trade agreements between two countries with disparate technologies would simply bolster complementarity and minimize the effect of trade on economic growth; and employing nationwide average nominal exchange rates, rather than sectoral ones, will benefit some industries while hurting others regardless of a country’s true comparative advantage.

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