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How Important is the Currency Denomination of Exports in Open-Economy Models?

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How Important is the Currency Denomination of Exports in Open-Economy Models?*

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Abstract

We show that standard alternative assumptions about the currency in which firms price export goods are virtually inconsequential for the properties of aggregate variables, other than the terms of trade, in a quantitative open-economy model. This result is in contrast to a large literature that emphasizes the importance of the currency denomination of exports for the properties of open-economy models.

Keywords: local currency pricing; producer currency pricing; international relative prices; exchange rates; nontraded goods; distribution services.

JEL classification: F3, F41

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1 Introduction

The high volatility and persistence of real exchange rate movements are a well-known puzzle in international macroeconomics. Standard decompositions of real exchange rate movements systematically find that movements in the relative price of traded goods across countries are key in understanding real exchange rate behavior whereas movements in the relative price of traded to nontraded goods across countries play a smaller role.[1] In the data, the behavior of the relative price of traded goods (and even highly traded goods) across countries mimics closely the behavior of real exchange rates. This finding has generated much interest in the behavior of the relative price of traded goods across countries. Furthermore, in the context of open-economy macroeconomic models with nominal price rigidities, this evidence has generated an extensive debate on the nature of the pricing decisions of firms that operate in different national markets and on the implications of alternative price-setting regimes for exporters.[2]

There are two standard price-setting regimes for exporters in models with nominal price rigidities, typically referred to as producer currency pricing (PCP) and local currency pricing (LCP).[3] Under PCP, exports are priced in the currency of the producer and the foreign price of home exports varies one-to-one with nominal exchange rate changes.[4] That is, while the domestic-currency price of a good is sticky, its foreign-currency price is not. Therefore, in these models, the adjustment of the nominal exchange rate to exogenous shocks has an immediate impact on the demand for home goods relative to foreign goods. A nominal depreciation, for instance, makes foreign goods more expensive relative to domestic goods worldwide, directing world expenditure toward home goods (expenditure switching effect).[5] Note that in these models the law of one price holds for traded goods and, absent additional features, these models do not generate large movements in the the real exchange rate or in

[1] See Engel (1999) for the seminal contribution.

[2] See, for instance, Engel (2002), Obstfeld (2001), Obstfeld and Rogoff (2000a), and the references therein.

[3] There are also models in which some firms follow PCP and others follow LCP (e.g., Betts and Devereux, 2000, among others). Devereux, Engel, and Storgaard (2004) consider a model in which the currency-denomination of exports is endogenous, as opposed to the exogenous cases considered here.

[4] See, for instance, Obstfeld and Rogoff (1995).

[5] The expenditure switching effect is also a central mechanism in the traditional Mundell-Flemming-Dornbush open-economy models. (See Obstfeld and Rogoff (1996), chapter 9.)

the relative price of traded goods across countries.

Under LCP, it is assumed that firms are able to price discriminate across national markets and set prices in the currency of the buyer.[6] Consider first the case in which prices are pre-set one period in advance. Then, the current price in domestic currency of foreign goods does not respond to unanticipated movements of the nominal exchange rate and domestic consumer prices are insulated from exchange rate changes. This feature of the model implies that, in the short run, unanticipated exchange rate changes generate deviations from the law of one price and that these changes are not associated with an expenditure switching effect.[7] With richer and more realistic nominal price rigidities, prices of imports respond slowly to exchange rate changes under LCP. Therefore, these models are consistent with the empirical evidence on the slow pass-through of exchange rate changes to consumer prices and substantial deviations from the law of one price.[8] In fact, LCP is a common feature of models with nominal price rigidities that address real exchange rate behavior. These models can generate large movements in real exchange rates and the relative price of traded goods across countries.[9] The muted response of the price of imports to exchange rate changes is associated with a dampened expenditure switching effect in the short run in models with LCP. Obstfeld and Rogoff (2000b) present empirical evidence indicating a strong tendency for the terms of trade (defined as the relative price of imports to exports) to worsen with nominal exchange rate depreciations. This evidence supports the importance of the expenditure switching effect of exchange rate changes.[10] Thus, there is an ongoing debate regarding which pricing mechanism is the most appropriate.

In this paper, we contrast the implications of the two alternative pricing regimes that are standard in the open-economy macro literature, PCP and LCP, in a quantitative two-country model. The model features nontraded goods which are used both as an input

[6] See Betts and Devereux (1996, 2000) for the initial contributions.

[7] In models with prices set one period in advance, Devereux and Engel (2003) and Corsetti and Pesenti (2005) show that the pricing regime (and the magnitude of the expenditure switching effect) is critical for the optimal degree of exchange rate volatility between open economies. See also Duarte and Obstfeld (2008).

[8] See, for instance, Engel and Rogers (1996) and Goldberg and Knetter (1997) among many others.

[9] See, among many others, Bergin and Feenstra (2001), Kollmann (2001), Chari, Kehoe, and McGrattan (2003), Steinsson (2008), Carvalho and Nechio (2008).

[10] Obstfeld and Rogoff (2000b) point out that in a model with LCP and prices set one period in advance, the correlation between the terms of trade and the nominal exchange rate is instead negative.

into the production of retail goods and as consumption services. We find that different assumptions regarding the currency denomination of exports are virtually inconsequential for the properties of aggregate variables, other than the terms of trade. In particular, the real exchange rate and the international relative price of retail goods behave similarly across the two price-setting regimes. This result follows from the fact that trade represents a relatively small fraction of GDP and that the behavior of the nominal exchange rate is close to a random walk. The two pricing assumptions do, however, differ somewhat with respect to the behavior of the terms of trade and the price of imports and their correlations with other variables in the model. For instance, the terms of trade (as well as the price of imports) have a positive correlation with exchange rates in both models, but the correlation is higher under PCP. That is, exchange rate depreciations worsen the terms of trade under both price-setting regimes, but this effect is somewhat stronger in the PCP model. Nevertheless, it is hard to discriminate between the two pricing regimes based on these correlations alone. Our results highlight the fact that in the context of a quantitative open-economy model, the difference between the polar international pricing regimes is not as extensive as standard analyses may suggest.

The paper is organized as follows. In the next section, we present the model and briefly discuss the calibration. In section 3, we consider the implications of two polar alternative price-setting regimes for the producers of traded goods; we conclude in section 4.

2 Alternative Price Setting Regimes

In this section, we look at the two alternative price-setting regimes for firms that sell in different national markets when prices are set one period in advance. In the next section, we describe our benchmark model, where we imbed these firms in a general equilibrium model that also includes nontraded and retail goods and allow for richer and more realistic nominal rigidities.

Consider a model with two countries: home and foreign. In each country there is a continuum of firms producing differentiated varieties of a country-specific good. That is, firm i, $i \in [0, 1]$, located in the home country produces variety i of the home good. All varieties of the home and foreign good are imperfect substitutes in consumption. Hence, consumers in both countries consume all varieties of home and foreign goods, and thus each firm sells in both markets.

Let $y_H^d(i)$ and $y_H^{d*}(i)$ denote the downward-sloping demand functions from the home and foreign markets faced by firm i located in the home country. This firm produces with a linear technology in labor $y_H(i) = z_H l(i)$, where z_H is a stochastic country-specific technology level. Firms choose prices before the realization of uncertainty and cannot adjust prices for one period. Given the preset prices, firms meet ex-post demand.

Under PCP, firm i chooses one price $P_{H,t}^{PCP}(i)$, denominated in home currency, at time $t-1$. Hence, in period t home consumers face the price $P_{H,t}^{PCP}(i)$ for home-variety i and foreign consumers face the foreign-currency price $P_{H,t}^{*PCP}(i) = P_{H,t}^{PCP}(i)/S_t$, where S_t is the equilibrium exchange rate in the period t. It follows that under PCP the law of one price holds, $P_{H,t}^{PCP}(i) = S_t P_{H,t}^{*PCP}(i)$. Firm i chooses its price at time $t-1$ to maximize expected profits from sales in both markets in period t:

$$\max_{P_{H,t}^{PCP}(i)} \mathrm{E}_{t-1}\left[\vartheta_{t|t-1}\left(P_{H,t}^{PCP}(i) - \Psi_{H,t}\right)\left(y_{H,t}^d(i) + y_{H,t}^{*d}(i)\right)\right],$$

where ϑ is the pricing kernel and $\Psi_{H,t}$ is nominal marginal cost in period t. The optimal price chosen in period $t-1$ is a function of next period's expected output of firm i and nominal marginal cost.

Under PCP, the price of the composite domestic good in period t (an aggregate of the prices of all domestic varieties $P_{H,t}^{PCP}(i)$) is pre-determined and does not respond for one period to unanticipated shocks in period t. The price of the imported good, however, varies one-to-one with movements in the nominal exchange rate S_t. Therefore, after a shock that, say, depreciates the nominal exchange rate, the foreign good becomes more expensive relative to the home good in both countries for one period. Under standard demand functions, demand for the home good relative to the foreign good increases in the period of the shock. Note that the terms of trade of the home country, defined as the domestic-currency price of imports relative to the price of exports, is given by

$$\frac{P_{F,t}^{PCP}}{S_t P_{H,t}^{*PCP}}. \tag{1}$$

Under PCP, this equation can be re-written as

$$\frac{S_t P_{F,t}^{*PCP}}{P_{H,t}^{PCP}},$$

where $P_{F,t}^{*PCP}$ and $P_{H,t}^{PCP}$ are pre-determined. Therefore, under PCP, a nominal depreciation generates a terms of trade depreciation in the period of the shock.

Under LCP, firm i chooses two prices, $P_{H,t}^{LCP}(i)$ and $P_{H,t}^{*LCP}(i)$, denominated in home and foreign currency, respectively, at time $t-1$. These prices maximize expected profits from sales in each market in period t:

$$\max_{P_{H,t}^{LCP}(i), P_{H,t}^{*LCP}(i)} \mathrm{E_{t-1}} \left[\vartheta_{t|t-1} \left(P_{H,t}^{LCP}(i) - \Psi_{H,t} \right) y_{H,t}^{d}(i) + \left(S_t P_{H,t}^{*LCP}(i) - \Psi_{H,t} \right) y_{H,t}^{*d}(i) \right].$$

In this case, in period t, home consumers face the price $P_{H,t}^{LCP}(i)$ and foreign consumers face the price $P_{H,t}^{*LCP}(i)$ for home-variety i. Note that both prices are pre-determined and thus in period t the law of one price need not hold.

Under LCP, both the price of imports and the price of domestic goods are pre-determined in each country. Therefore, shocks that affect the exchange rate, do not affect relative demand for goods in either country for one period. That is, under LCP, relative demand is insulated from exchange rate fluctuations and there is no expenditure switching effect. Note also that because prices are pre-determined in the currency of the consumer, the terms of trade of the home country fall with a nominal exchange rate depreciation (see equation 1).

When firms set prices one period in advance, the price-setting regime has stark implications for the behavior of the relative price of imports to domestic goods and the terms of trade in each country and the correlation of these variables with exchange rate changes. Under PCP, the law of one price always holds and the correlation between the terms of trade and the exchange rate is 1. Under LCP, the relative price of imports does not immediately respond to exchange rates and the correlation between the terms of trade and the exchange rate is -1.

In the following section, we develop a model with a more general characterization of price rigidity. Instead, each period one-fourth of the mass of firms chooses prices (after the realization of uncertainty) that are fixed for four periods. We also consider the role of nontraded goods in consumption and in the production of retail goods. We find that in our calibrated model the differences between the two price-setting regimes are much diminished. We argue that this finding is robust to critical model variations.

3 The Model

We consider a model economy with two countries: denominated home and foreign. The model follows closely that of Dotsey and Duarte (2008). Each country is populated by a representative household, a continuum of firms, and a monetary authority. The production structure of each economy is depicted in Figure 1. Each country produces nontraded goods and intermediate traded goods using capital and labor. In addition, each country produces retail goods using local and imported intermediate traded goods together with nontraded goods (retail services). Households in each country consume retail goods and nontraded consumption goods. They rent capital and labor services to firms in the intermediate traded goods sector and the nontraded goods sector, and they trade noncontingent nominal bonds with the foreign household.

In what follows, we describe the economy of the home country. The foreign economy is analogous, and asterisks denote foreign country variables.

3.1 Production

There are three sectors of production in the model: the nontraded goods sector, the intermediate traded goods sector, and the retail sector. The three sectors are treated symmetrically in assuming that firms in each sector produce a continuum of differentiated varieties and set prices in a staggered fashion.

3.1.1 The Intermediate Traded Goods Sector

Intermediate traded goods are produced using primary inputs, capital and labor. There is a continuum of firms in this sector, each producing a differentiated variety h, $h \in [0,1]$. The production function is $y_{H,t}(h) = z_{H,t} k_{H,t}(h)^{\alpha} l_{H,t}(h)^{1-\alpha}$, where H refers to the home intermediate traded goods sector.[11] The term $z_{H,t}$ represents a productivity shock specific to this sector, and $k_{H,t}(h)$ and $l_{H,t}(h)$ denote the use of capital and labor services by firm h.

Each firm in this sector sells its variety to firms in the domestic and foreign retail sectors. Firms in this sector are monopolistically competitive, and we consider two alternative pricing regimes: producer currency pricing and local currency pricing.

Under PCP, each firm chooses one price, denominated in units of domestic currency, for home and foreign markets. We assume that firms set prices for J periods in a staggered way. That is, each period, $1/J$ of firms optimally choose prices that are set for J periods. The problem of a firm adjusting its price in period t is described by

$$\max_{P_{H,t}(0)} \sum_{j=0}^{J-1} \mathrm{E_t} \left[\vartheta_{t+j|t} \left(P_{H,t}(0) - P_{t+j} \psi_{H,t+j} \right) y_{H,t+j}(j) \right], \tag{2}$$

where $y_{H,t+j}(j) = x_{H,t+j}(j) + x^{*}_{H,t+j}(j)$, and $x_{H,t+j}(j)$ and $x^{*}_{H,t+j}(j)$ denote the constant-elasticity ς demand curves from home and foreign markets faced by this firm in period $t+j$ and $\psi_{H,t}$ is the real marginal cost of production in this sector. The term $\vartheta_{t+j|t}$ denotes the pricing kernel, used to value profits at date $t+j$, which are random as of t, and P_{t+j} is the aggregate price level. As is standard in the New Keynesian literature, the price chosen by firms that adjust prices in period t, $P_{H,t}(0)$, is a function of current and future marginal cost, and current and future output. Specifically,

$$P_{H,t}(0) = \frac{\varsigma}{\varsigma - 1} \frac{\sum_{j=0}^{J-1} \mathrm{E_t} \left[\beta^j u_{c,t+j} \psi_{H,t+j} y_{H,t+j}(j) \right]}{\sum_{j=0}^{J-1} \mathrm{E_t} \left[\beta^j \frac{u_{c,t+j}}{P_{t+j}} y_{H,t+j}(j) \right]}. \tag{3}$$

Under PCP, the law of one price holds for all intermediate traded goods, regardless of when

[11]In the foreign country, firms in the intermediate traded goods sector produce differentiated varieties $y_{F,t}(f)$, $f \in [0,1]$.

prices were last adjusted,

$$P^*_{H,t}(j) = \frac{P_{H,t}(j)}{S_t}, \quad j = 0, \ldots, J-1, \tag{4}$$

where S denotes the nominal exchange rate (expressed as units of domestic currency per unit of foreign currency).

Under LCP, each period $1/J$ of firms optimally choose a price, denominated in the buyer's currency, for each market. These two prices are set for J periods. The problem of a firm adjusting its prices in period t is given by

$$\max_{P_{H,t}(0),P^*_{H,t}(0)} \sum_{j=0}^{J-1} \mathrm{E_t}\left[\vartheta_{t+j|t}\left(\left(P_{H,t}(0) - P_{t+j}\psi_{H,t+j}\right)x_{H,t+j}(j) + \left(S_{t+j}P^*_{H,t}(0) - P_{t+j}\psi_{H,t+j}\right)x^*_{H,t+j}(j)\right)\right]. \tag{5}$$

The optimal prices chosen by firms that adjust prices in period t now depend on current and future sales in each market and are given by

$$P_{H,t}(0) = \frac{\varsigma}{\varsigma - 1}\frac{\sum_{j=0}^{J-1}\mathrm{E_t}\left[\beta^j u_{c,t+j}\psi_{H,t+j}x_{H,t+j}(j)\right]}{\sum_{j=0}^{J-1}\mathrm{E_t}\left[\beta^j \frac{u_{c,t+j}}{P_{t+j}} x_{H,t+j}(j)\right]}, \tag{6}$$

$$P^*_{H,t}(0) = \frac{\varsigma}{\varsigma - 1}\frac{\sum_{j=0}^{J-1}\mathrm{E_t}\left[\beta^j u_{c,t+j}\psi_{H,t+j}x^*_{H,t+j}(j)\right]}{\sum_{j=0}^{J-1}\mathrm{E_t}\left[\beta^j \frac{u_{c,t+j}}{P_{t+j}} S_{t+j}x^*_{H,t+j}(j)\right]}. \tag{7}$$

Under LCP, the law of one price need not hold for any vintage of prices. First, firms that reset prices in the current period may choose to price discriminate across markets and choose prices such that $P_{H,t}(0) \neq S_t P^*_{H,t}(0)$. Second, unanticipated movements in the nominal exchange rate imply automatic deviations from the law of one price for the remaining $J-1$ vintages of prices that are not reset in period t, since prices in each market are set in the buyer's currency and, thus, insulated from exchange rate changes by construction.

Note that the pricing regime affects the equilibrium of the model because prices are sticky. With flexible prices the optimal price depends only on the nominal marginal cost of production and the price elasticity of demand ς. It follows that in our model, under LCP, firms choose prices in domestic and foreign currencies that obey the law of one price.

3.1.2 The Nontraded Goods Sector

This sector, indexed by N, has a structure analogous to the intermediate traded goods sector. Each firm n, $n \in [0,1]$, operates the production function $y_{N,t}(n) = z_{N,t}k_{N,t}(n)^{\alpha}l_{N,t}(n)^{1-\alpha}$, where all the variables have analogous interpretations. The price-setting problem for a firm in this sector is

$$\max_{P_{N,t}(0)} \sum_{j=0}^{J-1} \mathrm{E_t}\left[\vartheta_{t+j|t}\left(P_{N,t}(0) - P_{t+j}\psi_{N,t+j}\right)y_{N,t+j}(j)\right],$$

where $y_{N,t+j}(j) = x_{N,t+j}(j) + c_{N,t+j}(j)$ represents demand from firms in the retail sector and consumers faced by this firm in period $t+j$. The optimal price is given by an expression analogous to equation (3).

3.1.3 The Retail Sector

Firms in this sector combine domestic and imported traded goods with (nontraded) retail services in fixed proportions to bring retail goods to consumers. There is a continuum of firms in this sector, indexed by R, each producing a differentiated variety r, $r \in [0,1]$. Each firm combines all varieties of domestic and imported intermediate traded goods to produce the composite good x_T, given by

$$x_{T,t}(r) = \left[\omega_H^{\frac{1}{\xi}}x_{H,t}(r)^{\frac{\xi-1}{\xi}} + (1-\omega_H)^{\frac{1}{\xi}}x_{F,t}(r)^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}}, \tag{8}$$

where $x_{H,t}(r)$ and $x_{F,t}(r)$ are Dixit-Stiglitz aggregators of all home and foreign intermediate traded varieties, respectively, with elasticity of substitution ς between any two varieties. Each firm also combines all nontraded varieties to produce x_N, using a Dixit-Stiglitz aggregator. Firms then bring the intermediate traded good x_T to market by combining it in fixed proportions with nontraded goods x_N. The production function of variety r of the retail good is

$$y_{R,t}(r) = \min\left\{\frac{x_{N,t}(r)}{\omega}, \frac{x_{T,t}(r)}{1-\omega}\right\}. \tag{9}$$

Firms in this sector sell their differentiated varieties to consumers for consumption and investment purposes. These firms set prices for J periods in a staggered way and the problem of a firm adjusting its price in period t is given by

$$\max_{P_{R,t}(0)} \sum_{j=0}^{J-1} \mathrm{E}_t \left[\vartheta_{t+j|t} \left(P_{R,t}(0) - P_{t+j}\psi_{R,t+j} \right) y_{R,t+j}(j) \right],$$

where $y_{R,t+j}(j) = c_{R,t+j}(j) + i_{t+j}(j)$ represents the demand for consumption and investment purposes faced by this firm in period $t+j$. The optimal price is given by an expression analogous to equation (3).

3.2 Households

The problem of the household is standard. The representative household in the home country maximizes the expected value of lifetime utility, given by

$$U_0 = \mathrm{E}_0 \sum_{t=0}^{\infty} \frac{\beta^t}{1-\sigma} \left\{ \left(a c_t^{\eta} + (1-a) \left(\frac{M_{t+1}}{P_t} \right)^{\eta} \right)^{\frac{1-\sigma}{\eta}} \exp\left\{ \frac{-\psi_0}{1+\psi_1} l_t^{1+\psi_1} (1-\sigma) \right\} - 1 \right\}, \quad (10)$$

where l_t denotes hours worked, M_{t+1}/P_t denotes real money balances held from period t to period $t+1$, and c_t denotes consumption of a composite good which is an aggregate of the retail good $c_{R,t}$ and the nontraded good $c_{N,t}$, and is given by

$$c_t = \left(\omega_R^{\frac{1}{\gamma}} c_{R,t}^{\frac{\gamma-1}{\gamma}} + (1-\omega_R)^{\frac{1}{\gamma}} c_{N,t}^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}}, \gamma > 0. \quad (11)$$

The parameter γ denotes the elasticity of substitution between retail and nontraded goods and ω_R is a weight. The consumption of retail goods and nontraded goods, c_R and c_N, are each Dixit-Stiglitz aggregators of all the varieties of the retail and nontraded goods, $c_R(r)$ and $c_N(n)$, $r, n \in [0,1]$, respectively, with constant elasticity of substitution ς.

The representative consumer in the home country owns the capital stock k_t, holds domestic currency, and trades a riskless bond denominated in home-currency units with the foreign representative consumer. The stock of bonds held by the household at the beginning of period t is denoted by B_{t-1}. These bonds pay the gross nominal interest rate R_{t-1}. There is a cost of holding bonds given by $\Phi_b(B_{t-1}/P_t)$, where $\Phi_b(\cdot)$ is a convex function.[12] The

[12]This cost of holding bonds guarantees that the equilibrium dynamics of our model are stationary. See

consumer rents labor services l_t and capital services k_t to domestic firms at rates w_t and r_t, respectively, both expressed in units of consumption goods. Finally, households receive nominal dividends D_t from domestic firms and transfers T_t from the monetary authority. The period-t budget constraint of the representative consumer, expressed in home-currency units, is given by

$$P_t c_t + P_{R,t} i_t + M_{t+1} + B_t + P_t \Phi_b \left(\frac{B_{t-1}}{P_t} \right) \leq P_t \left(w_t l_t + r_t k_t \right) + R_{t-1} B_{t-1} + D_t + M_t + T_t. \quad (12)$$

The law of motion for capital accumulation is

$$k_{t+1} = k_t (1 - \delta) + k_t \Phi_k \left(\frac{i_t}{k_t} \right), \quad (13)$$

where δ is the depreciation rate of capital and $\Phi_k(\cdot)$ is a convex function representing capital adjustment costs.[13]

Households choose sequences of consumption, hours worked, investment, money holdings, debt holdings, and capital stock to maximize the expected discounted lifetime utility (10) subject to the sequence of budget constraints (12) and laws of motion of capital (13).

3.3 The Monetary Authority

The monetary authority issues domestic currency. Additions to the money stock are distributed to consumers through lump-sum transfers $T_t = M_t^s - M_{t-1}^s$. The monetary authority is assumed to follow an interest rate rule similar to those studied in the literature. In particular, the interest rate is given by

$$R_t = \rho_R R_{t-1} + (1 - \rho_R) \left[\bar{R} + \rho_{R,\pi} \left(E_t \pi_{t+1} - \bar{\pi} \right) + \rho_{R,y} \ln \left(y_t / \bar{y} \right) \right], \quad (14)$$

where π_t denotes CPI inflation, y_t denotes real GDP, and a barred variable represents its target value.

Schmitt-Grohé and Uribe (2003) for a discussion and alternative approaches.

[13] Capital adjustment costs are incorporated to reduce the response of investment to country-specific shocks. In their absence, the model would imply excessive investment volatility. See, for instance, Baxter and Crucini (1995).

3.4 Market Clearing Conditions and Model Solution

The model is closed by imposing standard market clearing conditions for labor, capital, and bonds. We focus on the symmetric and stationary equilibrium of the model. The model is solved by linearizing the equations characterizing the equilibrium around the steady-state and solving numerically the resulting system of linear difference equations.

The parameter values used to solve the model are reported in Table 1. We assume that the world economy is symmetric so that the two countries share the same structure and parameter values. The model is calibrated using U.S. data and productivity data from the OECD STAN database, with a period in our model corresponding to one quarter.

We now discuss some key parameter values and refer the reader to Dotsey and Duarte (2008) for a detailed discussion of the calibration of the model. We choose the weights on consumption of retail goods ω_R, on nontraded retail services ω, and on domestic traded inputs ω_H to simultaneously match, given all other parameter choices, the average share of consumption of nontraded goods in GDP, the average share of retail services in GDP, and the average share of imports in GDP.[14] Over the period 1973-2004, these shares averaged 0.44, 0.19, and 0.13, respectively, in the United States. Therefore, our model is consistent with the weight of the external sector and the weight of nontraded goods in GDP.[15]

The elasticity of substitution between domestic and imported traded goods, ξ in equation (8), is a critical parameter in two-country models.[16] In our benchmark calibration, we set this elasticity to 0.85, close to the mid-point of import and export price elasticities estimated by Hooper, Johnson, and Marquez (1998) for the United States. In section 4.1, we also consider a version of the model with a lower elasticity of substitution between domestic and imported inputs.

We assume that technology shocks follow independent $AR(1)$ processes. Based on regressions using data on total factor productivity (TFP) for manufacturing and for wholesale

[14]We measure retail services in the data as the value added from retail trade, wholesale trade, and transportation excluding transit and ground transportation services. We measure consumption of nontraded goods in the data as consumption services.

[15]Given these parameter choices, the model implies that the share of nontraded consumption in total consumption in steady-state is 0.55. This value is consistent with empirical findings for the United States. See, for instance, Stockman and Tesar (1995).

[16]See, for example, Heathcote and Perri (2002) and Corsetti, Dedola, and Leduc (2008).

and retail services for the United States and an aggregate of its major trading partners, we set the autocorrelation coefficient to 0.98 for all processes. This characterization of productivity as a stationary but highly persistent process is consistent with other data series on productivity in manufacturing. Consistent with these regressions we also set the ratio of the standard deviations of innovations to TFP on manufacturing and services to 2. The level of the standard deviation of innovations to TFP on manufacturing is chosen to match the volatility of GDP.

4 Implications of the Pricing Regime

Firms in the intermediate traded goods sector sell the good they produce to retail firms in the domestic and foreign markets. We consider the implications of two polar price-setting regimes for producers of intermediate traded goods.

Under PCP, these firms choose one price which is set for 4 periods.[17] This price is denominated in the currency of the producer and the price charged to foreigners is its foreign-currency value. Therefore, under PCP, the law of one price always holds for all vintages of traded goods. Note that while prices of locally-produced traded inputs are sticky, the prices of all vintages of imported varieties vary one-to-one with exchange rate changes.

Under LCP, producers of intermediate traded goods are able to discriminate across markets and choose a price for each market. Prices are denominated in the currency of the buyer and are set for 4 periods. Hence, in this case, prices of imported goods are sticky in the buyer's currency and an unanticipated exchange rate change generates a deviation from the law of one price for the three vintages of intermediate traded goods whose prices are preset. Regarding the newly reset prices, under LCP, producers choose the prices of their good that maximize discounted expected profits in each market (see equations (6) and (7)). The log-linearized equations for the prices chosen in period t for the home intermediate traded good

[17] Therefore, at any date there are four vintages of intermediate traded goods: the vintage whose price was reset the current period and three vintages with preset prices (chosen in each of the three previous periods).

sold at home and abroad are given by,

$$\hat{P}_{H,t}(0) = \mathrm{E}_t \left[\sum_{j=0}^{J-1} \rho_j \left(\hat{\psi}_{H,t+j} + \hat{P}_{t+j} \right) \right], \tag{15}$$

and

$$\hat{P}^*_{H,t}(0) = \hat{P}_{H,t}(0) - \mathrm{E}_t \left[\sum_{j=0}^{J-1} \rho_j \hat{S}_{t+j} \right], \tag{16}$$

respectively.[18] Note that the law of one price holds for newly priced goods when the exchange rate follows a random walk. Therefore, if the exchange rate is close to a random walk, then the law of one price holds approximately for newly priced goods and differences across the two price- setting regimes following a shock only arise from deviations from the law of one price for the three vintages of intermediate traded goods whose prices are preset. However, as additional vintages of firms reset their prices after a shock, the distinction between the two price-setting mechanisms disappears and, thus, any potential differences are short lived.

Columns I and II in Table 2 report statistics of the model under the two pricing regimes. Two main features arise. First, the business-cycle statistics reported in Table 2, other than correlations of the terms of trade and price of imports, are not affected substantially by the pricing regime. For example, the standard deviations of the real exchange rate and the terms of trade under PCP relative to those under LCP are 1.02 and 0.99. The nominal exchange rate is slightly more volatile under PCP, with the ratio 1.14. The model also implies similar persistence across pricing mechanisms as well as cross-country correlations and correlations of real exchange rates with other aggregate variables. Second, the correlations of the terms of trade and the price of imports with other variables (particularly so exchange rates) are substantially higher under PCP than LCP.[19]

To gain some intuition on the differences between the two pricing regimes, Figures 2 and 3

[18]A hat denotes the deviation from steady-state of the log of the variable, and we have linearized around a zero inflation steady state. Note that variables that scale the level of demand do not enter these equations because, to a first-order approximation around the optimal price, they influence marginal cost and marginal revenue to the same extent. The term ρ_j is $\beta^j / \left(\sum_{j=0}^{J-1} \beta^j \right)$. For β close to one, $\rho_j \approx 1/J$.

[19]We note that the similar behavior of variables other than the terms of trade and price of imports across price setting regimes does not depend on the nature of monetary policy, given by equation (14). We obtain similar results when we replace equation (14) with a money-supply rule.

plot the responses of selected variables to a productivity shock in the traded and nontraded goods sectors, respectively, under the two regimes. In each figure, the panels on the left plot the response under PCP and the panels on the right plot the response under LCP. A first glance at these figures reveals that these responses are almost indistinguishable between the two pricing mechanisms, except for the response of the terms of trade and the price of imports to a shock in the nontraded goods sector.

In response to a shock to productivity in the traded goods sector, the behavior of all variables is similar under both pricing arrangements. As Figure 2 shows, the response of the nominal exchange rate to this shock is small.[20] As a result, under LCP, unanticipated shocks to productivity in the traded goods sector do not generate large deviations from the law of one price, even for traded inputs whose prices are preset. Therefore, the response of all variables is similar across the two pricing mechanisms.

In contrast, a positive shock to productivity in the nontraded goods sector generates a sharp exchange rate depreciation. Therefore, this shock has the potential to generate large differences between the two pricing regimes. We find that in response to this shock, the behavior of the terms of trade, the price of imports, and (to a lesser extent) the price of the traded composite x_T differs markedly across the two pricing arrangements. However, these differences do not feed through and aggregate variables such as exchange rates, output, and the price level behave similarly across the two pricing arrangements.

The terms of trade represent the relative price of imports in terms of exports in the home country, and it is given by $\tau = P_F/(SP_H^*)$, where P_F and SP_H^* are the domestic-currency price of imports and exports in the home country. Under PCP the law of one price holds and the terms of trade can be re-written as $\tau = SP_F^*/P_H$. Note also that under PCP P_H and P_F^* are sticky. Therefore, following a positive shock to productivity in the nontraded goods sector, the terms of trade depreciate, together with the nominal exchange rate, generating an expenditure-switching effect toward domestic goods.[21] In contrast, P_F and P_H^* are sticky

[20] The response of exchange rates to shocks to productivity in the traded goods sector is small because home and foreign retail firms use home and foreign intermediate traded inputs in about the same proportion (i.e., ω_H in equation (8) is close to 1/2). For further discussion, see Dotsey and Duarte (2008).

[21] Following this shock, the price in local currency of the imported composite good P_F rises by more than the exchange rate. The newly reset prices of imported goods rise (in foreign currency) in response to the increase in domestic demand, and all prices of imported goods (newly reset and preset) move one-for-one (in

under LCP. Thus, on impact, the depreciation of the nominal exchange rate lowers the price of imported goods relative to exports. However, as additional vintages of firms adjust their prices, the pricing effect dominates and the terms of trade eventually depreciates.

Despite the different responses of the prices of traded goods and the terms of trade, aggregate variables such as GDP, exchange rates, and the price level (among other variables) respond similarly across the two pricing regimes. We point to two reasons behind this result. First, trade is a small portion of the economy. Although the response of the price of imports to shocks to productivity in the nontraded goods sector differs markedly between PCP and LCP, this difference diminishes as prices are aggregated up to the consumer price level (see the top panels in Figure 3). In fact, there is not a substantial difference even in the behavior of the price of the composite intermediate traded good P_{x_T} under the different pricing regimes. Second, in our model, nominal exchange rates are very persistent. Thus, it follows from equations (15) and (16) that price setters respond much the same way under LCP as they do under PCP. Thus, any difference between the two mechanisms follows from the existence of preset prices. However, as successive vintages of firms reset their prices, the behavior of the price of imports across the two pricing regimes converges quickly and the differences between the two regimes are short-lived.

The distinguishing feature between the two alternative pricing mechanisms is the higher cross-correlations of the terms of trade and the price of imports with other variables under PCP than under LCP. In particular, the correlation coefficient between the terms of trade and the nominal and real exchange rates is 0.52 and 0.62 with PCP and 0.12 and 0.26 with LCP. The corresponding cross-correlations for the United States are 0.39 and 0.30, which suggests that the truth lies somewhere between the two extreme pricing specifications.[22] However, the pricing specification mostly affects only these correlations, while other features of the model appear to be insensitive to whether one works with a LCP or PCP view of the

local currency) with the exchange rate. In turn, the domestic price of exports rises by less than the exchange rate since only the newly reset price (in domestic currency) of exports rises as domestic firms re-adjust their prices (due to higher domestic wages).

[22] We emphasize the cross-correlations for the United States because we have calibrated the model to U.S. data. We point out that the United States is not an outlier in terms of these cross-correlations. For example, the correlation of the terms of trade with the nominal exchange rate for Canada, France, Germany, Italy, and the United Kingdom ranges from 0.34 to 0.70, with an average of 0.47.

world.

4.1 Two Variations

In this section, we consider two variations to our benchmark model. First, we consider a version of the model that generates higher nominal exchange rate volatility than the benchmark model. Second, we consider a version of the model with a higher import share.

Differences between the two pricing assumptions arise from the interplay between unanticipated movements in the nominal exchange rate and nominal price rigidities. That is, the larger the response of the nominal exchange rate to exogenous shocks, the larger the potential for the two pricing regimes to differ. To further explore the importance of the currency denomination of exports we consider a version of our model with a lower elasticity of substitution between domestic and imported inputs. As in Corsetti, Dedola, and Leduc (2008), a low elasticity of substitution generates strong wealth effects and implies higher volatility of exchange rates relative to output. In Table 2, we report results for $\xi = 0.47$.[23] With this lower elasticity the model implies that exchange rates and the terms of trade are much more volatile than output. Under PCP, exchange rates are more than three times as volatile as output. We find that the nominal and real exchange rates become more volatile under PCP than LCP (about 20 and 15 percent respectively). However, despite this difference and a much higher volatility of the nominal exchange rate, we still find that the behavior of other aggregate variables is not much different across the two pricing regimes. Also as before, we find that the correlations of the terms of trade and the price of imports are substantially higher under PCP than LCP.

Finally, we consider a version of the model with a higher share of imports. A higher import share also has the potential to strengthen the importance of the currency denomination of exports. We raise the import share to 25 percent maintaining all other targets unchanged. In particular, we maintain constant the weight of nontraded goods in the economy. Therefore, this exercise asks about the implications of the currency denomination of exports in a model calibrated to the United States but with a counter-factually higher import share. The model

[23] We recalibrate the model to match all other targets.

generates higher import shares by lowering the bias of retail firms for domestically produced inputs (determined by the weight ω_H in equation 8). In our benchmark model, $\omega_H = 0.59$ while an import share of 25 percent implies $\omega_H = 0.20$. That is, with a higher import share a positive productivity shock to the traded goods sector of the home country benefits foreign firms (who use the home input more intensively than home firms) disproportionately.[24] The properties of the model with an import share of 25 percent are reported in the last two columns of Table 2.[25] With a higher import share, business cycles are more synchronized across countries and net exports, employment, and investment are more volatile compared with the benchmark economy. Nominal and real exchange rates, however, are less volatile with a higher import share. With higher import share shocks to productivity in the traded goods sector generate more volatility in output than shocks to productivity in the nontraded goods sector. But it is still the case that shocks to traded productivity generate very small responses of nominal and real exchange rates. In response to a shock to z_H, the home terms of trade depreciate (since domestic traded goods are cheaper relative to foreign traded goods). Given the bias of retail firms toward imported inputs, this depreciation contributes to an appreciation of the real exchange rate. In turn, the price of nontraded goods increases in the foreign country relative to the home country, contributing to a depreciation of the real exchange rate.[26] Overall, the response of the real exchange rate to this shock is very small. Since price levels are very smooth, the response of the nominal exchange rate is also very small.[27] Therefore, we find that the behavior of aggregate variables is not much different across the two pricing regimes. The exceptions are the volatility of net exports and the co-movement of the terms of trade and the price of imports with exchange rates. With a

[24]The weight $\omega_H = 0.59$ implies that in steady state the ratio of domestically produced to imported traded inputs used by retail firms is 1.44. For $\omega_H = 0.2$ this ratio falls to 0.25.

[25]In this experiment we use the benchmark elasticity of substitution between domestic and imported traded goods.

[26]To gain some intuition note that, with flexible prices, changes in the real exchange rate can be written as $\hat{q}_t = (1 - \omega_R + \omega_R \omega)\hat{q_N}_t + \omega_R(1-\omega)(2\omega_H - 1)\hat{\tau}_t$, where $q_N = SP_N^*/P_N$. The coefficient on $\hat{q_N}$ is 0.72 while the coefficient on $\hat{\tau}$ is -0.16 when the import share is 25 percent and 0.05 in the benchmark case. Therefore, when ω_H is smaller than 1/2, a depreciation in the terms of trade acts to appreciate the real exchange rate, dampening the effect of $\hat{q_N}$, and resulting in lower exchange rate volatility.

[27]The contribution of terms of trade depreciation to real exchange rate appreciation when the import share is high also underlies the smaller response of exchange rates to shocks to productivity in the nontraded goods sector compared with the benchmark economy.

higher import share, net exports are more than twice as volatile under PCP than LCP and the terms of trade and the price of imports are more strongly correlated with exchange rates.

5 Conclusion

In this paper we contrast the implications of producer currency pricing and local currency pricing in a quantitative two-country model. The model features nontraded goods that are used as final service consumption and in the production of retail goods. The model is consistent with the weight of nontraded goods and the weight of the external sector in the U.S. economy. We find that different assumptions regarding the currency denomination of exports are virtually inconsequential for the properties of aggregate variables, other than the terms of trade. We also note that our basic result carries through in our calibrated model without nontraded goods. We choose to include nontraded goods in our benchmark model for two reasons. First, nontraded final consumption and nontraded retail services are not trivial in the U.S. economy and our model has implications that are closer in line with the data than a model that abstracts from nontraded goods. Second, the calibrated model with nontraded goods generates higher nominal exchange rate volatility than the model without nontraded goods. It is important that the benchmark model can generate large responses of the nominal exchange rate since differences between the two pricing mechanisms arise from the interplay between unanticipated movements in the nominal exchange rate and nominal price rigidities.

The key finding in our benchmark model and two variations is that the two pricing regimes differ only with respect to the behavior of the terms of trade and price of imports and their correlations with other variables in the model. For instance, the terms of trade have a higher positive correlation with exchange rates under PCP than with LCP. Importantly, our results highlight the fact that in the context of a quantitative open-economy model the difference between the polar international pricing regimes is not as extensive as standard analyses may suggest.

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Table 1: Calibration

Preferences	
Coefficient of risk aversion (σ)	2
Elasticity of labor supply	2
Time spent working	0.25
Interest elasticity of money demand ($1/(\nu-1)$)	-0.03
Weight on consumption (a)	0.99
Aggregates	
Elast. of substitution c_N and c_R (γ)	0.74
Elast. of substitution x_N and x_T (ρ)	0.001
Elast. of substitution x_H and x_F (ξ)	0.85
Elast. of substitution individual varieties	10
Share of imports in GDP	0.13
Share of x_N in GDP	0.19
Share of c_N in GDP	0.44
Production and Adjustment Functions	
Capital share (α)	1/3
Price stickiness (J)	4
Depreciation rate (δ)	0.025
Relative volatility of consumption	0.64
Bond holdings (θ_b)	0.001
Monetary Policy	
Coeff. on lagged interest rate (ρ_R)	0.9
Coeff. on expected inflation ($\rho_{R,\pi}$)	1.8
Coeff. on output ($\rho_{R,y}$)	0.07
Productivity Shocks	
Autocorrelation coeff. (A)	0.98
Std. dev. of innovations to $z_H \& z_N$	0.006 & 0.003

Table 2: Model results

Statistic	Benchmark PCP	Benchmark LCP	Low elastic. PCP	Low elastic. LCP	High import PCP	High import LCP
Stand. dev. rel. to GDP						
Consumption	0.64	0.64	0.64	0.64	0.64	0.64
Investment	2.41	2.55	3.09	3.07	3.07	3.08
Employment	1.10	1.16	1.25	1.33	1.40	1.42
Price Level	0.22	0.24	0.26	0.30	0.32	0.33
Nominal e.r. (S)	1.54	1.35	3.22	2.63	1.08	0.90
Real e.r. (q)	1.50	1.47	3.27	2.87	1.09	1.06
Terms of trade (τ)	2.27	2.29	4.70	4.30	1.92	1.84
Stand. dev. of nx	0.35	0.38	0.67	0.59	0.69	0.70
Auto-correlations						
Nominal e.r.	0.80	0.79	0.79	0.79	0.80	0.79
Real e.r.	0.80	0.81	0.80	0.81	0.81	0.82
Terms of trade	0.88	0.88	0.87	0.88	0.89	0.90
Cross-correlations						
Between S and q	0.99	0.99	0.99	0.99	0.95	0.94
Between q and						
GDP	0.47	0.41	0.32	0.28	0.21	0.18
Consumption	0.46	0.42	-0.02	0.02	0.21	0.22
Rel. consumptions	0.83	0.82	-0.04	0.04	0.53	0.56
Cross-country						
GDP	0.36	0.50	0.63	0.72	0.86	0.88
Consumption	0.40	0.48	0.56	0.59	0.69	0.69
Investment	0.44	0.45	0.11	0.21	0.32	0.34
Employment	0.52	0.63	0.75	0.75	0.79	0.79
Between τ and						
GDP	0.48	0.29	0.27	0.16	0.21	0.16
Nominal e.r.	0.52	0.12	0.90	0.45	0.17	-0.17
Real e.r.	0.63	0.27	0.93	0.52	0.46	0.17
Between P_F and						
GDP	0.39	0.27	0.26	0.19	0.14	0.10
Nominal e.r.	0.72	0.49	0.94	0.74	0.49	0.23
Real e.r.	0.78	0.58	0.96	0.78	0.66	0.46

Notes: nx denotes real net exports relative to GDP.

Figure 1: Production Structure of the Home Economy

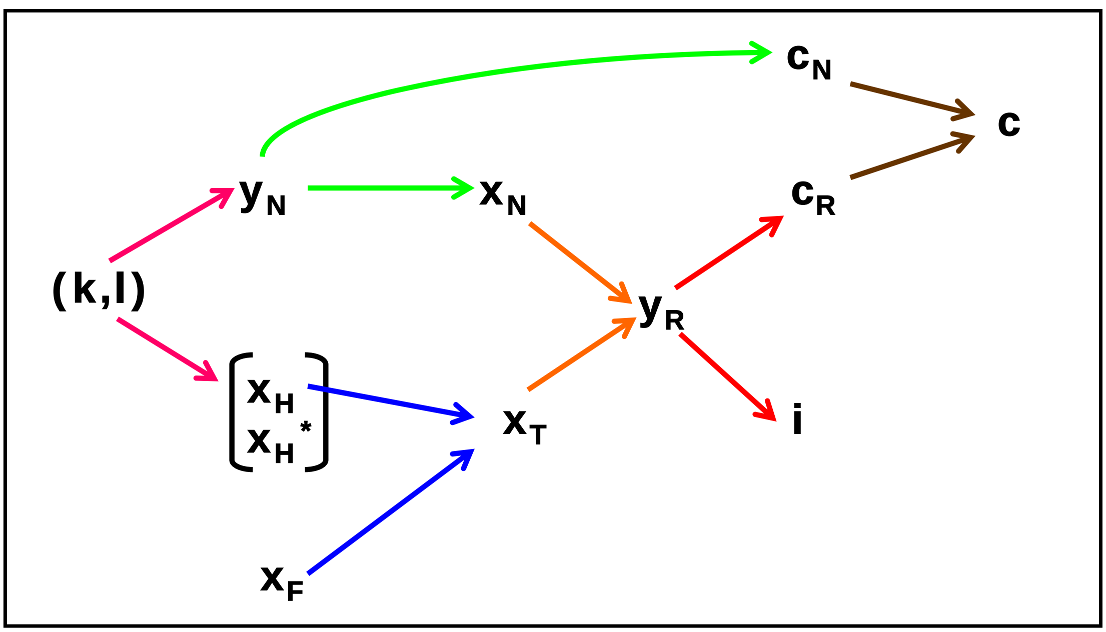
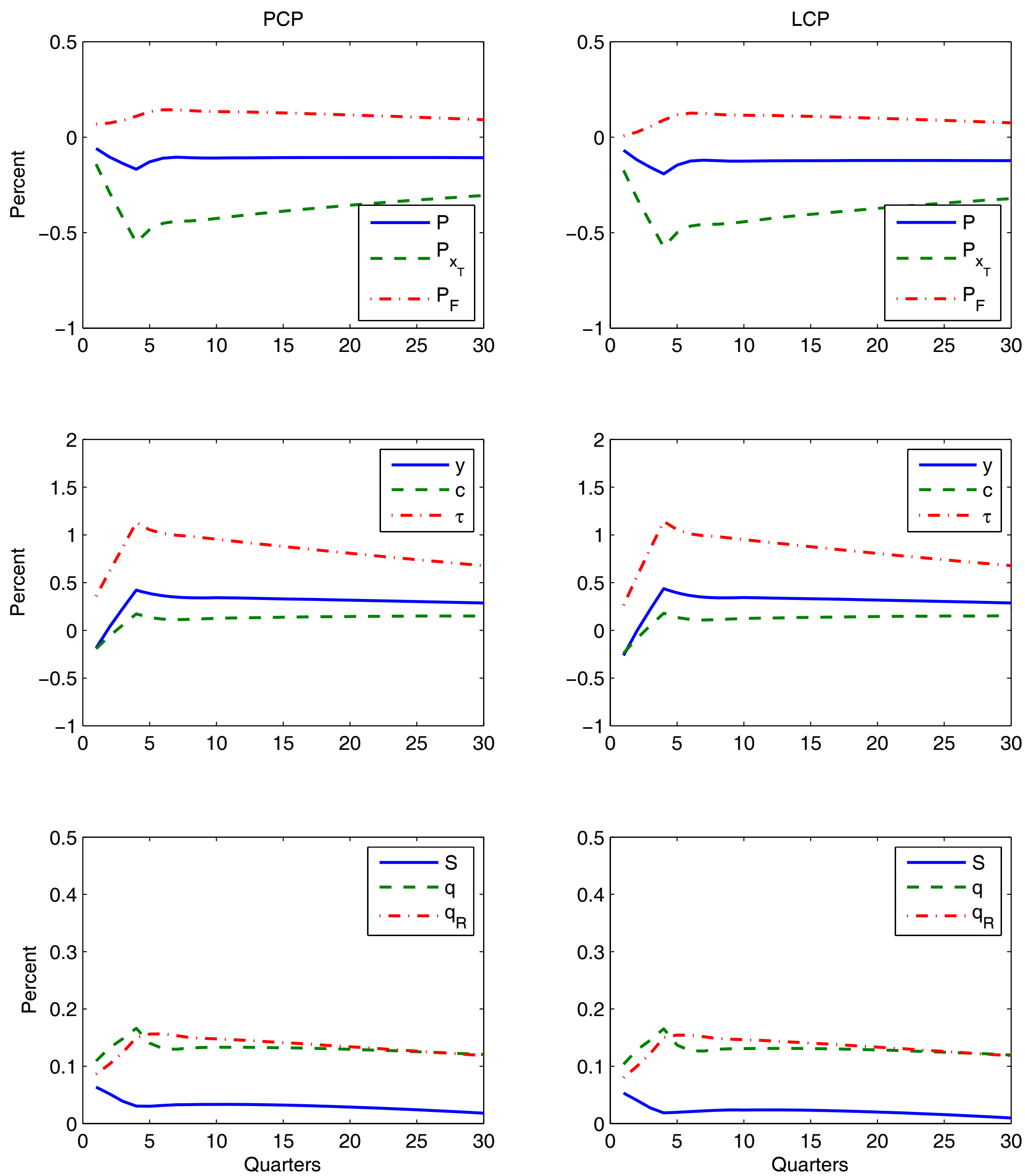


Figure 2: PCP versus LCP - Positive Shock to z_H



Note: P - price level; P_{x_T} - price of intermediate traded inputs; P_F - price of imports; y - real output; c - consumption; τ - terms of trade; S - nominal exchange rate; q - real exchange rate; q_R - relative price of retail goods across countries.

Figure 3: PCP versus LCP - Positive Shock to z_N