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Quantitative Assessment of the Role of Incomplete Asset Markets on the Dynamics of the Real Exchange Rate*

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Abstract

I develop a two-country New Keynesian model with capital accumulation and incomplete international asset markets that provides novel insights on the effect that imperfect international risk-sharing has on international business cycles and RER dynamics. I find that business cycles appear similar whether international asset markets are complete or not when driven by a combination of non-persistent monetary shocks and persistent productivity (TFP) shocks. In turn, international asset market incompleteness has sizeable effects if (persistent) investment-specific technology (IST) shocks are a main driver of business cycles. I also show that the model with incomplete international asset markets can approximate the RER volatility and persistence observed in the data, for instance, if IST shocks are near-unit-root. Hence, I conclude that the nature of shocks, the extent of financial integration across countries and the existing limitations on asset trading are central to understand the dynamics of the real exchange rate and the endogenous international transmission over the business cycles.

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1 Introduction

Explaining the volatility and persistence of the real exchange rate (RER) remains a major puzzle in international macroeconomics. A large strand of the literature has focused on imperfections in the goods markets (nominal rigidities) as a possible reason for RER fluctuations. Building on that, many New Open Economy Macro (NOEM) models look closely at the pricing decisions of firms to quantify the contribution of those distortions to account for the stylized facts of the RER. Most of these models, however, take for granted that international asset markets are complete—a modelling assumption that is convenient, but seemingly unrealistic.

The functioning of international asset markets determines the extent to which households can efficiently insure themselves across borders to smooth their consumption path in the presence of country-specific shocks. In that regard, asset markets play an important role for the propagation and transmission of business cycle fluctuations across countries. Hence, the question arises of how sensitive the findings in the literature are to the assumption of complete international asset markets. In this paper, I retain the standard features of the NOEM model with capital accumulation (Martínez-García and Søndergaard (2013)), but abandoning the assumption of complete asset markets in order to provide a quantitative evaluation of the role asset markets play in RER fluctuations.

I adopt a standard incomplete international asset markets specification that restricts the financial assets available to households to just two uncontingent nominal bonds in zero-net supply adding a quadratic cost on international borrowing tied to the real net foreign asset position of the home country (Benigno and Thoenissen (2008) and Benigno (2009)). This set-up represents a departure from the complete international asset market assumption, that also ensures the stationarity of the model solution.

The emphasis of the paper is clearly on the different RER dynamics implied by complete and incomplete asset markets which, in turn, depend on other features of the economy—such as the extent of nominal rigidities, the role of capital accumulation and the nature of shocks. Under complete international asset markets, capital accumulation gives households in both countries a margin of intertemporal adjustment, thereby making the consumption and RER paths smoother. Investment contributes to significantly lower the consumption and RER volatility—irrespective of the shocks driving the business cycle (Martínez-García and Søndergaard (2013)).

Adjustment costs can slow the response of investment to shocks, making it costlier for households to adjust intertemporally through capital accumulation and pushing the volatility of consumption and the RER up. Hence, one of the key implications of the literature is that aggregate productivity (TFP) shocks and even investment-specific technology (IST) shocks cannot induce sufficiently volatile RERs without severely limiting capital accumulation (Martínez-García and Søndergaard (2013)). Nominal rigidities and pricing-to-market can lead to larger deviations of the law of one price and high RER volatility in the NOEM model whenever business cycles are primarily driven by monetary shocks (Betts and Devereux (2000)). However, the RER persistence still falls short of what is observed in the data (see, e.g., Chari *et al.* (2002)) and monetary shocks can hardly be seen as the primary driver of cycles in reality.[1]

This paper departs from the assumption of complete international asset markets that underlies most of the previous findings in the literature. Breaking from perfect international risk-sharing and the tight link this imposes between the RER and relative consumption, I find that a bond economy subject to international borrowing costs generates similar international business cycle patterns in response to productivity (TFP) and monetary shocks (see also the related work of Baxter and Crucini (1995), Heathcote and Perri (2002) and Chari *et al.* (2002)) as the NOEM model with complete asset markets.

[1] High RER persistence tends to occur in response to persistent productivity shocks, but appears tied to the specification of the Taylor (1993) monetary policy (its inertia), the persistence of the monetary shocks themselves, and even the adjustment cost function on capital accumulation.

Asset market incompleteness, however, tends to result in significantly lower RER volatility whenever the business cycles are primarily driven by (persistent but not permanent) IST shocks. IST shocks also induce excessive investment volatility and countercyclical consumption patterns that are inconsistent with the data. The optimal decision to postpone consumption to invest more in response to a positive IST shock leads the RER to appreciate on impact while domestic output increases, but the opposite occurs with either productivity or monetary shocks.

The remainder of the paper is structured as follows: section 2 describes the two-country NOEM model with capital accumulation and incomplete asset markets. Section 3 summarizes the parameterization strategy used for the simulations. Section 4 highlights the quantitative findings, and section 5 concludes. There is also a companion on-line Technical Appendix with additional results, which also characterizes the zero-inflation steady state and derives the optimality conditions, and their log-linearization.[2]

2 A Monetary Model with Incomplete International Asset Markets

2.1 Intertemporal Consumption and Savings

I specify a stochastic, two-country general equilibrium model with nominal rigidities and incomplete asset markets. Each country is populated by an infinitely-lived (representative) household. In each period, the domestic households' utility function is additively separable in consumption, C_t, and labor, L_t. The domestic household maximizes,

$$\sum\nolimits_{\tau=0}^{+\infty} \beta^{\tau} \mathbb{E}_t \left[\frac{1}{1-\sigma^{-1}} \left(C_{t+\tau}\right)^{1-\sigma^{-1}} - \frac{1}{1+\varphi} \left(L_{t+\tau}\right)^{1+\varphi} \right], \tag{1}$$

where $0 < \beta < 1$ is the subjective intertemporal discount factor. The elasticity of intertemporal substitution satisfies that $\sigma > 0$ ($\sigma \neq 1$) and the inverse of the Frisch elasticity of labor supply is $\varphi > 0$.

I assume that households operate under incomplete asset markets with trade in two nominal (uncontigent) riskless bonds denominated in domestic and foreign currency. The domestic household maximizes its lifetime utility in (1) subject to the sequence of budget constraints described by,

$$P_t \left(C_t + X_t + A\left(U_t\right) \widetilde{K}_t \right) + \frac{1}{I_t} B_{t+1} + \frac{1}{I_t^*} S_t B_{t+1}^{F*} + \frac{\mu}{2} \frac{P_t}{I_t^*} \left(\frac{S_t B_{t+1}^{F*}}{P_t} - \overline{a} \right)^2 \leq B_t + S_t B_t^{F*} + W_t L_t + Z_t U_t \widetilde{K}_t + Pr_t, \tag{2}$$

and the law of motion for physical capital,

$$\widetilde{K}_{t+1} \leq (1-\delta) \widetilde{K}_t + V_t \Phi\left(X_t, X_{t-1}, K_t\right) X_t. \tag{3}$$

The foreign household maximizes its lifetime utility (the foreign counterpart of (1)) subject to the sequence of budget constraints described by,

$$P_t^* \left(C_t^* + X_t^* + A\left(U_t^*\right) \widetilde{K}_t^* \right) + \frac{1}{I_t^*} B_{t+1}^* \leq B_t^* + W_t^* L_t^* + Z_t^* U_t^* \widetilde{K}_t^* + Pr_t^* + Tr_t^*, \tag{4}$$

and a law of motion for physical capital analogous to the one described in (3). Here, W_t and W_t^* are the domestic and foreign nominal wages respectively, while P_t and P_t^* are the domestic and foreign CPI indexes. Moreover, X_t and X_t^* are domestic and foreign real investment, Z_t and Z_t^* define the nominal rental rate on

[2] All derivations of the optimality conditions of the model and the log-linearized system of equations used for the simulations are described in Martínez-García (2011) and the on-line Technical Appendix for this paper. Both can be found at: https://sites.google.com/site/emg07uw/.

capital in the domestic and foreign country, and Pr_t and Pr_t^* are the nominal profits generated by the domestic and foreign firms respectively.

I model the exogenous investment-specific technological (IST) shocks in the domestic and foreign country, V_t and V_t^*, with the following vector-autoregressive specification:

$$\begin{bmatrix} \ln V_t \\ \ln V_t^* \end{bmatrix} = \begin{bmatrix} \rho_v & 0 \\ 0 & \rho_v \end{bmatrix} \begin{bmatrix} \ln V_{t-1} \\ \ln V_{t-1}^* \end{bmatrix} + \begin{bmatrix} \epsilon_t^v \\ \epsilon_t^{v^*} \end{bmatrix}, \tag{5}$$

where $\mathbb{E}_t\left(\epsilon_t^v\right) = \mathbb{E}_t\left(\epsilon_t^{v^*}\right) = 0$, $\mathbb{E}_t\left(\left(\epsilon_t^v\right)^2\right) = \mathbb{E}_t\left(\left(\epsilon_t^{v^*}\right)^2\right) = \sigma_v^2$, and $\mathbb{E}_t\left(\epsilon_t^v, \epsilon_t^{v^*}\right) = \sigma_v\sigma_v\psi_v$ for all t.

Capital services in the domestic and foreign country, K_t and K_t^*, are related to the corresponding stock of physical capital, $\widetilde{K}_t$ and $\widetilde{K}_t^*$, by the following expressions,

$$K_t = U_t\widetilde{K}_t,\ K_t^* = U_t^*\widetilde{K}_t^*. \tag{6}$$

Hence, capital services can be different from physical capital and U_t and U_t^* denote the domestic and foreign utilization rate of capital (Christiano *et al.* (2005)). The increasing, convex functions, $A\left(U_t\right)\widetilde{K}_t$ and $A\left(U_t^*\right)\widetilde{K}_t^*$, denote the cost, in units of their respective consumption goods, incurred by setting the utilization rate in each country.

Finally, B_{t+1} is the domestic demand for the nominal (uncontingent) one-period domestic bond maturing at $t+1$, B_{t+1}^{F*} is the domestic demand for the nominal (uncontingent) one-period foreign bond, and B_{t+1}^* is the foreign nominal demand for the (uncontingent) one-period foreign bond. The domestic- and foreign-currency denominated bonds are issued respectively by the domestic and foreign governments in zero-net supply, and S_t denotes the nominal exchange rate. As in Benigno (2009), I assume quadratic costs on international borrowing that penalize deviations of the real net foreign asset position, $\frac{S_tB_{t+1}^{F*}}{P_t}$, away from a constant value of $\overline{a}$ and a corresponding transfer function $Tr_t^* = \frac{\mu}{2}\frac{P_t}{S_tI_t^*}\left(\frac{S_tB_{t+1}^{F*}}{P_t} - \overline{a}\right)^2$. Foreign households accrue the revenue generated from these international borrowing costs. The parameter $\mu > 0$ measures the size of the international borrowing cost in units of the consumption good, which is then re-scaled by $\frac{P_t}{I_t^*}$ for analytical convenience.

The asymmetry in the financial market structure between domestic and foreign households is made for simplicity. For an extension of this set-up in which domestic and foreign households can trade in bonds denominated in both currencies, see Benigno (2009). I re-interpret the model presented here as a polar case of Benigno (2009) in which the costs of international borrowing are prohibitively high for the foreign household, but not for the domestic household. This modelling assumption introduce an asset market structure that is incomplete internationally (Benigno and Thoenissen (2008) and Benigno (2009)) and serves to close the model down inducing stationarity of the real foreign asset position.[3]

Adjustment Costs on Capital Investment. The capital accumulation in (3) may be subject to adjustment costs captured by the function $\Phi\left(\cdot\right)$. I consider three special cases: the no adjustment costs (NAC) case, the capital adjustment cost (CAC) case, and the investment adjustment cost (IAC) case. The NAC function is simply $\Phi\left(X_t, X_{t-1}, K_t\right) = 1$. The NAC function for the foreign law of motion for capital accumulation is the obvious counterpart. This implies that in steady state $\Phi\left(\overline{X}, \overline{X}, \overline{K}\right) = 1$, $\Phi'\left(\overline{X}, \overline{X}, \overline{K}\right) = 0$, and $\Phi''\left(\overline{X}, \overline{X}, \overline{K}\right) = 0$.

The capital adjustment cost (CAC) function (Chari *et al.* (2002)) and the investment adjustment cost (IAC)

[3] Mandelman *et al.* (2011) provide a related implementation of incomplete international asset markets within a standard international real business cycle model. Consumers trade across countries on an uncontingent international one-period riskless bond denominated in units of Home-country intermediate goods with an arbitrarily small cost of bondholdings expressed in the same units—which induces stationarity, but does not significantly affect the dynamics of the model.

function (Christiano *et al.* (2005)) imply that the function $\Phi(\cdot)$ in (3) takes the following form,

$$\Phi\left(\frac{X_t}{K_t}\right) = 1 - \frac{1}{2}\chi\frac{\left(\frac{X_t}{K_t}-\delta\right)^2}{\frac{X_t}{K_t}}, \qquad \Phi\left(\frac{X_t}{X_{t-1}}\right) = 1 - \frac{1}{2}\kappa\frac{\left(\frac{X_t}{X_{t-1}}-1\right)^2}{\frac{X_t}{X_{t-1}}}, \tag{7}$$

where $\frac{X_t}{K_t}$ is the investment-to-capital ratio, $\frac{X_t}{X_{t-1}}$ is the gross rate of investment, δ is the depreciation rate from the law of motion for capital, and $\chi \geq 0$ and $\kappa \geq 0$ measure the curvature of each cost function. Similarly for the foreign household's problem. Hence, the CAC case implies in steady state that $\Phi(\delta) = 1$, $\Phi'(\delta) = 0$, and $\Phi''(\delta) = -\frac{\chi}{\delta}$, while the IAC case has that $\Phi(1) = 1$, $\Phi'(1) = 0$, and $\Phi''(1) = -\kappa$.

Aggregation Rules and the Price Indexes. I assume that investment, like consumption, is a composite index of domestic and imported foreign varieties. The home and foreign consumption bundles of the domestic household, C_t^H and C_t^F, as well as the investment bundles, X_t^H and X_t^F, are aggregated by means of a CES index as,

$$C_t^H = \left[\int_0^1 C_t(h)^{\frac{\theta-1}{\theta}} dh\right]^{\frac{\theta}{\theta-1}}, \; C_t^F = \left[\int_0^1 C_t(f)^{\frac{\theta-1}{\theta}} df\right]^{\frac{\theta}{\theta-1}}, \tag{8}$$

$$X_t^H = \left[\int_0^1 X_t(h)^{\frac{\theta-1}{\theta}} dh\right]^{\frac{\theta}{\theta-1}}, \; X_t^F = \left[\int_0^1 X_t(f)^{\frac{\theta-1}{\theta}} df\right]^{\frac{\theta}{\theta-1}}, \tag{9}$$

while aggregate consumption and investment, C_t and X_t, are defined with another CES index as,

$$C_t = \left[\phi_H^{\frac{1}{\eta}}\left(C_t^H\right)^{\frac{\eta-1}{\eta}} + \phi_F^{\frac{1}{\eta}}\left(C_t^F\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \; X_t = \left[\phi_H^{\frac{1}{\eta}}\left(X_t^H\right)^{\frac{\eta-1}{\eta}} + \phi_F^{\frac{1}{\eta}}\left(X_t^F\right)^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}. \tag{10}$$

The elasticity of substitution across varieties produced within a country is $\theta > 1$, and the elasticity of intratemporal substitution between the home and foreign bundles of varieties is $\eta > 0$. The share of the home goods in the domestic aggregators is ϕ_H, while the share of foreign goods is ϕ_F. Similarly, I define the aggregators for the foreign household assuming that the share of foreign goods in the foreign aggregator is ϕ_H while the share of domestic goods in the foreign aggregator is ϕ_F. I assume the shares are homogeneous, i.e. $\phi_H + \phi_F = 1$.

Under standard results on functional separability, the CPI indexes which correspond to my specification of the domestic aggregators in (10) and their foreign counterparts are,

$$P_t = \left[\phi_H\left(P_t^H\right)^{1-\eta} + \phi_F\left(P_t^F\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}, \; P_t^* = \left[\phi_F\left(P_t^{H*}\right)^{1-\eta} + \phi_H\left(P_t^{F*}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}}, \tag{11}$$

and the price sub-indexes are,

$$P_t^H = \left[\int_0^1 \left(P_t(h)\right)^{1-\theta} dh\right]^{\frac{1}{1-\theta}}, \; P_t^F = \left[\int_0^1 \left(P_t(f)\right)^{1-\theta} df\right]^{\frac{1}{1-\theta}}, \tag{12}$$

$$P_t^{H*} = \left[\int_0^1 \left(P_t^*(h)\right)^{1-\theta} dh\right]^{\frac{1}{1-\theta}}, \; P_t^{F*} = \left[\int_0^1 \left(P_t^*(f)\right)^{1-\theta} df\right]^{\frac{1}{1-\theta}}, \tag{13}$$

where P_t^H and P_t^F are the price sub-indexes for the home- and foreign-produced bundle of goods in units of the home currency. Similarly for P_t^{H*} and P_t^{F*} in units of the foreign currency. I define the real exchange rate as $RS_t \equiv \frac{S_t P_t^*}{P_t}$, where S_t denotes the nominal exchange rate.

2.2 The Price-Setting Behavior

Each firm supplies the home and foreign market, and sets prices in the local currency (henceforth, local-currency pricing (LCP) or pricing-to-market). Re-selling is infeasible and, furthermore, firms enjoy monopolistic power in their own variety. Frictions in the goods market are modelled with nominal price stickiness à la Calvo (1983). At time t any firm (whether domestic or foreign) is forced to maintain its previous period prices in the domestic and foreign markets with probability $0 < \alpha < 1$. Instead, with probability $(1-\alpha)$, the firm receives a signal to optimally reset both prices.

Local production operates under a Cobb-Douglas technology, i.e.,

$$Y_t(h) = A_t (K_t(h))^{1-\psi} (L_t(h))^{\psi}, \ \forall h \in [0,1], \tag{14}$$

$$Y_t^*(f) = A_t^* (K_t^*(f))^{1-\psi} (L_t^*(f))^{\psi}, \ \forall f \in [0,1], \tag{15}$$

where A_t and A_t^* are the (aggregate) domestic and foreign productivity (TFP) shocks. The TFP shock process is modeled with the following vector-autoregressive specification:

$$\begin{bmatrix} \ln A_t \\ \ln A_t^* \end{bmatrix} = \begin{bmatrix} \rho_a & 0 \\ 0 & \rho_a \end{bmatrix} \begin{bmatrix} \ln A_{t-1} \\ \ln A_{t-1}^* \end{bmatrix} + \begin{bmatrix} \epsilon_t^a \\ \epsilon_t^{a^*} \end{bmatrix}, \tag{16}$$

where $\mathbb{E}_t(\epsilon_t^a) = \mathbb{E}_t\left(\epsilon_t^{a^*}\right) = 0$, $\mathbb{E}_t\left((\epsilon_t^a)^2\right) = \mathbb{E}_t\left(\left(\epsilon_t^{a^*}\right)^2\right) = \sigma_a^2$, and $\mathbb{E}_t\left(\epsilon_t^a, \epsilon_t^{a^*}\right) = \sigma_a \sigma_a \psi_a$ for all t.

The labor share in the production function is represented by $0 \leq \psi \leq 1$.[4] Solving the cost-minimization problem of each individual firm yields an efficiency condition linking the capital-to-labor ratio to the factor price ratio which helps characterize the nominal marginal costs as follows,

$$\frac{K_t}{L_t} = \frac{K_t(h)}{L_t(h)} = \frac{1-\psi}{\psi}\frac{W_t}{Z_t}, \ \forall h \in [0,1], \ MC_t = \frac{1}{A_t}\frac{1}{\psi^{\psi}(1-\psi)^{1-\psi}}(W_t)^{\psi}(Z_t)^{1-\psi}, \tag{17}$$

$$\frac{K_t^*}{L_t^*} = \frac{K_t^*(f)}{L_t^*(f)} = \frac{1-\psi}{\psi}\frac{W_t^*}{Z_t^*}, \ \forall f \in [0,1], \ MC_t^* = \frac{1}{A_t^*}\frac{1}{\psi^{\psi}(1-\psi)^{1-\psi}}(W_t^*)^{\psi}(Z_t^*)^{1-\psi}. \tag{18}$$

Wages equalize within each country, i.e. $W_t(h) = W_t$ for all $h \in [0,1]$ and $W_t^*(f) = W_t^*$ for all $f \in [0,1]$. Naturally, so does the rental rate on capital, i.e. $Z_t(h) = Z_t$ for all $h \in [0,1]$ and $Z_t^*(f) = Z_t^*$ for all $f \in [0,1]$. Then, all local firms select the same capital-to-labor ratio and the factors of production are compensated according to their marginal products across all firms.

The Optimal Pricing Problem. A re-optimizing domestic firm h under LCP pricing chooses a domestic and a foreign price, $\widetilde{P}_t(h)$ and $\widetilde{P}_t^*(h)$, to maximize the expected discounted value of its net profits,

$$\sum_{\tau=0}^{+\infty} \mathbb{E}_t \left\{ \alpha^{\tau} M_{t,t+\tau} \left[\begin{array}{c} \left(\widetilde{C}_{t,t+\tau}(h) + \widetilde{X}_{t,t+\tau}(h)\right)\left(\widetilde{P}_t(h) - MC_{t+\tau}\right) + ... \\ \left(\widetilde{C}_{t,t+\tau}^*(h) + \widetilde{X}_{t,t+\tau}^*(h)\right)\left(S_{t+\tau}\widetilde{P}_t^*(h) - MC_{t+\tau}\right) \end{array} \right] \right\}, \tag{19}$$

where $M_{t,t+\tau} \equiv \beta^{\tau}\left(\frac{C_{t+\tau}}{C_t}\right)^{-\sigma^{-1}} \frac{P_t}{P_{t+\tau}}$ is the stochastic discount factor (SDF) for τ-periods ahead nominal payoffs (derived from the domestic representative household), subject to a pair of demand constraints in each goods

[4] The aggregate capital accumulated by households in the domestic and foreign country is $K_t = \int_0^1 K_t(h)\,dh$ and $K_t^* = \int_0^1 K_t(f)\,df$ respectively, while aggregate labor is $L_t = \int_0^1 L_t(h)\,dh$ and $L_t^* = \int_0^1 L_t(f)\,df$ respectively.

market,

$$\widetilde{C}_{t,t+\tau}(h)+\widetilde{X}_{t,t+\tau}(h) = \left(\frac{\widetilde{P}_t(h)}{P^H_{t+\tau}}\right)^{-\theta}\left(C^H_{t+\tau}+X^H_{t+\tau}\right), \quad (20)$$

$$\widetilde{C}^*_{t,t+\tau}(h)+\widetilde{X}^*_{t,t+\tau}(h) = \left(\frac{\widetilde{P}^*_t(h)}{P^{H*}_{t+\tau}}\right)^{-\theta}\left(C^{H*}_{t+\tau}+X^{H*}_{t+\tau}\right). \quad (21)$$

Here, $\widetilde{C}_{t,t+\tau}(h)$ and $\widetilde{C}^*_{t,t+\tau}(h)$ indicate the consumption demand for any variety h at home and abroad respectively, given that prices $\widetilde{P}_t(h)$ and $\widetilde{P}^*_t(h)$ remain unchanged between time t and $t+\tau$. Similarly, $\widetilde{X}_{t,t+\tau}(h)$ and $\widetilde{X}^*_{t,t+\tau}(h)$ indicate the households' investment demand at those same prices.[5] I characterize the problem of the foreign firm in analogous terms to optimally set $\widetilde{P}_t(f)$ and $\widetilde{P}^*_t(f)$.

2.3 Monetary Policy

The policy instrument of the domestic and foreign monetary authorities are the short-term rates I_t and I^*_t respectively, while $\overline{I}$ and $\overline{I}^*$ are their corresponding steady state values. I assume that the monetary authorities of both countries set short-term nominal interest rates according to Taylor (1993) type rules,[6]

$$\begin{aligned} I_t &= M_t\left(I_{t-1}\right)^{\rho_i}\left[\overline{I}\left(\frac{\Pi_t}{\overline{\Pi}}\right)^{\psi_\pi}\left(\frac{Y_t}{\overline{Y}}\right)^{\psi_y}\right]^{1-\rho_i}, \\ I^*_t &= M^*_t\left(I^*_{t-1}\right)^{\rho_i}\left[\overline{I}^*\left(\frac{\Pi^*_t}{\overline{\Pi}^*}\right)^{\psi_\pi}\left(\frac{Y^*_t}{\overline{Y}^*}\right)^{\psi_y}\right]^{1-\rho_i}, \end{aligned} \quad (22)$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ and $\Pi^*_t \equiv \frac{P^*_t}{P^*_{t-1}}$ are the (gross) CPI inflation rates, Y_t and Y^*_t are the respective output levels, and M_t and M^*_t are the domestic and foreign monetary policy shocks. The monetary shock process is modeled with the following vector-autoregressive specification:

$$\begin{bmatrix} \ln M_t \\ \ln M^*_t \end{bmatrix} = \begin{bmatrix} \rho_m & 0 \\ 0 & \rho_m \end{bmatrix}\begin{bmatrix} \ln M_{t-1} \\ \ln M^*_{t-1} \end{bmatrix} + \begin{bmatrix} \epsilon^m_t \\ \epsilon^{m^*}_t \end{bmatrix}, \quad (23)$$

where $\mathbb{E}_t\left(\epsilon^m_t\right)=\mathbb{E}_t\left(\epsilon^{m^*}_t\right)=0$, $\mathbb{E}_t\left(\left(\epsilon^m_t\right)^2\right)=\mathbb{E}_t\left(\left(\epsilon^{m^*}_t\right)^2\right)=\sigma^2_m$, and $\mathbb{E}_t\left(\epsilon^m_t,\epsilon^{m^*}_t\right)=\sigma_m\sigma_m\psi_m$ for all t.

Finally, $\overline{\Pi}$ and $\overline{\Pi}^*$ are the steady state (gross) CPI inflation rates, and $\overline{Y}$ and $\overline{Y}^*$ are the corresponding steady state output levels. In other words, the monetary policy rules in (22) respond to local CPI inflation and output deviations from their respective steady state levels. The index captures both a smoothing term and a systematic policy component.

3 Parameterization

The parameterization is roughly similar to that in Chari *et al.* (2002), except where otherwise noted. The intertemporal discount factor, β, equals 0.99 and the intertemporal elasticity of substitution, σ, is 1/5. The share of foreign goods, ϕ_F, is set to 0.06. The elasticity of substitution across varieties, θ, is chosen to equal 10 to be consistent with a price mark-up of 11%. Moreover, θ pins down the steady state investment share (over

[5] Alternatively, I consider a different assumption on pricing behavior whereby firms maximize their expected discounted net profits setting one price for each variety in the local currency of the producer (i.e., $\widetilde{P}_t(h)=\widetilde{P}^*_t(h)$ and $\widetilde{P}_t(f)=\widetilde{P}^*_t(f)$). This is known as producer-currency pricing (PCP).

[6] This index specification of the Taylor rule takes the standard form once it is log-linearized.

GDP), $\gamma_x \equiv \delta \left[\frac{1-\psi}{\left(\frac{\theta(1-\bar{\xi})}{\theta-1}\right)\left(\beta^{-1}-(1-\delta)\right)} \right]$, at 0.203. I set the labor share in the production function, ψ, equal to 2/3 and the depreciation rate, δ, equal to 0.021.

I choose the intratemporal elasticity of substitution, η, to be equal to 1.5. The inverse of the Frisch elasticity of labor supply, φ, is set at 3 (see the micro evidence in Browning *et al.* (1999)). When appropriate, I set the elasticity of the capital utilization cost, λ, at 5.80. The Calvo price stickiness parameter, α, is assumed to be 0.75. This implies that the average price duration in the model is 4 quarters. As in Steinsson (2008), the interest rate inertia parameter, ρ_i, equals 0.85, while the sensitivity of the nominal policy rate to the inflation target, ψ_π, equals 2, and the sensitivity to the output target, ψ_y, is 0.5.

As in Ghironi *et al.* (2009) and Benigno (2009), I assume that the costs of adjusting the foreign bond holdings with respect to the steady state are such that $\mu = 0.01$ (see Benigno (2009, footnote 9) on this point). I choose $\overline{a}$ to match the $1970 - 2007$ average of the U.S. annual ratio of net foreign assets over GDP which stands at -4.06% according to data from the Lane and Milesi-Ferretti (2007) dataset.[7]

Shock Processes and Adjustment Costs. When defining the shock processes, I assume in my benchmark parameterization that the shock processes are symmetric in both countries. The persistence of the productivity shock, ρ_a, is fixed at 0.9 as in Steinsson (2008). Likewise, I set the persistence of the IST shock, ρ_v, at 0.9. In turn, I assume that monetary shocks are non-persistent by setting ρ_m equal to 0.

I choose the standard deviation of the productivity shock innovation σ_a to 0.7 and the cross-country correlation ψ_a to 0.25 (as in Heathcote and Perri (2002) and Chari *et al.* (2002)). I parameterize the volatility and the cross-correlation of the innovations of the other shock—the monetary or IST shock—to match the observed volatility of U.S. real GDP (1.54) and the observed cross-correlation of U.S. and Euro area real GDP (0.44). In variants of the model that include IST shocks, I set the standard deviation σ_v and the cross-country correlation of the IST innovations ψ_v to replicate those two moments. Similarly, whenever the model specification includes monetary shocks instead of IST shocks, I choose the standard deviation σ_m and the cross-country correlation of the monetary innovations ψ_m to match them.

When appropriate, I select the parameter governing the adjustment cost function—either χ (CAC) or κ (IAC)—to ensure that the volatility of investment relative to output roughly matches the data (3.38 times the volatility of U.S. real GDP). In the simulations with IST shocks an exact match of the investment and output volatilities cannot be attained without pushing the adjustment cost and the IST shock volatility parameters beyond a reasonable range of values. In that case, I match the volatility of U.S. real GDP with the volatility of the IST shock bounded at 10, and I pick the adjustment cost to keep the volatility of investment as low as possible.

[7] For a parameterization of the model that implies $\eta = 1.5$, $\phi_F = 0.06$, $\phi_H = 1 - \phi_F = 0.94$, $\beta = 0.99$ and $\overline{a}^a = -0.04065$, the steady state gives terms of trade that are equal to $\frac{\overline{P}^F}{\overline{P}^H} = 1.0137$. This means a steady state with the domestic country holding a negative amount of real net foreign assets (i.e. $\overline{a}^a < 0$) can only occur if the terms of trade are higher than one (i.e. $\frac{\overline{P}^F}{\overline{P}^H} > 1$)—only in that case I can reconcile the fact that in the steady state the domestic country is a net borrower from the foreign country. Based on the same parameterization, the ratio of real net foreign assets of the domestic household over domestic output must be equal to,

$$\overline{a}^y = \overline{a}^a \left(1 - (1-\beta)\,\overline{a}^a\right)^{\frac{\eta}{1-\eta}} = -0.0406.$$

Therefore, the parameterization is consistent with real net foreign assets over output being around -4.06%, which corresponds to the average annual ratio for the U.S. during the $1970 - 2007$ period based on the data compiled by Lane and Milesi-Ferretti (2007).

4 Quantitative Findings

The model presented in the paper incorporates a standard channel of capital accumulation and the basic features of the NOEM literature—price stickiness and pricing-to-market—while significantly departing from the conventional assumption of complete international asset markets. Furthermore, the model nests a wide range of alternative specifications from linear-in-labor technologies without capital to multiple variants with capital accumulation, different adjustment costs and even variable capital utilization rates.

I start by revisiting the conventional case under complete international asset markets for different variants of the model with capital accumulation in Table 1. The case with no capital (NoC), which is closer to that considered by Steinsson (2008), is compared against a variant of the model with capital accumulation that includes investment adjustment costs (IAC), a variant with capital adjustment costs (CAC), and another variant with no adjustment costs (NAC). I report all those simulations in Columns $3-6$ of Table 1. I conduct some sensitivity analysis in Columns $7-10$.[8] I also contemplate different scenarios in which the business cycles are driven by a combination of productivity (TFP) shocks and IST shocks (Panel 1 of Table 1) or alternatively by a combination of productivity (TFP) shocks and monetary shocks (Panel 2 of Table 1).

[Insert Table 1 about here]

Capital accumulation leads to significantly lower RER volatility in the NOEM model—irrespective of the shocks driving the cycle, as noted also in Martínez-García and Søndergaard (2013). In a similar setting, Chari *et al.* (2002) showed that volatile RERs require monetary shocks to interact with nominal rigidities. These authors argue that if prices were sufficiently sticky (remaining unchanged for at least a year), the elasticity of intertemporal substitution was low, and preferences were additively separable, then the RER fluctuations generated by the model can approximate the RER volatility observed in the data although not its observed empirical persistence. The findings reported in Panel 2 of Table 1 are, not surprisingly, consistent with that previous finding.

In response to a combination of TFP and monetary shocks where the latter is the main driver of the cycle, a variant with capital and adjustment costs that penalizes the growth rate of investment—as proposed in Christiano *et al.* (2005)—rather than the investment-to-capital ratio—as preferred by Chari *et al.* (2002)—is better to account for the volatility of the RER and to match the fluctuations in output, consumption and investment observed in the data. However, it still falls short in terms of RER persistence.

High endogenous RER persistence tends to occur in response to persistent productivity (TFP) shocks or in response to a combination of persistent productivity (TFP) and IST shocks. However, such scenario is not capable of simultaneously generating enough RER volatility to match the data unless very high adjustment costs (or no capital accumulation as assumed by Steinsson (2008)) are imposed on the model—Panel 1 of Table 1 illustrates that point.

Finally, I also explore the sensitivity of the results reported in Table 1 to the parameterization of the adjustment cost function and inclusion of variable capital utilization.[9] I document how variable capital utilization has only modest effects on international business cycles and the real exchange rate, while higher adjustment costs making it more difficult for households to intertemporally smooth consumption through capital accumulation are very important to increase the volatility (and to some extent the persistence) of the RER. However, higher adjustments costs also lead to counterfactually larger investment volatility ratios.

[8] Columns $7-8$ show the results whenever the adjustment costs are set to match the volatility of consumption rather than investment. Columns $9-10$ present the simulations with variable capital utilization.

[9] More sensitivity results regarding the parameterization of the inertia in the Taylor (1993) rule are available in the on-line Technical Appendix.

The findings derived in Table 1 under local-currency pricing and complete international asset markets appear broadly—but not entirely—robust to departures that alter either one or both of these fundamental features of the model. In the next sub-section, I re-establish the law of one price by replacing the assumption of local-currency pricing with producer-currency pricing in international goods markets. In that case, the RER moves in tandem with terms of trade and solely because of differences in the consumption baskets across countries. I find that the distinction between producer-currency pricing and pricing-to-market is also discussed in Martínez-García and Søndergaard (2013) and of particular relevance to investigate the quantitative effects of monetary shocks.

I also depart later on from the assumption of complete international asset markets, which imposes perfect international risk-sharing and a tight link between the RER and relative consumption, by considering a bond economy with incomplete international asset markets and a quadratic cost on international borrowing tied to the real net foreign asset position of the home country (Benigno and Thoenissen (2008) and Benigno (2009)). I find that the complete and incomplete international asset market variants of the model generate very similar international business cycle patterns in response to productivity (TFP) and monetary shocks (along the lines of earlier findings in Baxter and Crucini (1995), Heathcote and Perri (2002) and Chari *et al.* (2002)). However, significant differences can arise between the complete and incomplete international asset markets cases whenever IST shocks are driving the business cycle—particularly if IST persistence is near unit root.

4.1 Producer-Currency Pricing and the Law of One Price

Price stickiness alone does not imply that the law of one price fails in the model. For that, market segmentation and the assumption of local-currency pricing (or pricing-to-market) are also needed. Hence, under producer-currency pricing all prices must equalize across countries when expressed in the same currency—that is, the law of one price must hold—and the RER fluctuates simply because of differences in the consumption baskets of the two countries. Engel (1999) provides empirical evidence supporting the view that deviations of the law of one price on traded goods account for most of the movements in the U.S. RER. While Engel (1999) also considers the possibility that traded-goods are weighted differently in the consumption basket of each country, he concludes that RER fluctuations tied to terms-of-trade movements in that way are not very important in the data.

Not surprisingly, the results reported in Table 2 complement Engel's (1999) data analysis by suggesting that consumption basket differences alone are not able to explain overall RER movements—in fact, the RER performance of the model with producer-currency pricing reported in Table 2 is generally worse than that of the model with local-currency pricing in Table 1. The case with no capital (NoC) is compared against a variant of the model with capital accumulation that includes investment adjustment costs (IAC), a variant with capital adjustment costs (CAC), and another variant with no adjustment costs (NAC). I report all those simulations in Columns $3-6$. I conduct some sensitivity analysis in Columns $7-10$.[10] I contemplate different scenarios in which either the business cycle is driven by a combination of productivity (TFP) shocks and IST shocks (Panel 1 of Table 2) or by a combination of productivity (TFP) shocks and monetary shocks (Panel 2 of Table 2).

`[Insert Table 2 about here]`

Betts and Devereux (2000) argue that local-currency pricing and staggered prices can magnify the response of the RER and distort the international transmission mechanism of monetary policy shocks resulting in lower

[10] Columns $7-8$ show the results whenever the adjustment costs are set to match the volatility of consumption rather than investment. Columns $9-10$ present the simulations with variable capital utilization.

consumption comovement across countries—see also Chari *et al.* (2002) on this point. I observe that the same pattern emerges irrespective of the way capital is modelled by comparing Panel 2 of Table 1 (under local-currency pricing) with Panel 2 of Tables 2 (under producer-currency pricing) where monetary shocks are a major source of business cycle fluctuations. Endogenous persistence tends to be slightly higher with local-currency pricing than in the experiments with producer-currency pricing, but the RER volatility ratio is definitely larger when aided by a large decline in the cross-country consumption correlation and by a small increase in consumption volatility (the mechanics of which are explained in greater detail in Martínez-García and Søndergaard (2013)).

By contrast, the RER volatility amplification attained with local-currency pricing and deviations of the law of one price is much smaller with a combination of productivity (TFP) shocks and IST shocks (Panel 1 of Table 1 vs. Panel 1 of Table 2). The effect of either local-currency pricing or producer-currency pricing on the endogenous RER persistence remains rather modest. What these findings illustrate is that large and distortionary deviations of the law of one price depend on the nature of the shocks. Not surprisingly, most of the international macro models that investigate the RER dynamics through this channel have focused their attention primarily on the connection between nominal rigidities, local-currency pricing and monetary shocks (see Betts and Devereux (2000) and Chari *et al.* (2002)).

I explore the sensitivity of the results reported in Table 2 to the parameterization of the adjustment cost function and the inclusion of variable capital utilization.[11] Interestingly, inspecting these results I find that producer-currency pricing may have a more significant effect on RER volatility than my previous results would suggest—particularly notable whenever the business cycle is primarily driven by a combination of productivity (TFP) shocks and IST shocks but arising at the expense of a counterfactually large investment volatility.[12] The effect of variable capital utilization on the RER dynamics, however, is small irrespective of the combination of shocks that drive the cycle.

Finally, whether I assume local-currency pricing or producer-currency pricing, it is still the case that RERs still tend to be less volatile the easier it gets for households to utilize capital accumulation to intertemporally smooth their consumption.

4.2 IST Shocks and International Asset Market Incompleteness

The functioning of international asset markets determines the extent to which households across countries can efficiently insure amongst themselves to smooth their consumption in the presence of country-specific shocks. Asset markets are crucial for the propagation and transmission of business cycle fluctuations across countries, but most of the existing NOEM literature has often abstracted from asset market frictions of any sort to focus instead on understanding the role of frictions in the goods markets in explaining the RER dynamics.

I observe that the standard bond economy with international borrowing costs, which I laid out in this paper, closely replicates the persistence and volatility of the RER under complete international asset markets (something that is consistent with findings reported in Baxter and Crucini (1995) and Chari *et al.* (2002)). While this seems to hold true in most cases, it depends on the nature of the shocks—in fact, I find that this is not the case whenever IST shocks are one of the main drivers of the business cycle.

The model I adopted allows for capital accumulation and includes nominal rigidities (under local-currency pricing), but restricts the financial assets available to just two uncontingent nominal bonds in zero-net supply with a quadratic cost on international borrowing tied to the real net foreign asset position of the home country (Benigno and Thoenissen (2008) and Benigno (2009)). The main implication of the model is that breaking

[11] More sensitivity results regarding the parameterization of the inertia in the Taylor (1993) rule are available in the on-line Technical Appendix.

[12] Interestingly, with higher adjustment costs the RER volatility increases somewhat while investment volatility declines if the cycle is driven by a combination of productivity (TFP) shocks and monetary shocks.

down the perfect international risk-sharing condition introduces—up to a first-order approximation—deviations in the *uncovered interest rate parity* condition that are linked to bond trading costs and the evolution of the domestic real net foreign asset position.

The full results under incomplete international asset markets are reported in Table 3, and can be compared against the set of results from the complete asset market case in Table 1. The case with no capital (NoC) is compared against a variant of the model with capital accumulation that includes investment adjustment costs (IAC), a variant with capital adjustment costs (CAC), and another variant with no adjustment costs (NAC). I report all those simulations in Columns $3-6$. I conduct some sensitivity analysis in Columns $7-10$.[13] I contemplate two different scenarios in which the business cycles are either driven by a combination of productivity (TFP) shocks and IST shocks (Panel 1 of Table 3) or by a combination of productivity (TFP) shocks and monetary shocks (Panel 2 of Table 3).

`[Insert Table 3 about here]`

My exploration of the model suggests that the complete and incomplete international asset markets cases are pretty close to each other whenever a combination of persistent productivity (TFP) shocks and non-persistent monetary shocks drive the business cycle (Panel 2 of Table 3 compared to Panel 2 of Table 1). The international real business cycle literature without nominal rigidities also shows that a bond economy closely approximates the complete asset markets allocation when driven by persistent productivity shocks—unless, productivity shocks are permanent (or near-permanent) without spill-overs or stricter financial autarky is imposed (Baxter and Crucini (1995) and Heathcote and Perri (2002)). Chari *et al.* (2002) document a similar result in a model with nominal rigidities and non-persistent monetary shocks as the main driver of the cycle.

By contrast, Panel 1 of Table 3 compared to Panel 1 of Table 1 shows that with a combination of productivity (TFP) shocks and IST shocks the RER can become somewhat more persistent but tends to be significantly less volatile than with complete international asset markets. This is an important finding that has gone largely unnoticed in the literature until now—albeit one that cautions about the promising role of IST shocks in international business cycles suggested by Raffo (2010) and re-assessed by Mandelman *et al.* (2011) among others.

Understanding the Contribution of Productivity (TFP) and IST Shocks to RER Dynamics. Raffo (2010) shows that IST shocks can help reconcile the international real business cycle model with certain hard-to-match stylized facts—the negative correlation between the RER and relative consumption (the *Backus-Smith puzzle*) and the volatility of terms of trade and trade flows—while preserving countercyclical trade balances. Raffo's (2010) model does not feature nominal rigidities or other imperfections in the goods markets, so RER fluctuations are solely due to differences in the consumption baskets across countries (a channel also present in my model). Raffo (2010) suggests dependence on that one channel makes it difficult for the international real business cycle model driven by IST shocks to account for the volatility and persistence of the RER. In turn, incorporating—as I do—a richer market structure that allows for pricing-to-market (local-currency pricing) and large deviations of the law of one price due to nominal rigidities could help reconcile the model with the data.

Chari *et al.* (2002) find that a bond economy has the potential to weaken the link between the RER and relative consumption, but show that in practice this avenue is not very successful at eliminating the consumption-real exchange rate anomaly (the *Backus-Smith puzzle*). The consumption-real exchange rate correlation remains closer to one with conventional additively separable preferences, while the empirical counterpart lies somewhere

[13] Columns $7-8$ show the results whenever the adjustment costs are set to match the volatility of consumption rather than investment. Columns $9-10$ present the simulations with variable capital utilization.

around −0.35 (as reported in Chari *et al.* (2002, Table 6)). Not surprisingly, I find that the correlation between relative consumption and the RER is close to one in models with a combination of persistent productivity (TFP) shocks and non-persistent monetary shocks. Only in variants of the model with IST shocks and incomplete international asset markets, the NOEM framework presented in this paper is able to lower this correlation significantly—see Martínez-García (2011) on this point.[14]

Mandelman *et al.* (2011) introduce IST shocks in a framework related to that of Raffo (2010), assuming flexible prices in the international real business cycle tradition but featuring international asset market incompleteness.[15] Using OECD data on the relative price of investment, these authors suggest there is some evidence suggesting that productivity (TFP) and IST shocks between the U.S. and the rest of the world could be cointegrated of order $C(1,1)$ and their dynamics follow a vector error correction model (VECM) specification. Mandelman *et al.* (2011) argue that with such shock processes, the model is less powerful to explain conventional RER puzzles—and related international business cycle moments—than the international real business cycle model of Raffo (2010) with near-unit-root IST shocks and no spillovers across countries.

Here, I offer a NOEM framework with which to evaluate Raffo's (2010) conjecture about the potential importance of deviations of the law of one price without abandoning his assumptions on the stationarity of the shock processes.[16] In my set-up, I take the stationarity of the exogenous shock processes as given and investigate their endogenous propagation mechanism when nominal rigidities are coupled with pricing-to-market behavior and incomplete international asset markets.

The findings reported in Tables 1 and 2 suggest that whether the law of one price holds (under producer-currency pricing) or not (under local-currency pricing) may have limited effects on the ability of the model driven primarily by productivity (TFP) shocks and IST shocks to account for the volatility and persistence of the RERs. However, Table 3 indicates that the structure of the international asset markets has a significant and large effect on the dynamics of the RER (especially its volatility).

In general, adding persistent IST shocks tends to imply fairly persistent endogenous RERs—but less than with persistent productivity shocks alone. Moreover, it often implies smaller consumption cross-correlations and higher consumption and RER volatilities than with persistent productivity shocks alone—although not enough to resolve the *quantity puzzle* or match the empirical RER volatility. In fact, the simulated consumption cross-correlation is systematically higher than the cross-country output correlation of 0.44 found in my data (which I match in all my simulations), while the empirical consumption cross-correlation tends to be smaller (0.33 in my data).

I explore the sensitivity of the results reported in Table 3 with productivity (TFP) and IST shocks in Figure 1. In this figure, I consider the baseline parameterization of the incomplete asset markets model with investment adjustment costs (IAC) and capital adjustment costs (CAC), letting the persistence ρ_v and volatility σ_v of the domestic IST shock vary along a plausible range. In this sense, I introduce asymmetries in the specification of the IST shock process. In so doing, my findings show that an arbitrary near-unit-root IST process in at least one country is the "silver bullet" needed to bring the model-implied RER volatility closer to that observed in the data (while also reasonably matching the observed high RER persistence). Moreover, Figure 1 also indicates that the impact of the incomplete international asset market specification on RER volatility can also be significantly larger than what is reported in Table 3 when the IST shock innovations have noticeably different volatilities across countries.

[Insert Figure 1 about here]

[14] A more in-depth exploration of the *Backus-Smith puzzle* is left for future research.

[15] In the model of Mandelman *et al.* (2011), as in Raffo (2010), the only source of RER fluctuations is the presence of home bias. Nominal rigidities in my model add another important dimension to the dynamics of the RER.

[16] The significance of the specification of the shock process has been already investigated in Mandelman *et al.* (2011).

What hides behind these results? A positive IST shock makes investment temporarily more productive. Households tend to invest more to take advantage of that situation, but do so partly by working and producing more and partly by sacrificing consumption in the short-run. As a result, consumption becomes countercyclical due to the strong intrinsic incentives to invest now and consume later that arise in the model in response to a positive IST shock.[17]

The incentive to postpone consumption in response to a domestic IST shock often is more pronounced in the home country, leading to a short-run appreciation of the RER—which reverses itself over time—in spite of the fact that domestic output is rising more than foreign output . In contrast, the RER unequivocally depreciates in response to a (positive) domestic productivity (TFP) shock or an expansionary (negative) domestic monetary shock that make domestic goods temporarily more abundant than foreign goods (see, e.g., Martínez-García and Søndergaard (2013)).

Adding even small adjustment costs is generally counterproductive to match the data when business cycles are driven by a combination of productivity (TFP) and IST shocks. Doing so requires an even larger IST shock volatility to replicate the standard deviation of U.S. real GDP, which—in turn—usually increases the endogenous volatility of investment. However, adjustment costs give households an incentive to invest more gradually and so the RER persistence tends to go up as a result. The internal tension that IST shocks bring into the model shows up in investment volatility becoming larger than in the data while consumption becomes countercyclical (unlike the data).

These findings suggest that incorporating IST shocks as a major driver of the business cycle makes it harder to balance the competing goals of accounting for RER fluctuations while also fitting the volatilities of output, investment and consumption. With conventional (additively separable and isoelastic) preferences and IST shocks, introducing large deviations of the law of one price—through price stickiness and local-currency pricing—does not suffice to reconcile the NOEM model with capital accumulation with the empirical evidence on RERs, and less so under incomplete asset markets. The "silver bullet" needed to bring the model-implied RER volatility and persistence closer to the data with international incomplete asset markets arise from differences in the IST innovation volatilities across countries or from near-unit-root persistence in the IST shock process of at least one of the two countries.

5 Concluding Remarks

Martínez-García and Søndergaard (2013), among others, have extensively investigated the international business cycle implications of the NOEM model and the channels through which it generates volatility and persistence of the real exchange rate (RER). Often the NOEM literature takes for granted the assumption of complete international asset markets. This paper provides a detailed discussion of how to extend the open-economy New Keynesian framework with capital accumulation and nominal rigidities in a tractable manner to break away from the assumption of asset market completeness and perfect international risk-sharing. To do so, I set-up a bond economy with costs on domestic international borrowing (Benigno and Thoenissen (2008) and Benigno (2009)).

I find that irrespective of whether the model has capital or not, productivity (TFP) shocks trigger highly persistent RERs while monetary shocks generally do not—although the amount of endogenous persistence is often sensitive to the specification of the adjustment cost function. Conversely, monetary shocks trigger highly volatile RERs while productivity shocks generally do not—subject to similar caveats on the sensitivity of the

[17] See Raffo (2010) for a discussion on the role of the preference specification and the wealth effects on labor supply on this and other counterfactual predictions (including the *Backus-Smith puzzle*).

results to the specification of the adjustment cost function. These findings seem consistent with conventional wisdom (Chari *et al.* (2002)), but also showcase the challenges the literature has faced in replicating basic stylized facts of the RER such as their persistence and volatility.

I find that the bond economy setting with incomplete international asset markets is pretty close to the conventional specification with complete international asset markets whenever the cycle is driven primarily by either non-persistent monetary shocks or persistent productivity (TFP) shocks. In turn, asset market incompleteness results in significantly lower RER volatility in response to persistent investment-specific technology (IST) shocks. I illustrate that the NOEM model with IST shocks as one of the main drivers of the business cycle can approximate the observed RER dynamics whenever IST shocks follow a near-unit-root (at least for one of the countries) or whenever differences arise across countries in the volatility of the IST innovations.

This paper explores the importance of asset market linkages for the features of international business cycles. I have found that restrictions on asset trade may be important for business cycles, but that this result is sensitive to the persistence and nature of the shocks (specially for IST shocks). The paper makes a significant contribution to the literature in identifying the importance for the propagation of business cycles of the interaction between imperfect international risk-sharing conditions and the IST shock process.

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Table 1. RER, Investment and Consumption
Under Local-Currency Pricing and Complete International Asset Markets

	U.S. Data	NoC	Capital Specs. IAC	Capital Specs. CAC	NAC	High Adj. Costs IAC	High Adj. Costs CAC	Var. Capital Utiliz. IAC+CU	Var. Capital Utiliz. CAC+CU
		$\to +\infty$	$\kappa = 0.04$	$\chi = 0.2$	$\to 0$	$\kappa = 2.35$	$\chi = 18.85$	$\kappa = 0.04$	$\chi = 0.2$
		Productivity + IST Shocks							
Std. dev. to GDP									
Consumption	0.81	0.91	0.47	0.32	0.31	0.76	0.56	0.45	0.32
Investment	3.38	–	6.71	5.90	5.87	7.87	7.04	6.38	5.83
RER	5.14	3.17	2.36	1.54	1.49	3.68	2.75	2.25	1.52
Autocorrelation									
Consumption	0.87	0.84	0.75	0.71	0.70	0.84	0.78	0.75	0.71
Investment	0.91	–	0.60	0.28	0.26	0.91	0.62	0.62	0.29
RER	0.78	0.85	0.75	0.71	0.70	0.83	0.76	0.74	0.71
Cross-correlation									
Consumption	0.33	0.76	0.49	0.53	0.55	0.53	0.52	0.50	0.54
Investment	0.33	–	0.28	0.33	0.34	0.22	0.28	0.29	0.33

	U.S. Data	NoC	Capital Specs. IAC	Capital Specs. CAC	NAC	High Adj. Costs IAC	High Adj. Costs CAC	Var. Capital Utiliz. IAC+CU	Var. Capital Utiliz. CAC+CU
		$\to +\infty$	$\kappa = 2.32$	$\chi = 31.1$	$\to 0$	$\kappa = 4.2$	$\chi = 95.5$	$\kappa = 1.18$	$\chi = 23.75$
		Productivity + Monetary Shocks							
Std. dev. to GDP									
Consumption	0.81	1.05	0.63	0.45	0.08	0.81	0.81	0.39	0.36
Investment	3.38	–	3.38	3.38	4.91	2.83	2.05	3.38	3.38
RER	5.14	6.26	3.77	2.70	0.40	4.87	4.85	2.26	2.11
Autocorrelation									
Consumption	0.87	0.46	0.35	0.43	0.75	0.39	0.44	0.32	0.45
Investment	0.91	–	0.83	0.39	0.06	0.85	0.43	0.80	0.39
RER	0.78	0.47	0.37	0.44	0.76	0.40	0.45	0.34	0.45
Cross-correlation									
Consumption	0.33	0.30	0.29	0.29	0.52	0.27	0.28	0.33	0.31
Investment	0.33	–	0.16	0.29	0.33	0.15	0.28	0.21	0.30

This table reports the theoretical moments for each series given my parameterization. All statistics are computed after each series is H-P filtered (smoothing parameter=1600). NAC denotes the no adjustment cost case, CAC denotes the capital adjustment cost case, IAC denotes the investment adjustment cost case, and +CU indicates that capital utilization is variable. NoC is the model stripped from capital where technologies are linear-in-labor. I use Matlab 7.4.0 and Dynare v3.065 for the stochastic simulation.

Data Sources: The OECD's Quarterly National Accounts, OECD's Economic Outlook, and OECD's Main Economic Indicators. Some series are complemented with data from the Bureau of Economic Analysis, the Bureau of Labor Statistics, the Federal Reserve System, the European Central Bank (ECB), and WM/Reuters. Sample period: 1973:I-2006:IV. GDP, consumption and investment are in per capita terms. All series are logged, multiplied by 100 and H-P filtered (smoothing parameter=1600). The dataset can be obtained upon request.

Table 2. RER, Investment and Consumption

Under Producer-Currency Pricing and Complete International Asset Markets

Variable	U.S. Data	NoC	Capital Specs. IAC	Capital Specs. CAC	NAC	High Adj. Costs IAC	High Adj. Costs CAC	Var. Capital Utiliz. IAC+CU	Var. Capital Utiliz. CAC+CU
		$\to +\infty$	$\kappa = 0.04$	$\chi = 0.2$	$\to 0$	$\kappa = 2.35$	$\chi = 17.2$	$\kappa = 0.04$	$\chi = 0.2$
		Productivity + IST Shocks							
Std. dev. to GDP									
Consumption	0.81	0.87	0.46	0.31	0.30	0.72	0.55	0.44	0.31
Investment	3.38	–	7.72	6.37	6.30	8.39	8.14	7.28	6.27
RER	5.14	1.89	2.18	1.34	1.27	2.76	2.55	2.03	1.30
Autocorrelation									
Consumption	0.87	0.84	0.75	0.71	0.70	0.85	0.78	0.75	0.71
Investment	0.91	–	0.63	0.31	0.29	0.91	0.62	0.64	0.31
RER	0.78	0.88	0.76	0.71	0.70	0.86	0.76	0.76	0.71
Cross-correlation									
Consumption	0.33	0.91	0.55	0.63	0.65	0.71	0.56	0.57	0.64
Investment	0.33	–	−0.03	0.14	0.16	0.08	−0.05	−0.00	0.15

Variable	U.S. Data	NoC	Capital Specs. IAC	Capital Specs. CAC	NAC	High Adj. Costs IAC	High Adj. Costs CAC	Var. Capital Utiliz. IAC+CU	Var. Capital Utiliz. CAC+CU
		$\to +\infty$	$\kappa = 0.99$	$\chi = 19.1$	$\to 0$	$\kappa = 8.25$	$\chi = 176$	$\kappa = 0.52$	$\chi = 15.3$
		Productivity + Monetary Shocks							
Std. dev. to GDP									
Consumption	0.81	0.87	0.36	0.29	0.08	0.81	0.81	0.23	0.24
Investment	3.38	–	3.38	3.38	4.83	1.69	1.13	3.38	3.38
RER	5.14	1.88	1.23	1.10	0.31	1.82	1.83	0.92	0.98
Autocorrelation									
Consumption	0.87	0.46	0.29	0.43	0.75	0.41	0.44	0.28	0.46
Investment	0.91	–	0.77	0.36	0.06	0.87	0.43	0.73	0.36
RER	0.78	0.46	0.32	0.46	0.77	0.41	0.45	0.31	0.48
Cross-correlation									
Consumption	0.33	0.91	0.77	0.71	0.68	0.90	0.90	0.69	0.68
Investment	0.33	–	0.66	0.69	0.37	0.81	0.89	0.56	0.65

This table reports the theoretical moments for each series given my parameterization. All statistics are computed after each series is H-P filtered (smoothing parameter=1600). NAC denotes the no adjustment cost case, CAC denotes the capital adjustment cost case, IAC denotes the investment adjustment cost case, and +CU indicates that capital utilization is variable. NoC is the model stripped from capital where technologies are linear-in-labor. I use Matlab 7.4.0 and Dynare v3.065 for the stochastic simulation.

Data Sources: The OECD's Quarterly National Accounts, OECD's Economic Outlook, and OECD's Main Economic Indicators. Some series are complemented with data from the Bureau of Economic Analysis, the Bureau of Labor Statistics, the Federal Reserve System, the European Central Bank (ECB), and WM/Reuters. The dataset can be obtained upon request.

Table 3. RER, Investment and Consumption
Under Local-Currency Pricing and Incomplete International Asset Markets

Variable	U.S. Data	NoC	Capital Specs. IAC	CAC	NAC	High Adj. Costs IAC	CAC	Var. Capital Utiliz. IAC+CU	CAC+CU
		$\to +\infty$	$\kappa = 0.04$	$\chi = 0.2$	$\to 0$	$\kappa = 2.88$	$\chi = 18.75$	$\kappa = 0.04$	$\chi = 0.2$
		Productivity + IST Shocks							
Std. dev. to GDP									
Consumption	0.81	0.92	0.47	0.32	0.32	0.77	0.57	0.46	0.32
Investment	3.38	–	6.64	5.87	5.85	7.56	6.97	6.32	5.80
RER	5.14	2.48	1.58	1.11	1.06	2.15	1.88	1.47	1.07
RER/RER(T)*		0.70	0.65	0.70	0.68	0.56	0.64	0.63	0.68
Autocorrelation									
Consumption	0.87	0.84	0.75	0.71	0.70	0.84	0.77	0.74	0.71
Investment	0.91	–	0.60	0.28	0.26	0.91	0.61	0.61	0.28
RER	0.78	0.88	0.80	0.75	0.74	0.90	0.83	0.80	0.75
Cross-correlation									
Consumption	0.33	0.70	0.47	0.51	0.52	0.51	0.46	0.47	0.51
Investment	0.33	–	0.31	0.34	0.35	0.31	0.30	0.32	0.35

Variable	U.S. Data	NoC	Capital Specs. IAC	CAC	NAC	High Adj. Costs IAC	CAC	Var. Capital Utiliz. IAC+CU	CAC+CU
		$\to +\infty$	$\kappa = 2.28$	$\chi = 31.15$	$\to 0$	$\kappa = 4.25$	$\chi = 95.2$	$\kappa = 1.15$	$\chi = 23.65$
		Productivity + Monetary Shocks							
Std. dev. to GDP									
Consumption	0.81	1.06	0.63	0.46	0.08	0.81	0.81	0.38	0.36
Investment	3.38	–	3.38	3.38	4.90	2.80	2.05	3.38	3.38
RER	5.14	6.06	3.93	2.81	0.55	5.04	4.82	2.42	2.22
RER/RER(T)*		0.96	1.06	1.04	1.38	1.04	0.99	1.10	1.06
Autocorrelation									
Consumption	0.87	0.46	0.35	0.43	0.75	0.39	0.44	0.32	0.45
Investment	0.91	–	0.82	0.39	0.06	0.85	0.43	0.79	0.39
RER	0.78	0.46	0.38	0.44	0.76	0.41	0.45	0.36	0.45
Cross-correlation									
Consumption	0.33	0.29	0.29	0.29	0.52	0.27	0.27	0.34	0.32
Investment	0.33	–	0.17	0.29	0.33	0.16	0.28	0.22	0.30

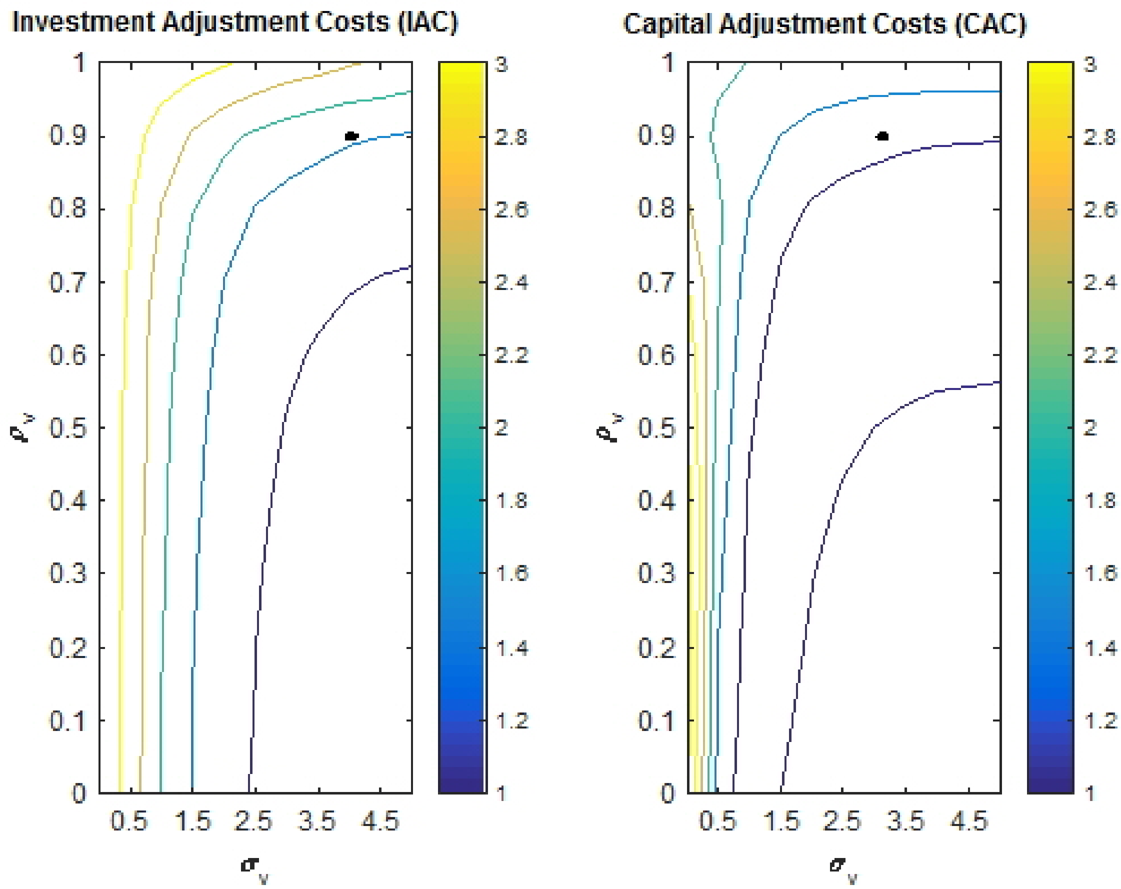
This table reports the theoretical moments for each series given my parameterization. All statistics are computed after each series is H-P filtered (smoothing parameter=1600). NAC denotes the no adjustment cost case, CAC denotes the capital adjustment cost case, IAC denotes the investment adjustment cost case, and +CU indicates that capital utilization is variable. NoC is the model stripped from capital where technologies are linear-in-labor. I use Matlab 7.4.0 and Dynare v3.065 for the stochastic simulation.

* RER/RER(T) denotes the ratio between the standard deviation of the RER implied by the model and its theoretical standard deviation under complete asset markets. Under asset market completeness, the ratio should be equal to one except for rounding up error. Under any form of asset market incompleteness, the ratio measures the volatility wedge that opens up relative to the complete asset markets benchmark.

Data Sources: The OECD's Quarterly National Accounts, OECD's Economic Outlook, and OECD's Main Economic Indicators. Some series are complemented with data from the Bureau of Economic Analysis, the Bureau of Labor Statistics, the Federal Reserve System, the European Central Bank (ECB), and WM/Reuters. The dataset can be obtained upon request.

A Figures

Figure 1. RER Volatility over Output Volatility When IST Shocks Are Asymmetric Across Countries



These graphs report the volatility of the RER whenever I allow the persistence ρ_v and the volatility σ_v of the domestic IST shock to vary within a range that includes the baseline parameterization while keeping the same parameters for the foreign IST shock at their baseline values. All other structural parameters remain invariant. The statistics are computed after each series is H-P filtered (smoothing parameter=1600). I report my findings for both the capital adjustment cost (CAC) case and the investment adjustment cost (IAC) case, without variable capital utilization. The baseline parameterization is marked with a black dot. I use Matlab 7.4.0 and Dynare v3.065 for the stochastic simulation.