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Monetary Shocks and Real Exchange Rate Dynamics: A Reappraisal *

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Abstract:

This paper proposes a two-country general equilibrium model incorporating a tradeable sector with pricing-to-market as well as a non tradeable sector. In that case, real exchange rate fluctuations arise from two sources: changes in the relative price of traded good, that exemplify deviations from the law of one price, and movements in the relative price of traded to non traded goods across countries. Our framework sheds light on the propagation mechanisms through which monetary shocks affect the real exchange rate. More specifically, the two components respond in opposite directions to monetary disturbances, which is consistent with data. Besides, the introduction of non traded goods does not alter the predictive power of monetary shocks because the presence of non traded goods magnifies the response of the deviation from the law of one price.

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1 Introduction

The volatility and persistence of real exchange rates constitute the central puzzle in international business cycles. In order to solve this puzzle, recent developments in the new open economy literature lay stress on the role of monetary shocks interacting with credit market frictions (Hairault, Patureau and Sopraseuth [2004]) or price stickiness and monopolistic competition. [1] A popular story supported by Betts and Devereux [1996], Devereux and Engel [2002] and Chari, Kehoe and McGrattan [2002] among others insists on the role of fluctuations in the relative price of tradables in the understanding of real exchange rate dynamics. Pricing-To-Market behavior (hereafter PTM) associated with price stickiness in a monopolistic competition framework generates deviation from the law of one price whose volatility is somewhat consistent with the data. Chari *and al.* [2002] conclude that monetary shocks alone account for real exchange rate movements.

Chari *and al.* [2002]'s model abstracts from the presence of non tradeables while the non tradeable sector represents a sizeable part of any industrial country. With the introduction of non traded goods in Chari *and al.* [2002]'s framework, real exchange rate fluctuations could be decomposed into two elements: the deviation from the law of one price and the relative price of non traded to traded goods across countries. Chari *and al.* [2002]'s model focus only on the first component. The second component constitutes a second channel of propagation for monetary shocks. Does the non traded good relative price magnify the real exchange rate response to the monetary shock or does it reduce the impact of this disturbance? Is this element quantitatively important? If so, the understanding of real exchange rate dynamics might require the use of sectoral productivity shocks, as suggested by Balassa [1964] and Samuelson [1964], which would not support Chari *and al.* [2002]'s stress on monetary shocks.

This paper aims at capturing the features that characterize the inner real exchange rate dynamics and the interplay between its components. We first characterize the business cycle properties of the real exchange rate. We document the empirical volatility of the real exchange rate and that of its two components: the relative price of traded goods (or the deviation from the law of one price) and the relative price of non traded to traded goods across countries. We also examine the correlation between the two components of the real exchange rate. Consistent with previous empirical studies, a substantial fraction of real exchange rate volatility is due to fluctuations in the relative price of traded goods. Moreover, the non traded good relative price is about 10 times less volatile than the real exchange rate, which is small but statistically significant. Finally, the two components of the real exchange rate exhibit a significant negative correlation.

Chari *and al.* [2002] only focus on the behavior of the relative traded good price. In this paper, the exchange rate dynamics also include that of the relative price of non traded to traded good. This work seeks to assess the robustness of Chari *and al.* [2002]'s conclusions on the ability of monetary shocks to capture exchange rate dynamics. In particular, we want to know if monetary shocks alone are able to account for fluctuations in the non traded good relative price and the negative comovement between both components of the real exchange rate.

We extend Chari *and al.* [2002]'s framework in order to incorporate non traded goods. For the benchmark calibration, the monetary shock affects the deviation from the law of one price (as in Chari *and al.* [2002]) *as well as* the relative price of non traded goods. Moreover, the response of the deviation from the law of one price is larger in presence of non traded goods. Finally, interestingly, in response to the monetary shock, both components of the real exchange rate display a negative correlation. The introduction of non tradeables does improve our understanding of real exchange rate fluctuations. Surprisingly, the popular monetary story is robust to the introduction of non tradeables. This conclusion is relevant for realistic sizes of the non tradeable sector or when prices are more sticky in the non traded sector than in the traded sector, which seems supported by data. In a previous work (Hairault and Sopraseuth [2004b]), we developed an analytical version of a two-country model with PTM and non traded goods. This paper extends our analysis by measuring the quantitative implications of this model and measures its ability to match the data.

After documenting the statistical behavior of the real exchange rate (section 2), the building blocks of the model with PTM and non tradeables are presented in section 3. The qualitative as well as the quantitative implications of the model are explored in section 4. A sensitivity analysis on the pricing-to-market, the size of the non tradeable sector and the asymmetry in price stickiness is performed in section 5. Section 6 concludes.

2 Stylized Facts

This section provides key statistics on the business cycle behavior of relative prices and real exchange rates for individual industrialized countries.

The Sources of Real Exchange Rate Fluctuations

Dwelling on the fact that households consume traded as well as non traded goods, movements in the real exchange rate could be decomposed into two components: the deviation from the law of one price (i.e. the relative price of traded goods) and changes in the relative price of non traded to traded goods across countries. To investigate the magnitude of these two sources of real exchange rate fluctuations, let the consumer price index be defined as $p_1^C = (1-\xi_1)p_1^T + \xi_1 p_1^N$ (in logarithmic terms in country 1) and $p_2^C = (1-\xi_2)p_2^T + \xi_2 p_2^N$ (in country 2), where p_i^T and p_i^N denote traded and non traded good price indices in country i and ξ_i the consumption share of non traded good in country i. The real exchange rate, given by $\Gamma = e + p_2^C - p_1^C$ where e is the nominal exchange rate between country 1 and country 2, then consists of two elements:

$$\Gamma = \left(e + p_2^T - p_{1t}^T\right) + \xi_2\left(p_2^N - p_2^T\right) - \xi_1\left(p_1^N - p_{1t}^T\right)$$

The first source of real exchange rate fluctuations, $\left(e + p_2^T - p_{1t}^T\right)$, arises from the deviation from the law of one price (hereafter deviation from LOP). Indeed, if the law of one price holds, the relative price of traded goods is constant. The second component of the real exchange rate is the relative price of non traded to traded goods across countries written as $\xi_2\left(p_2^N - p_2^T\right) - \xi_1\left(p_1^N - p_{1t}^T\right)$. What is the relative importance of these two components in the understanding of real exchange rate fluctuations? This section aims at answering this question.

This section documents the business cycle properties of the bilateral real exchange rate and its two components between the United States and some key industrialized countries.

Following Engel [1999], the quarterly series are constructed from consumer price indices collected by the OECD. Appendix A provides further details regarding the measures of traded and non traded good prices. The data are quarterly and cover the period from 1971Q3 through 2000Q2. The cyclical component is identified using Hodrick and Prescott [1997] filter (hereafter HP - filter).

Table 1 reports the standard deviation of the HP - filtered real exchange rate and its two components vis-à-vis the US dollar relative to that of GDP. The last column presents the correlation between the deviation from the law of one price and the relative price of non traded to traded goods across countries. In order to gauge the significance of each computed statistics, we resort to bootstrap techniques since the distribution of all variables is unknown. The standard deviation of each statistical property is reported in tiny characters.

INSERT Table 1 Here

The real exchange rate is 4 times more volatile than GDP. This is the so-called "price puzzle" in Backus, Kehoe and Kydland [1995]'s terminology. The relative standard deviation of the relative price of traded good is very similar. Notice that the second component of the real exchange rate displays some variability (with a relative volatility of 0.470). Although the relative standard deviation of this component is rather small compared to that of the deviation from the law of one price, it is statistically different from zero. Furthermore, the correlation between the two sources of real exchange rate fluctuations is quite negative, with a median value of -0.476, and statistically different from zero. By abstracting from non traded goods, Chari *and al.* [2002] neglect the last two columns of table 1: the standard deviation of the relative price of non traded to traded goods as well as the negative correlation between the two components of the real exchange rate. One can then question Chari *and al.* [2002]'s conclusion: are monetary shocks still able to capture *all* dimensions of real exchange rate fluctuations (i.e. the large deviation from the law of one price *as well as* the non constant relative price of non traded to traded goods and the negative correlation between the two elements of the real exchange rate)? This paper provides a first answer to this question.

Persistence

Table 2 reports the autocorrelation of the HP - filtered real exchange rate and its components. As documented by previous studies, the real exchange rate as well as the deviation from the law of one price display very persistent fluctuations (with a median value of 0.83 for the 12 industrialized countries of our sample). The relative price of traded to non traded goods also exhibit a high autocorrelation (with 0.73 as a median value). However, the persistence is slightly lower than that observed for the real exchange rate and the relative price of traded goods. Recall that Chari *and al.* [2002] demonstrate that monetary shocks interacting with sticky prices account for the magnitude of the real exchange rate fluctuations. Nonetheless, they fail to match the high persistence of the real exchange rate. Autocorrelation is then an important statistical property that one has to take into account when studying real exchange rate dynamics.

INSERT Table 2 Here

3 A Model with PTM and Non Traded Goods

In order to assess the impact of monetary shocks on real exchange rate dynamics, we introduce a non tradable sector in Chari *and al.* [2002]'s framework. We propose a simplified version of Chari *and al.* [2002]'s model. In particular, as this economy is characterized by two sectors, nominal rigidities are modelled as resulting from adjustment costs on prices. A staggering-price structure *à la* Chari *and al.* [2002] would make the model less tractable in this framework. Moreover, we abstract from the intermediate sector.

The model consists of two equally-sized countries: country 1 (Home) and country 2 (Foreign) whose sizes are n and $1-n$ respectively. Following Blanchard and Kiyotaki [1987]'s formulation, firms face a monopolistic competition environment. Home produces an array of differentiated tradable goods indexed by the interval $[0, n]$. Foreign's tradables are indexed by the interval $[n, 1]$. In each country, a fraction s of goods cannot be traded freely across countries by consumers (due to high transportation costs or custom regulations). As a result, for these goods, the law of one price does not hold. Hence, a fraction s of firms can "price-to-market" by setting different prices for the local and the foreign markets. Prices for these goods are set in the buyer's currency. The remaining $(1-s)$ fraction of goods can be freely traded by households so the law of one price holds for those goods. Non PTM firms set a unified price across countries in the seller's currency. In addition, each country produces a continuum of differentiated non traded goods indexed by $[0, 1]$.

Households

Preferences are identical across countries. Each country is inhabited by many identical, infinitely living agents. The representative household approach is thus adopted. The lifetime utility of country i agent is given by

$$E_0 = \sum_{t=0}^{\infty} \beta^t U\left(C_{it}^C, \frac{M_{it}}{P_{it}^C}, H_{it}\right) \qquad i = 1, 2$$

where

$$U\left(C_{it}^C, \frac{M_{it}}{P_{it}^C}, L_{it}\right) = \frac{\left(C_{it}^C\right)^{1-\rho}}{1-\rho} + \frac{\gamma_M}{1-\varepsilon}\left(\frac{M_{it}}{P_{it}^C}\right)^{1-\varepsilon} + \gamma_H \ln\left(1 - H_{it}\right) \qquad i = 1, 2$$

C_{it}^C is the consumption index, M_{it} nominal money holdings and P_{it}^C the consumer price index. The time period is normalized to unity. H_{it} denotes the amount of labor supplied by the representative agent to the tradable as well as to the non tradable firms, that is

$$H_{it} = H_{it}^N + H_{it}^T \qquad i = 1, 2$$

with H_{it}^N (respectively H_{it}^T) the working time in the tradable sector (respectively non tradable sector). The bundle of consumption is defined as

$$C_{it}^C = \left[(1-\xi)^{\frac{1}{\theta}} \left(C_{it}^T\right)^{\frac{\theta-1}{\theta}} + \xi^{\frac{1}{\theta}} \left(C_{it}^N\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \qquad i = 1, 2 \tag{1}$$

where C_{it}^T $\left(\text{respectively } C_{it}^N\right)$ is the quantity of tradable (non tradable) consumed by agent i, θ denotes the elasticity of substitution between tradables and non tradables and ξ

the share of non tradable goods in the consumption basket. Consumption bundles in terms of tradables and non tradables are defined as

$$C_{it}^{N} = \left[\int_0^1 c_{it}^{N}(z)^{\frac{\eta-1}{\eta}} dz\right]^{\frac{\eta}{\eta-1}} \qquad i = 1,2 \tag{2}$$

$$C_{it}^{T} = \left[\int_0^1 c_{it}^{T}(z)^{\frac{\eta-1}{\eta}} dz\right]^{\frac{\eta}{\eta-1}} \qquad i = 1,2 \tag{3}$$

with $\eta > 1$ the elasticity of substitution between goods of the same category.

Domestic-currency consumption indexed for the three preceding consumption baskets (1), (2) and (3) are respectively P_{it}^{C}, P_{it}^{N} and P_{it}^{T}. The consumption index for the consumption basket C_{it}^{C} is

$$P_{it}^{C} = \left[(1-\xi)\left(P_{it}^{T}\right)^{1-\theta} + \xi\left(P_{it}^{N}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \qquad i = 1,2 \tag{4}$$

The first element of P_{it}^{C} is the price index for non tradables, that is

$$P_{it}^{N} = \left[\int_0^1 p_{it}^{N}(z)^{1-\eta} dz\right]^{\frac{1}{1-\eta}} \qquad i = 1,2$$

The price of goods produced in the domestic (foreign) country is subscripted with a 1 (with a 2). When prices are set by a home (foreign) non PTM firm, the price $\tilde{p}_{1t}$ ($\tilde{p}_{2t}$) is labelled in units of domestic (foreign) currency. The good is sold on the other market at the price $\frac{\tilde{p}_{1t}}{e_t}$ ($e_t \tilde{p}_{2t}$) where e_t is the nominal exchange rate between Home and Foreign monies (One unit of foreign currency is worth e_t units of home currency so that an increase in e_t is a depreciation of country 1 currency). In contrast, a Home PTM firm chooses a price p_{1t} for the local market in units of the domestic currency and another price p_{1t}^{*} in foreign currency for goods sold in the foreign country. Country 2 PTM firms do the same. The price index for tradable consumption C_{it}^T is then

$$P_{1t}^T = \left[\int_0^{ns} p_{1t}(z)^{1-\eta} dz + \int_{ns}^{n} \tilde{p}_{1t}(z)^{1-\eta} dz + \int_n^{n+(1-n)s} p_{2t}^*(z)^{1-\eta} dz + \int_{n+(1-n)s}^{1} \left(e_t \tilde{p}_{2t}(z)\right)^{1-\eta} dz \right]^{\frac{1}{1-\eta}}$$

$$P_{2t}^T = \left[\int_0^{ns} p_{1t}^*(z)^{1-\eta} dz + \int_{ns}^{n} \left(\frac{\tilde{p}_{1t}(z)}{e_t} \right)^{1-\eta} dz + \int_n^{n+(1-n)s} p_{2t}(z)^{1-\eta} dz + \int_{n+(1-n)s}^{1} \tilde{p}_{2t}(z)^{1-\eta} dz \right]^{\frac{1}{1-\eta}}$$

Country i household accumulates the stock of capital and rents it to local firms. The stock of capital evolves as

$$K_{it+1}^C = (1-\delta) K_{it}^C + I_{it}^C \qquad i = 1, 2$$

where $\delta \in]0, 1[$ denotes the rate of depreciation and I_{it}^C the amount of investment. I_{it}^C has the same structure as the consumption index

$$I_{it}^C = \left[(1-\xi)^{\frac{1}{\theta}} \left(I_{it}^T\right)^{\frac{\theta-1}{\theta}} + \xi^{\frac{1}{\theta}} \left(I_{it}^N\right)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \qquad i = 1, 2$$

with

$$I_{it}^T = \left[\int_0^1 i_{it}^T(z)^{\frac{\eta-1}{\eta}} dz \right]^{\frac{\eta}{\eta-1}} \qquad i = 1, 2$$

$$I_{it}^N = \left[\int_0^1 i_{it}^N(z)^{\frac{\eta-1}{\eta}} dz \right]^{\frac{\eta}{\eta-1}} \qquad i = 1, 2$$

Capital is free to move across countries but capital accumulation is submitted to adjustment costs that are paid in terms of goods

$$
\begin{aligned}
CI_{it}^{C} &= \frac{\phi}{2}\left(K_{it+1}^{C}-K_{it}^{C}\right)^{2} \qquad \text{with } \phi>0 \\
CI_{it}^{C} &= \left[(1-\xi)^{\frac{1}{\theta}}\left(CI_{it}^{T}\right)^{\frac{\theta-1}{\theta}}+\xi^{\frac{1}{\theta}}\left(CI_{it}^{N}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}
\end{aligned}
$$

In the following paragraphs, the Home household's program is presented. The foreign household's problem can be inferred by symmetry. Markets are complete. For each state, there is a contingent claim $B_i(s_{t+1})$ bought by country i household at period t that yields one unit of *domestic currency* if, at period $t+1$, the realized state is s_{t+1}. The home consumer chooses consumption, labor, nominal balances, investment and one-period bonds so as to maximize her lifetime utility subject to the following budget constraint

$$
\begin{aligned}
&P_{1t}^{C}\left(C_{1t}^{C}+K_{1t+1}^{C}+CI_{1t}^{C}\right)+M_{1t+1}+\int\chi(s_{t+1})B_1(s_{t+1})ds_{t+1} \\
&\leq M_{1t}+N_{1t}+P_{1t}^{C}w_{1t}H_{1t}+B_1\left(s_t\right)+\int_0^n\Pi_{1t}(z)dz+P_{1t}^{C}(1-\delta+z_{1t})K_{1t}^{C}+\int_0^1\Pi_t^N(z)dz
\end{aligned} \tag{5}
$$

The household enters the period with an initial money stock M_{1t} and receives money transfers from the government N_{1t}. As the owner of the local firms, he gets the profits from firms in both sectors $\int_0^n\Pi_{1t}(z)dz+\int_0^1\Pi_t^N(z)dz$. The other components of the domestic household's income consist of wages paid in terms of composite goods ($P_{1t}^{C}w_{1t}H_{1t}$) and capital income $(P^C_{1t} z_{1t} K^C_{1t})$. The optimization program of country 1 agent is

$$V\left[M_{1t}, B_1(s_t), K_{1t}\right] = Max \left\{ \begin{array}{c} U\left(C_{1t}, \frac{M_{1t}}{P^C_{1t}}, L_{1t}\right) \\ +\beta \int V\left[M_{1t+1}, B_1(s_{t+1}), K_{1t+1}\right] f(s_{t+1}, s_t) ds_{t+1} \end{array} \right\}$$

subject to (5)

Let $f(s_{t+1}, s_t)$ be the density function that describes how s_t becomes s_{t+1}.

Firms

Technologies are identical across countries and across firms. The constant-return-to-scale production function requires capital and labor such that

$$F\left(k_{it}(z), h_{it}(z)\right) = k_{it}(z)^{\alpha_j} h_{it}(z)^{1-\alpha_j} \qquad i = 1, 2 \text{ and } j = N, T$$

with $\alpha_j \in \left]0, 1\right[$. Let $y_{it}(z)$ be the quantity of good z produced by a non PTM firm in country i while $x_{it}(z)$ ($x^*_{it}(z)$) is the quantity produced by a non PTM firm in country i and sold in country i (in the other country). $y^N_{it}(z)$ denotes the production of a non tradable goods z. More precisely,

$$F\left(\tilde{k}_{it}(z), \tilde{h}_{it}(z)\right) = y_{it}(z) \quad \text{if } z \text{ is a tradable PTM good}$$

$$F\left(k_{it}(z), h_{it}(z)\right) = x_{it}(z) + x^*_{it}(z) \quad \text{if } z \text{ is a tradable non PTM good}$$

$$F\left(k^N_{it}(z), h^N_{it}(z)\right) = y^N_{it}(z) \quad \text{if } z \text{ is a non tradable good}$$

As the relative degree of nominal rigidities across sectors turns out to be a key ingredient in this framework, we chose to model price rigidities as resulting from price adjustments costs. The sensitivity analysis is then more tractable with this specification than with the price-staggering used by Chari *and al.* [2002]. Price adjustments costs are quadratic (Hairault and Portier [1993], Ireland [1997]):

$$\tilde{C}P_{it}^{C} = \frac{\Phi^T}{2}\left(\frac{\tilde{p}_{it}(z)}{\tilde{p}_{it-1}(z)} - \bar{\pi}\right)^2 \quad \text{if } z \text{ is a tradable non PTM good}$$
$$CP_{it}^{C} = \frac{\Phi^T}{2}\left(\frac{p_{it}(z)}{p_{it-1}(z)} - \bar{\pi}\right)^2 \quad \text{if } z \text{ is a tradable PTM good}$$
$$CP_{it}^{*C} = \frac{\Phi^T}{2}\left(\frac{p^*_{it}(z)}{p^*_{it-1}(z)} - \bar{\pi}\right)^2 \quad \text{if } z \text{ is a tradable PTM good}$$
$$CP_{it}^{NC} = \frac{\Phi^N}{2}\left(\frac{p^N_{it}(z)}{p^N_{it-1}(z)} - \bar{\pi}\right)^2 \quad \text{if } z \text{ is a non tradable good}$$

Adjustment costs are quadratic and null at the steady state. $\bar{\pi}$ is the price growth rate at the steady state. Adjustment costs are paid by firms in terms of composite goods.

Tradables. This section presents the program of a non PTM firm in country 1. $\tilde{h}_{1t}(z)$ and $\tilde{k}_{1t}(z)$ are demands for labor and capital from a country 1 non PTM firm whose program is

$$V\left[\tilde{p}_{1t-1}(z)\right] = Max \left\{ \begin{array}{c} \tilde{p}_{1t}(z)y_{1t}(z) - P_{1t}^C\left(w_{1t}\tilde{h}_{1t}(z) + z_{1t}\tilde{k}_{1t}(z)\right) \\ -P_{1t}^C\frac{\Phi^T}{2}\left(\frac{\tilde{p}_{1t}(z)}{\tilde{p}_{1t-1}(z)} - \bar{\pi}\right)^2 + \int \chi(s_{t+1})V\left[\tilde{p}_{1t}(z)\right]ds_{t+1} \end{array} \right\}$$

$$\text{subject to} \left\{ \begin{array}{l} y_{1t}(z) \leq y_{1t}^d(z) \\ y_{1t}(z) \leq F\left(\tilde{k}_{1t}(z), \tilde{h}_{1t}(z)\right) \end{array} \right.$$

Demand for good z is given by

$$y_{1t}^{d}(z)=\sum_{j=1}^{2}\left(c_{jt}^{T}(z)+i_{jt}^{T}(z)+ci_{jt}^{T}(z)+\tilde{c}p_{jt}^{T}(z)+cp_{jt}^{T}(z)+cp_{jt}^{T*}(z)+cp_{jt}^{TN}(z)\right)$$
$$y_{1t}^{d}(z)=\left[\frac{\tilde{p}_{1t}(z)}{P_{1t}^{T}}\right]^{-\eta}D_{1t}^{T}+\left[\frac{\tilde{p}_{1t}(z)}{e_tP_{2t}^{T}}\right]^{-\eta}D_{2t}^{T}$$

where $D_{it}^{T}=C_{it}^{T}+I_{it}^{T}+CI_{it}^{T}+\tilde{C}P_{it}^{T}+CP_{it}^{T}+CP_{it}^{*T}$ is the total demand for tradable consumption basket in country i.

A Country 1 PTM firm chooses its demands for labor $h_{1t}(z)$ and capital $k_{1t}(z)$, output levels $x_{1t}(z)$ and $x_{1t}^{*}(z)$ as well as its prices $p_{1t}(z)$ in domestic currency and $p_{1t}^{*}(z)$ in foreign currency such that

$$V\left[p_{1t-1}(z),p_{1t-1}^{*}(z)\right]=$$
$$Max\left\{\begin{array}{c} p_{1t}(z)x_{1t}(z)+e_tp_{1t}^{*}(z)x_{1t}^{*}(z)-P_{1t}^{C}\left(w_{1t}h_{1t}(z)+z_{1t}k_{1t}(z)\right)\\ -P_{1t}^{C}\frac{\Phi^{T}}{2}\left(\frac{p_{1t}(z)}{p_{1t-1}(z)}-\bar{\pi}\right)^{2}-P_{1t}^{C}\frac{\Phi^{T}}{2}\left(\frac{p_{1t}^{*}(z)}{p_{1t-1}^{*}(z)}-\bar{\pi}\right)^{2}\\ +\int\chi(s_{t+1})V\left[p_{1t}(z),p_{1t}^{*}(z)\right]ds_{t+1}\end{array}\right\}$$

$$\text{subject to}\left\{\begin{array}{l} x_{1t}(z)\leq x_{1t}^{d}(z)\\ x_{1t}^{*}(z)\leq x_{1t}^{d*}(z)\\ x_{1t}(z)+x_{1t}^{*}(z)\leq F\left(k_{1t}(z),h_{1t}(z)\right)\end{array}\right.$$

The PTM firm faces two kinds of demand: the demand from the home market $x_{1t}^{d}(z)$ and the demand from the foreign market $x_{1t}^{d*}(z)$

$$x_{1t}^{d}(z) = \left[\frac{p_{1t}(z)}{P_{1t}^{T}}\right]^{-\eta} D_{1t}^{T}$$
$$x_{1t}^{d*}(z) = \left[\frac{p_{1t}^{*}(z)}{P_{2t}^{T}}\right]^{-\eta} D_{2t}^{T}$$

Non Tradables. The value function of a non tradable firm in country i is

$$V\left[p_{it-1}^{N}(z)\right] = Max \left\{ \begin{array}{c} p_{it}^{N}(z)y_{it}^{N}(z) - P_{it}^{C}\left(w_{it}h_{it}^{N}(z) + z_{it}k_{it}^{N}(z)\right) \\ -P_{it}^{C}\frac{\Phi^{N}}{2}\left(\frac{p_{it}^{N}(z)}{p_{it-1}^{N}(z)} - \bar{\pi}\right)^{2} + \int \chi(s_{t+1})V\left[p_{it}^{N}(z)\right] ds_{t+1} \end{array} \right\}$$

$$\text{subject to} \left\{ \begin{array}{l} y_{it}^{N}(z) \leq y_{it}^{Nd}(z) \\ y_{it}^{N}(z) \leq F\left(k_{it}^{N}(z), h_{it}^{N}(z)\right) \end{array} \right.$$

The demand for non tradables consists of local consumption, investment as well as adjustment costs on capital and prices

$$y_{it}^{Nd}(z) = c_{it}^{N}(z) + i_{it}^{N}(z) + ci_{it}^{N}(z) + \tilde{c}p_{it}^{N}(z) + cp_{it}^{N}(z) + cp_{it}^{N*}(z) + cp_{it}^{NN}(z)$$
$$y_{it}^{Nd}(z) = \left[\frac{p_{it}^{N}(z)}{P_{it}^{N}}\right]^{-\eta}\left(C_{it}^{N} + I_{it}^{N} + CI_{it}^{N} + C\tilde{P}_{it}^{N} + CP_{it}^{N} + CP_{it}^{*N} + CP_{it}^{NN}\right)$$

The Government and Symmetric Equilibrium

Each period, the central bank has a balanced budget. The increase in the money supply

N_{it} is given to the local household.

$$M_{it+1} - M_{it} = N_{it} \qquad i = 1, 2$$

The growth factor of the money supply is g_{it} such that $M_{it+1} = g_{it} M_{it} \qquad i = 1, 2$. The disturbances to the money growth rate are assumed to follow an AR(1) process

$$\begin{pmatrix} \log(g_{1t}) \\ \log(g_{2t}) \end{pmatrix} = \begin{pmatrix} \rho_{g1} & \rho_{12}^{g} \\ \rho_{12}^{g} & \rho_{g2} \end{pmatrix} \begin{pmatrix} \log(g_{1t-1}) \\ \log(g_{2t-1}) \end{pmatrix} + \begin{pmatrix} 1-\rho_{g1} & -\rho_{12}^{g} \\ -\rho_{12}^{g} & 1-\rho_{g2} \end{pmatrix} \begin{pmatrix} \log(g_{1}) \\ \log(g_{2}) \end{pmatrix} + \begin{pmatrix} 1 & \psi_m \\ \psi_m & 1 \end{pmatrix} \begin{pmatrix} \varepsilon_{1t}^{g} \\ \varepsilon_{2t}^{g} \end{pmatrix}$$

In the symmetric equilibrium, firms of the same category face the same demand, their productions and their demands for labor and capital are similar. The labor market equilibrium thus becomes

$$H_{1t} = nsh_{1t} + n(1-s)\tilde{h}_{1t} + h_{1t}^{N}$$

$$H_{2t} = (1-n)sh_{2t} + (1-n)(1-s)\tilde{h}_{2t} + h_{2t}^{N}$$

while the capital market equilibrium is given by

$$K_{1t} = nsk_{1t} + n(1-s)\tilde{k}_{1t} + k_{1t}^{N}$$

$$K_{2t} = (1-n)sk_{2t} + (1-n)(1-s)\tilde{k}_{2t} + k_{2t}^{N}$$

Demand equals supply on the financial market, that is

$$B_1(s_t) + B_2(s_t) = 0 \quad \forall s_t$$

Symmetry among non tradable firms implies

$$P_{it}^N = p_{it}^N \qquad i = 1, 2 \tag{6}$$

whereas price indexes for the tradable consumption basket becomes

$$P_{1t}^T = \left[nsp_{1t}^{1-\eta} + n(1-s)\tilde{p}_{1t}^{1-\eta} + (1-n)sp_{2t}^{*1-\eta} + (1-n)(1-s)\left(e_t\tilde{p}_{2t}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{7}$$

$$P_{2t}^T = \left[ns\left(p_{1t}^*\right)^{1-\eta} + n(1-s)\left(\frac{\tilde{p}_{1t}}{e_t}\right)^{1-\eta} + (1-n)sp_{2t}^{1-\eta} + (1-n)(1-s)\tilde{p}_{2t}^{1-\eta}\right]^{\frac{1}{1-\eta}} \tag{8}$$

Output of each non traded good must equal consumption, investment as well as price and capital adjustment costs within the country

$$y_{it}^N = C_{it}^N + I_{it}^N + CI_{it}^N + \tilde{C}P_{it}^N + CP_{it}^N + CP_{it}^{*N} + CP_{it}^{NN} \qquad i = 1, 2$$

The world budget constraint stems from the households' budget constraints, the governments' budget constraints, the equilibrium on the bond market and the profits of firms.

$$D_{1t}^C + \Gamma_t D_{2t}^C = ns\left(\frac{p_{1t}x_{1t} + e_t p_{1t}^* x_{1t}^*}{P_{1t}^C}\right) + n(1-s)\frac{\tilde{p}_{1t}}{P_{1t}^C}y_{1t} + p_{1t}^N y_{1t}^N +$$
$$(1-n)s\Gamma_t\left(\frac{p_{2t}x_{2t} + \frac{p_{2t}^*}{e_t}x_{2t}^*}{P_{2t}^C}\right) + (1-n)(1-s)\Gamma_t\frac{\tilde{p}_{2t}}{P_{2t}^C}y_{2t} + \Gamma_t p_{2t}^N y_{2t}^N$$
$$+ (1-n)(1-s)\Gamma_t\frac{\tilde{p}_{2t}}{P_{2t}^C}y_{2t}$$

Calibration

The benchmark calibration follows Chari *and al.* [2002]. Parameter values related to the non tradable sector are taken from Stockman and Tesar [1995].

The following parameter values are based on Chari *and al.* [2002]. We consider two equally-sized countries such that $n = 0.5$. At the steady state, initial wealth is equally shared. γ_H is chosen such that working time is 25%. The discount factor β is 0.99, which corresponds to an annual real return to capital of 4% steady state quarterly interest rate. The depreciation of capital is $\delta = 0.021$ per quarter. All firms in the tradable sector resort to price discrimination ($s = 1$). The average mark-up rate μ is set to 0.11.

According to Chari *and al.* [2002]'s estimates, the persistence of the monetary shock amounts to $\rho_g = 0.57$. The standard deviation of the shocks is chosen such that the model with non tradables ($\xi = 0$ and $s = 1$) yields the same volatility for output as in the US data. Similarly, the cross-correlation of these shocks is set so as to produce a cross- correlation for output that is similar to that in the data. The contemporaneous correlation between ε_{1t}^g and

ε_{2t}^{g} equals 0.5.

A second set of parameter values are slightly different from Chari *and al.* [2002]'s calibration since we consider a simplified version of their model. Adjustment costs on investment ϕ are chosen to reproduce the relative volatility of investment to output. Chari *and al.* [2002] set the curvature parameter ρ to 6. We calibrate the risk aversion parameter to a more plausible value ($\rho = 0.75$). Since consumption and real money holdings have the same intertemporal elasticity of substitution in Chari *and al.* [2002]'s model, $\varepsilon = \rho = 0.75$. Following Hairault and Portier [1993], real money balance is set to 10% of steady state output. Φ^T and Φ^N determine the magnitude of price adjustment costs whose steady state value is zero. As a result, these parameters cannot be estimated. Φ^T and Φ^N are set such that the model replicates the standard deviation of inflation on consumer price index. In the benchmark calibration, nominal rigidities do not differ across sectors ($\Phi^T = \Phi^N$). Table 4 reports the real adjustment cost of an increase of 0.01% of the price growth rate as a percentage of the steady state output ($\frac{CA(0.01)}{Y}$).

The parameter values corresponding to the tradable and non tradable sectors are taken from Stockman and Tesar [1995]. They find a low elasticity of substitution between tradables and non tradables ($\theta = 0.44$). The share of non traded-good consumption in total consumer's consumption bundle is $\xi = 0.5$. The labor share in traded-good industry (respectively non traded-good industry) is $1-\alpha^T = 0.61$ (respectively $1-\alpha^N = 0.56$). Tables 3 to 5 summarize the calibration.

INSERT tables 3, 4 and 5

4 The Propagation Mechanisms of Monetary Shocks

The Components of the Real Exchange Rate

In this section, we identify the elements that drive real exchange rate dynamics in response to monetary shocks. Recall that, in the model, the real exchange rate is given by

$$\Gamma_t = \frac{e_t P_{2t}^C}{P_{1t}^C}$$

Using the steady state values of the relative prices as well as equations (4), (6), (7) and (8), we get

$$\hat{\Gamma}_t = \left(\hat{e}_t + \hat{P}_{2t}^T - \hat{P}_{1t}^T\right) + \xi\left(\hat{P}_{2t}^N - \hat{P}_{2t}^T + \hat{P}_{1t}^T - \hat{P}_{1t}^N\right) \tag{9}$$

where hat variables denote percentage deviation from steady state. Let

$$\hat{\Gamma}_t^T = \hat{e}_t + \hat{P}_{2t}^T - \hat{P}_{1t}^T \tag{10}$$

and

$$\hat{\Gamma}_t^N = \xi\left(\hat{P}_{2t}^N - \hat{P}_{2t}^T + \hat{P}_{1t}^T - \hat{P}_{1t}^N\right) \tag{11}$$

Changes in the real exchange rate become

$$\hat{\Gamma}_t = \hat{\Gamma}_t^T + \hat{\Gamma}_t^N \tag{12}$$

Movements in the real exchange rate thus arise from two sources: deviation from the law of one price for traded goods (captured by $\hat{\Gamma}_t^T$) and movements in the relative price of non traded to traded goods across countries ($\hat{\Gamma}_t^N$). Obviously, changes in the first component $\hat{\Gamma}_t^T$ stem from the PTM behavior as underlined by Chari *and al.* [2002]. Indeed, with no PTM in the economy ($s = 0$), the law of one price holds for all traded goods, thus $\hat{\Gamma}_t^T$ always equals zero. The increase in the share of PTM firms in the economy results in larger departure from the law of one price, thus driving up the volatility of the real exchange rate. Hence, hereafter, we will refer to the relative price of traded goods, $\hat{\Gamma}_t^T$, as the PTM component of the real exchange rate. Hau [2000] focuses on the relative price of non traded to traded good across countries, $\hat{\Gamma}_t^N$, that denotes the non PTM element of the real exchange rate.

The literature investigates in separate frameworks the impact of the PTM and the non PTM components on real exchange rate dynamics. Is it possible to account for all dimensions of real exchange rate dynamics by adding the two mechanisms in the same model? The next section sheds light on this issue.

Real Exchange Rate Dynamics After a Monetary Shock

We consider a 1% increase in Home monetary innovation. We only comment on the response of the real exchange rate and that of its components for the benchmark calibration, in order to identify the potential double-sided propagation of the monetary shocks. Figure 1 reports responses computed for $\xi = 0$ (Chari *and al.* [2002] case), $\xi = 0.5$ (benchmark calibration). We are then able to assess the impact of the introduction of non tradables in the economy.

INSERT Figure 1 Here

Chari *and al.* [2002] abstract from the presence of non traded goods ($\xi = 0$) such that real exchange rate changes stem only from the deviation from the law of one price (Γ^T).

For the benchmark calibration, the monetary shock actually affects the *two* sources of real exchange rate: the deviation from the law of one price *as well as* the relative price across sectors. Notice also that while the relative price of traded goods depreciates, the relative price of non traded to traded goods appreciates. This negative correlation between the two elements of the real exchange rate is consistent with the features found in the data.

The mechanisms that account for this double propagation of the monetary shock are straightforward. As can be seen from equations (10) and (11), the effects of the Home monetary shock on the real exchange rate depend on the evolution of relative prices across countries and across sectors. In this framework, prices respond to changes in the demand for goods. In particular, in order to escape the persistent inflation, the Home consumer invests more. This increase in investment induces an expansion in the domestic aggregate demand that consists of domestic goods (whether tradable or not) as well as Foreign tradable goods. The response of the prices of tradable and non tradable goods, thus the response of the real exchange rate, is driven by this change in the demand for each category of good.

As in Hau [2000], as ξ the share of non traded goods increases in the consumption basket, the demand falls more on this category of goods, which entails a larger response of the price of non traded goods in country 1. As can be seen on equation (11), this induces a more negative response of the relative price of non traded to traded goods across countries.

In more closed economies (with higher ξ), the response of the deviation from the law of one price is larger. Indeed, when ξ goes up, the expansion in the demand falls mainly on non tradable goods. The inflation in the Home tradable sector ($\hat{P}_1^T$) then decreases with large values of ξ (equation 10). By neglecting non tradeables, Chari *and al.* [2002] ignored this impact of the size of the non tradable sector on the PTM component.

Finally, notice that, for the benchmark calibration ($\xi = 0.5$), the real exchange rate exhibits more persistent fluctuations than in Chari *and al.* [2002]'s framework ($\xi = 0$).

In a nutshell, the monetary shock affects *both* components of the real exchange rate. The PTM behavior implies movements in the relative price of traded goods. In addition, the relative price of non traded to traded goods in each country responds to changes in demands. It is noticeable that the *two* components of the real exchange rate produce *opposite* effects on $\hat{\Gamma}_t$, which is consistent with the stylized facts documented in section 2. For the benchmark calibration, the PTM effect gets the upper hand so that the real exchange rate depreciates following the Home monetary shock. Does the magnitude of the responses of the two sources of real exchange rate fluctuations match the standard deviations found in data? The next section provides quantitative predictions of the model.

Quantitative Findings

We carry out simulations based on independent draws of monetary shocks in both countries. The averages over 300 simulations are reported below.

<u>Volatility</u>. Table 6 reports the standard deviation of the real exchange rate relative to that of output, $\frac{\sigma_\Gamma}{\sigma_y}$, as well as the volatility of each of its component (Γ^T and Γ^N) for the benchmark calibration. The volatilities of Γ^T and Γ^N are divided by that of real exchange rate. We

also report the correlation between the PTM component and the non PTM component ($\text{Corr}\big(\Gamma^T, \Gamma^N\big)$).

INSERT Table 6 Here

First, the model does not quite match the relative standard deviation of the real exchange rate. The real exchange rate displays fluctuations that are 2.57 times more volatile than output, which is below the ratio found in data. However in this paper we rather focus on the interplay between the real exchange rate components. This inner dynamics is summarized by the relative standard deviation of each of the real exchange rate elements as well as the negative correlation between both sources of real exchange rate fluctuations.

The model does better along these dimensions. First, the real exchange rate and the relative price of tradeables exhibit quite similar standard deviations. Moreover, the model generates fluctuations in the relative price of non traded to traded goods across countries whose standard deviation is smaller than that of the PTM component. Finally, the model predicts a negative correlation between the two sources of real exchange rate fluctuations. These three features are consistent with the stylized facts documented in section 2.

However, the level of the statistics is not quite right: the relative price of non tradeables exhibits a larger volatility than in the data. Besides, the correlation between the two components of the real exchange rate is too negative to be consistent with the observed statistics. The benchmark calibration for ξ as well as the symmetric degree of price stickiness across sectors might be responsible for these flaws. Besides, alternative realistic values for the degree of openness might improve the model's predictions. Section 5 addresses this issue.

Persistence. Chari *and al.* [2002]'s model fails to explain the real exchange rate autocorrelation. In their model, the real exchange rate displays persistence (0.63 in their benchmark economy), but somewhat less than in the data (0.83 in their data). Chari *and al.* [2002] solve the price puzzle without accounting for the real exchange rate autocorrelation. Table 7 shows that Chari *and al.* [2002]'s model with non traded goods actually matches the real exchange rate persistence.

For the benchmark calibration, the model accounts for the autocorrelation of the real exchange rate as well as that of each of its components (table 7). The relative price of non traded to traded goods displays slightly more persistent fluctuations (0.80) than in the data (0.73). However, this level of persistence is consistent with the autocorrelations found in France (0.778), Belgium (0.787), Japan (0.770) or Germany (0.780) (table 2). As far as persistence is concerned, our model does better than Chari *and al.* [2002] who fail to account for the high exchange rate autocorrelation.

INSERT Table 2 Here

The mechanisms behind this result are mentioned in section 3. The two sources of real exchange rate fluctuations exhibit more persistent fluctuations as the share of non traded goods increases.

5 Sensitivity Analysis

The decomposition of the sources of real exchange rate fluctuations (equation (9)) shows that the real exchange rate response to monetary shocks depends on 3 key parameters: the share of pricing-to-market, the share of non traded goods in the economy as well as the degree of price rigidity across sectors. This section examines the model's predictions for alternative values of these parameters. We will focus only on relative volatilities since the model does not quite match these statistics.

Sensitivity to the Degree of PTM

So as to gauge the impact of pricing-to-market, this section investigates the model's predictions for alternative calibrations of PTM. The benchmark calibration is such that all firms in the traded good sector price - to - market ($s = 1$). Table 8 summarizes the implied real exchange rate volatility for decreasing degrees of PTM.

INSERT Table 8 Here

The first point which deserves to be mentioned is that the relative volatility of the real exchange rate to output is decreasing with pricing-to-market. The major source of variations in the real exchange rate are due to large deviations from the law of one price. When s goes to zero, the PTM component of the real exchange rate is less and less volatile. It bottoms down at 0 for $s = 0$. For this value the volatility of the real exchange rate is also at its minimum value. It must be stressed that the real exchange rate volatility is dominated by the variations in the relative price component Γ^N only for very low values of s (s lower than 0.1).

This sensitivity analysis allows to confirm that it is essential to take into account a high degree of pricing-to-market in order to explain real exchange rate volatility, the predominant role of deviations from LOP in its volatility and the negative correlation between its two components. Pricing-to-market seems to play a crucial role in the ability of monetary shocks to explain all dimensions of real exchange dynamics.

Sensitivity to the Degree of Openness

Stockman and Tesar [1990] point out that the size of the non tradeable sector varies across countries. This section examines the model's predictions for different calibrations of the share of non traded goods.

Table 9 reports the standard deviation of the real exchange rate relative to that of output, $\frac{\sigma_\Gamma}{\sigma_y}$, as well as that of each of its component (Γ^T and Γ^N) for increasing values of ξ, the size of the non traded goods in the consumption basket. The volatilities of Γ^T and Γ^N are divided by that of real exchange rate. We also report the correlation between the PTM component and the non PTM component.

INSERT Table 9 Here

With $\xi = 0.4$, the real exchange rate as well as the relative price of tradeables exhibit very similar standard deviations. Moreover, the model generates fluctuations in the relative price of non traded to traded goods across countries whose magnitude (0.17) is consistent with data (0.11). Finally, the model predicts a negative correlation between the two sources of real exchange rate fluctuations (-0.58) that fairly matches the data (-0.48).

Notice that, as households consume more non tradeables, the standard deviation of the real exchange rate relative to that of output increases. By abstracting from non traded goods, Chari *and al.* [2002] somewhat under-estimate the ability of their model to account for the price puzzle. Moreover, in more closed economies, the model produces more volatility in the two sources of real exchange rate fluctuations. The higher volatility in the relative price of non traded to traded goods is not surprising. As underlined in section 3, it is consistent with Hau [2000]'s findings. A more interesting result deals with the impact of the share of non tradeables on the standard deviation of departure from the law of one price: as mentioned in section 3, the larger ξ, the higher the variance of the relative price of traded goods.

In a nutshell, the model predicts that monetary shocks alone, interacting with sticky good prices, capture the main dimensions of real exchange rate fluctuations: the real exchange rate as well as the deviation from the law of one price display large fluctuations of the same magnitude. The model accounts for the volatility of the relative price of non traded to traded goods across countries in response to monetary shocks. The magnitude of the fluctuations of this variable is consistent with the stylized facts. Finally, the monetary shocks match the negative correlation between the two sources of real exchange rate fluctuations found in data. In that sense, Chari *and al.* [2002]'s conclusion about the ability of monetary shocks alone to account for real exchange rate dynamics is robust to the introduction of non traded goods.

Sensitivity to the Relative Degree of Nominal Rigidities $(\Phi^N - \Phi^T)$

Quantitative findings reported in table 9 succeed in accounting for the stylized facts with $\xi = 0.4$. However, they are not quite satisfactory for the benchmark calibration ($\xi = 0.5$). Indeed, when households consume half of their basket in non traded goods, the correlation between the two sources of real exchange rate fluctuations is too negative (-0.88) while volatility of the relative price of non traded to traded goods is too high compared to that observed in data (0.40).

Even if Stockman and Tesar [1990]'s estimates about the value of ξ vary across countries, one might prefer to retain a median value of one half. For the benchmark calibration ($\xi = 0.5$), the quantitative predictions of the model could then be improved assuming that price rigidity differs across sector. The data supports this hypothesis since the price index for traded good displays a higher volatility than the price index for non traded goods: the median value for the 12 industrialized countries of our sample amounts to 1.16, which suggests more sluggish prices in the non traded good sector.

Table 10 reports predictions of the model as prices adjust more slowly in the non traded sector (the scale parameter for adjustment costs, Φ^N, increases relative to Φ^T). The first column gives the real adjustment cost of an increase of 0.01% of the price growth rate as a percentage of the steady state output ($\frac{CA(0.01)}{Y}$) in the non traded good sector. Notice that, in spite of the increase in the cost of changing prices, this cost remains small in terms of steady state output.

INSERT Table 10 Here

As prices become more sticky in the non traded sector, the volatility of the price index for traded goods is larger than that for non traded goods. Moreover, since non traded good prices respond less to the monetary shock, the volatility of the relative price of non traded to traded good across countries is reduced, which tends to lower the negative correlation between the two sources of real exchange rate fluctuations.

Lines II and III in table 10 report quantitative predictions that are more consistent with data. The real exchange rate as well as the deviation from the law of one price display volatilities of the same magnitude while fluctuations in the relative price of non traded to traded good exhibit a relative standard deviation (0.23) that matches Canadian data (0.341 / 1.421 = 0.24). Moreover, the correlation between the two components of the real exchange rate (-0.68 on line II and -0.50 on line III) is closer to the median value found in the 12 industrialized countries (-0.48).

6 Conclusion

This paper proposes a two-country general equilibrium model incorporating a tradeable sector with pricing-to-market as well as a non tradeable sector. In that case, real exchange rate fluctuations arise from two sources: changes in the relative price of traded good, that exemplify deviations from the law of one price, and movements in the relative price of traded to non traded goods across countries. Our framework sheds light on the propagation mechanisms through which monetary shocks affect the real exchange rate. More specifically, the two components respond in opposite directions to monetary disturbances, which is consistent with data. Besides, the introduction of non traded goods does not alter the predictive power of monetary shocks because the presence of non traded goods magnifies the response of the deviation from the law of one price.

Our model shows that Chari *and al.* [2002]'s monetary story is robust. Monetary shocks alone capture the volatility of the real exchange rate, the standard deviation of both components as well as the negative comovement between the deviation from the law of one price and the relative price of non traded goods. This conclusion holds for realistic degrees of openness or asymmetric price stickiness across sectors, which is supported by the data.

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Notes

[1]Some of the recent works on the so-called New Open Economy Perspective are presented in Hairault and Sopraseuth [2004a].

APPENDIX

A Data

The quarterly nominal exchange rates are monthly averages from the OECD Main Economic Indicator database. Section 2 utilizes consumer price index data collected by the OECD to construct measures of the traded and non traded good prices for France, Italy, the

Netherlands, Belgium, Canada, Japan, Australia, Norway, Germany, Spain, New Zealand and Switzerland. The data used are quarterly series reflecting the cost to consumers of all items (AI), all goods less food (AGLF), food, (F), services less rent (SLR) and rent (R). All series all seasonally unadjusted. We follow Engel [1999]'s methodology to compute the price indices for the traded and non traded goods. Geometric weights for each of the four components of the all items series are estimated from logarithmic regressions:

$$\Delta(ai - r) = \phi_1 \Delta\left(aglf - r\right) + \phi_2 \Delta\left(f - r\right) + \phi_3 \Delta\left(slr - r\right) + \varepsilon$$

where $\Delta\left(\right)$ denotes the first difference operator and lower case letters logarithms. The weight for rent is computed residually as $\phi_4 = 1 - \phi_1 - \phi_2 - \phi_3$. The price indices for traded and non traded goods are computed in logarithmic form as

$$\begin{aligned} p^T &= \frac{\phi_1}{\phi_1 + \phi_2}\left(aglf\right) + \frac{\phi_2}{\phi_1 + \phi_2}\left(f\right) \\ p^N &= \frac{\phi_3}{\phi_3 + \phi_4}\left(slr\right) + \frac{\phi_4}{\phi_3 + \phi_4}\left(r\right) \end{aligned}$$

The weight for non traded goods, which is used to decompose the real exchange into two components ($\Gamma = \Gamma^T + \Gamma^N$) is computed for each country as $\phi_3 + \phi_4$. For the US, $\phi_3 + \phi_4$ is set to 0.58172, a value given by the Federal Reserve Bank of Saint Louis for the relative importance of services in the US Consumer Price Indexes, city average, December 2000.

	Real exch. rate (1)	Dev. from LOP (2)	Ratio of rel. price of NT to T goods (3)	Correlation between (2) and (3)
France	6.319 (0.56)	6.416 (0.58)	0.585 (0.05)	-0.428 (0.08)
Italy	4.305 (0.45)	4.568 (0.50)	0.476 (0.05)	-0.524 (0.07)
Netherlands	5.373 (0.64)	5.454 (0.65)	0.620 (0.07)	-0.037 (0.09)
Belgium	5.430 (0.49)	5.392 (0.50)	0.765 (0.09)	-0.235 (0.09)
Canada	1.421 (0.13)	1.354 (0.13)	0.341 (0.03)	-0.010 (0.09)
Japan	5.821 (0.63)	5.889 (0.68)	0.577 (0.07)	-0.830 (0.03)
Australia	3.040 (0.36)	3.084 (0.46)	0.455 (0.01)	-0.009 (0.09)
Norway	3.687 (0.40)	3.820 (0.41)	0.449 (0.04)	-0.635 (0.06)
Germany	4.057 (0.46)	4.172 (0.49)	0.453 (0.05)	-0.155 (0.09)
Spain	6.136 (0.54)	6.342 (0.58)	0.254 (0.02)	-0.559 (0.06)
New Zealand	2.524 (0.34)	2.566 (0.33)	0.237 (0.03)	-0.546 (0.06)
Switzerland	3.378 (0.35)	3.513 0.46()	0.328 (0.03)	-0.693 (0.05)
Median	4.229 (0.45)	4.341 (0.49)	0.470 (0.06)	-0.476 (0.05)

Table 1: HP - filtered Quarterly Data (OECD 1971:3-2000:2)

	Real exchange rate	Deviation from LOP	Ratio of rel. price of NT to T goods
	(1)	(2)	(3)
France	0.835 (0.028)	0.844 (0.026)	0.778 (0.036)
Italy	0.828 (0.029)	0.838 (0.027)	0.715 (0.045)
Netherlands	0.823 (0.030)	0.822 (0.030)	0.627 (0.056)
Belgium	0.839 (0.027)	0.834 (0.028)	0.787 (0.035)
Canada	0.874 (0.022)	0.842 (0.027)	0.737 (0.042)
Japan	0.837 0.027()	0.835 (0.028)	0.770 (0.037)
Australia	0.810 (0.031)	0.794 (0.034)	0.724 (0.044)
Norway	0.772 (0.037)	0.792 (0.034)	0.747 (0.041)
Germany	0.826 (0.029)	0.828 (0.029)	0.780 (0.036)
Spain	0.863 (0.023)	0.860 (0.024)	0.729 0.043()
New Zealand	0.876 (0.021)	0.871 (0.022)	0.692 (0.048)
Switzerland	0.819 (0.030)	0.825 (0.029)	0.679 (0.049)
Median	0.831 (0.03)	0.834 (0.02)	0.733 (0.04)

Table 2: Autocorrelation of the Real Exchange Rate and its Components

n	H	β	δ	s	μ	ρ_g	$\text{Corr}(\varepsilon_{1t}^g, \varepsilon_{2t}^g)$
0.5	0.25	0.99	0.021	1	0.11	0.57	0.5

Table 3: Chari, Kehoe and McGrattan [2002]'s Calibration

ϕ	ρ	ε	$\frac{M}{P^C Y}$	$\frac{CA(0.01)}{Y}$
0.5	0.75	0.75	0.1	0.02%

Table 4: Parameter Values

ξ	θ	$1-\alpha^T$	$1-\alpha^N$
0.5	0.44	0.61	0.56

Table 5: Parameter Values: Tradables and Non Tradables

	Relative	Standard	deviation $\frac{\sigma_{\cdot}}{\sigma_{\Gamma}}$		
	real exch. rate $\frac{\sigma_{\Gamma}}{\sigma_{y}}$	real exch. rate Γ	Dev. from LOP Γ^{T}	Rel. price of NT to T goods Γ^{N}	$\mathrm{Corr}\left(\Gamma^{T},\Gamma^{N}\right)$
Model	2.57	1	1.33	0.40	-0.88
Data (Median)	4.23	1	1.03	0.11	-0.48

Table 6: Relative Exchange Rate Volatility. Benchmark Calibration ξ=0.5

	real exchange rate Γ	Dev. from LOP Γ^T	Rel. price of NT to T goods Γ^N
Model	0.79	0.78	0.80
Data (Median)	0.83	0.83	0.73

Table 7: Autocorrelation . Benchmark Calibration ξ=0.5

Share of PTM s	real exch. rate $\frac{\sigma_\Gamma}{\sigma_y}$	Relative Standard deviation $\frac{\sigma_{\cdot}}{\sigma_\Gamma}$ real exch. rate Γ	Dev. from LOP Γ^T	Rel. price of NT to T goods Γ^N	$\text{Corr}\left(\Gamma^T, \Gamma^N\right)$
1	2.55	1	1.33	0.40	-0.88
0.9	2.55	1	1.30	0.36	-0.86
0.8	2.50	1	1.25	0.33	-0.82
0.7	2.39	1	1.19	0.28	-0.75
0.6	2.34	1	1.14	0.24	-0.64
0.5	2.25	1	1.05	0.20	-0.37
0.4	2.17	1	0.95	0.19	0.10
0.3	2.03	1	0.82	0.25	0.60
0.2	1.93	1	0.65	0.38	0.84
0.1	1.71	1	0.39	0.62	0.93
0	1.44	1	0	1	0
Data (Median)	4.23	1	1.02	0.11	-0.48

Table 8: Sensitiveness to PTM

Share of NT goods ξ	real exch. rate $\frac{\sigma_\Gamma}{\sigma_y}$	Relative Standard deviation $\frac{\sigma_\cdot}{\sigma_\Gamma}$: real exch. rate Γ	Dev. from LOP Γ^T	Rel. price of NT to T goods Γ^N	$\text{Corr}\left(\Gamma^T, \Gamma^N\right)$
0	2.09	1	1	0	0
0.1	2.23	1	0.93	0.09	0.53
0.2	2.25	1	0.94	0.11	0.48
0.3	2.37	1	0.98	0.12	0.13
0.4	*2.46*	1	*1.09*	*0.17*	*-0.58*
0.5	2.57	1	1.33	0.39	-0.88
0.6	2.69	1	1.84	0.91	-0.96
Data (Median)	4.23	1	1.02	0.11	-0.48

Table 9: Relative Exchange Rate Volatility. Simulated Data

$\frac{CA(0.01)}{Y}$	Relative price index volatility $\frac{\sigma_{P^T}}{\sigma_{P^N}}$	real exch. rate $\frac{\sigma_\Gamma}{\sigma_y}$	Relative standard dev. $\frac{\sigma_\cdot}{\sigma_\Gamma}$: real exch. rate Γ	Dev.from LOP Γ^T	Rel. price of NT to T goods Γ^N	$\text{Corr}(\Gamma^T, \Gamma^N)$
I. 0.2%	1	2.57	1	1.33	0.40	-0.88
II. *0.3%*	*1.14*	*2.64*	1	*1.15*	*0.26*	*-0.68*
III. *0.4%*	*1.25*	*2.66*	1	*1.09*	*0.23*	*-0.50*
IV. 0.6%	1.47	2.70	1	1.00	0.22	-0.13
Data	1.16	4.23	1	1.02	0.11	-0.48

Table 10: Sensitiveness to Price Stickiness Across Sectors, $\xi = 0.5$

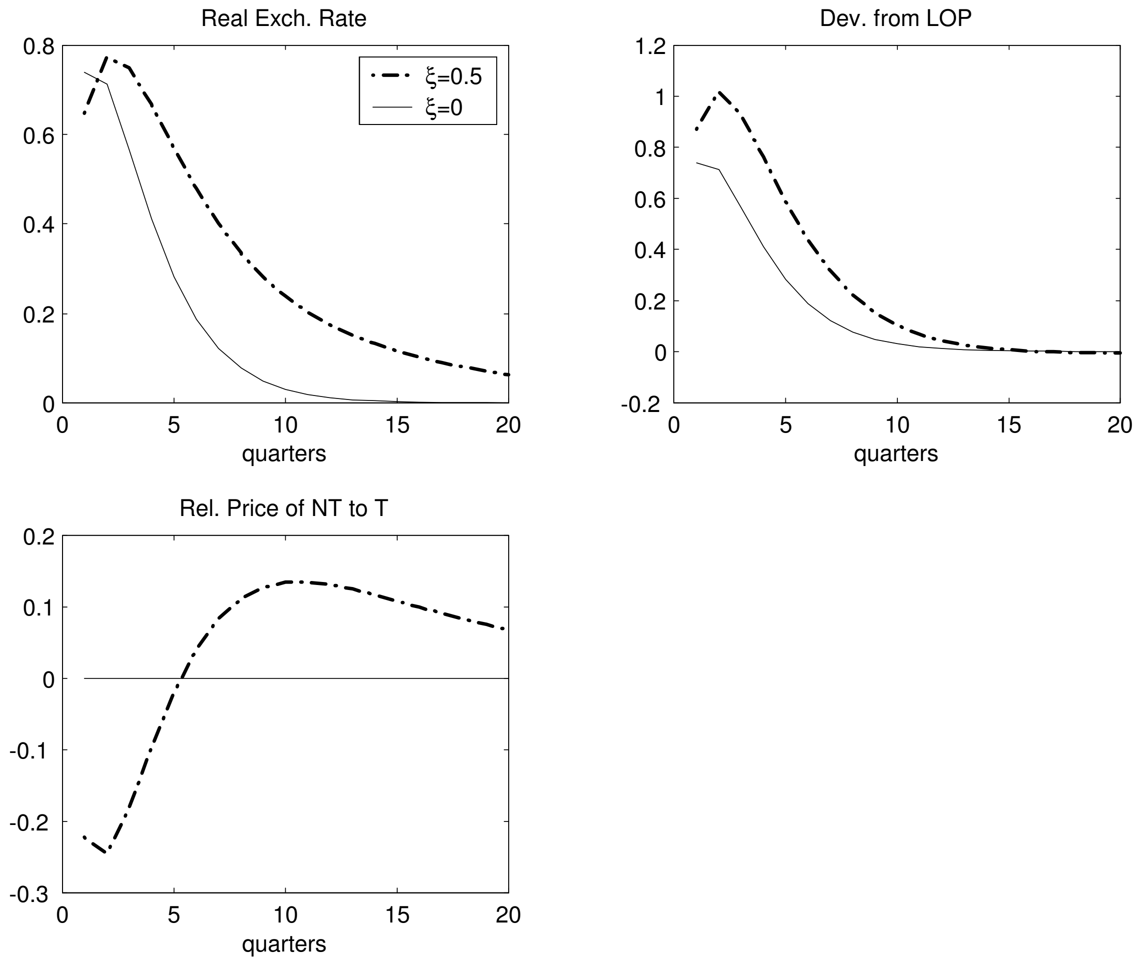

Figure 1: Responses to the Home Monetary Shock: Real Exchange Rate (Γ), Deviation from the Law of One Price (Γ^T), Relative Price of Non Traded to Traded Goods (Γ^N)