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Nontraded Goods, Market Segmentation, and Exchange Rates

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Nontraded Goods, Market Segmentation, and Exchange Rates *

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Abstract

Empirical evidence suggests that movements in international relative prices are large and persistent. Nontraded goods, both in the form of final consumption goods and as an input into the production of final tradable goods, are an important aspect driving international relative price movements. In this paper we show that nontraded goods play an important role in the context of an otherwise standard open-economy macromodel. Our quantitative study with nontraded goods generates implications along several dimensions that are more closely in line with the data relative to the model that abstracts from nontraded goods. In addition, contrary to a large literature, standard alternative assumptions about the currency in which firms price their goods are virtually inconsequential for the properties of aggregate variables in our model, other than the terms of trade.

Keywords: exchange rates; nontraded goods; distribution services; incomplete asset markets.

JEL classification: F3, F41

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1 Introduction

Empirical evidence regarding international relative prices at the consumer level suggests that arbitrage in international markets is not rapid and that these markets are highly segmented. In fact, even markets for tradable goods appear to be highly segmented internationally: in the data, movements of real exchange rates and movements of the relative price of tradable goods across countries are large and persistent. Moreover, the behavior of these relative prices resembles closely the behavior of relative consumer price indices (CPI) across countries for nontraded goods in the short and medium runs.[1]

Nontraded goods are an important source of segmentation of consumer markets across countries. In the United States, for instance, consumption of nontraded goods represents about 40 percent of GDP. Distribution services, in turn, represent about 20 percent of GDP.[2] This evidence suggests that final goods contain a substantial nontraded component, which accounts for a large fraction of measured deviations from the law of one price. Moreover, empirical evidence suggests that the degree of tradability of the inputs of a good plays an important role in accounting for its relative price differentials across countries.[3]

In this paper we find that nontraded goods play an important role in exchange rate behavior in the context of an otherwise standard open-economy macromodel. Our quantitative study with nontraded goods generates implications along several dimensions that are more closely in line with the data relative to the model that abstracts from nontraded goods. Further, model decompositions of real exchange rate movements into fluctuations in the relative price of tradable goods across countries and fluctuations in the relative price of nontraded goods to tradable goods are broadly consistent with empirical estimates.

We build a two-country general equilibrium model of exchange rates that features two roles for nontraded goods: as final consumption and as an input into the production of final tradable goods. Final tradable goods are produced using local and imported intermediate

[1] See, for instance, Engel (1999), Obstfeld and Rogoff (2000a), among others.

[2] These numbers are computed as the average share of personal consumption of services in private GDP from 1973 to 2004 and the average share of wholesale and retail services and transportation in private GDP from 1987 to 1997. The dichotomy between traded and nontraded goods is not, of course, a clear one. Here we adopt a conventional dichotomy that associates services with nontraded goods.

[3] See, for instance, the findings in Crucini, Telmer, and Zachariadis (2005).

traded inputs and nontraded goods. Intermediate traded goods and nontraded goods, in turn, are produced using local labor and capital services. Thus, the model has an input-output structure (as in Obstfeld, 2001), where the output of some sectors is used as an input to the production of final goods. In addition to intermediate goods, agents in the two countries also trade one riskless nominal bond. The model is driven by shocks to productivity in the intermediate traded goods sector and the nontraded goods sector.

The presence of nontraded goods in the model increases the volatility of exchange rates. Importantly, fluctuations in the relative price of nontraded goods account for a small fraction of real exchange rate volatility, which is broadly consistent with the data. The intuition behind this result hinges on the fact that in the model with nontraded goods, shocks to productivity in the nontraded goods sector generate sharp nominal exchange rate movements. These movements, in turn, generate large fluctuations in the relative price of tradable goods across countries relative to the fluctuations in the relative price of nontraded goods.

Also the cross-correlations of exchange rates with other variables are lower in the presence of nontraded goods. These lower correlations hinge on the fact that the benchmark model is driven by two different shocks that, in isolation, have markedly different implications for exchange rate variability and the co-movement of exchange rates with other variables. In contrast to shocks to productivity in the nontraded goods sector, shocks to productivity in the traded goods sector generate a very small response of exchange rates relative to the response of other variables in the presence of nontraded goods. In the absence of nontraded goods, shocks to productivity in the traded goods sector imply larger exchange rate movements and larger co-movements of exchange rates with other variables. Therefore, these different implications of shocks to productivity in the traded and nontraded goods sectors imply that the presence of nontraded goods in the model is associated with more volatile exchange rates and lower cross-correlations of exchange rates with other variables than in the absence of nontraded goods.

The discussion of the properties of relative international prices has been closely tied with a discussion on the nature of the pricing decisions by firms.[4] In much of the recent work in open economy models with nominal price rigidities, deviations from the law of one price have

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

been associated with the pricing-setting regime of exporters rather than with the nontraded component of final tradable goods. In particular, deviations from the law of one price are associated with the assumption that consumer markets are segmented and that exporters set prices in the currency of the buyer. In this environment, known as local currency pricing (LCP), an unanticipated nominal depreciation is automatically associated with a deviation of the law of one price for those goods whose prices are not adjusted immediately. Since prices of imported goods respond slowly to exchange rate changes, this pricing mechanism dampens the expenditure-switching effect of nominal exchange rate movements. However, this effect, a central feature of models in which imports are priced in the currency of the seller (producer currency pricing or PCP), is consistent with empirical evidence suggesting that exchange rate movements are positively correlated with a country's terms of trade.[5] Our setup allows us to disentangle the implications of these two alternative pricing mechanisms that are standard in the open-economy macro literature. In our model, different assumptions regarding the pricing decisions of firms 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 final tradable 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 differ with respect to the correlations of the terms of trade and price of imports with other variables in the model. In particular, the terms of trade have a higher positive correlation with exchange rates under producer currency pricing than with local currency pricing. However, it is hard to discriminate between these alternative pricing mechanisms based on these correlations alone.

Our paper is related to recent quantitative studies of exchange rate behavior. Corsetti, Dedola, and Leduc (2008a) explore the role of (nontraded) distribution services in explaining the negative correlation between real exchange rates and relative consumption across countries, and Corsetti, Dedola, and Leduc (2008b) examine the behavior of pass-through in a model that includes distribution services. These two papers explore the implications of the lower price elasticity of traded inputs brought about by the location of distribution

[5] See Obstfeld and Rogoff (2000b).

services in the production chain. In contrast, in our framework, the price elasticity of traded inputs is not affected by distribution services. This paper is also related to the work of Chari, Kehoe, and McGrattan (2002), who assume that all goods are traded and explore the interaction between local currency pricing and monetary shocks in explaining real exchange rate behavior. Our study is in the general methodological spirit of theirs, but highlights the importance of nontraded goods in accounting for exchange rate behavior.

The paper is organized as follows. In Section 2 we describe the model and in Section 3 we discuss the calibration. Section 4 presents the results and discusses the role of nontraded goods in the model. In Section 5 we consider the implications of alternative price setting mechanisms. In section 6 we discuss the robustness of our results and we conclude in Section 7.

2 The Model

The world economy consists of two countries, denominated home and foreign. Each country is populated by a representative household, a continuum of firms, and a monetary authority. A distinctive feature of the model is the input-output structure of the production side of the economy. This structure emphasizes two distinct uses for nontraded goods: as final consumption and as an input into the production of final tradable goods.

In what follows, the home country economy is described, starting with production. The consumer's problem is standard and is described later. The foreign country economy is analogous to the home country economy and asterisks denote foreign country variables.[6]

2.1 Production

There are three sectors of production in the model: the nontraded goods sector, the intermediate traded goods sector, and the final tradable goods sector. The three sectors are treated symmetrically in assuming that firms in each sector produce a continuum of differentiated

[6] As with other open-economy macromodels, there are many variables in our model and notation is complicated. The interested reader can download a table of notation, included as supplementary material on Science Direct along with this article.

varieties and set prices in a staggered fashion.

Figure 1 depicts the production structure of the economy. Capital and labor are employed by firms in the intermediate and nontraded goods sectors to produce a differentiated variety of the intermediate traded good and the nontraded good. With respect to intermediate traded inputs, countries specialize in production. Thus, there are home intermediate goods and foreign intermediate goods. Firms in the final tradable sector combine an aggregate of all varieties of domestic and imported intermediate traded inputs with an aggregate of all nontraded varieties to produce a differentiated variety of a final tradable good. We interpret the nontraded input of final tradable goods as distribution services.[7] The use of nontraded goods in final tradable goods implies that these goods cannot be traded and that consumers cannot arbitrage cross-country price differentials for these goods. Households consume final tradable goods and nontraded goods and invest using final tradable goods. We now describe each sector, first looking at intermediate traded goods, then nontraded goods and, finally, the production of final tradable goods.

2.1.1 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. 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. The real marginal cost of production (common to all firms in this sector) is given by

$$\psi_{H,t} = \frac{1}{z_{H,t}} \left(\frac{r_t}{\alpha}\right)^{\alpha} \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}, \tag{1}$$

where r_t and w_t denote the rental rates of capital and labor.

Firms in this sector are monopolistically competitive and each firm sells its variety to firms in the domestic and foreign final tradable goods sectors. Each firm chooses one price,

[7] This characterization of nontraded goods used in production is also taken by Burstein, Neves, and Rebelo (2003) and Corsetti, Dedola, and Leduc (2008a).

denominated in units of domestic currency, for home and foreign markets.[8] Thus, the law of one price holds for intermediate traded inputs.[9] 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 demand curves from home and foreign markets faced by this firm in period $t + j$. 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. In equilibrium, $\vartheta_{t+j|t}$ is given by the consumer's intertemporal marginal rate of substitution in consumption, $\beta^j(u_{c,t+j}/u_{c,t})P_t/P_{t+j}$. 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,

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

2.1.2 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

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

[8]Note that, in contrast to Corsetti and Dedola (2005), in our setup the presence of distribution services does not generate an incentive for intermediate traded goods firms to price discriminate across countries. This difference between the two models arises from the different location of distribution services in the production chain. See footnote 10.

[9]We note that the alternative pricing assumption under which intermediate goods producers can price discriminate across countries and choose to set prices in the currency of the buyer (local currency pricing) is virtually inconsequential for the properties of aggregate variables in our model, other than the terms of trade. See Dotsey and Duarte (2008).

where $y_{N,t+j}(j) = x_{N,t+j}(j) + c_{N,t+j}(j)$ represents demand (from the final tradable goods sector and consumers) faced by this firm in period $t+j$. The real marginal cost of production in this sector is given by $\psi_{N,t} = \psi_{H,t} z_{H,t}/z_{N,t}$. The optimal price is given by an expression analogous to equation (3).

2.1.3 The Final Tradable Goods Sector

There is a continuum of firms in this sector, indexed by T, 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

$$x_{T,t}(r) = \left[\omega_H^{\frac{1}{\xi}} x_{H,t}(r)^{\frac{\xi-1}{\xi}} + (1-\omega_H)^{\frac{1}{\xi}} x_{F,t}(r)^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}}, \tag{4}$$

where $x_{H,t}(r)$ and $x_{F,t}(r)$ are Dixit-Stiglitz aggregators of all home and foreign intermediate traded varieties, respectively. That is, for each firm in this sector

$$x_H = \left(\int_0^1 (x_H(h))^{\frac{\varsigma-1}{\varsigma}} dh\right)^{\frac{\varsigma}{\varsigma-1}}, \tag{5}$$

where ς is the elasticity of substitution between any two varieties and the r index is suppressed. The foreign intermediate traded good x_F is defined in an analogous way. The parameter ξ in equation (4) denotes the elasticity of substitution between home and foreign traded inputs and the weight ω_H determines the bias toward the local traded input.

Each firm also combines all nontraded varieties to produce x_N, using a Dixit-Stiglitz aggregator analogous to (5). Firms then bring the intermediate traded good x_T to market by combining it with nontraded goods x_N. The production function of variety r of the final tradable good is

$$y_{T,t}(r) = \left(\omega^{\frac{1}{\rho}} x_{N,t}(r)^{\frac{\rho-1}{\rho}} + (1-\omega)^{\frac{1}{\rho}} x_{T,t}(r)^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \quad \rho > 0, \tag{6}$$

where ρ denotes the elasticity of substitution between $x_{T,t}(r)$ and $x_{N,t}(r)$ and ω is a weight.

The nontraded goods x_N used in the production of the final tradable good are interpreted as distribution services and we associate this sector with the wholesale, retail, and transportation sectors in the data. Since the retail sector, which is composed of firms engaged in the final step in the distribution of merchandise for personal consumption, is the largest of the three sectors that comprise distribution services, we will refer interchangeably to $x_{N,t}(r)$ as distribution or retail services used by firm r and to this sector as the final tradable goods sector or the retail sector.[10]

Given prices of each home intermediate traded variety, $P_{H,t}(h)$, $h \in [0,1]$, the price index of the home intermediate traded good, $P_{H,t}$, and the demand functions for each variety, $x_{H,t}(h)$, are obtained by solving a standard expenditure minimization problem subject to (5).[11] In particular,

$$P_{H,t} = \left(\int_0^1 (P_{H,t}(h))^{1-\varsigma} \, dh \right)^{\frac{1}{1-\varsigma}}, \tag{7}$$

$$x_{H,t}(h) = \left(\frac{P_{H,t}}{P_{H,t}(h)} \right)^{\varsigma} x_{H,t}. \tag{8}$$

The price indices of the foreign intermediate traded good and nontraded good, $P_{F,t}$ and $P_{N,t}$, and the demand for varieties $x_{F,t}(f)$ and $x_{N,t}(n)$, $f, n \in [0,1]$, are given by expressions analogous to (7) and (8).

Given prices of the domestic and imported intermediate traded inputs, $P_{H,t}$ and $P_{F,t}$, the price index of the composite intermediate traded input $x_{T,t}$ and demand functions for $x_{H,t}$

[10] In our setup, each firm in the final tradable goods sector combines nontraded inputs x_N with a bundle of local and imported traded inputs x_T. Alternatively, firms in this sector could incur distribution costs with each intermediate input variety ($x_H(h)$ and $x_F(f)$, $h, f \in [0,1]$), prior to combining them into a composite traded good, as in Corsetti and Dedola (2005). Note that in this alternative specification, distribution costs lower the price elasticity of intermediate inputs, while in our model they do not. We believe our equations (4) and (6) represent a reasonable specification of the production process for two reasons. First, a large fraction of U.S. trade consists of intermediate inputs that enter into the production of other goods and that do not require a lot of wholesale or retail trade. Second, retail trade is the largest component of distribution services in value added.

[11] See, for example, Obstfeld and Rogoff (1996), Chapter 10.

and $x_{F,t}$, are obtained as described above. In particular,

$$P_{x_T,t} = \left(\omega_H P_{H,t}^{1-\xi} + (1-\omega_H) P_{F,t}^{1-\xi}\right)^{\frac{1}{1-\xi}}, \tag{9}$$

$$x_{H,t} = \omega_H \left(\frac{P_{H,t}}{P_{x_T,t}}\right)^{-\xi} x_{T,t}, \tag{10}$$

$$x_{F,t} = (1-\omega_H) \left(\frac{P_{F,t}}{P_{x_T,t}}\right)^{-\xi} x_{T,t}. \tag{11}$$

Given prices $P_{N,t}$ and $P_{x_T,t}$, the real marginal cost of production in the final tradable goods sector, common to all firms in this sector, is ψ_T,

$$\psi_{T,t} = \left[\omega \left(\frac{P_{N,t}}{P_t}\right)^{1-\rho} + (1-\omega) \left(\frac{P_{x_T,t}}{P_t}\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{12}$$

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

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

where $y_{T,t+j}(j) = c_{T,t+j}(j) + i_{t+j}(j)$ 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).

2.2 Households

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

$$U_0 = \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, l_t, \frac{M_{t+1}}{P_t}\right), \tag{13}$$

where u represents the momentary utility function, 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 final tradable good $c_{T,t}$ and the nontraded good $c_{N,t}$, and is given by

$$c_t = \left(\omega_T^{\frac{1}{\gamma}} c_{T,t}^{\frac{\gamma-1}{\gamma}} + (1-\omega_T)^{\frac{1}{\gamma}} c_{N,t}^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}}, \gamma > 0. \tag{14}$$

The parameter γ denotes the elasticity of substitution between tradable and nontraded goods and ω_T is a weight. Given prices of tradable and nontraded goods, $P_{T,t}$ and $P_{N,t}$, the demand functions for these goods and the consumption-based price index, P_t, are obtained as described above and are given by expressions analogous to equations (10), (11), and (9).

The consumption of final tradable goods and nontraded goods, c_T and c_N, are each a Dixit-Stiglitz aggregator as (5) of all the varieties of the tradable and nontraded goods, $c_T(r)$ and $c_N(n)$, $r, n \in [0,1]$, respectively. As before, expenditure minimization problems analogous to the one described above yield demand functions for each individual variety, $c_{T,t}(r)$ and $c_{N,t}(n)$, and the consumption-based prices of one unit of the final tradable good and nontraded good, $P_{T,t}$ and $P_{N,t}$, given home-currency prices of individual varieties, $P_{T,t}(r)$ and $P_{N,t}(n)$.

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 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 final 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

$$P_t c_t + P_{T,t} i_t + M_{t+1} + B_t + P_t \Phi_b \left(\frac{B_{t-1}}{P_t} \right) \leq P_t \left(w_t l_t + r_t k_t \right) + R_{t-1} B_{t-1} + D_t + M_t + T_t. \tag{15}$$

[12]This cost of holding bonds guarantees that the equilibrium dynamics of our model are stationary. See Schmitt-Grohé and Uribe (2003) for a discussion and alternative approaches.

It is assumed that investment i_t is carried out in final tradable goods. This assumption is consistent with empirical evidence suggesting that investment has a substantial nontraded component and that the import content of investment is larger than that of consumption.[13] The law of motion for capital accumulation is

$$k_{t+1} = k_t(1-\delta) + k_t \Phi_k \left(\frac{i_t}{k_t} \right), \tag{16}$$

where δ is the depreciation rate of capital and $\Phi_k(\cdot)$ is a convex function representing capital adjustment costs.[14]

Households choose sequences of consumption, hours worked, investment, money holdings, debt holdings, and capital stock to maximize the expected discounted lifetime utility (13) subject to the sequence of budget constraints (15) and laws of motion of capital (16).

2.3 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

$$R_t = \rho_R R_{t-1} + (1-\rho_R) \left[\bar{R} + \rho_{R,\pi} \left(E_t \pi_{t+1} - \bar{\pi} \right) + \rho_{R,y} \ln \left(y_t / \bar{y} \right) \right], \tag{17}$$

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

2.4 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

[13] See Burstein, Neves, and Rebelo (2004).

[14] 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).

solved by linearizing the equations characterizing the equilibrium around the steady-state and solving numerically the resulting system of linear difference equations.

We now define some variables of interest. The real exchange rate q, defined as the relative price of consumption across countries, is given by $q = SP^*/P$, where S denotes the nominal exchange rate (expressed as units of domestic currency per unit of foreign currency). The terms of trade τ represent the relative price of imports in terms of exports in the home country and are given by $\tau = P_F/(SP_H^*)$, where P_F and SP_H^* are home-currency prices of imports and exports of the home country. Nominal GDP in the home country is given by $Y = Pc + P_T i + NX$, where $NX = P_H x_H^* - P_F x_F$ represents nominal net exports. Real GDP is obtained by constructing a chain-weighted index as in the National Income and Product Accounts.

Finally, note that the crucial condition for real exchange rate determination in models with incomplete asset markets is given by

$$R_t = \beta \mathrm{E_t}\left[\frac{u_{c,t+1}}{P_{t+1}}\frac{P_t}{u_{c,t}}\right] = \beta \mathrm{E_t}\left[\frac{u^*_{c,t+1}}{S_{t+1}P^*_{t+1}}\frac{S_t P^*_t}{u^*_{c,t}}\right].$$

This condition is obtained by combining the first-order conditions for bond holdings by home and foreign households and it equates the intertemporal marginal rate of substitution of domestic money in expectation across countries. The interest rate rule in equation (17) followed by monetary authorities implies that in our model price levels in each country are smooth. Therefore, nominal exchange rates follow real exchange rates closely.

3 Calibration

In this section we report the benchmark parameter values used in solving the model. The benchmark calibration assumes that the world economy is symmetric so that the two countries share the same structure and parameter values. The model is calibrated largely using U.S. data as well as productivity data from the OECD STAN database, with a period in our model corresponding to one quarter. The benchmark calibration is summarized in Table 1.

3.1 Preferences and Production

We assume a momentary utility function of the form

$$u\left(c, l, \frac{M}{P}\right) = \frac{1}{1-\sigma}\left\{\left(ac^{\eta} + (1-a)\left(\frac{M}{P}\right)^{\eta}\right)^{\frac{1-\sigma}{\eta}} \exp\{-v(l)(1-\sigma)\} - 1\right\}. \tag{18}$$

The discount factor β is set to 0.99, implying a 4 percent annual real rate in the stationary economy. The curvature parameter σ is set equal to two.

The parameters a and η are obtained from estimating the money demand equation implied by the first-order conditions for bond and money holdings. Using the utility function defined above, this equation can be written as

$$\log \frac{M_t}{P_t} = \frac{1}{\eta - 1} \log \frac{a}{1-a} + \log c_t + \frac{1}{\eta - 1} \log \frac{R_t - 1}{R_t}. \tag{19}$$

The data consist of $M1$, the three-month interest rate on T-bills, consumption of nondurables and services, and the price index is the deflator on personal consumption expenditures. The sample period is 1959:1-2004:3.[15] The estimation yields values of $\eta = -32$ and $a = 0.99$. Therefore, our calibration is close to imposing separability between consumption and real money balances.

Labor disutility is assumed to take the form

$$v(l) = \frac{\psi_0}{1+\psi_1} l^{1+\psi_1}.$$

The parameters ψ_0 and ψ_1 are set to 3.47 and 0.15, respectively, so that the fraction of working time in steady-state is 0.25 and the elasticity of labor supply, with marginal utility of consumption held constant, is 2. This elasticity is consistent with estimates in Mulligan

[15] The estimation is carried out in two steps. Because real $M1$ is nonstationary and not co-integrated with consumption, equation (19) is first differenced. The coefficient estimate on consumption is 0.975 and is not statistically different from one, so the assumption of a unitary consumption elasticity implied by the utility function is consistent with the data. The coefficient on the interest rate term is -0.021, and we calibrate η to be -32, which implies an interest elasticity of -0.03. Next, we form a residual $u_t = \log(M_t/P_t) - \log c_t - \log((R_t - 1)/R_t)/(\eta - 1)$. This residual is a random walk with drift, and we use a Kalman filter to estimate the drift term, which is the constant in equation (19). The estimation procedure neglects sampling error, because in the second stage we are treating η as a parameter rather than as an estimate.

(1998) and Solon, Barsky, and Parker (1994).

The elasticity of substitution between tradable and nontraded goods in consumption, γ, is set to 0.74 following Mendoza's (1995) estimate for a sample of industrialized countries. We assume that the nontraded input and the composite traded input are used in fixed proportions in the production of final tradable goods.[16] Thus the elasticity of substitution ρ is set to 0.001. There is considerable uncertainty regarding estimates of the elasticity of substitution between domestic and imported goods, ξ. In addition, this parameter has been shown to play a crucial role in key business cycle properties of two-country models.[17] A reference estimate of this elasticity for the United States has been 1.5 from Whalley (1985). Hooper, Johnson, and Marquez (1998) estimate import and export price elasticities for G-7 countries and report elasticities for the United States between 0.3 and 1.5. This elasticity is set to close to the mid-point in this range (0.85).

We choose the weights on consumption of tradable goods ω_T, on nontraded distribution services ω, and on domestic traded inputs ω_H to simultaneously match, given all other parameter choices, the share of consumption of nontraded goods in GDP, the share of distribution services in GDP, and the average share of imports in GDP.[18] Over the period 1973-2004, these shares averaged 0.44, 0.19, and 0.13, respectively, in the United States. For our benchmark model, these shares imply the values $\omega_T = 0.44$, $\omega = 0.38$, and $\omega_H = 0.59$. 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] This assumption is standard. See, for instance, Burstein, Neves, and Rebelo (2003), Corsetti and Dedola (2005), and Corsetti, Dedola, and Leduc (2008a and 2008b). The assumption of fixed proportions in retail markets is also common in the industrial organization literature. See, for instance, Tirole (1995). This assumption seems reasonable to us, although overtime the degree of services incorporated in delivering a good to market as well as the distribution of types of retailers offering different amounts of services along with the goods they sell may vary. These features of retailing, however, seem more secular in nature and, thus, the Leontief specification for production in the retail sector appears reasonable for analyzing cyclical behavior.

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

[18] We measure distribution services in the data as the value added from retail trade, wholesale trade, and transportation excluding transit and ground transportation services. Other expenses that are not included in our measure and that affect the cost of bringing goods to market include information acquisition, marketing, and currency conversion, to name a few. We, therefore, believe our calibration of distribution services leans on the conservative side. We measure consumption of nontraded goods in the data as consumption services.

The elasticity of substitution between varieties of a given good, ς, is set equal to 10. As usual, this elasticity is related to the markup chosen when firms adjust their prices, which is $\varsigma/(\varsigma-1)$. This choice for ς implies a markup of 1.11, which is consistent with the empirical work of Basu and Fernald (1997). The benchmark calibration assumes that all firms set prices for four quarters ($J=4$).

Regarding production, we take the standard value of $\alpha = 1/3$, implying that one-third of payments to factors of production goes to capital services.

3.2 Monetary Policy Rule

The parameters of the nominal interest rate rule (17) are taken from the estimates in Clarida, Galí, and Gertler (1998) for the United States. Specifically, $\rho_R = 0.9$, $\rho_{R,\pi} = 1.8$, and $\rho_{R,y} = 0.07$. The target values for R, π, and y are their steady-state values, and we assume a steady-state inflation rate of 2 percent per year.

3.3 Capital Adjustment and Bond Holding Costs

Capital adjustment costs are modeled as an increasing convex function of the investment to capital stock ratio. Specifically, $\Phi_k(i/k) = \phi_0 + \phi_1(i/k)^{\phi_2}$. This function is parameterized so that $\Phi_k(\delta) = \delta$, $\Phi_k'(\delta) = 1$, and the volatility of HP-filtered consumption relative to that of HP-filtered GDP is approximately 0.64, as in the U.S. data.

The bond holdings cost function is $\Phi_b(B_t/P_t) = \theta_b (B_t/P_t)^2/2$, as in Neumeyer and Perri (2005). The parameter θ_b is set to 0.001, the lowest value that guarantees that the solution of the model is stationary, without affecting the short-run properties of the model.

3.4 Productivity Shocks

The technology shocks are assumed to follow independent $AR(1)$ processes $z_{i,t}^j = Az_{i,t-1}^j + \varepsilon_{i,t}^j$, where $i = \{mf, sv\}$ and $j = \{U.S., ROW\}$; mf stands for manufacturing, sv for services, and ROW for rest of world. ε_i^j represents the innovation to z_i^j and has standard deviation σ_i^j. The data are taken from the OECD STAN data set on total factor productivity (TFP) for manufacturing and for wholesale and retail services.[19] The data are annual and run from 1971 to 1993, making for a very short sample in which to infer the time series characteristics of these measures. We cannot reject a unit root for any of the series, which is consistent with other data series on productivity in manufacturing, namely that constructed by the Bureau of Labor Statistics or Basu, Fernald, and Kimball (2004).

The shortness of the time series on TFP prevents us from estimating any richer characterization of TFP with any precision.[20] The coefficient estimates of the univariate autoregressive processes range from 0.9 for U.S. manufacturing to 1.05 for *ROW* services. Therefore, we use as a benchmark stationary but highly persistent processes for each of the technology shocks. Based on these simple regressions, we set $A = 0.98$, and the ratio of the standard deviations of innovations to TFP on manufacturing and services, $\sigma_{\varepsilon_{mf}}/\sigma_{\varepsilon_{sv}}$, is set to 2. Then, the level of $\sigma_{\varepsilon_{mf}}$ is chosen to match the volatility of GDP.

4 Findings

In this section the role of nontraded goods in our model is assessed. We find that the presence of nontraded goods has important implications for the business-cycle properties of the model, bringing it closer to the data along several dimensions. HP-filtered population moments for our model under the benchmark and alternative parameterizations are reported in Table 2.[21] In addition, we report statistics for HP-filtered data, which take the United States as the home country and a composite of its major trading partners as the foreign country for the period 1973:Q1−2004:Q3.[22] Except for net exports, the table reports the standard deviation of variables divided by that of GDP. Net exports is measured as the HP-filtered ratio of net exports to GDP, and the standard deviation reported in the table is the standard deviation of this ratio.

Nontraded goods enter the benchmark model in two ways. First, households derive

[19]The *ROW* aggregate comprises Canada, Japan, West Germany, and the United Kingdom.

[20]A VAR was estimated to investigate the relationship across the four TFP series. It was hard to make sense of the results. In this regard our results are similar to those of Baxter and Farr (2001), who analyze the relationship between TFP in manufacturing between the United States and Canada.

[21]We thank Robert G. King for providing the algorithms that compute population moments.

[22]The data are described in the Appendix.

utility from the consumption of nontraded goods. Second, production of final tradable goods requires a fixed proportion of nontraded inputs and traded inputs. Columns I and II of Table 2 contain statistics for the benchmark economy and for the economy without nontraded goods.[23]

The presence of nontraded goods increases the volatility of real and nominal exchange rates relative to GDP. The benchmark model implies that nominal and real exchange rates are about 1.5 times as volatile as real GDP. In our data, dollar nominal and real exchange rates are about 3.3 and 3.2 times as volatile as real GDP. Abstracting from nontraded goods lowers the volatility of the real exchange rate relative to the volatility of real GDP from 1.50 to 1.16. The effect of nontraded goods on nominal exchange rate volatility is similar. As in the data, exchange rates are highly correlated with each other (0.99) in both versions of the model.

There is a large empirical literature that studies real exchange rate fluctuations by decomposing the real exchange rate into the relative price of tradable goods across countries, rer_T, and a function of the relative prices of nontraded to tradable goods across countries, rer_N. It is important to verify that our model can account for this decomposition. The decomposition is given by $\log(q) = \log(rer_T) + \log(rer_N)$.[24] When using consumer price indices (CPI) to measure the price of tradable goods, empirical evidence suggests that fluctuations in real exchange rates are almost exclusively accounted for by movements in rer_T^{CPI}.[25] The corresponding decomposition in our model is $\log(q) = \log(q_T) + \log(q_{N,T})$, where $q_T = SP_T^*/P_T$, $q_{N,T} = \left(\frac{\omega_T + (1-\omega_T)\left(P_N^*/P_T^*\right)^{1-\gamma}}{\omega_T + (1-\omega_T)(P_N/P_T)^{1-\gamma}}\right)^{\frac{1}{1-\gamma}}$, and P_T is the consumer price of tradable goods. In our model the variance of q_T accounts for 81 percent of the variance of q, which is broadly consistent with the data.[26] That is, even though the presence of nontraded goods increases the

[23]Nontraded goods are eliminated by setting the share of distribution services and the share of nontraded consumption goods in GDP to 0.001. The economy is re-calibrated to match all other targets.

[24]See, for example, Engel (1999).

[25]Engel (1999), Chari, Kehoe, and McGrattan (2002), and Burstein, Eichenbaum, and Rebelo (2005) find that fluctuations in rer_T^{CPI} account for more than 95 percent of fluctuations in the U.S. real exchange rate. Also using consumer prices for tradable goods, Betts and Kehoe (2006) find that the trade-weighted average of the contribution of rer_T^{CPI} for U.S. real exchange rate fluctuations ranges between 81 percent and 93 percent, for different de-trending methods.

[26]The variance-decomposition measure used is $var(\log q_T)/(var(\log q_T) + var(\log q_{N,T}))$. This measure allocates the covariance between $\log q_T$ and $\log q_{N,T}$ to fluctuations in $\log q_T$ in proportion to the relative size of its variance.

volatility of the real exchange rate, movements in the relative price of nontraded to tradable goods play a small role in real exchange rate movements when using consumer prices. This result follows from the fact that, as we will see later, shocks to productivity in the nontraded goods sector generate sharp nominal exchange rate movements while prices adjust slowly due to the presence of nominal price rigidities. These exchange rate movements, in turn, are associated with movements in the relative price of tradable goods across countries (q_T).

The previous decomposition of real exchange rates does not completely isolate the role of fluctuations in the relative price of nontraded goods in accounting for real exchange rate movements since consumer prices include a substantial nontraded component. There is, however, a lack of empirical consensus regarding the importance of fluctuations in the relative price of nontraded goods in real exchange rate volatility. For example, Burstein, Eichenbaum, and Rebelo (2005) use prices at the dock of pure-traded goods to measure rer_T. They find that the contribution of movements in the relative price of traded goods in accounting for U.S. real exchange rate fluctuations ranges between 29 and 44 percent. In our model, we can isolate the role of nontraded goods in real exchange rate fluctuations by decomposing q as $\log(q) = \log(q_X) + \log(q_{N,X})$, where $q_X = SP^*_{x_T}/P_{x_T}$, P_{x_T} is the price of the intermediate traded input, and $q_{N,X}$ is a complicated function of P_N/P_{x_T} and $P^*_N/P^*_{x_T}$. In our model the variance of q_X is found to account for 27 percent of the variance of q. Therefore, our model implies decompositions of real exchange rate variance that are in line with the empirical evidence of Burstein et al (2005).

The presence of nontraded goods also brings the cross-correlations of the real exchange rate with other variables closer in line with the data. In particular, the cross-correlations between the real exchange rate and real GDP, the terms of trade, and the ratio of consumption across countries rises as we eliminate nontraded goods. In the benchmark model the cross-correlations of the terms of trade with nominal and real exchange rates are 0.51 and 0.62. In the data, the correlations of the U.S. terms of trade with U.S. nominal and real effective exchange rates are 0.39 and 0.30. In the absence of nontraded goods, the cross-correlation of the terms of trade with exchange rates is 0.99.

To gain some intuition, note that when prices are flexible the real exchange rate can be written as a function of the relative price of nontraded goods across countries, SP^*_N/P_N, and the terms of trade, τ, using the equations for P, P_T, and P_{x_T}. In log-linear terms,

$$\hat{q}_t = (1 - \omega_T + \omega_T \omega)(\hat{S}_t + \hat{P}^*_{N,t} - \hat{P}_{N,t}) + \omega_T(1-\omega)(2\omega_H - 1)\hat{\tau}_t, \qquad (20)$$

where a hat represents the deviation from steady-state of the log of the variable. Thus, movements in the real exchange rate are composed of movements in the relative price of nontraded goods across countries weighted by the fraction of consumption composed of nontraded goods, and movements in the terms of trade weighted by the fraction of traded goods (domestic and imported) in consumption. In the absence of nontraded goods, this expression simplifies to $\hat{q}_t = (2\omega_H - 1)\hat{\tau}_t$ and it follows that the correlation between these two variables implied by the model is 1. With nontraded goods, the real exchange rate depends both on the terms of trade and the relative price of nontraded goods across countries. As long as these two variables are not perfectly correlated, it follows that the correlation between the terms of trade and the real exchange rate is below one. In our benchmark model with sticky prices, the correlation between the relative price of nontraded goods across countries and the terms of trade is 0.57 and the correlation between the real exchange rate and the terms of trade is 0.62.

In addition to increasing the volatility of exchange rates and providing consistent decompositions of real exchange rate fluctuations, the presence of nontraded goods also lowers the correlation of the real exchange rate with GDP and the ratio of consumption across countries, from 0.64 and 0.99 to 0.47 and 0.83. The intuition behind these lower correlations hinges on the presence of two exogenous shocks with markedly different implications for exchange rates and other macrovariables. In the absence of nontraded goods, the model is driven by fluctuations in z_H only. In this case, shocks to z_H generate large movements in exchange rates and other variables. Thus, the correlations between exchange rates and other variables implied by the model are high. In the presence of nontraded goods, however, shocks to z_H imply very small responses of exchange rates relative to other variables (and low co-movement between these variables) while shocks to z_N imply large responses of exchange rates and high co-movements of exchange rates with other variables. The presence of both shocks in the model with nontraded goods allows exchange rates to exhibit relatively high volatility with lower co-movement of exchange rates with other variables.[27] Nevertheless, the model with nontraded goods implies correlations that are large compared to the data.

For completeness, other statistics are reported in Table 2. The presence of nontraded goods also brings the cross-country correlations of GDP, consumption, and investment closer in line with the data. With nontraded goods the cross-correlation of consumption falls from 0.54 to 0.40 while the cross-correlation of output increases from 0.16 to 0.36. Nevertheless, the cross-country correlation of GDP is lower than in the data (0.36 versus 0.57).[28]

The model is driven by country-specific shocks to productivity in the traded and non-traded goods sectors. To further understand the role of nontraded goods in our model, we now focus on the role of these goods in the adjustment of the economy following shocks to productivity in each sector.

4.1 Shocks to Traded Goods Productivity

The response of selected variables to a positive 1 percent shock to productivity in the traded goods sector is depicted in Figure 2. In response to a positive shock in the home country, the price of home intermediate traded goods falls. Consumption, hours worked, and real GDP fall slightly on impact, but they rise as traded goods firms lower their prices. Since the price of home intermediate inputs falls relative to both foreign intermediate inputs (the inverse of the terms of trade) and nontraded goods, the home country's demand for intermediate inputs increases and home and foreign producers of final tradable goods substitute toward home traded inputs and away from foreign traded inputs.

A shock to productivity in the traded goods sector generates a very small response of nominal and real exchange rates. To see why this happens, note first that in this case agents come close to optimally sharing risk to traded goods productivity with one nominal bond only.[29] In addition, note that in the benchmark model home and foreign producers of

[27] See Duarte and Stockman (2002) for a related argument.

[28] It should be noted that in our benchmark calibration all exogenous shocks are independent across countries, and thus, these positive cross-country correlations reflect the endogenous transmission mechanism of shocks across countries in our model.

[29] This feature is standard in two-country models, in which equilibrium allocations with complete asset markets or one riskless bond only are very close. See, for example, Baxter and Crucini (1995), Chari, Kehoe, and McGrattan (2002), and Duarte and Stockman (2005).

final tradable goods use local and imported goods in roughly the same proportion ($\omega_H = 0.59$). That is, the home and foreign economies are close to being symmetric, implying that these shocks do not disproportionately benefit the local economy. Therefore, the effect of a technology shock z_H in our setting is very close to what would happen under symmetry and complete asset markets, implying that the real exchange rate does not respond very much to this shock. Since price levels are very smooth, the response of the nominal exchange rate is also small.

It also follows that the condition $q_t = u^*_{c,t}/u_{c,t}$ approximately holds in response to these shocks.[30] Combining this condition with the observation that home agents work less relative to foreign agents because prices and demand adjust slowly, implies that, on impact, the foreign agent must consume more relative to the home agent for marginal utilities to be roughly equated (recall that utility is nonseparable). As prices adjust and relative demand for the home intermediate traded good increases, hours worked, and consumption in the home country increase relative to those in the foreign country.

Given the small response of exchange rates relative to the response of other variables after a shock to productivity in the traded goods sector, the model would imply low correlations between exchange rates and other aggregate variables if it were driven only by shocks to productivity in the traded goods sector. In this case, the correlations of the real exchange rate with output and the ratio of consumption across countries are 0.36 and -0.15.

In the absence of nontraded goods the model requires a high degree of home bias (as measured by the parameter ω_H) in order for it to match the target import share. In this case $\omega_H = 0.86$ and the two countries are no longer close to being symmetric since a positive shock to z_H disproportionately benefits local producers of final tradable goods relative to foreign ones. Therefore, in the absence of nontraded goods, this shock is associated with larger exchange rate depreciations and larger responses of other home variables. As a consequence, the co-movement between exchange rates and other variables is larger in the model without nontraded goods (see column II of Table 2). Thus, with respect to a shock to z_H, the presence of nontraded goods affects the variability of the exchange rate largely because the degree of home bias must be re-calibrated in order to match the import share.

[30] For a derivation of this condition see, for instance, Chari, Kehoe, and McGrattan (2002).

4.2 Shocks to Nontraded Goods Productivity

We now focus on the response to a productivity shock in the nontraded goods sector, depicted in Figure 3. In contrast to the response to a productivity shock in the traded goods sector, asset trade in one bond is not a good approximation to complete asset markets. Here we find that exchange rates depreciate sharply after a positive productivity shock in the nontraded goods sector and the price of nontraded goods falls. In the absence of a response of monetary policy, the price level also falls. When the monetary authority follows the interest rate rule in (17), the money stock expands, largely keeping the price level constant in response to this shock.[31]

Following a persistent shock to productivity in the nontraded goods sector (and the associated response of monetary policy), real GDP, consumption, and investment in the home country increase on impact and later gradually fall to their deterministic steady-state levels. Thus, home consumers want to consume more of both final tradable goods and nontraded goods and want to invest more in order to increase the capital stock in the nontraded sector. Final tradable goods, however, require the use of traded and nontraded goods in fixed proportions and, thus, firms cannot substitute toward the relatively cheaper input. Therefore, the country runs a current account deficit (and becomes a net debtor) in response to a positive productivity shock. The Leontief assumption between distribution services and traded inputs in the production of final tradable goods is important. Note also that this assumption matters only in the response to shocks to z_N since in response to shocks to z_H firms can substitute between domestic and imported traded goods in the production of the composite traded good x_T.

The real exchange rate depreciates following the positive shock to productivity in the nontraded goods sector. Recall from equation (20) that movements in the real exchange rate are associated with movements in the relative price of nontraded goods across countries and movements in the terms of trade. Following this shock, the price of nontraded goods in the foreign country relative to its price in the home country rises. Moreover, the terms of trade

[31] It should be noted that, while the magnitude of the responses of most variables in Figure 2 is small relative to those in Figure 3, the standard deviation of innovations to productivity in the traded goods sector is twice as large that of the nontraded goods sector. Therefore, when considered in isolation, both calibrated shocks generate about the same absolute volatility of output.

τ (defined as the relative price of domestic imports in terms of domestic exports) also rise.[32] In the absence of terms of trade movement, the demand for home and foreign inputs would increase proportionately to satisfy higher domestic investment and consumption of tradable goods. The depreciation of the terms of trade makes domestic firms substitute domestically produced inputs for imported goods, dampening the demand for foreign inputs and the required adjustment of foreign labor hours. The nominal exchange rate also depreciates following this shock. It moves closely together with the real exchange rate, since monetary policy ensures that price levels remain relatively constant.

Note that a positive shock to productivity in the nontraded goods sector is associated with a depreciation of exchange rates and the terms of trade and an increase in domestic output and consumption. Hence, if the model were driven only by shocks to this sector, it would imply large cross-correlations of exchange rates with other variables. For instance, with shocks to productivity to the nontraded goods sector only, the cross-correlation of the real exchange rate with output is 0.55, with the terms of trade is 0.98, and with the ratio of consumption across countries is 0.97.

As mentioned, the response to productivity shocks in the nontraded goods sector depends crucially on the asset market structure. With incomplete asset markets, exchange rates depreciate sharply in response to a positive productivity shock in the nontraded goods sector and the depreciation of the domestic exchange rate and terms of trade ensures a substitution effect toward inputs produced in the home country and away from inputs produced in the foreign country. With optimal risk sharing, in contrast, the foreign agent works more (and substitutes hours toward the traded sector and away from the nontraded sector) and consumes less in response to this shock. That is, relative to the incomplete markets case, the foreign agent produces more traded goods and a smaller terms of trade and exchange rate depreciation is needed to equate the demand and supply of foreign traded goods when asset markets are complete.

Statistics for our model driven by shocks to productivity in the traded and nontraded goods sectors when asset markets are complete are reported in column III of Table 2. Due

[32]In our model $P_H = SP_H^*$ and $P_F = SP_F^*$ since the law of one price holds. Thus, $\tau = SP_F^*/P_H$, where P_F^* and P_H adjust slowly.

to the presence of nontraded goods, the properties of equilibrium allocations depend on the asset market structure. Consistent with the previous discussion, exchange rates and the terms of trade are found to be less volatile relative to GDP with complete markets than in the benchmark model while employment is more volatile. In addition, employment and output are more highly correlated across countries when asset markets are complete than when they are incomplete. It is also interesting to note that in our model with complete markets, GDP is more highly correlated across countries than consumption. This implication of the model is consistent with the data, where the cross-country correlation of GDP is typically higher than the cross-country correlation of consumption. However, two-country models with optimal risk sharing typically have the opposite implication since agents can pool optimally their consumption risk while it is efficient for the country that receives a high productivity shock to produce relatively more.[33] The results in Table 2 suggest that the implications of the model for the quantity puzzle depend critically both on the structure of production (through the presence of nontraded goods) and on the asset market structure.

5 Alternative Price Setting Mechanisms

The importance of fluctuations in the relative price of tradable goods across countries in understanding real exchange rate fluctuations has generated an extensive debate on the nature and implications of alternative price setting regimes for exporters. In much recent work in open economy models with nominal price rigidities, deviations from the law of one price are driven by the assumption that firms are able to price discriminate across markets and set prices in the currency of the buyer (LCP). In this setup, the price in local currency of imported goods does not respond to unanticipated movements of the nominal exchange rate, generating a deviation from the law of one price in the short run. Note that, in this case, a nominal depreciation does not affect prices that consumers face and does not generate an expenditure switching effect in the short run. The empirical evidence on the slow pass-through of exchange rate changes to consumer prices and substantial deviations from the law

[33]See, for instance, Backus, Kehoe, and Kydland (1992). The difficulty in accounting for the greater cross-country correlation of output relative to that of consumption is known as the "quantity puzzle" in international economics.

of one price suggest that prices of imported goods are sticky in the currency of the buyer. However, as Obstfeld and Rogoff (2000b) argue, the LCP assumption is not consistent with empirical evidence supporting the expenditure switching effect of exchange rate changes in the short run.[34]

In this section we study the implications for the properties of our model of the alternative pricing mechanism under which producers of traded goods set prices in the currency of the buyer (LCP). The pricing mechanism affects the equilibrium of the model because prices are sticky. In particular, in our model, at any date there are four vintages of varieties of any given good: the vintage of varieties whose price was reset the current period and three vintages of varieties with preset prices (chosen in each of the three previous periods). Under PCP (our benchmark model), traded goods firms choose one price (denominated in the currency of the producer) and the law of one price always holds for all vintages of prices. Therefore, 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 set prices in the currency of the buyer. That is, 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 varieties whose prices are preset. Regarding the newly reset prices, producers choose the price of their good, denominated in the currency of the buyer, that maximizes discounted expected profits in each market.[35] For simplicity, we look at the log-linearized pricing equations for the prices chosen in period t of the home traded good at home and abroad. These are given by,

$$\hat{P}_{H,t}(0) = \mathrm{E}_t \left[\sum_{j=0}^{J-1} \rho_j \left(\hat{\psi}_{H,t+j} + \hat{P}_{t+j} \right) \right], \tag{21}$$

[34] Obstfeld and Rogoff (2000b) present empirical evidence suggesting that nominal exchange rates and the terms of trade are positively correlated.

[35] The optimal prices are given by expressions analogous to equation (3). The only differences are that country-specific demand appears in each pricing equation and the optimal price chosen for the foreign market, $P^*_{H,t}(0)$, depends on current and future nominal exchange rates which convert foreign-currency revenues to domestic currency units.

and

$$\hat{P}^*_{H,t}(0) = \hat{P}_{H,t}(0) - \mathrm{E}_t\left[\sum_{j=0}^{J-1} \rho_j \hat{S}_{t+j}\right], \tag{22}$$

respectively.[36] 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 mechanisms following a shock only arise from differences in the relative price across countries of prices that 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.

Column IV in Table 2 reports the statistics of the model under LCP. Two main features arise. First, the business cycle statistics reported in Table 2, other than the correlation of the terms of trade with exchange rates, 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 0.97 The nominal exchange rate is slightly more volatile under PCP, with the ratio 1.14. Similarly, the model also implies similar persistence across pricing mechanisms as well as cross-country correlations. Second, the cross-correlations of the terms of trade with exchange rates are higher under PCP than LCP. In fact, the cross-correlations of the terms of trade and the price of imports, P_F, with other variables are systematically higher under PCP than LCP (see Table 3).

To gain some intuition on the differences between the two pricing mechanisms, Figures 4 and 5 plot the responses of selected variables to a productivity shock in the traded and nontraded goods sectors, respectively, under the two pricing mechanisms. In each figure, the panels on the left plot the response under PCP and the panels on the right plot the response under LCP. 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.

[36] As before, 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, $\rho_j \approx 1/J$.

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 4 shows, the response of the nominal exchange rate to this shock is small in both cases. 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 response to a shock to productivity in the nontraded goods sector, 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 exchange rates, output, and the price level behave similarly.

An increase in technology in the nontraded goods sector leads to a depreciation of the nominal exchange rate. Under PCP, 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 local currency) with the exchange rate. In turn, the domestic price of exports rises by less than the exchange rate: Only the newly reset price (in domestic currency) of exports rises as domestic firms readjust their prices, due to higher domestic wages. As a result, higher productivity in the domestic nontraded goods sector raises the price of imports relative to exports in the short run generating an expenditure-switching effect towards domestic goods. Under LCP, preset prices of imported goods are not affected by movements in the exchange rate. In addition, the domestic-currency price of domestic exports rises with the nominal exchange rate since domestic firms set the price of exports in foreign currency. 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, GDP, exchange rates, and the price level (among other variables) respond similarly. One reason is that trade is a small portion of the economy: Although the response of import prices differs between PCP and LCP, this difference diminishes as prices are aggregated up to the consumer price level. 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 systems. Another reason why the two pricing mechanisms lead to similar behavior of the nominal exchange rate, output, and the price level is that in our model nominal exchange rates are very persistent. Thus, if follows from equations (21) and (22) 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 different pricing mechanisms converges.[37]

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 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.[38] 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 world.

6 Sensitivity Analysis

In this section we perform sensitivity analysis on the role of nontraded goods in our model along 5 dimensions: the elasticity of substitution between distribution services and traded intermediate inputs, ρ, the elasticity of substitution between domestic and imported traded inputs, ξ, the nature of monetary policy, the presence of nominal price rigidities, and the specification of preferences.

[37] We note that the similar behavior of variables other than the terms of trade and price of imports across price setting mechanisms does not depend on the nature of monetary policy, given by equation (17). We obtain similar results when we replace equation (17) with a money supply rule.

[38] 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.

Elasticity of substitution between retail services and traded intermediate inputs First, we focus on the role of the elasticity of substitution between retail services and traded intermediate inputs in the production of final tradable goods, ρ. In our benchmark model we assume that these goods are used in fixed proportions ($\rho = 0.001$). In Table 4 we report business cycle statistics for our model with nontraded goods for ρ equal to 0.25 and 0.5. (Note that ρ does not affect the model without nontraded goods.) The elasticity of substitution ρ affects the role of nontraded goods in nominal and exchange rate volatility relative to that of output. For $\rho > 0$, domestic retail firms substitute towards nontraded distribution services and away from traded intermediate inputs following a positive productivity shock to the nontraded goods sector. This substitution dampens the demand for foreign traded inputs and the required terms of trade and exchange rate adjustment. Therefore, the ability to substitute between traded and nontraded inputs in the retail sector lowers the impact of nontraded goods on the relative volatility of exchange rates. The parameter ρ does not affect the role of nontraded goods in the co-movement of the real exchange rate with output or the ratio of consumption across countries. However, the cross-correlation between the real exchange rate and the terms of trade falls with ρ, as the volatility of the terms of trade and the co-movement of the terms of trade with the relative price of nontraded goods across countries falls.

Elasticity of substitution between domestic and imported inputs Second, we perform sensitivity analysis on the elasticity of substitution between domestic and imported traded inputs, ξ. In the benchmark model we use $\xi = 0.85$ and in Table 4 we report results for ξ equal to 0.6 and 0.99. Consistent with the findings in Perri and Heathcote (2002) and Corsetti, Dedola, and Leduc (2008a), this parameter affects the level of exchange rate volatility. A lower elasticity of substitution between domestic and imported inputs raises exchange rate volatility and lowers the correlation between the real exchange rate and the ratio of consumption across countries. In this case, the presence of nontraded goods amplifies exchange rate volatility, but by a smaller extent than in the benchmark model. A higher elasticity of substitution lowers exchange rate volatility. In this case, the presence of nontraded goods has a bigger impact on exchange rate volatility than in the case with a lower elasticity.

Monetary policy rule Third, we consider a money supply rule instead of the interest rate feedback rule in equation (17). Note that in the benchmark model the money supply in each country responds endogenously to productivity shocks. A money supply rule implies constant money stocks in each country since there are no exogenous shocks to monetary policy in our model. Table 5 reports business cycle statistics for this economy with and without nontraded goods. With constant money stocks, price levels are more volatile in each country; in the benchmark economy, the volatility of the price level relative to that of output is 0.22 and is almost three times as high when money supplies are constant. The nominal exchange rate is less volatile than in the benchmark model while the real exchange is more volatile. As in the benchmark model, the absence of nontraded goods lowers the volatility of nominal and real exchange rates. In addition, the presence of nontraded goods lowers the cross-correlation between the real exchange rate and the terms of trade and it increases the cross-country correlation of output.

Nominal price rigidities Forth, we verify the sensitivity of our results to the presence of nominal price rigidities. We note that our model is driven by real shocks and, thus, it generates movements in real exchange rates even in the absence of nominal rigidities. However, some form of nominal rigidities are required for the model to be consistent with empirical evidence. Table 5 reports results for the economies with and without nontraded goods when prices are flexible in all sectors. Qualitatively, the role of nontraded goods in our model does not depend on the presence of nominal price rigidities. With flexible prices, however, relative prices are more volatile. Therefore, the fraction of real exchange rate fluctuations accounted for by fluctuations in the relative price of traded goods is lower than in the benchmark model.

Preference specification In section 4 we saw that the non-separability of preferences in consumption and leisure dampens the response of exchange rates to shocks.[39] We now

[39] Chari, Kehoe, and McGrattan (2002) emphasize the importance of separability in consumption in leisure for the volatility of nominal and real exchange rates relative to that of GDP implied by their model. In their

consider the implications of a separable utility function for the role of nontraded goods in our model. We consider the momentary utility function

$$u\left(c, l, \frac{M}{P}\right) = \frac{1}{1-\sigma}\left\{\left(ac^{\eta} + (1-a)\left(\frac{M}{P}\right)^{\eta}\right)^{\frac{1-\sigma}{\eta}} + \exp\left\{-v(l)(1-\sigma)\right\}\right\},$$

where $v(l)$ takes the same form as before. The calibration strategy is the same as described in Section 3, and it implies that the values of σ, a, and η remain the same while $\psi_0 = 2.1$ and $\psi_1 = -0.12$. Relative standard deviations for our model with separable preferences in consumption and leisure are reported in Table 5. As in Chari, Kehoe, and McGrattan (2002), exchange rates are also more volatile relative to GDP when preferences are separable: 2.00 and 2.05 versus 1.54 and 1.50 with nonseparable preferences. Abstracting from nontraded goods in our model with separable preferences reduces the relative volatility of nominal and real exchange rates from 2.00 and 2.05 to 1.39 and 1.35. We conclude that the quantitative importance of nontraded goods for exchange rate variability emphasized in our benchmark specification is magnified if we consider separable preferences in consumption and leisure.

7 Conclusion

In this paper, we argue that nontraded goods play an important role in accounting for real exchange rate fluctuations. Our quantitative study suggests that nontraded goods improve the implications of our model compared to the model without consumption of nontraded goods and nontraded distribution services, while fluctuations in the relative price of nontraded goods account for a small fraction of real exchange rate fluctuations.

Given the work of Stockman and Tesar (1995), and the importance of nontraded goods in the economy, this analysis is a natural extension to existing work in open economy models. The overriding message is that nontraded goods serve a useful role in bringing the model closer to the data. The presence of nontraded goods magnifies the volatility of the real

benchmark calibration, preferences are separable, the degree of risk aversion is high, and prices are staggered and set for four quarters. This specification implies that the relative volatility of exchange rates is about 4.3. When preferences are non-separable, the relative standard deviations of nominal and real exchange rates are 0.07 and 0.05.

and nominal exchange rate relative to GDP. Importantly, the increase in the volatility of the real exchange rate is due largely to increased volatility in tradable goods prices rather than increased volatility in the relative price of nontraded goods across countries. Further, the presence of nontraded goods reduces the correlation of the real exchange rate with other variables and it improves the cross-country correlations implied by the model. Our benchmark model, however, is still at odds with the very low and often negative correlations between real exchange rates and relative consumptions across countries that are found in the data.

A Data

The data series for U.S. GDP, consumption, investment, and net exports are obtained from the OECD Quarterly National Accounts (QNA). They are, respectively, Gross Domestic Product, Private Final Consumption Expenditures plus Government Final Consumption Expenditures, Gross Fixed Capital Formation, and Exports minus Imports of Goods and Services. All series are measured at fixed constant prices. The data series for U.S. employment is the Civilian Employment Index from the OECD Main Economic Indicators (MEI).

The series for the U.S. nominal and real exchange rates are the Nominal and Price-Adjusted Major Currencies Dollar Indices published by the Federal Reserve Board. The series for the U.S. terms of trade is obtained from the OECD International Trade and Competitiveness Indicators.

For GDP, consumption, and investment in the rest of the world, we constructed an aggregate of Canada, Japan, and 15 European countries (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Norway, the Netherlands, Portugal, Spain, Sweden, and the UK). The data used are from OECD QNA for Canada, Japan, and EU15. The data are measured at fixed constant prices, and they are aggregated using PPP exchange rates. The data series for employment in the rest of the world are constructed from Civilian Employment Indices for Canada, Japan, and eight European countries from the OECD MEI (Comparative Subject Tables). These data are aggregated using population weights. The data are available from the authors upon request and can be accessed at www.economics.utoronto.ca/duarte/research/research.html

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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_T (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 retail services 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	Data	I Benchmark Economy	II No NT	III Complete Markets
Stand. Dev. Relative to GDP				
Consumption	0.64	0.64	0.64	0.64
Investment	2.87	2.41	2.01	2.57
Employment	0.66	1.10	0.24	1.22
Nominal e.r.	3.33	1.54	1.21	1.15
Real e.r.	3.19	1.50	1.16	1.07
Terms of trade	1.66	2.27	1.59	1.74
Net exports	0.39	0.31	0.09	0.38
Autocorrelations				
GDP	0.88	0.66	0.80	0.60
Nominal e.r.	0.85	0.80	0.80	0.80
Real e.r.	0.83	0.80	0.80	0.79
Terms of trade	0.81	0.88	0.86	0.88
Cross-correlations				
Between nominal and real e.r.	0.98	0.99	0.99	0.98
Between real exchange rate and				
GDP	0.16	0.47	0.64	0.41
Terms of trade	0.30	0.62	0.99	0.51
Relative consumptions	-0.07	0.83	0.99	0.88
Between n.e.r. and terms of trade	0.39	0.52	0.99	0.36
Between domestic and foreign				
GDP	0.57	0.36	0.16	0.48
Consumption	0.37	0.40	0.54	0.41
Investment	0.42	0.44	0.33	0.46
Employment	0.44	0.52	0.47	0.65
Variance Decompositions				
q_T	[0.81-0.93][a]	0.81	–	0.80
q_X	[0.29-0.44][b]	0.27	–	0.21

a: Betts and Kehoe (2006). *b*: Burstein, Eichenbaum, and Rebelo (2005).

Table 3: Model Correlations

Cross-correlations	PCP	LCP
Between terms of trade and		
output	0.48	0.27
nominal ex. rate	0.51	0.11
real ex. rate	0.63	0.26
price of imports	0.80	0.73
Between price of imports and		
output	0.38	0.25
nominal ex. rate	0.71	0.48
real ex. rate	0.77	0.58

Table 4: Sensitivity Analysis I

	Benchmark		ρ=0.25	ρ=0.5	ξ=0.6		ξ=0.99	
	w/ NT	no NT	w/ NT	w/ NT	w/ NT	no NT	w/ NT	no NT
Relative Stand. Dev.								
σ_S/σ_y	1.54	1.21	1.37	1.24	2.35	2.26	1.40	0.99
σ_q/σ_y	1.50	1.16	1.33	1.19	2.39	2.18	1.31	0.95
σ_τ/σ_y	2.27	1.59	2.14	2.04	3.63	2.92	1.91	1.28
Cross-correlations								
$\rho(q, y)$	0.47	0.64	0.47	0.47	0.44	0.59	0.45	0.66
$\rho(q, \tau)$	0.62	0.99	0.59	0.55	0.84	0.99	0.51	0.99
$\rho(q, c/c^*)$	0.83	0.99	0.84	0.84	0.47	0.93	0.87	0.99
Variance Decomp.								
q_T	0.81	–	0.80	0.81	0.84	–	0.80	–
q_X	0.27	–	0.25	0.25	0.37	–	0.20	–

Table 5: Sensitivity Analysis II

	Benchmark		Money Rule		Flexible Prices		Separable Pref.	
	w/ NT	no NT	w/ NT	no NT	w/ NT	no NT	w/ NT	no NT
Relative Stand. Dev.								
σ_S/σ_y	1.54	1.21	1.29	0.58	1.16	0.53	2.00	1.39
σ_q/σ_y	1.50	1.16	1.89	1.10	1.88	1.20	2.05	1.35
σ_τ/σ_y	2.27	1.59	3.18	1.65	3.27	1.70	3.74	1.84
Cross-correlations								
$\rho(q, y)$	0.47	0.64	0.50	0.61	0.53	0.68	0.58	0.70
$\rho(q, \tau)$	0.62	0.99	0.58	0.99	0.54	0.99	0.52	0.99
$\rho(q, c/c^*)$	0.83	0.99	0.85	0.82	0.99	0.99	0.98	0.99
Variance Decomp.								
q_T	0.81	–	0.73	–	0.69	–	0.80	–
q_X	0.27	–	0.26	–	0.25	–	0.25	–

Figure 1: Production Structure

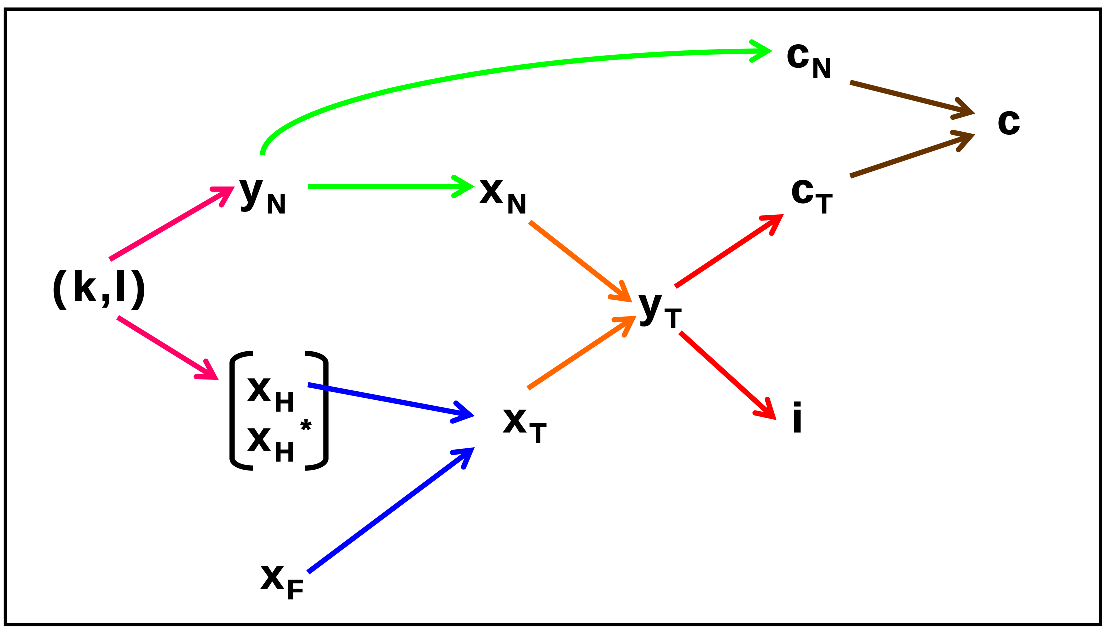

Figure 2: Benchmark Economy - positive shock to z_H

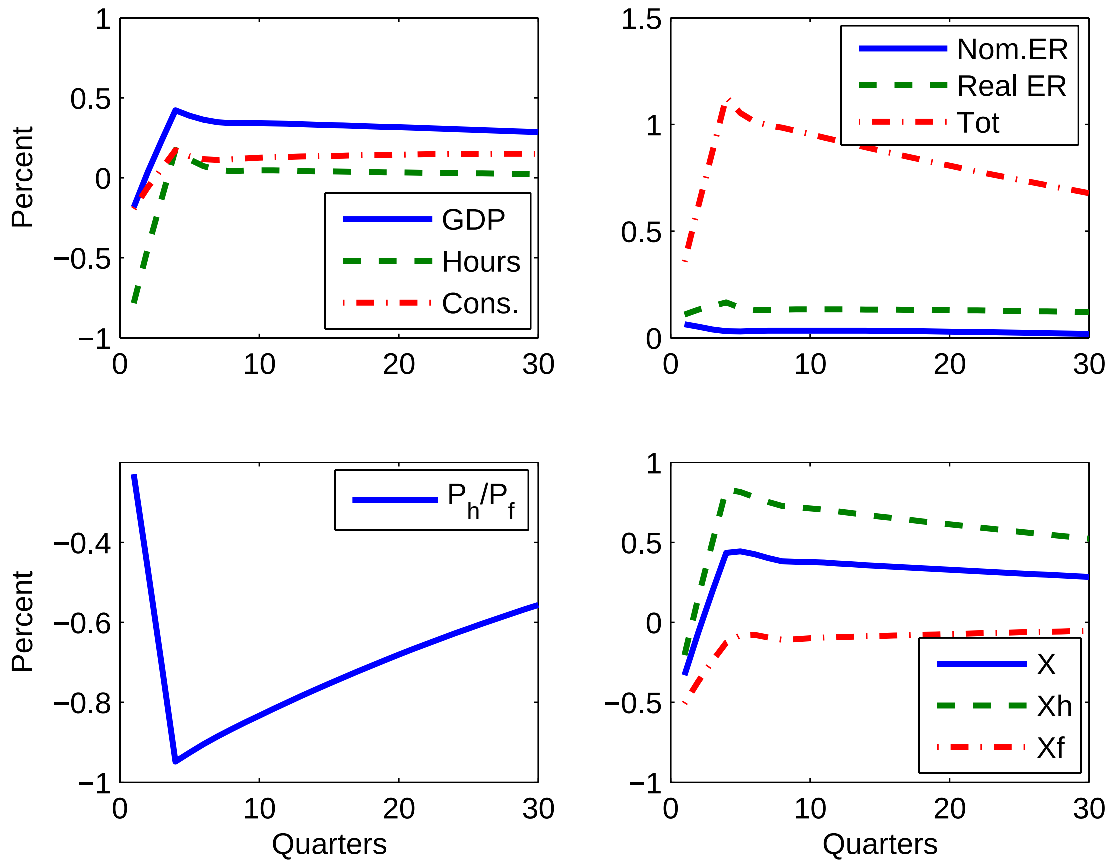

Figure 3: Benchmark Economy - positive shock to z_N

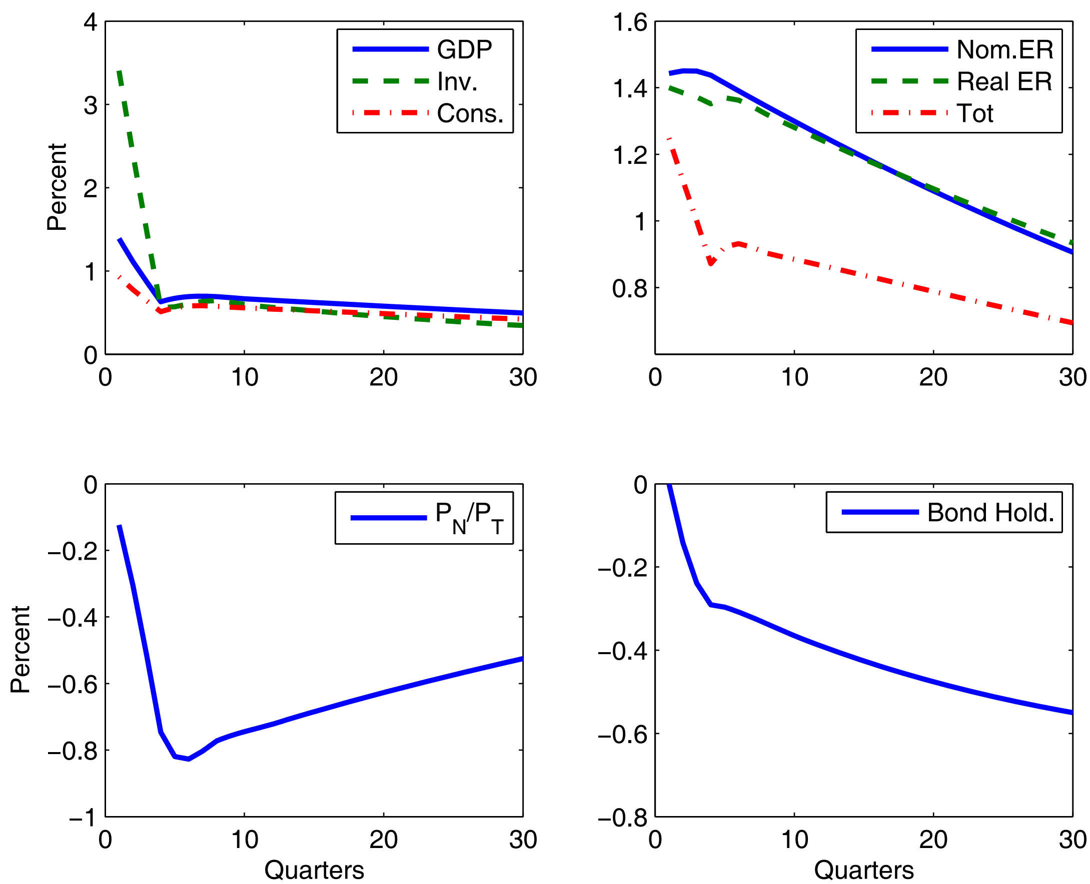

Figure 4: PCP versus LCP - positive shock to z_H

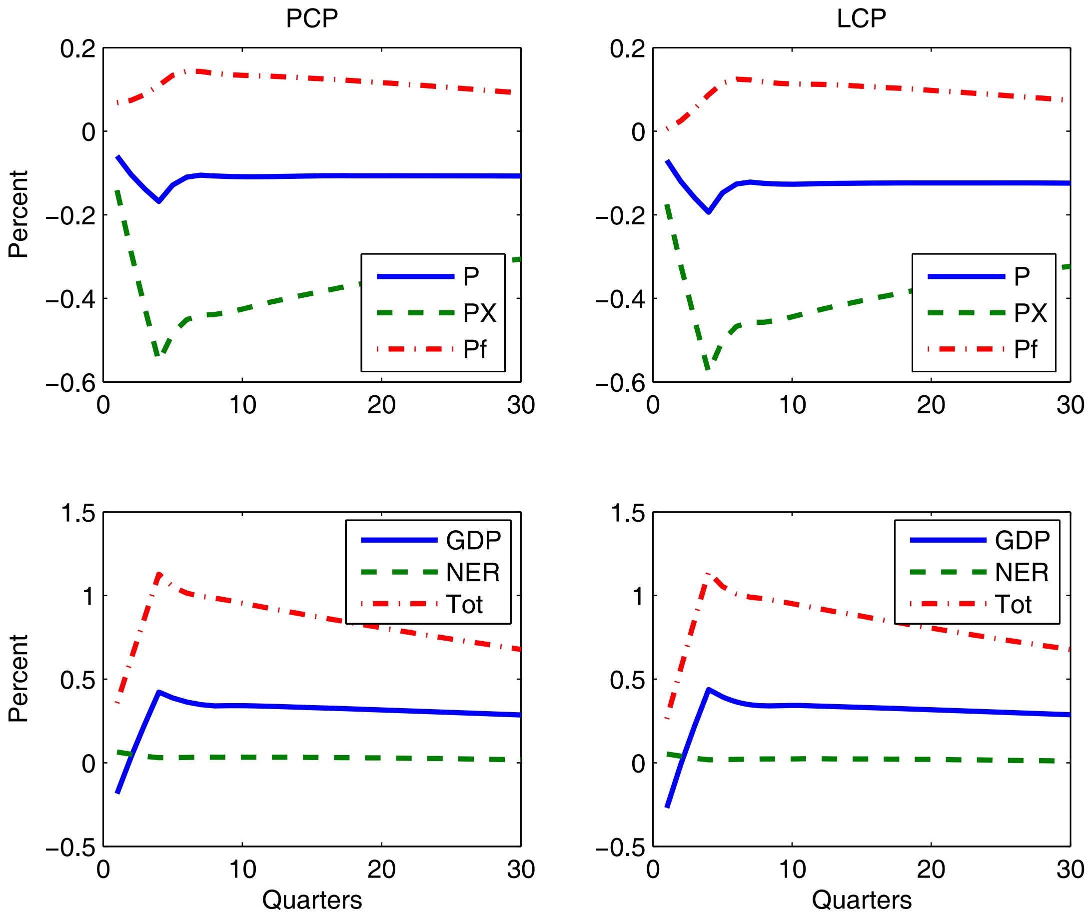

Figure 5: PCP versus LCP - positive shock to z_N