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# Pricing-to-market, limited participation and exchange rate dynamics

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**Abstract**

Explaining the wide gap between exchanges rates fluctuations and those of their macroeconomic fundamentals since 1973, remains a challenging task for international macroeconomics. Betts and Devereux [1996. The exchange rate in a model of pricing-to-market. European Economic Review 96, 1007–1021], among others, stress the role of pricing-to-market (PTM). Hairault et al. [2004. Overshooting and the exchange rate disconnect puzzle: a reappraisal. Journal of International Money and Finance 23, 615–643] highlight an alternative explanation based on credit market frictions through the limited participation assumption (LP). The paper investigates the combined role of both types of frictions in a two-country framework. Given PTM and LP, we show that monetary shocks generate amplified exchange rate volatilities. The model hence contributes to a better understanding of the large observed exchange rate fluctuations.


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## 1. Introduction

Since the collapse of the Bretton Woods system in 1973, most OECD countries have experienced floating exchange rate regimes *vis-à-vis* the US Dollar. One of the main international business cycle features of this period is the extremely volatile behavior of nominal and real exchange rates. This is all the more striking as no corresponding changes appeared in the distribution of macroeconomic fundamentals such as outputs, interest rates and money supplies. Table 1 highlights the wide gap between exchange rates and macroeconomic fundamentals. It presents the standard-deviations of the nominal exchange rate ($\sigma_e$), of the nominal exchange rate growth rate ($\sigma_{\Delta e}$, with $\Delta e \equiv \frac{e}{e_{-1}}$), the real exchange rate ($\sigma_\Gamma$), the monetary growth rate ($\sigma_g$),[1] GDP ($\sigma_y$) and the interest rate ($\sigma_R$) for the six G7 countries *vis-à-vis* the United States, based on quarterly series[2] over the period 1971:1–1998:4. Both nominal and real exchange rates are about 10 times more volatile than money supply for the median of the six G7 countries considered, and around 5 times more volatile than output.

Explaining the wide gap between exchange rates and macroeconomic fundamentals since the beginning of the 1970s has long been a challenging task for international macroeconomics. From the empirical side, numerous articles (Clarida and Gali, 1994; Eichenbaum and Evans, 1995; Kim and Roubini, 2000 among others) point out that monetary shocks are an important source of exchange rate fluctuations. Eichenbaum and Evans (1995) thus estimate that monetary innovations account for 40% of the nominal exchange rate variance.

If monetary shocks are one important source of exchange rate movements, one can ask through which transmission channels. A large number of articles consider the interaction between monetary shocks and price stickiness as the most 'popular' story accounting for exchange rates excess volatility. The New Open Economy Macroeconomics framework first developed by Obstfeld and Rogoff (1995), gives economists a new insight into the traditional monetary approach of exchange rates. In a micro-founded intertemporal setting with monopolistic competing firms, the focus is set on the interaction between nominal shocks and price rigidities as an explanation of short-run exchange rate dynamics.

Furthermore, recent developments on disaggregated data analysis suggest that deviations from purchasing power parity (hence, real exchange rate movements)[3] are

[1]Throughout the paper we use the terminology 'growth rate' to refer to gross rate.

[2]Data for GDP, interest rates and exchange rates come from the OECD BSDB database. Series cover the period 1971:1–1998:4 for nominal interest rates and exchange rates for France, Germany, Italy, until 1971:1–1998:3 for the Canadian nominal exchange rate. GDP series stop in 1996:4 for United Kingdom and 1998:4 for Japan. The UK GDP serie goes to 1996:4, the Japanese GDP serie to 1998:4. Consumer prices index series have been used to build the real exchange rates series. The monetary growth factor series were constructed through the M1 monetary aggregate coming from the OECD Main Economic Indicators database. Statistics for the interest rate is based on the nominal interest rate factor. All series are taken in logarithm then filtered according to the Hodrick and Prescott (1997) method.

[3]Recalling that purchasing power parity holds means that the real exchange rate is equal to one or at least constant.

Table 1
Stylized facts

| | $\sigma_e$ (%) | $\sigma_{\Delta e}$ (%) | $\sigma_\Gamma$ (%) | $\sigma_g$ (%) | $\sigma_y$ (%) | $\sigma_R$ (%) |
|---|---|---|---|---|---|---|
| Canada | 2.86 | 1.47 | 2.95 | 0.82 | 1.95 | 1.18 |
| France | 8.50 | 4.48 | 9.13 | 0.75 | 1.17 | 1.45 |
| Germany | 8.36 | 4.71 | 7.99 | 0.90 | 1.93 | 4.75 |
| Italy | 8.56 | 4.51 | 7.73 | 0.97 | 1.67 | 1.77 |
| Japan | 9.20 | 5.06 | 8.97 | 0.80 | 1.72 | 1.58 |
| United Kingdom | 8.08 | 4.62 | 7.74 | 0.59 | 2.18 | 1.80 |
| Mean | 7.59 | 4.14 | 7.41 | 0.81 | 1.77 | 2.02 |
| Median | 8.43 | 4.56 | 7.87 | 0.81 | 1.82 | 1.68 |

mainly attributable to deviations from the law of one price for a large number of tradable goods (Chari et al., 2002; Engel and Rogers, 1996). This suggests that, far from being integrated, these tradable goods markets are rather internationally segmented. One leading explanation relies on the behavior of market-powered firms in a monopolistic setting that price-to-market, i.e. set different prices for different sub-markets or countries (Krugman, 1987). The theoretical literature has therefore been investigating the role of pricing-to-market (hereafter PTM) in nominal and real exchange dynamics (Betts and Devereux, 1996). Chari et al. (2002) quantitatively evaluate the story in a dynamic general equilibrium model with monopolistic competition, price stickiness and PTM. Their results highlight the key role of price rigidity in the buyer's currency in exchange rate movements. Yet, if Chari et al. (2002) open a very promising route, their results are not truly convincing since they have to rely on some unappealing assumptions regards calibration of structural parameters to match the observed exchange rate fluctuations.

An alternative way of accounting for exchange rate dynamics focuses on Dornbusch's (1976) overshooting story. An expansionary monetary shock would generate a persistent fall in the nominal interest rate. As long as uncovered interest rate parity holds (UIP hereafter), this persistent decline in the spread between domestic and foreign interest rates results in a nominal exchange rate overshooting. Hairault et al. (2004) quantitatively evaluate the relevance of Dornbusch's reasoning in a small-open economy model with credit market frictions. Such frictions are namely based on the limited participation assumption (LP hereafter) first developed in a closed-economy setting by Fuerst (1992), Lucas (1990) and Christiano (1991) so as to reproduce the persistent fall in the nominal interest rate following a monetary expansion. In Hairault et al. (2004) setting, a positive monetary shock generates a nominal exchange rate overshooting which is shown to substantially contribute to its volatility. But their results remain limited to the nominal exchange rate analysis in a small-open economy setting where purchasing power parity holds.

The paper is based on the intuition that both types of frictions, on the goods market (PTM and price stickiness) and on the credit market (LP) complement each other, in particular regards exchange rate movements. A similar conclusion has been reached in a closed-economy setting. Christiano et al. (1997) yield the conclusion that any model with one type of friction (sticky prices or LP) cannot reproduce for the basic stylized facts of a money shock and stress the combined role of sticky prices and LP. A large number of papers confirm the potential of combining both type of frictions in a closed-economy setting (Hendry and Zhang, 2001; Papadopoulou, 2004 among others), which opens the route for such an analysis in an open-economy setting.

In the paper, we combine credit market frictions and price rigidity in the buyer's currency in a two-country general equilibrium model. We evaluate the relevance of introducing credit market frictions in the PTM model, primarily regards exchange rates cyclical properties. Furthermore, we pay a particular attention to the impulse function responses implied by each model in accordance with Christiano et al.'s (1997) view that any monetary model has to be consistent with the broad empirical effects of money shocks. While the PTM model badly performs on that criteria, we show that the model based on both types of frictions correctly accounts for the broad effects of such shocks identified in the data, in particular regards exchange rate dynamics.

The paper features UIP as a key ingredient of the analysis. Many papers in the VAR literature have studied its empirical relevancy. In a seminal contribution, Eichenbaum and Evans (1995) obtain results that question the validity of UIP based on evidence on delayed overshooting.[4] Yet things do not appear so clear-cut as other papers have found evidence more in line with Dornbusch's predictions (Faust and Rogers, 2000; Kim and Roubini, 2000 among others). Additionally, evidence of delayed overshooting should not necessarily be considered as an evidence of a failure of UIP, as pointed out by Mac Callum (1994) (among others). As a whole, empirical evidence is rather mixed on whether or not delayed overshooting is a relevant phenomena that would cast doubt on the validity of UIP. This certainly calls for further research in that area. Leaving apart the question of whether delayed or not, we argue here that it is important to understand why the nominal exchange rate overshoots following monetary shocks. In a setting where UIP holds, plausible models of the monetary transmission mechanism should be consistent with the following facts: a positive home monetary shock is found to generate a negative domestic interest rate response (the liquidity effect), a persistent negative interest rate differential between domestic and foreign countries, as well as a nominal exchange rate overshooting. In line with Christiano et al.'s (1997) view, we pay attention to the ability of our model to be consistent with the broad empirical effects of money shocks, namely regards exchange rates in an international setting.

The paper is organized as follows. Section 2 presents the building blocks of a two-country intertemporal general equilibrium model with monopolistic competition, price stickiness and PTM. Our analysis confirms that nominal price rigidity in the local variety acts as a key transmission channel of nominal shocks to exchange rates. Yet quantitative results are disappointing. First, a domestic monetary shock implies

[4] They get that, in response to a tighter US monetary policy, positive interest differentials are associated with *persistent* appreciation of the US dollar. The US dollar exhibits a delayed overshooting pattern of 2–3 years *vis-à-vis* the major currencies that is not consistent with Dornbusch's demonstration.

a monotonic depreciation of the home currency that is linked to an increase in the domestic interest rate and in the interest rate spread, which is largely counterfactual. Second, the weak magnitude of the exchange rate depreciation does not yield nominal and real exchange rate volatilities consistent enough with data. Section 3 introduces credit market imperfections in the PTM model. A home monetary shock now implies a nominal exchange rate overshooting that stems from the persistent negative interest rate differential. Such dynamics are consistent with econometric results. We then show that the joint assumption of PTM and LP enables the model to generate exchange rate volatilities much closer to stylized facts. Section 4 concludes.

## 2. Exchange rates in a PTM model

### 2.1. Structure of the model

The world economy is divided in two countries, country 1 (home) and country 2 (foreign). Infinitely lived households in each country consume a continuum of differentiated goods of total measure unity. A proportion $n$ of these goods is produced by country 1 firms while $(1-n)$ is produced by country 2 firms. There are three types of agents in each country: a representative household, a continuum of differentiated goods producing firms and the monetary authorities. The behavior of each type of agents is described in the following sections.

#### 2.1.1. The household

Preferences of the household are identical between countries. The country $i$ representative household maximizes her expected intertemporal utility:

$$\mathrm{E}_0 = \sum_{t=0}^{\infty} \beta^t U(C_{it}, L_{it}) \tag{1}$$

with $C_{it}$ the consumption index, $L_{it}$ leisure and $0<\beta<1$ the actualization factor. As time endowment is normalized to unity, working time $H_{it}$ is given by the following equation:

$$1 = H_{it} + L_{it}.$$

The instantaneous utility function is

$$U(C_{it}, L_{it}) = \frac{C_{it}^{1-\sigma}}{1-\sigma} + \gamma_H \log L_{it}, \quad \gamma_H > 0, \ \sigma > 0$$

with $\sigma$ the relative degree of risk-aversion. In each country the consumption bundle $C_{it}$ aggregates across the consumption bundle of the variety produced in the home country $C_{1t}^i$ and the foreign variety $C_{2t}^i$, according to the following CES function:

$$C_{it} = [\omega^{\frac{1}{\theta}}[C_{1t}^i]^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}}[C_{2t}^i]^{\frac{\theta-1}{\theta}}] \quad \text{for } i = 1, 2$$

with $0<\omega<1$ and $\theta>0$ the elasticity of substitution between the domestic and foreign varieties. Consumption indexes for each national variety are defined over a continuum of differentiated goods produced by firms in monopolistic competition. For the domestic and foreign varieties consumed in country $i$, they are defined as follows:

$$C^i_{1t} = n^{\frac{1}{1-\eta}}\left[\int_0^n [c^i_{1t}(z)]^{\frac{\eta-1}{\eta}}\,\mathrm{d}z\right]^{\frac{\eta}{\eta-1}},$$

$$C^i_{2t} = (1-n)^{\frac{1}{1-\eta}}\left[\int_n^1 [c^i_{2t}(z)]^{\frac{\eta-1}{\eta}}\,\mathrm{d}z\right]^{\frac{\eta}{\eta-1}},$$

where $\eta>1$ represents the elasticity of substitution of goods and $c^i_{1t}(z)$ ($c^i_{2t}(z)$) the quantity of good $z$ produced by a domestic (foreign) firm consumed by agent $i$. Goods produced by country 1 monopolistic firms are indexed by $z\in[0,n]$ and goods produced by country 2 monopolistic firms are indexed by $z\in[n,1]$. As in Corsetti and Pesenti (2001), preferences are symmetric across countries.[5]

As in Blanchard and Kiyotaki (1987), the country $i$ household's optimal allocation between goods leads to the following demand functions:

$$C^i_{1t} = \omega\left[\frac{P^i_{1t}}{P_{it}}\right]^{-\theta} C_{it},$$

$$C^i_{2t} = (1-\omega)\left[\frac{P^i_{2t}}{P_{it}}\right]^{-\theta} C_{it},$$

$$c^i_{1t}(z) = \left[\frac{p^i_{1t}(z)}{P^i_{1t}}\right]^{-\eta}\frac{C^i_{1t}}{n},$$

$$c^i_{2t}(z) = \left[\frac{p^i_{2t}(z)}{P^i_{2t}}\right]^{-\eta}\frac{C^i_{2t}}{1-n}$$

with $p^i_{1t}(z)$ ($p^i_{2t}(z)$) the price of variety $z$ that is produced by a domestic firm (a foreign firm) and sold in country $i$, $i=\{1,2\}$. $P_{it}$ is the country $i$ consumption price index and $P^i_{1t}$, $P^i_{2t}$ are the expenditure-minimizing price index of each domestic and foreign aggregates consumed in country $i$:

$$P_{it} = [\omega[P^i_{1t}]^{1-\theta} + (1-\omega)[P^i_{2t}]^{1-\theta}]^{\frac{1}{1-\theta}}, \quad (2)$$

$$P^i_{1t} = n^{\frac{1}{(\eta-1)}}\left[\int_0^n p^i_{1t}(z)^{1-\eta}\,\mathrm{d}z\right]^{\frac{1}{1-\eta}}, \quad (3)$$

$$P^i_{2t} = (1-n)^{\frac{1}{\eta-1}}\left[\int_n^1 p^i_{2t}(z)^{1-\eta}\,\mathrm{d}z\right]^{\frac{1}{1-\eta}}. \quad (4)$$

[5] In the benchmark calibration we set $\theta=1$. In that case, preferences across national varieties are Cobb–Douglas, as in Corsetti and Pesenti (2001) (among others). We adopt a more general CES specification which allows us to further make a sensitivity analysis to $\theta$.

By convention, the exponent refers to the country where the good $z$ is *sold* (1 or 2) and the number in superscript refers to the country where the good is *produced* (1 or 2). Given the PTM behavior of firms, prices are directly set in the buyer's currency. As a result, the nominal exchange rate does not enter domestic and foreign consumption price indexes: there is no exchange rate pass-through.

*2.1.1.1. Program of the domestic household.* We focus here on the intertemporal program of the domestic household.[6] Each period she faces two constraints, a cash-in-advance constraint on her consumption purchases (Eq. (5)) and a budget constraint (Eq. (6))

$$P_{1t}C_{1t} \leqslant M_{1t}, \tag{5}$$

$$\begin{aligned} P_{1t}C_{1t} + M_{1t+1} + \int \chi(s_{t+1})B_1(s_{t+1})\,\mathrm{d}s_{t+1} \\ \leqslant M_{1t} + T_{1t} + P_{1t}w_{1t}H_{1t} + B_1(s_t) + \int_0^n \pi^f_{1t}(z)\,\mathrm{d}z. \end{aligned} \tag{6}$$

In period $t$ the household decides her consumption level $C_{1t}$, her leisure time $L_{1t}$ and her money demand for tomorrow $M_{1t+1}$. The household can also save by holding state-contingent assets. Financial markets are complete and for each state of nature $s$ there is a contingent claim $B_i(s_{t+1})$ bought by the household at period $t$, for a price $\chi(s_{t+1})$ in domestic currency and that yields one unit of *domestic currency* if at period $t+1$ the realized state is $s_{t+1}$.[7]

The household enters the period with the predetermined amounts $M_{1t}$ and $B_1(s_t)$. She perceives her labor revenues (with $w_{1t}$ the real wage) and the money transfer from the government $T_{1t}$. Besides, the end-of-period profits of the domestic firms $\int_0^n \pi^f_{1t}(z)\,\mathrm{d}z$ are returned to the household as the owner of the firms.

The domestic household maximizes Eq. (1) subject to the cash-in-advance constraint (5) and the budget constraint (6). The optimization program is written as a Bellman equation:

$$\begin{aligned} V(M_{1t}, B_1(s_t)) = \max_{\{C_{1t}, L_{1t}, M_{1t+1}, B_{1t+1}\}} \Big\{ U(C_{1t}, L_{1t}) \\ + \beta \int V(M_{1t+1}, B_1(s_{t+1})) f(s_{t+1}, s_t)\,\mathrm{d}s_{t+1} \Big\} \end{aligned}$$

[6]For reasons due to space saving, we do not display here the programs of foreign agents. They are detailed (for both models) in the Appendices of the paper, that are available on the author's webpage (http://lise.patureau.free.fr).

[7]Several recent papers have argued that financial market incompleteness is a key element in explaining the huge and disconnected exchange rate fluctuations (Devereux and Engel, 2002; Duarte and Stockman, 2005). Yet we maintain the assumption of perfect risk sharing across countries in the benchmark model. We thus attempt to insulate the contribution of credit market imperfections to exchange rate dynamics, keeping in mind that they are conditional to our way of introducing money *via* a cash-in-advance constraint as developed further. We also simulate a version of the model with financial market incompleteness in Section 3.5.

with $\theta_1$ and $\lambda_1$ the multipliers, respectively, associated with each constraint (5) and (6). $f(s_{t+1}, s_t)$ is the density function that describes how $s_t$ becomes $s_{t+1}$. The first-order conditions are:

$$U'_{C_{1t}} = P_{1t}(\theta_{1t} + \lambda_{1t}), \tag{7}$$

$$U'_{L_{1t}} = P_{1t} w_{1t} \lambda_{1t}, \tag{8}$$

$$\chi(s_{t+1}) = \beta \frac{\lambda_{1t+1}}{\lambda_{1t}} f(s_{t+1}), \tag{9}$$

$$\lambda_{1t} = \beta \mathrm{E}_t \left[ \frac{U'_{C_{1t+1}}}{P_{1t+1}} \right]. \tag{10}$$

Eq. (7) represents the optimal choice for consumption: the marginal utility of consumption is set equal to its marginal cost, that is a budget cost ($\lambda_{1t}$) plus the requirement of having money holdings ($\theta_{1t}$). Eq. (8) determines the optimal labor supply by equating the marginal utility of leisure to its marginal cost. Eq. (10) states the optimal demand for money: the cost of one marginal unit of money ($\lambda_{1t}$) equates its expected marginal benefit that is the expected future marginal utility of consumption given the purchasing power of money in the $t+1$ period. Given the optimal choice of contingent assets in each country (Eq. (9) and its foreign counterpart), we obtain strict proportionality between the budget multipliers:

$$\lambda_{1t} = \Omega \lambda_{2t}, \quad \forall t, \tag{11}$$

where $\Omega$ is a positive constant term that represents the initial distribution of wealth between countries. We set $\Omega = 1$ consistent with the assumption of symmetry between countries. Denoting $\Gamma_t = \frac{e_t P_{2t}}{P_{1t}}$ the real exchange rate, $\Lambda_{1t} \equiv P_{1t}\lambda_{1t}$ and $\Lambda_{2t} \equiv e_t P_{2t} \lambda_{2t}$ the marginal utility of wealth in each country, it can be re-written in real terms as

$$\Lambda_{2t} = \Gamma_t \Lambda_{1t} \tag{12}$$

which states the equality between the ratio of marginal utilities of wealth between countries and the real exchange rate. Yet, Eq. (12) does not imply equality between the real exchange rate and the ratio of marginal utilities of consumption as commonly found in the literature that introduces money in the utility function in a complete markets setting (see Chari et al., 2002). In our setting, money is introduced through a cash-in-advance constraint which bridges a gap between the budget multiplier and the marginal utility of consumption ($U'_{C_{it}}$). Given the first-order conditions on consumption in both countries, the risk-sharing (11) can be written as

$$U'_{C_{1t}} \Gamma_t - U'_{C_{2t}} = e_t P_{2t}(\theta_{1t} - \theta_{2t}), \tag{13}$$

where $\theta_{it}$ is the multiplier on the cash-in-advance constraint. When money is introduced in the utility function, these multipliers are equal to zero and Eq. (13) becomes

$$U'_{C_{1t}} \Gamma_t = U'_{C_{2t}}. \tag{14}$$

With the usual money-in-utility function used in the literature[8] (see Obstfeld and Rogoff, 1996; Chari et al., 2002 among others), Eq. (14) (condition CKM hereafter) means that the real exchange rate volatility is linked to the volatility of the relative consumption. Chari et al. (2002) therefore face the following dilemma: unless they suppose a very high and somewhat implausible degree of risk aversion, they cannot generate a sufficiently high real exchange rate volatility (so as to mimic the data) without implying a corresponding high volatility of relative consumption, inconsistent with the stylized facts. On the contrary, and despite our assumption of market completeness, our setting allows to disentangle the real exchange rate and the relative consumption movements.

### 2.1.2. The firms

Technologies are identical across countries (up to asymmetrical technological shocks) and across firms. The goods market structure relies on Blanchard and Kiyotaki (1987). In a monopolistic competition setting, each differentiated firm sets its prices and quantities taking consumption price indices and aggregate demand functions as given. Country $i$ firm $z$ accumulates physical capital $k_{it}(z)$, determines its labor demand $h_{it}(z)$, its prices $p^i_{it}(z)$, $p^j_{it}(z)$ and quantities $x^i_{it}(z)$, $x^j_{it}(z)$ for local and export markets respectively.[9] Nominal rigidities are incorporated following Rotemberg (1982), by assuming that monopolistically competing firms face a quadratic cost on adjusting prices. Furthermore, all firms price-to-market by directly setting their prices in the buyer's currency.[10]

The production technology is given by a Cobb–Douglas function

$$F_{it}(k_{it}(z), h_{it}(z)) = A_{it} k_{it}(z)^{\alpha} h_{it}(z)^{1-\alpha}$$

$A_{it}$ designs the technology level in country $i$. It is assumed to follow a joint first-order autoregressive stochastic process:

$$\log A_{1t+1} = \rho_a \log A_{1t} + \rho_{a12} \log A_{2t} + (1 - \rho_a - \rho_{a12}) \log A + \varepsilon^a_{1,t+1} + \psi_a \varepsilon^a_{2t+1}, \tag{15}$$

$$\log A_{2t+1} = \rho_a \log A_{2t} + \rho_{a12} \log A_{1t} + (1 - \rho_a - \rho_{a12}) \log A + \varepsilon^a_{2,t+1} + \psi_a \varepsilon^a_{1t+1}, \tag{16}$$

where $\log A$ is the mean of the process and $\{\varepsilon^a_i\}_t$ is the vector of technological innovations serially independent in country $i$, with $\mathrm{E}[\varepsilon^a_1] = \mathrm{E}[\varepsilon^a_2] = 0$. We adopt a general specification by allowing some cross-country correlation in the technological processes through $\rho_{a12}$. Besides, our specification implies that technological innovations are correlated across countries through $\psi_a$.

[8]Namely as in the benchmark version of Chari et al. (2002), separable between consumption, leisure and money and CRRA on consumption.

[9]As for prices, we note $x^i_{it}(z)$ the amount of production by firm $z$ in country $i$ that is sold in the local market and $x^j_{it}(z)$ the amount sold in the export $j$ market.

[10]We do not distinguish between the terms *local currency pricing* and *PTM*. Both are considered as similar as we take the third-price discrimination firms behavior as exogenous.

Total individual output is sold on both markets which implies that

$$x^i_{it}(z) + x^j_{it}(z) = A_{it} k_{it}(z)^{\alpha} h_{it}(z)^{1-\alpha}. \tag{17}$$

The law of motion for the firm $z$ physical stock is given by the standard equation

$$k_{it+1}(z) = (1-\delta) k_{it}(z) + i_{it}(z) \tag{18}$$

with $i_{it}(z)$ the investment bundle of firm $z$ and $0<\delta<1$ the depreciation rate. For sake of simplicity the investment index is assumed to have the same structure than the consumption one. Besides, each firm faces adjustment costs on capital paid in terms of composite goods according to the Ireland (2001a) specification

$$ci_{it}(z) = \frac{\phi}{2} \frac{(k_{it+1}(z) - k_{it}(z))^2}{k_{it}(z)}$$

with $\phi > 0$. As well, adjustment costs are paid in terms of composite good according to the same structure as the consumption one.

Nominal price rigidities are introduced according to the '*menu costs*' literature. For a country $i$ firm $z$, the costs of adjusting prices on each local and export markets are written similar to Ireland (2001a)

$$cp^i_{it}(z) = \frac{\Phi}{2} \left( \frac{p^i_{it}(z)}{p^i_{it-1}(z)} - \pi_i \right)^2 x^i_{it}(z), \quad \Phi > 0,$$

$$cp^j_{it}(z) = \frac{\Phi}{2} \left( \frac{p^j_{it}(z)}{p^j_{it-1}(z)} - \pi_j \right)^2 x^j_{it}(z), \quad j \neq i.$$

As $\pi_i$ and $\pi_j$ represents the steady state price growth rate in country $i$ and country $j$, respectively, adjustment costs (paid in terms of composite goods) are null at the long term equilibrium.

Each country $i$ firm $z$ faces a demand function for its goods from each country. For a country 1 firm $z$, they are

$$x^{1d}_{1t}(z) = \left[ \frac{p^1_{1t}(z)}{P^1_{1t}} \right]^{-\eta} \frac{D^1_{1t}}{n}, \tag{19}$$

$$x^{2d}_{1t}(z) = \left[ \frac{p^2_{1t}(z)}{P^2_{1t}} \right]^{-\eta} \frac{D^2_{1t}}{n}, \tag{20}$$

with $D^1_{1t}$ and $D^2_{1t}$ the demand functions for the domestic aggregate variety coming from domestic and foreign agents, respectively, according to the following equations:

$$D^1_{1t} = \omega \left[ \frac{P^1_{1t}}{P_{1t}} \right]^{-\theta} D_{1t}, \tag{21}$$

$$D^2_{1t} = \omega \left[ \frac{P^2_{1t}}{P_{2t}} \right]^{-\theta} D_{2t} \tag{22}$$

with $D_{it} = C_{it} + I_{it} + CI_{it} + CP^i_{it} + CP^j_{it}$ total demand in country $i$ ($i = 1, 2$ and $j \neq i$), $I_{it}$ aggregate investment in country $i$ defined as $\int i_{it}(z)\,\mathrm{d}z$ and aggregate adjustment costs on capital and price similarly defined.[11]

The program of a country 1 firm $z$ that maximizes its intertemporal profit is written as a Bellman equation

$$V[p^1_{1t-1}(z), p^2_{1t-1}(z), k_{1t}(z)] = \max \left\{ \begin{array}{l} p^1_{1t}(z)x^1_{1t}(z) + e_t p^2_{1t}(z)x^2_{1t}(z) - P_{1t}w_{1t}h_{1t}(z) - P_{1t}i_{1t}(z) \\ \quad -P_{1t}\{cp^1_{1t}(z) + cp^2_{1t}(z) + ci_{1t}(z)\} \\ \quad + \int \chi(s_{t+1}) V[p^1_{1t}(z), p^2_{1t}(z), k_{1t+1}(z)]\,\mathrm{d}s_{t+1} \end{array} \right\}$$

given the law of motion for capital (Eq. (18)) and subject to the sequence of constraints

$$x^1_{1t}(z) + x^2_{1t}(z) = A_{1t}k_{1t}(z)^{\alpha}h_{1t}(z)^{1-\alpha} \quad (v_{1t}(z)), \tag{23}$$

$$x^1_{1t}(z) \leqslant \left[\frac{p^1_{1t}(z)}{P_{1t}}\right]^{-\eta} D^1_{1t} \quad (v^1_{1t}(z)), \tag{24}$$

$$x^2_{1t}(z) \leqslant \left[\frac{p^2_{1t}(z)}{P_{2t}}\right]^{-\eta} D^2_{1t} \quad (v^2_{1t}(z)), \tag{25}$$

where $v_{1t}(z)$, $v^1_{1t}(z)$ and $v^2_{1t}(z)$ are Lagrange multipliers associated with each constraint. The first-order conditions[12] are the following:

$$w_{1t} = \frac{1}{1 + \mu_{1t}(z)} \frac{p^1_{1t}(z)}{P_{1t}} \left[(1-\alpha)\frac{x^1_{1t}(z) + x^2_{1t}(z)}{h_{1t}(z)}\right], \tag{26}$$

$$P_{1t}q_{1t}(z) = \beta \mathrm{E}_t \left\{ \frac{\lambda_{1t+1}}{\lambda_{1t}} P_{1t+1} \left[ z_{1t+1}(z) + q_{1t+1}(z) - \delta + \frac{\phi}{2}\left(\frac{i_{1t+1}(z) - \delta k_{1t+1}(z)}{k_{1t+1}(z)}\right)^2 \right] \right\}, \tag{27}$$

$$p^1_{1t}(z) - P_{1t}\frac{cp^1_{1t}(z)}{x^1_{1t}(z)} - v^1_{1t}(z) = v_{1t}(z), \tag{28}$$

$$e_t p^2_{1t}(z) - P_{1t}\frac{cp^2_{1t}(z)}{x^2_{1t}(z)} - v^2_{1t}(z) = v_{1t}(z), \tag{29}$$

[11] More precisely country 1 aggregate investment is defined as $I_{1t} = \int_0^n i_{1t}(z)\,\mathrm{d}z$, while in country 2 we have $I_{2t} = \int_n^1 i_{2t}(z)\,\mathrm{d}z$.

[12] Relative to the optimal choices for $h_{1t}(z)$, $k_{1t+1}(z)$, $x^1_{1t}(z)$, $x^2_{1t}(z)$, $p^1_{1t}(z)$ and $p^2_{1t}(z)$, respectively.

$$x^1_{1t}(z) + \beta \mathrm{E}_t\left\{\frac{\lambda_{1t+1}}{\lambda_{1t}} P_{1t+1}\Phi\frac{p^1_{1t+1}(z)}{p^1_{1t}(z)}\frac{x^1_{1t+1}(z)}{p^1_{1t}(z)}\left(\frac{p^1_{1t+1}(z)}{p^1_{1t}(z)} - \pi_1\right)\right\}$$
$$= \eta\frac{v^1_{1t}(z)}{p^1_{1t}(z)}x^1_{1t}(z) + \Phi\frac{P_{1t}x^1_{1t}(z)}{p^1_{1t-1}(z)}\left\{\frac{p^1_{1t}(z)}{p^1_{1t-1}(z)} - \pi_1\right\}, \tag{30}$$

$$x^2_{1t}(z) + \beta \mathrm{E}_t\left\{\frac{\lambda_{1t+1}}{\lambda_{1t}} P_{1t+1}\Phi\frac{p^2_{1t+1}(z)}{e_t p^2_{1t}(z)}\frac{x^2_{1t+1}(z)}{p^2_{1t}(z)}\left(\frac{p^2_{1t+1}(z)}{p^2_{1t}(z)} - \pi_2\right)\right\}$$
$$= \eta\frac{v^2_{1t}(z)}{e_t p^2_{1t}(z)}x^2_{1t}(z) + \Phi\frac{P_{1t}x^2_{1t}(z)}{e_t p^2_{1t-1}(z)}\left\{\frac{p^2_{1t}(z)}{p^2_{1t-1}(z)} - \pi_2\right\} \tag{31}$$

with the Tobin $q$ defined as

$$q_{1t}(z) = 1 + \phi\frac{i_{1t}(z) - \delta k_{1t}(z)}{k_{1t}(z)} \tag{32}$$

and $z_{1t}$ as

$$z_{1t}(z) = \alpha\frac{1}{1+\mu^1_{1t}(z)}\frac{p^1_t(z)}{P_{1t}}\frac{x^1_{1t}(z) + x^2_{1t}(z)}{k_{1t}(z)}$$

$\mu^1_{1t}(z)$ and $\mu^2_{1t}(z)$ design the mark-up rates on each market whose expressions are[13]

$$\mu^1_{1t} = \frac{v^1_{1t} + P_{1t}\dfrac{cp^1_{1t}}{x^1_{1t}}}{p^1_{1t} - v^1_{1t} - P_{1t}\dfrac{cp^1_{1t}}{x^1_{1t}}}, \tag{33}$$

$$\mu^2_{1t} = \frac{v^2_{1t} + P_{1t}\dfrac{cp^2_{1t}}{x^2_{1t}}}{e_t p^2_{1t} - v^2_{1t} - P_{1t}\dfrac{cp^2_{1t}}{x^2_{1t}}}. \tag{34}$$

Because of market segmentation, the firm $z$ sets its prices $p^1_{1t}(z)$ and $p^2_{1t}(z)$ according to the localization of the buyer, both prices being linked through Eqs. (28) and (29). Eqs. (26) and (27) express optimal labor demand and the optimal investment choice, respectively. Eq. (26) shows that the usual equality between real wage and labor marginal productivity does not hold. Monopolistic competing firms set prices such as labor marginal productivity is above real wage since their market power allows them to pay the work force below her marginal productivity thus to extract positive rents. As well in Eq. (27) the expected marginal return of an investment in physical capital is given by the expected resell price of capital which is lower than the true marginal productivity. Price decisions (Eqs. (30) and (31)) show that, absent nominal price rigidity ($\Phi = 0$), the mark-up rate is constant equal to

[13]The derivation of the optimal mark-up rates can be found in the Appendix of the paper, available on the author's webpage.

$\mu = \frac{1}{\eta - 1}$. On the contrary when firms face adjustment costs on prices ($\Phi > 0$) mark-up rates are endogenous and fluctuate following nominal and real perturbations.

### 2.1.3. The central bank

Each period and in each country, the representative household receives money transfers from the monetary authorities. The monetary aggregate evolves as

$$M_{it+1} = M_{it} + T_{it}, \quad i = \{1, 2\}.$$

Assuming that the money transfer obeys the following equation:

$$T_{it} = (g_{it} - 1)M_{it}, \quad i = \{1, 2\}.$$

The money stock therefore evolves as

$$M_{it+1} = g_{it} M_{it}, \quad i = \{1, 2\}. \tag{35}$$

The monetary growth rates $\{g_{1t}, g_{2t}\}$ are modelled as a joint autoregressive stochastic process according to

$$\log g_{1t+1} = \rho_g \log g_{1t} + \rho_{g12} \log g_{2t} + (1 - \rho_g - \rho_{g12}) \log g + \varepsilon^g_{1,t+1} + \psi_g \varepsilon^g_{2t+1}, \tag{36}$$

$$\log g_{2t+1} = \rho_g \log g_{2t} + \rho_{g12} \log g_{1t} + (1 - \rho_g - \rho_{g12}) \log g + \varepsilon^g_{2,t+1} + \psi_g \varepsilon^g_{1t+1}, \tag{37}$$

where $\log g$ is the mean of the process and $\{\varepsilon^g_i\}_t$ is the vector of monetary innovations serially independent and correlated between countries.

Within the debate regards the most appropriate way to model monetary policy and stemming from the work by Taylor (1993), a recently popular way to deal with is to postulate an interest rate rule (IR hereafter). Yet in the benchmark model, we retain an exogenous money supply rule (Eqs. (36) and (37)) namely because our paper focuses on the occurrence of the liquidity effect of a monetary shock. Beyond being closest to the related literature (Dornbusch, 1976; Chari et al., 2002 among others), it allows us to insulate the effects of a 'pure' money shock in the world economy since money supply is thus completely exogenous. We also develop a version of the model with an endogenous IR in Section 3.5.

### 2.1.4. Equilibrium

Absent any idiosyncratic shock, equilibrium is symmetric within a country and all firms set the same prices: $p^i_{it}(z) = p^j_{it}, i = 1, 2$ and $j = 1, 2$. Consequently they face identical demand functions and decisions regards production, labor and capital are identical. Symmetry thus simplifies the expression of the price indexes. From Eqs. (3) and (4), we obtain in the symmetric equilibrium: $P^1_{1t} = p^1_{1t}$, $P^2_{1t} = p^2_{1t}$, $P^1_{2t} = p^1_{2t}$ and $P^2_{2t} = p^2_{2t}$. The expression of the consumption price index in each country thus becomes

$$P_{1t} = [\omega (p^1_{1t})^{1-\theta} + (1 - \omega)(p^1_{2t})^{1-\theta}]^{\frac{1}{1-\theta}}, \tag{38}$$

$$P_{2t} = [\omega(p_{1t}^2)^{1-\theta} + (1-\omega)(p_{2t}^2)^{1-\theta}]^{\frac{1}{1-\theta}}. \tag{39}$$

The world economy equilibrium consists in the sets of prices $\Omega_i^P = \{w_{it}, z_{it}, e_t, \chi(s_{t+1})\}_{t=0}^{\infty}$ and $\Omega_i^p = \{p_{it}^i, p_{it}^j\}_{t=0}^{\infty}$ and the sets of quantities $\Omega_i^C = \{C_{it}, H_{it}, B_i(s_{t+1}), M_{it+1}\}_{t=0}^{\infty}$ and $\Omega_i^Q = \{x_{it}^j, h_{it}, k_{it}\}_{t=0}^{\infty}$ for each country $i = \{1, 2\}$ and $j \neq i$ such as

- given the vectors $\Omega_i^P$, $\Omega_i^p$ and the vector of exogenous variables $\{A_{it}, g_{it}\}$, the set of quantities $\Omega_i^C$ maximizes the expected intertemporal utility of the country $i$ household subject to the budget and the cash-in-advance constraints;
- given the set $\Omega_i^P$ and the vector of exogenous variables $\{A_{it}, g_{it}\}$, the set of quantities $\Omega_i^Q$ and the set of firm-level prices $\Omega_i^p$ maximize the profits of firms;
- given the sets $\Omega_i^C$, $\Omega_i^Q$, $\Omega_i^p$ and the vector of exogenous variables $\{A_{it}, g_{it}\}$, the set of prices $\Omega_i^P$, $i = 1, 2$ equilibrates the different markets:
  - *Labor market*:

$$H_{1t} = nh_{1t}, \tag{40}$$

$$H_{2t} = (1-n)h_{2t}. \tag{41}$$

  - *Physical capital market*:

$$K_{1t} = nk_{1t}, \tag{42}$$

$$K_{2t} = (1-n)k_{2t}. \tag{43}$$

  - *Financial markets*:

$$B_1(s_t) + B_2(s_t) = 0, \quad \forall s_t. \tag{44}$$

  - *The composite good market*:

$$D_{1t} + \Gamma_t D_{2t} = n\left(\frac{p_{1t}^1 x_{1t}^1 + e_t p_{1t}^2 x_{1t}^2}{P_{1t}}\right) + (1-n)\Gamma_t\left(\frac{p_{2t}^1 x_{2t}^1 + \frac{p_{2t}^2}{e_t} x_{2t}^2}{P_{2t}}\right). \tag{45}$$

After having transformed the relevant equations so that they become stationary,[14] the long-run equilibrium is determined. Equations are then log-linearized around the steady state according to Farmer's (1993) methodology.[15]

### 2.2. Calibration

The period in the model is assumed to be a quarter. The calibration of the parameters is presented in Table 2.

[14]As we assume a positive money growth rate $g$, nominal variables are subject to long-run inflation. The first step then consists in transforming such variables so that they become stationary.

[15]The technical solving is detailed in the Appendix of the paper available on the author's webpage.

Table 2
Calibration

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\alpha$ | $\beta$ | $\delta$ | $\Phi$ | $\gamma$ | $\mu$ | $\rho_g$ | $\rho_{g12}$ | $\varepsilon_{\varepsilon g}$ | $\psi_g$ |
| 0.42 | 0.988 | 0.025 | 20 | 7 | 0.197 | 0.3 | 0 | 0.009 | 0.1 |
| $\omega$ | $\pi$ | $A$ | $H$ | $\sigma$ | $\theta$ | $\rho_a$ | $\rho_{a12}$ | $\sigma_{\varepsilon a}$ | $\psi_a$ |
| 0.5 | 1.014 | 1 | 0.35 | 1.5 | 1 | 0.906 | 0.088 | 0.00852 | 0.13 |

Given our assumption of symmetry ($n = 0.5$), values are set to correspond to a median OECD country. $\gamma_H$ is chosen such as working time is 35%, based on the Juster and Stafford (1991) estimates of leisure time. The discount factor $\beta$ is 0.988 which corresponds to a 1.2% steady state quarterly real interest rate. Since 1945 the wage to GDP ratio is around 0.58 in the United States which implies $\alpha = 0.42$, also consistent with the estimates of Kollmann (2002) on German data. The depreciation of capital is about 10% a year or $\delta = 0.025$ per quarter (Kollmann, 2002). The elasticity of substitution between goods $\eta$ is set using the steady state relation between the mark-up rate $\mu$ and $\eta : \mu = \frac{1}{\eta - 1}$ given Morrison's (1990) estimate of $\mu = 0.197$. The steady state level for inflation $\pi$ is assumed identical between countries and it equates the mean of the inflation rate for the G7 countries on the 1971:1–1998:4 period. The assumption of symmetry between countries implies that $n = 0.5$ and $\omega = 0.5$. We retain $\sigma = 1.5$ for the relative risk aversion degree, which is of same order as those usually retained in the literature (see Hendry and Zhang, 2001; Kollmann, 2001b) and close from the estimates of Barrionuevo (1991) for Japan, the United Kingdom and Germany.[16] As noted by Kollmann (2001b), the elasticity of substitution between domestic and foreign varieties ($\theta$) is equal to the price elasticity of its import demand function (see Eq. (22)). For the G7 countries, a vast consensus estimates this price elasticity between 0 and 1.5 (Hooper and Marquez, 1995 among others). We follow the literature (Corsetti and Pesenti, 2001; Kollmann, 2001b; Anderson and Beier, 2005) by setting $\theta = 1$.

As adjustment costs on prices and capital are null in the long run, we cannot draw any value for $\Phi$ and $\phi$ from the steady state equilibrium. In line with the principles of calibration stated by Lucas (1987), these parameters are set so that the model accounts for some statistical properties of the data. The values for $\Phi$ and $\phi$ are determined so as to mimic the relative volatility of investment (to output $\sigma_I/\sigma_Y$) and the volatility of inflation for G7 countries on the recent flexible exchange rate period.[17] It yields $\Phi = 20$ and $\phi = 7$.[18]

[16]Simulation experiences display that most results are hardly affected by the value for $\sigma$, whose main influence is on the volatility of consumption.

[17]Quarterly series comes from OECD BSDB database. Each serie is taken in logarithm then filtered through the Hodrick and Prescott (1997) methodology. The same treatment is done on the theoretical series subject to both monetary and technological innovations. In the data the standard deviation of inflation lies between 0.4 and 0.8. The empirical estimation of the relative volatility for investment, $\sigma_I/\sigma_Y$ lies between 3 and 4, consistent with Kollmann's (2001a) findings.

[18]As shown namely by Roberts (1995) and Keen and Wang (2005), there is a mapping between the New Phillips curve implied by Calvo's (1983) model and the one generated by the type of quadratic price

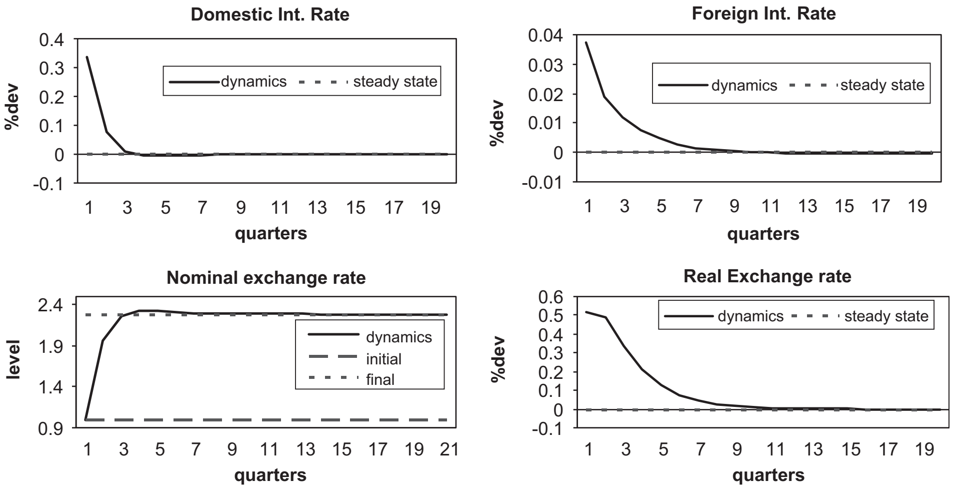


Fig. 1. Money shock, interest rate and exchange rates, PTM model.

The technological process parameters are taken from Backus et al. (1995), with the steady state technology level $A$ set to 1. The calibration of the monetary process is based on Kollmann (2001b), which estimates the joint process followed by the monetary aggregates of the United States and its G7 partners between 1973:3 and 1994:4.

## 2.3. PTM and exchange rates dynamics

### 2.3.1. Monetary shock and exchange rates dynamics

This section focuses on the impulse response functions of the nominal and real exchange rates following a domestic monetary shock. Fig. 1 presents the transition dynamics of the domestic and foreign nominal interest rates (top panel) and those of nominal and real exchange rates (bottom panel) in response to a 1% increase in the domestic monetary growth rate in period 1.[19]

As shown in Fig. 1, a home positive monetary shock generates a monotonic depreciation of the nominal exchange rate until it converges towards its new reference level. The model does not reproduce the nominal exchange rate overshooting following a monetary shock whereas it is identified in the empirical literature (Kim and Roubini, 2000; Kalyvitis and Michaelides, 2001).

(*footnote continued*)
adjustment costs used in the paper. It is useful to implement such a mapping to evaluate the length of price contracts implied by the calibrated value for $\Phi$. $\Phi = 20$ implies that on average, firms re-change their prices every 8 months, which is a plausible value consistent with the findings of Carlton (1986), even though slightly inferior to the one year duration often used in the literature (Kollmann, 2001a).

[19]To insulate the effects of a domestic monetary shock, we assume no international transmission in monetary processes for the IRFs analysis ($\psi_g = 0$). Besides, we arbitrarily assume an initial value equal to 1 for the nominal exchange rate.

This failure results from the absence of the liquidity effect in a setting where UIP holds. Since we assume complete financial markets, the model can be used to price a variety of assets, including nominal bonds and perfect arbitrage yields the UIP equation, i.e. (in log)

$$\widehat{R}_{1t} = \widehat{R}_{2t} + \mathrm{E}_t\widehat{e}_{t+1} - \widehat{e}_t \tag{46}$$

with $\widehat{R}_{it}$ the gross nominal interest rate return on nominal bonds in each country (in deviation from steady state). In the home country, the monetary shock raises current and expected inflation and the nominal interest rate (or the opportunity cost of money holdings) increases on impact because of the so-called Fisher effect. In the foreign country, the nominal interest rate slightly increases since inflation weakly reacts to the domestic monetary shock. As a result the interest rate differential remains positive until both nominal interest rates have come back to their steady state values.[20]

UIP (Eq. (46)) states that any return differential has to be offset by expected changes in nominal exchange rate. Here, since responses of nominal interest rates are determined by their Fisherian fundamentals, the persistent positive interest rate differential (in favor of the domestic country) is offset by an expected depreciation of domestic currency. As agents expectations are rational, the nominal exchange rate goes on depreciating after its immediate increase.

Besides, Fig. 1 shows that the 1% increase in the domestic money growth rate results in an almost similar 1% increase in the nominal exchange rate, suggesting the model lacks of powerful amplification mechanisms. It mitigates the significance of Betts and Devereux's (1996) argument. They analytically demonstrate that the degree of PTM, i.e. the number of firms that price-to-market amplifies the nominal exchange rate response to a money shock. As we assume that all firms to price-to-market, we *a priori* consider the most favorable case. Yet as an attempt to quantify this mechanism, Fig. 1 suggests the amplification effect on the nominal exchange rate is limited.[21]

Consider now the real exchange rate dynamics. Recalling that $\Gamma_t = \frac{e_t P_{2t}}{P_{1t}}$, it derives from the nominal exchange rate response and the relative price index behavior. In our setting, local currency pricing and nominal price rigidity are the deep sources of real exchange rate deviations as we do not model non-tradable goods sector. This is consistent with empirical literature that underlines that departures from the law of one price are the main source of deviations from purchasing power parity thereby

[20]For the benchmark calibration, the real interest rate decreases in both countries. Yet, this is not due to a similar nominal interest rate decrease but comes from the inflation response. Despite the rise in the nominal interest rate, the larger increase in expected inflation drives the real interest rate below its steady state value. With a higher degree of nominal price rigidity ($\Phi_P = 77$ as in Ireland, 2001a for instance), this inflation effect is smaller and the domestic real interest rate increases on impact as for the nominal interest rate.

[21]Betts and Devereux (1996) analytically demonstrate that, in a PTM world the nominal exchange rate response is larger than the initial monetary increase, i.e. $\frac{\Delta e}{\Delta m} > 1$. This is not the case in our setting since prices are moving within the period of the shock (even if the magnitude of price changes is limited because of nominal rigidities) while they are perfectly fixed in Betts and Devereux's (1996) model.

downplaying the role of non-tradable goods (Engel, 1999). In our model, nominal price rigidity induces firms to react to demand changes (i.e. the monetary shock) by adjusting mark-ups rates and quantities rather than sale prices. Since price stickiness puts a brake on the consumer price index changes following monetary shocks, it stands as a key transmission channel of nominal exchange rate movements to real exchange rate. Furthermore, PTM strengthens this channel by limiting the exchange rate pass-through to import prices.

Indeed, in the traditional case where firms price in their own currency (*producer currency pricing*), the nominal exchange rate depreciation (that follows a home positive monetary shock) implies an increase in the domestic country import prices and a decrease in the foreign country import prices. Through this channel and even though sale prices are rigid, a home monetary expansion exerts an upper pressure on the home CPI and a down pressure on the foreign CPI. As a result, CPIs movements counteract the impact of the nominal exchange rate movements on the real exchange rate.

On the contrary in our setting where all firms price-to-market, CPIs in both countries are independent of the nominal exchange rate since import prices are directly set in the buyer's currency (see Eq. (2) for $i = 1, 2$). Following monetary shocks, the equilibrium on the money market is no more ensured by CPI changes and requires larger nominal exchange rate movements. Consumption prices indices will change only with sale prices variations ($\widehat{p}_i^j$), whose magnitude is limited because of nominal rigidities. Hence, any nominal exchange rate movement translates into the real exchange rate. PTM and price stickiness are thus key elements for any monetary policy shock to generate large nominal and real exchange rate responses.[22]

Nevertheless Fig. 1 shows that the monetary injection has a limited impact on the nominal and real exchange rates instantaneous responses. Furthermore, the PTM model does not mimic the empirical consequences of monetary policy shocks such as a persistent negative interest rate differential and the nominal exchange rate overshooting. Despite nominal price rigidities, it fails generating amplified real exchange rate movements. The absence of any over-reaction in the exchange rates responses is likely to imply exchange rate volatilities much lower than stylized facts. Next section evaluates that point.

### *2.3.2. Monetary innovations and volatility*

This section analyzes the performances of the PTM model in quantitative terms. Statistics reported in Table 3 are obtained from 500 simulations of the theoretical

[22]Recent contributions have also been highlighting the role of distribution factors in the endogenous deviations from the law of one price (Corsetti and Dedola, 2003; Burstein et al., 2003). Our PTM story, in some sense, can be interpretated as including the presence of specific distribution sector which account for deviations from the law of one price. Nevertheless, we do not explicitly model this kind of explanation since the focus on the paper is rather on the interaction between LP and PTM. Besides, we refer to the conclusions drawn by Chari et al. (2002). They use alternative measures of price indices (CPI, tradable goods price index, wholesale price index) for constructing the real exchange rate series. They get measures of volatility are very close, which suggests that volatile distribution costs may not be a significant source of real exchange rate volatility.

Table 3
Cyclical properties of the PTM model

| | Technology shock (2) | Money shock (3) | Both shocks (4) | Data (5) |
|---|---|---|---|---|
| *Volatility (in %)* | | | | |
| $\Delta e$ | 0 | 1.15 | 1.15 | 4.56 |
| $\Gamma$ | 0 | 0.82 | 0.82 | 7.83 |
| $Y$ | 0.87 | 0.29 | 0.91 | 1.82 |
| $C$ | 0.59 | 0.53 | 0.80 | 1.30 |
| $I$ | 1.40 | 2.79 | 3.12 | 5.07 |
| $TB$ | 0.75 | 0.85 | 1.14 | 1.04 |
| $\pi$ | 0.33 | 0.58 | 0.67 | 0.54 |
| $R$ | 0.002 | 0.30 | 0.30 | 1.68 |
| *Persistence* | | | | |
| $\Gamma$ | — | 0.668 | 0.668 | 0.841 |
| $Y$ | 0.877 | 0.636 | 0.852 | 0.845 |
| *Correlation* | | | | |
| $\frac{e}{e_{-1}}, \Gamma$ | — | 0.774 | 0.775 | 0.988 |
| $Y_1, Y_2$ | 0.530 | 0.942 | 0.572 | 0.409 |
| $C_1, C_2$ | 1.00 | 0.290 | 0.681 | 0.035 |

series that are filtered according to Hodrick and Prescott (1997)'s methodology, when the model is subject to technological shocks (column 2), to monetary shocks (column 3) and to both shocks (column 4). Column 5 presents the same cyclical properties for the median of the G7 countries (except the United States) over the 1971:1–1998:4 period.[23]

Consider first column 2 that describes the quantitative implications of technological shocks. The model correctly reproduces the order of volatility regards real aggregates (output, consumption, investment) despite that it generates too little volatility as compared to the data. In terms of persistence, real variables inherit the high degree of autocorrelation in the technological process and display a degree of persistence consistent with stylized facts. Nevertheless column 2 confirms the conventional view that the single occurrence of real shocks is unable to explain the exchange rate cyclical behaviors, with exchange rates volatilities equal to zero. Column 3 presents the cyclical properties of the PTM model subject to monetary innovations. Monetary shocks hardly account for the magnitude of real aggregates fluctuations. On the contrary, the interaction between money shocks and local currency price rigidity allows for nominal and real exchange rates movements, consistently with the Clarida and Gali (1994) and the Eichenbaum and Evans (1995) empirical results. Indeed, were prices perfectly flexible ($\Phi = 0$), the law of one price would hold despite the firms PTM behavior. Given the symmetry of preferences between countries, purchasing power parity would hold as well and the real exchange rate would be constant and equal to one, even

[23]Quarterly series come from the OECD BSDB database (see description in footnote 2). All series are taken in logarithm (except trade balance which is divided by the mean of GDP on the period), before filtering. Cross-country correlations for consumption and production are calculated *vis-à-vis* the US series.

though unanticipated money shocks occur. This is no more the case when prices are sticky ($\Phi > 0$) and directly set in the buyer's currency.

Quantitative results when the model is subject to both monetary and technological innovations are presented in column 4. Consistently with data, investment fluctuates more than output, itself more volatile than consumption; yet the model has difficulty in matching their empirical volatilities.[24] Given market completeness, cross-country consumptions are too highly correlated and more correlated than cross-country productions which is counterfactual. As in the Backus et al. (1995) real business cycle model, the PTM model fails in front of the quantity anomaly. Yet, as in Kollmann (2001b), it is able to replicate the sign and the magnitude of order of the cross-country GDP correlation unlike most international real business cycle models (see Backus et al., 1995). Regards exchange rate cyclical properties, column 4 confirms the conclusions drawn from the impulse response analysis. The PTM model does not succeed in generating amplified movements of exchange rates as compared to those of their macroeconomic fundamentals: the real exchange rate standard-deviation remains lower than the one of output.

This failure drives us to introduce credit market imperfections in the PTM model, in line with Hairault et al.'s (2004) paper. Our objective is to assess the ability of such frictions to improve the PTM model performances, both regards the exchange rates dynamics induced by money shocks and in terms of their cyclical properties.

## 3. Including credit market frictions

### 3.1. Structure of the model

We now amend the PTM model with the introduction of credit market frictions, along the lines of Christiano (1991) and Christiano and Eichenbaum (1992). The world economy still consists in two countries 1 and 2, respectively, sized $n$ and $1-n$. Each country is now lived by four types of agents: a representative household, monopolistic good-producing firms, a government-central bank and financial intermediaries in perfect competition. Credit market frictions are modeled by assuming LP of the representative household to the loanable funds market. Besides, we add portfolio adjustment costs as first developed by Christiano and Eichenbaum (1992) and commonly used in the related literature (see King and Watson, 1996; Hendry and Zhang, 2001; Ireland and Papadopoulou, 2004 among others). To understand the modeling of the LP assumption, it is useful to decompose the timing of the period in five steps.

1. At the beginning of the period the monetary shock occurs: in both countries monetary authorities inject liquidity into the loanable funds markets.
2. In each country the credit market opens and the firms determine their demand for loans. As in Dow (1995) they borrow cash from the banks to finance investment in

[24] Precisely, regards consumption and output. Hence, it is necessarily true for investment as the parameter $\phi$ is set so as to reproduce the volatility of investment relative to output.

physical capital. The available loans supply is already known given the households' deposit inherited from previous period decisions and the central bank liquidity injection made in step 1. The firms also determine their demand for labor and capital.

3. Transactions in the labor market and the goods market occur. Each firm sells its production to the local and foreign households after setting goods prices directly in the buyer's currency, given aggregate demand and consumption prices indices in each country.
4. In each country the representative household determines her contingent claims portfolio. Labor income is collected and loans are repaid to the financial intermediary for a nominal interest factor $R_{it}$. The household receives interest payments on her deposits as well as dividend payments from the local banks and the local firms (as owner of both).
5. At the end of the period the households choose the amount of bank-deposit $M^b_{it+1}$ to put in the banks the next period and the amount $M^c_{it+1}$ of money-cash needed to consume next period.

#### 3.1.1. The program of the representative household

Only the intertemporal part of the household's problem is changed by the introduction of credit market frictions. The LP assumption stands in informational asymmetries on the loan market that we model as Andolfatto and Gomme (2003): in the $t$ period, the amounts of money-cash $M^c_{it}$ and of money-deposits $M^b_{it}$ are pre-determined, inherited from the past period choices and the household determines the optimal amounts $M^c_{it+1}$ and $M^b_{it+1}$. Besides, we introduce adjustment costs on portfolio decisions. Indeed, as noted by Christiano (1991) in a closed economy framework, if the standard LP model generates a liquidity effect following a positive monetary shock, the decrease in the interest rate is not strong and persistent enough as compared to stylized facts. One way to improve the liquidity effect is to modify the environment so that the financial sector remains more 'liquid' than the real sector for several periods after the shocks. As in Christiano and Eichenbaum (1992) and King and Watson (1996), we therefore include adjustment costs on money holdings. In a stochastic environment subject to monetary shocks, changing the consumption scheme, or equivalently money holdings, is time-costly: reorganizing the flow of funds deprives the household from time available to leisure or working activities.[25] Assuming that adjusting money-cash $M^c_{it}$ is costly implies that the time endowment (normalized to unity) is now written as

$$1 = L_{it} + H_{it} + \Omega_{it},$$

where $\Omega_{it}$ is the cost of changing money holdings supposed to be quadratic

$$\Omega_{it} = \frac{\xi}{2}\left(\frac{M^c_{it+1}}{M^c_{it}} - g\right)^2$$

[25]Such costs are considered as modelling the amount of time it takes to go to the bank, the financial loss of reducing interest-inducing deposits, etc.

$g$ represents the money holdings growth rate in the steady state equilibrium. The above formulation implies that adjustment costs on money holdings are null in the long run equilibrium.

Each period the representative household in country $i$ chooses her amount of aggregate consumption and her labor supply. Savings can take the form of money holdings, bank deposits or contingent claims. The intertemporal program for the domestic household is now written as:

$$\begin{aligned} V[M^c_{1t}, M^b_{1t}, B_1(s_t)] \\ = \max\left\{ U(C_{1t}, L_{1t}) + \beta \int V[M^c_{1t+1}, M^b_{1t+1}, B_1(s_{t+1})] f(s_{t+1}, s_t)\, \mathrm{d}s_{t+1} \right\} \end{aligned}$$

subject to:

$$P_{1t}C_{1t} \leqslant M^c_{1t} \quad (\theta_{1t}),$$

$$\begin{aligned} P_{1t}C_{1t} + M^c_{1t+1} + M^b_{1t+1} + \int \chi(s_{t+1}) B_1(s_{t+1})\, \mathrm{d}s_{t+1} \\ \leqslant P_{1t}w_{1t}(1 - L_{1t} - \Omega_{1t}) + M^c_{1t} + R_{1t}M^b_{1t} + B_1(s_t) + \int_0^n \pi^f_{1t}(z)\, \mathrm{d}z + \pi^b_{1t} \quad (\lambda_{1t}) \end{aligned}$$

with $\theta_{1t}$ and $\lambda_{1t}$ the Lagrange multipliers. $\pi^b_{1t}$ represents the profits received from the local banks and $R_{1t}$ the nominal interest rate on private deposits. First-order conditions related to consumption, leisure and contingent assets in the PTM model (Eqs. (7)–(9)) still hold. First-order conditions relative to bank deposits $M^b_{1t+1}$ and money-cash $M^c_{1t+1}$ are, respectively

$$\lambda_{1t} = \beta \mathrm{E}_t[R_{1t+1}\lambda_{1t+1}], \tag{47}$$

$$\begin{aligned} \lambda_{1t} + P_{1t}w_{1t}\lambda_{1t}\left( \xi \frac{1}{M^c_{1t}} \left\{ \frac{M^c_{1t+1}}{M^c_{1t}} - g \right\} \right) \\ = \beta \mathrm{E}_t\left[ \frac{U'_{C_{1t+1}}}{P_{1t+1}} \right] + \beta \mathrm{E}_t\left[ P_{1t+1}w_{1t+1}\lambda_{1t+1}\left( \xi \frac{M^c_{1t+2}}{(M^c_{1t+1})^2} \left\{ \frac{M^c_{1t+2}}{M^c_{1t+1}} - g \right\} \right) \right]. \end{aligned} \tag{48}$$

Eq. (47) represents the optimal choice of bank deposits: the marginal cost of increasing deposits ($\lambda_{1t}$) equates the expected marginal wealth it yields tomorrow given the future interest rate. Eq. (48) represents the optimal choice of money holdings. Note that it gives Eq. (10) when $\xi = 0$. The left member of the equation represents the marginal cost of one extra money-cash unit. The marginal cost does not only consists in the budget cost $\lambda_{1t}$ since the household has now to give up available time that implies some wage loss $\left( \frac{\partial \Omega_{it+1}}{\partial M^c_{it+1}} > 0 \right)$. The right member of Eq. (48) represents the marginal benefit of increasing $M^c_{1t+1}$: the amount of money-cash asked today for tomorrow entices the household to purchase goods the next period given the future purchasing power of money, and it now implies saving time tomorrow $\left(\frac{\partial \Omega_{it+1}}{\partial M^c_{it+1}} < 0\right)$. On optimum the marginal cost and the marginal benefit of increasing money holdings are equal.

Given the assumption of financial market completeness, Eq. (11) still holds. Combining it with the optimal choices of bank deposits in each country (Eq. (47) and its foreign counterpart) yields the UIP equation (in log):

$$\mathrm{E}_t\widehat{R}_{1t+1} - \mathrm{E}_t\widehat{R}_{2t+1} = \mathrm{E}_t\widehat{e}_{t+1} - \widehat{e}_t. \tag{49}$$

Eq. (49) has an interpretation similar to the UIP expression obtained in the PTM model, but it differs in the timing of the interest rates. While the standard UIP condition (Eq. (46)) states that any interest rate differential at time $t$ has to be offset by an expected exchange rate depreciation (between $t$ and $t+1$), Eq. (49) refers to the expected interest rate differential in $t+1$. This timing effect in the no-arbitrage condition comes from the LP assumption (independently of the existence of portfolio adjustment costs) and it plays a key role in nominal exchange rate dynamics as detailed below.

### 3.1.2. The firms

The firms program is slightly modified since investment is now a credit good. For country 1 firm $z$ this implies the following Bellman equation:

$$\begin{aligned} & V[p^1_{1t-1}(z), p^2_{1t-1}(z), k_{1t}(z)] \\ & = \max \left\{ \begin{aligned} & p^1_{1t}(z)x^1_{1t}(z) + e_t p^2_{1t}(z)x^2_{1t}(z) - P_{1t}w_{1t}h_{1t}(z) - R_{1t}P_{1t}i_{1t}(z) \\ & \quad -P_{1t}(ci_{1t}(z) + cp^1_{1t}(z) + cp^2_{1t}(z)) \\ & \quad + \int \chi(s_{t+1}) V[p^1_{1t}(z), p^2_{1t}(z), k_{1t+1}(z)\, \mathrm{d}s_{t+1}] \end{aligned} \right\} \end{aligned}$$

subject to the same set of constraints (Eqs. (18)– (25)). Only the first-order condition for investment decision has changed to become

$$\begin{aligned} q_{1t}(z) + R_{1t} - 1 = \beta \mathrm{E}_t \Bigg\{ \frac{\Lambda_{1t+1}}{\Lambda_{1t}} \Bigg[ & z_{1t+1}(z) + q_{1t+1}(z) - 1 + (1-\delta)R_{1t+1} \\ & + \frac{\phi}{2}\left(\frac{i_{1t+1}(z) - \delta k_{1t+1}(z)}{k_{1t+1}(z)}\right)^2 \Bigg] \Bigg\}. \end{aligned} \tag{50}$$

The nominal interest rate now intervenes in the arbitrage condition. The marginal cost of investment is equal to the shadow price of capital $q_{1t}$ plus the borrowing cost $R_{1t}$. The expected marginal return consists in the marginal product to be sold tomorrow (given the future mark-up rate), net from depreciation, plus what is saved from not buying this extra unit of capital tomorrow, that includes the expected nominal interest rate and the future shadow price of capital.

### 3.1.3. The central bank and the financial intermediaries

The program of monetary authorities is identical to the one described in Section 2.1.3.

In each country financial intermediaries perfectly compete with each other. They accept bank deposits from the households ($M_{it}^b$) that are paid back at the end of the period for a nominal interest rate $R_{it}$. They also receive cash injection $T_{it}$ from their local central bank. Banks resources are loaned to local firms that shall borrow to invest in physical capital. The end-of-period profits are given back to the owner (the household) as dividends. The asset balance of the representative bank leads to

$$\Delta_{it} = M_{it}^b + T_{it}, \quad \forall i = 1, 2,$$

where $\Delta_{it}$ represents the loans granted to the firms $i$. At the end of the period the bank dividends are

$$\pi_{it}^b = (1 + R_{it})\Delta_{it} - (1 + R_{it})M_{it}^b, \quad \forall i = 1, 2.$$

### 3.1.4. Equilibrium

At the symmetric equilibrium, consumer price indexes are defined through Eq. (2) for $i = \{1, 2\}$. The different markets (labor, capital, goods, contingent claims) are equilibrated according to Eqs. (40)–(45). The loanable funds market equilibrium in each country is given by

$$P_{it}I_{it} = M_{it}^b + (g_{it} - 1)M_{it}, \quad i = \{1, 2\} \tag{51}$$

and the money market equilibrium in each country requires

$$M_{it} = M_{it}^c + M_{it}^b, \quad i = \{1, 2\}. \tag{52}$$

The model is solved as in Section 2. After the stationarizing of equations, the long-run equilibrium is determined still given that countries are symmetric and trade balance accounts null.[26] The equations are then log-linearized around the steady state according to Farmer's (1993) methodology.

## 3.2. Calibration

The set of structural parameters $\{\alpha, \beta, \delta, \mu, n, A, \pi, \theta, \omega, \sigma, H\}$ and the calibration of stochastic processes in Table 2 are kept identical. Absent any reference value for the degree of adjustment costs on money holdings in the literature, we adopt the benchmark value $\xi = 1$ as in Hendry and Zhang (2001). As common in the literature, we assess this value regards the corresponding cost of steady state leisure and in terms of minute per week: $\xi = 1$ implies that a 1% increase in the ratio $\frac{M_{it+1}^c}{M_{it}^c}$ beyond its stationary value represents a cost of 0.0077% of steady state leisure, or around 0.5 min per week[27]: In line

[26] The LP assumption stands for informational asymmetries on the credit market that disappear in the long run equilibrium. Besides, adjustment costs on money holdings are null in the steady state equilibrium. As a result, the long run equilibrium of the model is quite similar to the one of the PTM model. See Appendix (on the author's webpage) for details.

[27] These calculations are based on Juster and Stafford's (1991) results. These authors estimate available time not allocated to work for the United States in 1981. Mean for both men and women of personal time amounts to 110 h per 168 h (a week).

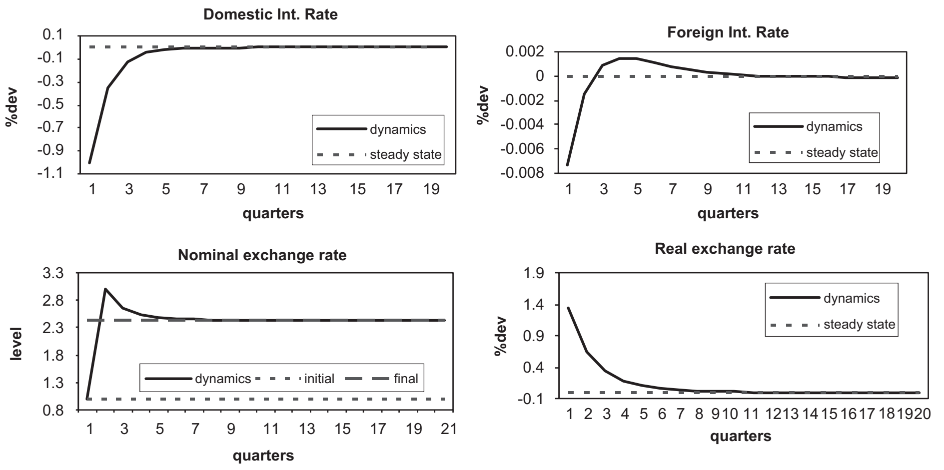


Fig. 2. The effects of a domestic money shock, PTM + LP model (1).

with Christiano and Eichenbaum (1992), the idea is to analyze the consequences of introducing very small adjustment costs on money holdings.

The parameters $\phi$ and $\Phi$ are calibrated implementing the same strategy as previously, so as to mimic the observed standard deviations of investment (relative to output) and inflation. It yields the values $\phi = 25$ and $\Phi = 20$.[28]

### 3.3. The dynamics of a money shock

#### 3.3.1. Interest rates and exchange rates dynamics

Fig. 2 shows the dynamics of interest rates and exchange rates following a 1% increase in the domestic monetary growth rate in period 1.[29]

The domestic monetary shock now generates a liquidity effect in both countries. Since the domestic nominal interest rate decreases more on impact and more persistently than the foreign one, the interest rate spread turns out to be persistently negative and the nominal exchange rate displays an overshooting dynamics.[30] The model with PTM and LP thus accounts for the empirical effects of a monetary shock that are a strong and persistent liquidity effect in the home country, a negative interest rate differential and a nominal exchange rate overshooting.

[28]When the model is subject to technological and monetary shocks. The value of $\phi$ is higher in the PTM + LP model, since investment (as a credit good) is much more reactive to monetary shocks as next section will make clear. Besides, to compare the performances of both models with the same set of parameters, we also perform simulations on the PTM model with this calibration.

[29]As in the PTM model, IRFs are presented assuming no international transmission in monetary processes ($\psi_g = 0$). As well, we still assume an initial value equal to 1 for the nominal exchange rate response.

[30]Besides, we check that both domestic and foreign real interest rates now decline below steady state level with a positive home monetary injection.

The mechanisms behind such dynamics are straightforward. Consider first the nominal exchange rate response. The overshooting path results from the combination of a negative interest rate spread and UIP. Precisely, given the UIP condition (Eq. (49)), it is crucial that the interest rate differential remains *persistently* negative following the domestic money shock for the nominal exchange rate to overshoot (the time $t$ interest rate differential has no influence in the no-arbitrage condition). This is the case for the benchmark calibration as shown in Fig. 2.[31] In order to generate such a dynamics, our paper as well as Dornbusch (1976) introduce rigidities on the market where the nominal interest rate is determined so that a home monetary expansion generates a large and persistent decrease in the domestic interest rate (and the interest rate differential) and a subsequent nominal exchange rate overshooting. The traditional Dornbusch's (1976) model as the New Open Economy Macroeconomics literature (Obstfeld and Rogoff, 1995) in a fully micro-founded set-up lay stress on price rigidities combined with UIP as main ingredients to exchange rate dynamics. On the contrary, in our setting the key rigidity lies in the credit market through LP and portfolio adjustment costs.[32] Both Dornbusch's model and our's are then able to generate a liquidity effect in the home country, a persistent negative interest rate spread and a subsequent overshooting dynamics for the nominal exchange rate given UIP. In accordance with Dornbusch (1976)'s argument, this crucially depends on changes on the market where the interest rate is determined. This drives us to analyze the mechanisms of the model on the loanable funds market.

Consider first the domestic country. Each period, the equilibrium interest rate adjusts to clear the loanable funds market. To understand the impulse response function in Fig. 2, we have to analyze the way loan demand and loan supply react to the monetary shock *ceteris paribus* for the given interest rate.

In the period of the shock, every thing else equal the monetary injection translates into an increase in the supply of loans since the household's deposits are predetermined. On the opposite side, *ceteris paribus* for the given interest rate loan demand increases for two reasons. First, the positive wealth effect induced by the money shock affects the auctioneers's valuation of a marginal investment and entices firms to invest more.[33] Second, as firms are reluctant to adjust prices, they respond to the positive demand shock by adjusting mark-ups and quantities rather than sale prices. The stickier good prices, the higher the increase in loan demand for a given interest rate, which tends to counteract the reduction in the equilibrium interest rate that the initial increase in loan supply i.e. the monetary injection, would otherwise generate. Everything else equal, a higher degree of nominal price rigidity plays

[31] The persistence in the liquidity effect is linked to portfolio adjustment costs. Absent any adjustment cost on money holdings ($\xi = 0$), the domestic monetary policy generates a strong liquidity effect but that does not persist beyond the period of the shock, as in Christiano (1991). As a result, the nominal exchange rate does not exhibit an overshooting dynamics following a monetary shock (see Appendix); the resulting exchange rate volatilities remain below the stylized facts. Yet only a small degree of adjustment costs on money holdings is needed for the model to account for nominal exchange rate overshooting and to explain a substantial part of exchange rate movements (as shown in Section 3.4).

[32] As Hairault et al. (2004) make clear in a pure flexible-price small-open economy setting.

[33] We do not display all IRFs in the paper, but complements can be found on the author's webpage.

against the immediate liquidity effect. Yet Fig. 2 shows that the interest rate decreases on impact. The reason dwells on the presence of adjustment costs on capital $\phi$ that influence the investment response, hence loan demand. When adjusting capital is costly ($\phi$ high) the firms incentive to dramatically invest in physical capital is limited. With high values of $\phi$, the increase in loan supply (that comes from the monetary injection) dominates the rise in loan demand and the equilibrium interest rate has to decrease to clear the loanable funds market.

The periods after the shock, the home interest rate response results from both behaviors of private demand and supply of loans. As shown by Christiano and Eichenbaum (1992) the persistence of the liquidity effect is closely related to the private loan supply behavior. In the first period the household chooses the amount of money-cash and money-deposit for the next period. Because of the expected inflation effect, she is willing to increase her money holdings to preserve her future consumption. However it is costly for the household to raise the ratio $\frac{M^c_{1t+1}}{M^c_{1t}}$ dramatically since it deprives her for time available to working activities or leisure. According to Eq. (48), larger portfolio adjustment costs make more expensive any variation in the money holdings ratio in the first period and the household will rather wait. As a result in the period of the monetary injection, the household increases $M^c_{1t+1}$ only by a small amount. She rather prefers to increase her bank deposits given that the domestic wealth effect is maximum in the first period. The second period on, the significant increase in private deposits enlarges the effects of public monetary injection and partially explains the persistent reduction in the equilibrium domestic interest rate.

On the opposite side of the market, loan demand contracts every thing else equal. Indeed, with the initial boom in investment, capital marginal productivity decreases the second period on. Besides, mark-up rates gradually come back to their initial steady state level as the effects of the monetary shock vanish. Both reasons entice firms to disinvest. As a result, for some periods after the shock, loan demand contracts while loan supply goes on increasing. The persistent decrease in the equilibrium interest rate therefore results from the combination of both mechanisms.

In the foreign country, the nominal interest rate slightly decreases with the domestic monetary expansion. In the absence of any governmental liquidity injection, it adjusts to movements in the private loan supply and demand. *Ceteris paribus* in the period of the shock loan demand vanishes because of a negative wealth effect in country 2. To understand this, consider the equation of perfect-risk sharing (Eq. (12), in log). State-contingents assets being labelled in domestic currency, the real exchange rate depreciation ($\widehat{\Gamma} > 0$) tends to reduce the foreign household real wealth *ceteris paribus*. Despite financial market completeness and the domestic positive wealth effect ($\widehat{\Lambda}_1 < 0$), this effect dominates in equilibrium ($\widehat{\Lambda}_2 > 0$) and aggregate foreign demand decreases (both consumption and investment). The reduction in investment translates into a contraction in loan demand, implying a decrease in the equilibrium nominal interest rate. The second period on, the household is willing to preserve her consumption by arbitrating in favor of money-cash rather than deposits and the supply of loans contracts. As a result, the foreign interest rate slightly increases beyond its steady state level.

Given the nominal interest rate responses in both countries, the interest rate spread $(R_1 - R_2)$ remains persistently negative, which requires a nominal exchange rate overshooting to restore UIP.

Fig. 2 shows that the real exchange rate monotonically depreciates with the domestic monetary expansion. If the dynamic path of real exchange rate is qualitatively similar to the one obtained in the PTM model (Fig. 1), the magnitude of its depreciation is much higher. Indeed, in the current setting with credit market imperfections, the nominal exchange rate now over-reacts to monetary shocks and the real exchange rate response inherits this magnified response given price rigidity in the buyer's currency. The introduction of credit market frictions in the PTM model amplifies both nominal and real exchange rate responses to monetary impulses and it enables the model to generate a strong and persistent liquidity effect, a lasting negative interest rate differential and a resulting nominal exchange rate overshooting, consistently with stylized facts.

### 3.3.2. A model consistent with the empirical effects of monetary shocks?

In line with Christiano et al. (1997), we now check whether the model is consistent with the broad empirical effects of monetary shocks by focusing on the IRFs of main macroeconomic aggregates. Christiano et al. (1998) survey that despite the various techniques of identifying money shocks, the empirical literature converges on some consensus regards the effects of a money shock on real variables: after a positive monetary policy shock, aggregate output ultimately raises. Besides, the GDP response is found to be hump-shaped, with a peak at 6–8 quarters (depending on the country). Unemployment decreases after a delay, consumption and investment increase, the latter being more reactive.

Fig. 3 presents the responses of output, consumption, investment and hours in the domestic country, following a 1% increase in the home money growth rate in period 1. Output, employment and investment go up while consumption decreases with the monetary shock.

The rationale of such responses is the following. The positive wealth effect induces the domestic household to raise her leisure time, all the more as consumption is subject to inflationary pressures. Investment raises since the household, as the auctioneer of the domestic firms also decides to escape inflation tax by investing in physical capital and benefit from the reduced cost of borrowing. As a result, aggregate demand increases in the domestic country, which firms react to by adjusting quantities. On the domestic labor market, labor demand therefore increases and dominates the reduction in labor supply: on equilibrium, the employment level and the real wage increase. Given the immediate increase in employment, the maximal effect on GDP of the shock is on impact. As a result, the model does not account for the empirical hump-shaped response of output to money shock. Yet the IRFs of GDP, investment and hours shown in Fig. 3 can be considered as broadly consistent with the data, as a positive monetary shock drives output, employment and investment up, the latter being the most reactive. While consumption increases in the data, its theoretical response is negative because of the cash-in-advance constraint and the inflation effect.

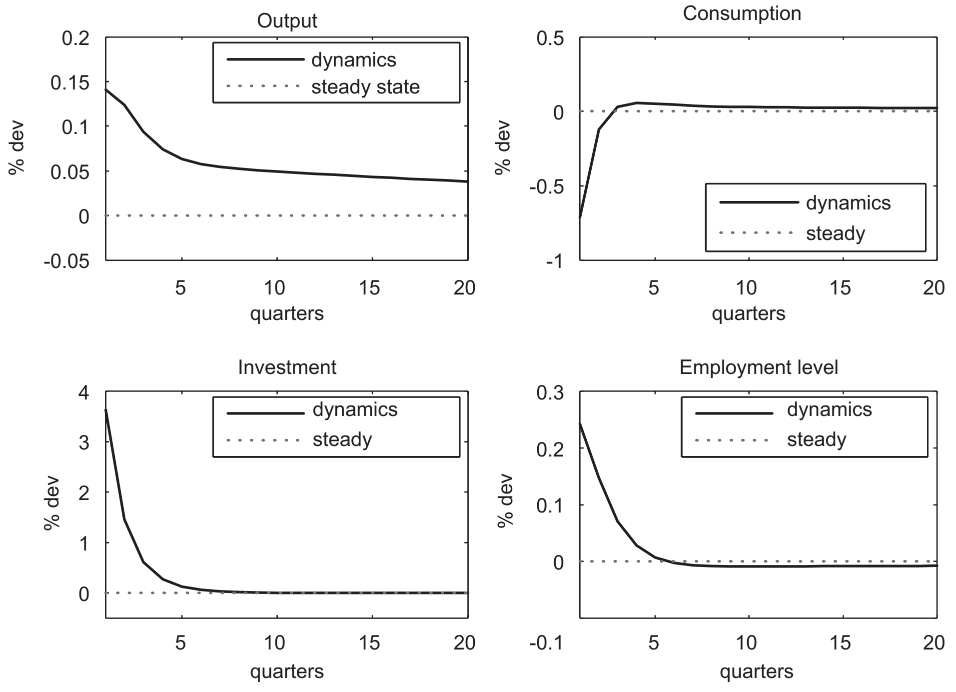


Fig. 3. The effects of a domestic money shock, PTM + LP model (2).

The increase in aggregate demand generates larger sales revenues for domestic firms, which results into higher profits despite the rise in marginal costs. The IRFs for wages and profits are consistent with the empirical findings of Christiano et al. (1997). In a closed-economy setting, they conclude on the relevance of adding credit market frictions in a sticky-price model in order to generate the correct answer of profits and wages to a money shock. Our results obtained in a two-country setting go in the same direction. Indeed, the model is able to rationalize the raise in output, employment and investment after an expansionary monetary shock, as well as the gradual price adjustment (given nominal price rigidity) and the positive response of wages and profits. Regards open economy dynamics, the model accounts for the nominal exchange rate overshooting and the real exchange rate monotonic depreciation. Besides, as compared to the PTM model, the impulse response functions of both exchange rates are significantly magnified, which might help the model account for a substantial part of their observed volatility. The next step consists in assessing the performances of the model regards its cyclical properties.

### 3.4. From a quantitative point of view

Table 4 presents the statistical properties of the model subject to technological shocks (column 2), monetary shocks (column 3) and both shocks (column 4).

Table 4
Cyclical properties

| | Model with PTM + LP | | | PTM model | Data (6) |
|---|---|---|---|---|---|
| | Technology shocks (2) | Money shocks (3) | Both shocks (4) | Both shocks (5) | |
| *Volatility* (%) | | | | | |
| $\Delta e$ | 0.01 | 2.18 | **2.18** | **1.15** | 4.56 |
| $\Gamma$ | $\simeq 0$ | 1.49 | **1.49** | **0.82** | 7.83 |
| $Y$ | 0.81 | 0.21 | **0.83** | **0.84** | 1.82 |
| $C$ | 0.65 | 0.66 | 0.93 | 0.82 | 1.30 |
| $I$ | 0.81 | 3.30 | 3.40 | 1.29 | 5.07 |
| $TB$ | 0.73 | 0.40 | 0.84 | 0.87 | 1.04 |
| $\pi$ | 0.35 | 0.68 | 0.76 | 0.65 | 0.54 |
| $R$ | 0.04 | 0.91 | 0.91 | 0.29 | 1.68 |
| *Persistence* | | | | | |
| $\Gamma$ | 0.191 | 0.361 | 0.361 | 0.806 | 0.841 |
| $Y$ | 0.859 | 0.569 | **0.841** | 0.668 | **0.845** |
| *Correlation* | | | | | |
| $\frac{e}{e_{-1}}, \Gamma$ | 0.648 | 0.780 | **0.781** | **0.775** | **0.988** |
| $Y_1, Y_2$ | 0.454 | 0.938 | **0.485** | **0.499** | **0.409** |
| $C_1, C_2$ | 0.999 | 0.406 | 0.699 | 0.697 | 0.035 |

Statistics are obtained from 500 simulations of the series that are filtered according through Hodrick and Prescott's (1997) method. Column 5 displays the results of the PTM model with the same set of parameters (i.e. with $\phi = 25$ and $\Phi = 20$), to compare the performances of both models every thing else equal. Column 6 recalls the corresponding empirical moments.

As in the PTM model, column 2 shows that technological shocks do not help better explaining exchange rate moments: their volatilities remain far below the empirical ones. Regards the impact of monetary perturbations on exchange rate moments, quantitative results are significantly altered by the adding of credit market frictions as shown in column 3. Volatilities of both nominal and real exchange rates are now closer to their empirical counterparts. First, the nominal exchange rate is more reactive to monetary shocks, the larger magnitude of the overshooting dynamics translating into a higher volatility. Second, in presence of local currency price rigidity, the higher nominal exchange rate volatility is transmitted to the real exchange rate. The lower persistence of real exchange rate comes as a side effect of its higher volatility. If the PTM + LP model better matches the real exchange rate volatility (nominal shocks now generate amplified instantaneous real exchange rate responses), it meets some difficulty in *simultaneously* generating enough real exchange rate persistence as compared to stylized facts. This is not a surprising result as other international dynamic stochastic general equilibrium models also meet some difficulty in replicating the empirical persistence of the real exchange rate (Chari et al., 2002). Besides, this should not necessarily be considered as a problem according to Imbs et al.'s (2005) results. Indeed, they show that empirical estimates of the *aggregate* real exchange rate persistence that do not account for sectorial heterogeneity are subject to substantial upward bias. Once such effects have been purged, the estimated persistence degree is significantly lower and one-sector models as Chari et al.'s (2002) and ours, do not perform so poorly on that front. Their results suggest that multi-sector models are needed to match the real exchange rate persistence obtained on aggregate data.

When the model is subject to both real and monetary shocks (column 4), the result that nominal and real exchange rates are much more volatile in presence of credit market frictions remains. Regards real aggregates, consumption volatility has increased while the opposite holds for output as compared to the PTM model (Table 3 and column 5). Output is now slightly less volatile than consumption. As detailed in the sensitivity analysis, this shortcoming can be related to the value of the elasticity of substitution between varieties and could be overcome assuming higher values for $\theta$ but namely at the expense of the positive cross-country GDP correlation. Trade balance standard deviation is almost unchanged as compared to the PTM model. The volatility of the nominal interest rate has significantly increased which is not so surprising given that the nominal interest rate now plays a central role in the model; moreover its theoretical volatility remains below the empirical one, which shows that the model generates a strong volatility of the nominal exchange rate without relying on an implausible one regards nominal interest rate. Performances regards cross-country correlations are similar to the PTM model; in particular the model correctly replicates the positive cross-country output correlation.

On the whole, the model suffers from generating too little volatility in the macroeconomic real aggregates, as already the case in the PTM model. In the same time, the model including credit market frictions displays exchange rate fluctuations higher than in the PTM model. Indeed, the comparison between both models for the same calibration (columns 4 and 5) shows that the adding of credit market frictions in the PTM framework raises the standard deviation of nominal and real exchange rate by around 80%. Table 5 compares the performances of both models in terms of nominal and real exchange rates volatilities relative to those of output and the monetary growth rate, in the case of monetary innovations (columns 2 and 3) and both monetary and technological innovations (columns 4 and 5). Results in Table 5 confirm that the propagation mechanisms of the PTM-LP model help improving the predicted exchange rate volatilities, both from an absolute and relative point of view.

When subject to real and monetary shocks, both nominal and real exchange rates are now much more volatile than output and money supply; the nominal exchange rate standard-deviation is twice higher than output. In the PTM model, the predicted relative volatility of real exchange rate (with respect to output) is below one while it amounts to 2 when credit market frictions are included. Besides, the correlation between the nominal and real exchange rate is slightly increased in Table 4 as compared to Table 3. From that point of view, the introduction of credit market frictions improves the ability of the PTM model to better explain the nominal and real exchange rate cyclical properties, both regards volatilities and co-movements.

Given the consensus in the VAR literature that attributes to monetary policy innovations a limited share of the variance in the main macroeconomic variables,

Table 5
Elements of comparison

| | Monetary shocks | | Both shocks | |
|---|---|---|---|---|
| | PTM | PTM + LP | PTM | PTM + LP |
| $\sigma_{\Delta e}/\sigma_Y$ | 3.96 | **10.38** | 1.26 | **2.62** |
| $\sigma_{\Delta e}/\sigma_g$ | 1.20 | 2.28 | 1.21 | 2.29 |
| $\sigma_\Gamma/\sigma_Y$ | 2.83 | **7.09** | 0.90 | **1.79** |
| $\sigma_\Gamma/\sigma_g$ | 0.86 | 1.56 | 0.86 | 1.56 |

our goal is not to explain the whole variability of exchange rates. We rather aim at showing that the interaction between both types of frictions builds up a powerful amplification mechanism of monetary shocks on exchange rates. Besides, we focus here on one source of real exchange rates fluctuations, i.e. changes in the relative traded-goods prices between countries. Our results allow us to claim that our setting delivers a partial but convincing explanation of the huge nominal and real exchange rate fluctuations observed in the data.

In comparison with Chari et al.'s (2002) model, we show that properties of the PTM model are substantially improved regards exchange rates when adding credit market frictions. The model is able to display nominal and real exchange rate volatilities much larger to those of their macroeconomic fundamentals, without relying on a implausibly high degree of risk-aversion. Our paper is also related to Kollmann (2001b), which develops a two-country stochastic general equilibrium model mostly oriented to highlight the role of price and wage rigidities regards international comovements of output (as compared to a flexible-price setting). Our paper differs on that respect since it focuses most on exchange rate movements. Yet on the cross-country GDP correlation front, our model correctly reproduces the sign and the scale of the empirical cross-country GDP correlation as Kollmann (2001b). Furthermore, it displays improved results regards the relative volatility of both nominal and real exchange rates (relative to output).[34] A large number of papers confirm the potential role for combining both sticky-prices and LP in a closed-economy setting (Hendry and Zhang, 2001; Papadopoulou, 2004 among others). Our paper goes one-step further. Our results demonstrate the relevance of adding credit market imperfections to sticky-prices in an international framework.

We investigate the robustness of our results to the calibration of some key parameters.[35] IRFs analysis (Section 3.3) makes clear that the degree of nominal price rigidity $\Phi$, the degree of capital adjustment costs $\phi$ and the degree of portfolio

[34]In Kollmann's (2001b) paper, in the baseline model with a similar calibration of technological and monetary shocks, the real exchange rate volatility relative to output remains inferior to 1 while it is slightly superior to 1 for the nominal exchange rate.

[35]Tables relative to the sensitivity analysis to $\xi$, $\Phi$, $\phi$, $\theta$ are displayed in the Appendix of the paper available on the author's webpage. We sum up main results here.

adjustment costs $\xi$ substantially influence the exchange rate dynamics through their role on loan demand behavior on the credit market. This is confirmed when considering their influence on exchange rate volatilities. The higher $\xi$ and/or the higher $\phi$, the larger nominal exchange rate overshooting and the larger real exchange rate depreciation. In quantitative terms, it translates into higher nominal and real exchange rates volatilities. On the contrary, the nominal exchange rate volatility is hardly affected by the degree of nominal price rigidity. This is not the case for the real exchange rate whose volatility substantially increases with $\Phi$. As import prices are directly set in the buyer's currency, consumption price indices are independent of nominal exchange rate movements. Hence CPIs changes are due to sale prices variations, whose magnitude is limited when $\Phi$ is high. With a higher degree of price rigidity, for a given nominal exchange rate depreciation (following a money shock), the real exchange rate depreciates all the more as prices are rigid, and the implied real exchange rate volatility as well.

Kollmann (2001b) underlines that the elasticity of substitution between varieties $\theta$ has a significant influence on international comovements of output, namely in response to technological shocks. We investigate this point through a sensitivity analysis to $\theta$ and we obtain results consistent with Kollmann (2001b)'s findings. A high value of $\theta$ makes the GDP cross-country correlation negative while it also raises GDP standard-deviation (following technological shocks, and both real and nominal shocks). If a higher elasticity of substitution between national varieties improves the performances of the model regards output volatility, it comes at the cost of counterfactual predictions for international output comovements.

### *3.5. Variants*

The sensitivity analysis to some key parameters allows us to improve our understanding of the mechanisms of the model and to gauge the robustness of our results. We now examine the sensitivity of our findings by varying assumptions about two features of the reference model. First, several papers have recently tried to account for the large nominal and real exchange rate fluctuations by arguing that incomplete financial markets are a key element of the explanation. We therefore simulate a version of the PTM + LP model with financial markets incompleteness. Second, a large bulk of papers stemming from Taylor's (1993) paper, describe the behavior of the monetary authorities of developed countries through an endogenous IR. We thus amend the model in that direction.

Table 6 presents the quantitative results when the incomplete markets (IM hereafter) version of the benchmark model is simulated (column 2). It also reports the quantitative results of the variant of the model with an endogenous Taylor rule (column 3), and for sake of comparison, the same statistics obtained in the benchmark model (column 4).[36]

[36]Results are displayed when the models are subject to monetary and technological shocks. Statistics are obtained from 500 simulations of the series that are filtered according through Hodrick and Prescott's (1997) method.

Table 6
Results of the variants

| | IM version | IR rule | Benchmark |
|---|---|---|---|
| *Volatility (in %)* | | | |
| $\Delta e$ | 2.16 | 0.65 | 2.18 |
| $\Gamma$ | 1.47 | 0.45 | 1.49 |
| $Y$ | 0.84 | 0.83 | 0.83 |
| $C$ | 0.93 | 0.67 | 0.93 |
| $I$ | 3.41 | 1.27 | 3.40 |
| $TB$ | 0.84 | 0.74 | 0.84 |
| $R$ | 0.90 | 0.22 | 0.91 |
| $\pi$ | 0.76 | 0.27 | 0.76 |
| *Persistence* | | | |
| $\Delta e$ | −0.201 | −0.198 | −0.202 |
| $\Gamma$ | 0.362 | 0.364 | 0.361 |
| $Y$ | 0.841 | 0.862 | 0.841 |
| *Correlation* | | | |
| $\Delta e, \Gamma$ | 0.781 | 0.774 | 0.780 |
| $Y_1, Y_2$ | 0.481 | 0.480 | 0.485 |
| $C_1, C_2$ | 0.701 | 0.949 | 0.699 |

### 3.5.1. *The model with market incompleteness*

We introduce financial market incompleteness in the PTM + LP model, in line with the papers by Devereux and Engel (2002), Duarte and Stockman (2005) and Ghironi (2001) which show the role of IM in the international transmission of shocks.

We now consider that only a no-risk interest rate bond is issued whatever the state of nature. The international bond is issued in domestic currency; when subscribed in period $t$, it yields a no-risk nominal interest rate $i_t$ in $t+1$. As discussed by Ghironi (2001), the introduction of incomplete asset markets alters the property of stationarity of the model, since temporary shocks have permanent effects on macroeconomic variables. The recent literature on the subject proposes alternative ways of avoiding non-stationarity. Corsetti et al. (2004) achieve steady state determinacy by using an endogenous discount factor. Kollmann (2004) introduces adjustment costs on assets for similar purposes. We adopt Kollmann's method by assuming that each household faces adjustment costs in terms of composite goods when increasing her stock of international assets.[37]

Only the intertemporal program of the domestic and foreign households is altered by the introduction of market incompleteness. The household maximizes her intertemporal utility, subject to the cash-in-advance constraint (Eq. (5)) and the

[37]Schmitt-Grohe and Uribe (2003) investigate the quantitative differences implied by alternative approaches proposed in the literature to induce stationarity. The main finding of the paper is that all versions deliver virtually identical dynamics at business-cycle frequencies.

budget constraint that is now written

$$P_{1t}C_{1t} + M^c_{1t+1} + M^b_{1t+1} + B_1 + P_{1t}\frac{\phi_B}{2}\left(\frac{B_{1t+1}}{P_{1t}}\right)^2$$
$$\leqslant M^c_{1t} + P_{1t}w_{1t}(1 - L_{1t} - \Omega_{1t}) + R_{1t}M^b_{1t} + (1 + i_t)B_{1t}$$
$$+ \int_0^n \pi^f_{1t}(z)\,\mathrm{d}z + \pi^b_{1t} \quad (\lambda_{1t})$$

with $i_t$ the nominal interest rate on the international asset and $\phi_B > 0$ the parameter of adjustment costs on international assets. Eqs. (7), (8), (47) and (48) for the optimal choices of $C_{1t}, L_{1t}, M^b_{1t+1}$ and $M^c_{1t+1}$ still hold. Regards the optimal choice of international assets, we get

$$\lambda_{1t} + \phi_B\lambda_{1t}\left(\frac{B_{1t+1}}{P_{1t}}\right) = \beta \mathrm{E}_t[(1 + i_{t+1})\lambda_{t+1}].$$

A similar expression holds in the foreign country. After taking into account the different market equilibrium conditions, we get the law of motion of international assets for each country, that is the evolution of its balance of payments:

$$B_{1t+1} - B_{1t} = i_t B_{1t} + n[p^1_{1t}x^1_{1t} + e_t p^2_{1t}x^2_{1t}] - P_{1t}D_{1t}$$

with the right-hand sight of the equation representing the domestic current account and $D_{1t}$ aggregate domestic demand (including the demand for adjusting international assets).

A standard result of financial market incompleteness is to break the link between relative marginal utility of wealth and the real exchange rate since Eq. (12) no longer holds. From that point of view, financial markets incompleteness allows to disentangle the real exchange rate from macroeconomic variables which makes it considered as a critical element for explaining the exchange rate disconnect puzzle in the related literature. To investigate that point, the model is solved and simulated. We assume that trade balances are null and the stock of international assets in each country is null as well in the steady state equilibrium; the stock of foreign assets $B_{it+1}$ is linearized around the steady state level of output as in Ghironi (2001). The only free parameter to set is $\phi_B$ as the other structural parameters are kept identical. We follow Kollmann (2004) by calibrating the ratio $\phi_B/\chi$ with $\chi$ the steady state value for exports. In line with Kollmann's paper and Lane and Milesi-Ferretti's (2001) empirical results on major developed countries, the value for $\phi_B$ is set so as $\phi_B/\chi = 0.0038$.

As shown in Table 6, the introduction of market incompleteness does not substantially improve the quantitative results obtained in the benchmark model regards exchange rate dynamics. Neither volatilities, persistence nor co-movements between nominal and real exchange rates are significantly affected by the incompleteness of financial assets market which stands in contrast with the results of Duarte and Stockman (2005) and Devereux and Engel (2002). However, both these papers and our's reach the similar conclusion on the importance of breaking the CKM risk-sharing condition (Eq. (14)) if one is willing to generate empirically plausible exchange rates volatilities with a realistic risk aversion degree. In contrast to these papers, we show that it can be fulfilled under complete markets with an alternative way of introducing money (through a cash-in-advance constraint). Adding financial markets incompleteness is not then very helpful given that such a modelling has already allowed to break the link between exchange rates and relative consumption.

### 3.5.2. The model with an endogenous IR

The implementation of monetary policy by the central banks in the United States and Europe is extensively debated. For the benchmark economy, we have considered that central banks follow a simple rule, namely exogenous processes for monetary growth rates. Nevertheless, stemming from Taylor's (1993) paper, the related literature points out that the actual monetary authorities behavior is better approximated by an endogenous IR. We thus amend the benchmark model to adopt an endogenous IR. More precisely, we assume that the central bank in each country gradually adjusts the short-term nominal interest rate $R_{it}$ in response to deviations of output, inflation and money growth from their steady state values $Y$, $\pi$ and $g$ according to the policy rule[38]

$$\ln\frac{R_{it}}{R} = \rho_r \ln\frac{R_{it-1}}{R} + \rho_\pi \ln\frac{\pi_{it}}{\pi} + \rho_y \ln\frac{Y_{it}}{Y} + \rho_g \ln\frac{g_{it}}{g} + \varepsilon_{R,it+1}, \quad i = 1,2. \tag{53}$$

The specified rule is commonly found in the literature and its calibration is similar to Papadopoulou (2004). Parameters $\rho_y$ and $\rho_\pi$ are strictly positive as long as central banks are willing to stabilize output and inflation. We set them equal to 0.01 and 0.5, respectively. As discussed in Clarida et al. (2000), OECD central banks have a tendency to smooth interest rates which implies $0<\rho_r<1$. We set $\rho_r = 0.75$. Besides, we allow monetary authorities to react to the current money growth rate as in Ireland (2001b) and we set $\rho_g = 0.5$. The standard deviation of the *iid* monetary innovation is equal to 0.004.

When simulating the model with an IR, we find that the performances regards exchange rate volatilities are rather limited: in Table 6, nominal and real exchange rates display less volatility than with an exogenous monetary process (columns 3 and 4). Moments related to real aggregates are not significantly altered.

The lower exchange rate volatilities in the IR model can be accounted by the innovation-propagation mechanism at the heart of the model. First, the monetary innovation is twice lower in the IR version than both in the benchmark and IM models (0.004 as compared to 0.009) and this helps explaining the lower theoretical volatilities of the nominal variables (interest rate, inflation, nominal exchange rate). From the propagation mechanisms side, two opposite effects come into play. On the one hand, the endogenous policy reaction tends to offset the impact of the monetary innovation. As the monetary innovation tends to raise inflation and output in the contemporaneous and subsequent periods, it leads the central bank to

[38] As a result, Eqs. (36) and (37) disappear from the relevant equations system, replaced by Eq. (53) for $i = 1,2$. Monetary growth rates are now endogenous.

endogenously increase the nominal interest rate. This effect tends to dampen the liquidity effect. On the other hand, the interest rate smoothing behavior and the presence of credit-market frictions contribute to the persistence of the liquidity effect.[39] As a result, if the width of the immediate interest rate decrease is limited, it nevertheless persists over time, generating a nominal exchange rate overshooting to restore UIP.

The model does more poorly when monetary policy is conducted through an IR specified as Eq. (53). The result that monetary innovations play a limited role in the macroeconomic fluctuations is in line with the empirical consensus in the VAR literature that it is the systematic portion of monetary policy that really matters, i.e. the endogenous behavior of the interest rate, rather than exogenous innovations (Leeper et al., 1996). Besides, the somehow disappointing quantitative results of the IR model could suggest that the IR specified and calibrated as in Eq. (53) is not necessary the appropriate one. This opens the route to further developments of the model in that direction.

## 4. Conclusion

In line with the New Open Economy Macroeconomics, recent international business cycle literature stresses out the role of the interaction between monetary shocks, sticky prices and pricing-to-market (PTM) in the large nominal and real exchange rates movements. Another route has been recently advanced by Hairault et al. (2004) which show the role of credit market frictions in the nominal exchange rate movements. The paper goes one step further. It is based on the intuition that both mechanisms are interacting as a powerful transmission channel of monetary shocks on exchange rates.

Our results confirm this intuition. The introduction of credit market frictions substantially improves the performances of the PTM model. In that setting, a positive domestic monetary shock generates a persistent home liquidity effect that translates into a persistent negative interest rate differential and a nominal exchange rate overshooting. With small adjustment costs on money holdings and prices, overshooting substantially contributes to the nominal and real exchange rate volatility. Moreover, the model generates impulse response functions for interest rates, exchange and real aggregates that are consistent with the empirical effects of monetary policy shocks as shown in the related VAR literature.

Our paper also gives interesting insights regards the link between the way of modelling money and the exchange rate puzzle. Indeed, we highlight the importance of breaking the CKM perfect risk-sharing condition to generate empirically plausible exchange rates volatilities with a reasonable risk aversion degree. *Per se* this has already been underlined in the literature (see Duarte and Stockman, 2005; Devereux and Engel, 2002). Our originality is to show that it can be fulfilled without relying on financial markets incompleteness. Our way of introducing money (through a

[39] Precisely, the fact that the interest rate smoothing contributes to the persistence of the liquidity effect is conditional on the initial reduction in the interest rate.

cash-in-advance constraint) breaks the link between exchange rates and relative consumption, even though financial markets are complete. We thus show that adding markets incompleteness in such a setting does not substantially improve the results regards exchange rates moments.

Our paper can be extended in the following directions. First, it would be interesting to go one step further in the evaluation of the empirical performances of the model by implementing structural estimation methods, in line with the papers by Ireland (2001a), Kim (2000) or Altig et al. (2005) (among others). Second, if credit market frictions improve the ability of the PTM model regards exchange rates volatilities, it has difficulty in simultaneously explaining the strong persistence degree of real exchange rate observed empirically. The real exchange rate persistence puzzle remains and calls for further research. Third, the model with an IR displays quantitative results less satisfactory than with an exogenous money supply rule whereas it certainly constitutes a better description of the actual monetary authorities behavior. More research is needed to improve the model in that direction.

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