Exchange Rate Disconnect in General Equilibrium

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We propose a dynamic general equilibrium model of exchange rate determination that accounts for all major exchange rate puzzles, including Meese-Rogoff, Backus-Smith, purchasing power parity, and uncovered interest rate parity puzzles. We build on a standard international real business cycle model with home bias in consumption, augmented with shocks in the financial market that result in a volatile near-martingale behavior of exchange rates and ensure their empirically relevant comovement with macroeconomic variables, both nominal and real. Combining financial shocks with conventional productivity and monetary shocks allows the model to reproduce the exchange rate disconnect properties without compromising the fit of the business cycle moments.

I. Introduction

Equilibrium exchange rate dynamics is a foundational topic in international macroeconomics (Dornbusch 1976; Obstfeld and Rogoff 1995).

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At the same time, exchange rate disconnect remains among the most challenging and persistent puzzles (Obstfeld and Rogoff 2001). The term "disconnect" narrowly refers to the lack of correlation between exchange rates and other macro variables, but the broader puzzle is more pervasive and nests a number of additional empirical patterns, which stand at odds with conventional international macro models. We define the broader exchange rate disconnect to include the following:

1. Meese and Rogoff (1983) puzzle: the nominal exchange rate follows a random-walk-like process, which is not robustly correlated, even contemporaneously, with macroeconomic fundamentals (see also Engel and West 2005). Furthermore, the exchange rate is an order of magnitude more volatile than macroeconomic aggregates such as consumption, output, and inflation.
2. Purchasing power parity (PPP) puzzle (Rogoff 1996): the real exchange rate closely tracks the nominal exchange rate at most frequencies and in particular exhibits a similarly large persistence and volatility as the nominal exchange rate. Mean reversion, if any, takes a very long time, with half-life estimates in the range of 3–5 years, much in excess of conventional durations of price stickiness (see also Chari, Kehoe, and McGrattan 2002).
3. Terms of trade are weakly positively correlated with the real exchange rate yet exhibit a markedly lower volatility, in contrast with the predictions of standard models (Atkeson and Burstein 2008).
4. Backus and Smith (1993) puzzle: the international risk-sharing condition that relative consumption across countries should be strongly positively correlated with the real exchange rates (implying high relative consumption in periods of low relative prices) is sharply violated in the data, with a mildly negative correlation and a markedly lower volatility of relative consumption (see Kollmann 1995; Corsetti, Dedola, and Leduc 2008).
5. Forward premium puzzle (Fama 1984), or the violation of the uncovered interest rate parity (UIP): cross-currency interest rate differentials are not balanced out by expected depreciations and instead predict exchange rate appreciations (albeit with a very low R^2), resulting in positive expected returns on currency carry trades (see also McCallum 1994; Engel 1996).

We summarize the above puzzles as a set of moments characterizing comovement between exchange rates and macro variables in developed

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countries under a floating regime and use them as quantitative goals in our analysis (see table 1 in sec. IV).

Existing general equilibrium international macro models either feature these puzzles or attempt to address one puzzle at a time, often at the expense of aggravating the other puzzles, resulting in a lack of a unifying framework that exhibits satisfactory exchange rate properties. This is a major challenge for the academic and policy discussion, since exchange rates are the core prices in any international model and failing to match their basic properties jeopardizes the conclusions one can draw from the analysis. In particular, would the conclusions in the vast literatures on currency unions, international policy spillovers, and international transmission of shocks survive in a model with realistic exchange rate properties? Furthermore, what are the implications of such a model for the numerous micro-level empirical studies that treat exchange rate shocks as a source of exogenous variation?

The goal of this paper is to offer a unifying theory of exchange rates that can simultaneously account for all stylized facts introduced above. Our theory builds on a standard international macro model, with a conventional transmission mechanism, and emphasizes shocks in the financial market. Common productivity and monetary shocks, while successful in explaining the business cycle comovement, result in counterfactual exchange rate dynamics, as reflected in the puzzles above. In contrast, we show that shocks in the financial market simultaneously resolve all exchange rate puzzles and deliver the empirically relevant comovement properties between exchange rates and macro variables, including a large gap in their volatilities. Furthermore, when combined together, the two sets of shocks allow the model to reproduce the exchange rate disconnect behavior together with the standard international business cycle comovement of the macro variables (as in, e.g., Backus, Kehoe, and Kydland 1992).[1] In other words, our multishock model does not compromise the fit of the international business cycle moments to reproduce the empirical properties of the exchange rates.[2]

[1] The relative volatilities of the two types of shocks are identified by the Backus-Smith correlation between real exchange rate and relative consumption growth, which results in financial shocks dominating the variance decompositions of the exchange rates, while consumption and output are still largely determined by conventional macroeconomic shocks.

[2] Our framework is related to the international dynamic stochastic general equilibrium models in Kollmann (2001, 2005) and Devereux and Engel (2002), as well as to the open-economy wedge accounting (see Guillén 2013; Eaton, Kortum, and Neiman 2016). What sets our analysis apart is the emphasis on simultaneously resolving a broad range of exchange rate disconnect puzzles using a concise and tractable framework. In particular, we show that a small-scale model with just two shocks—financial and productivity—robustly explains the comovement of all international macro variables. Our work is also related to the vector autoregression literature, which studies impulse responses of international macro variables to structural shocks (Eichenbaum and Evans 1995; Erceg, Guerrieri, and Gust 2006; Scholl and Uhlig 2008; Stavrakeva and Tang 2015; Schmitt-Grohé and Uribe 2018). In view

Our disconnect mechanism relies on two essential ingredients: home bias in the product market (following Obstfeld and Rogoff 2001) and an imperfect financial market featuring equilibrium UIP violations. In particular, we introduce a segmented financial market with noise traders and limits to arbitrage, following De Long et al. (1990), Jeanne and Rose (2002), and Gabaix and Maggiori (2015), into an otherwise conventional international business cycle model. In the model, households can trade only local bonds, and their net foreign asset positions need to be intermediated by arbitrageurs, who take on the exchange rate risk. The arbitrageurs are risk averse and demand a risk premium for their intermediation of the positions of both households and noise traders, resulting in equilibrium UIP deviations, without implying equivalent violations of the covered interest parity (CIP).[3]

Furthermore, our analysis underscores that exchange rate disconnect is a robust implication of a standard international macro model augmented with financial shocks, without relying on other specific assumptions or a particular parameterization. The baseline model does not feature nominal rigidities or other sources of incomplete exchange rate pass-through, emphasizing that the empirically relevant extent of home bias is sufficient to mute the transmission of exchange rate volatility into macroeconomic aggregates, even in small open economies. We then show how various sources of incomplete pass-through, including pricing to market and foreign-currency price stickiness, can improve the quantitative fit of the model.

We supplement the quantitative analysis with analytical results in the context of a simplified version of the model, which admits a tractable closed-form solution yet maintains the main disconnect properties of a richer quantitative environment. This analytical framework delivers three main conceptual insights. First, we characterize equilibrium exchange rate dynamics, which emerges as an interplay between forces in the financial and the real (product and factor) markets. In particular, we show that a demand shock for the foreign-currency bonds results in a UIP violation

of large uncertainty around conditional moments in the data—e.g., the existence of delayed overshooting (see Kim and Roubini 2000)—we focus on the unconditional moments as our primary targets (see discussion in Nakamura and Steinsson 2018).

[3] Exogenous UIP shocks are commonly used in the international macro literature (see, e.g., Devereux and Engel 2002; Kollmann 2005; Farhi and Werning 2012) and can be viewed to emerge from exogenous asset demand, as in the literature following Kouri (1976, 1983). Alternative models of endogenous UIP deviations include models with incomplete information, expectational errors, and heterogeneous beliefs (Evans and Lyons 2002; Gourinchas and Tornell 2004; Bacchetta and van Wincoop 2006; Burnside et al. 2011), financial frictions (Adrian, Etula, and Shin 2015; Camanho, Hau, and Rey 2018), habits, long-run risk, and rare disasters (Verdelhan 2010; Colacito and Croce 2013; Farhi and Gabaix 2016), and alternative formulations of segmented markets (Alvarez, Atkeson, and Kehoe 2009). We show that the disconnect mechanism requires that UIP deviations are not associated with large contemporaneous shocks to productivity or money supply.

and a slow but persistent expected appreciation of the home currency—to ensure equilibrium in the financial market. In turn, this needs to be balanced out by an unexpected depreciation on impact—to satisfy the intertemporal budget constraint. The more persistent the shock, the larger the initial depreciation and thus the closer the behavior of the nominal exchange rate to a random walk. Other persistent shocks, including productivity, result in a similar near-martingale behavior (see also Engel and West 2005). However, unlike productivity and other macro shocks, financial shocks generate excess volatility in exchange rates relative to macro aggregates, which is an essential feature of exchange rate disconnect (see also Devereux and Engel 2002). As the economy becomes less open to international trade, financial shocks result in more volatile exchange rate fluctuations with vanishingly small effects on the rest of the economy.[4]

Second, we address the equilibrium properties of the real exchange rate, and in particular the PPP puzzle, which is often viewed as the prime evidence in support of long-lasting real effects of nominal rigidities (as surveyed in Rogoff 1996). However, in view of the moderate empirical durations of nominal prices, calibrated sticky price models are incapable of generating persistent PPP deviations observed in the data (see Chari, Kehoe, and McGrattan 2002). The baseline assumption in this analysis is that monetary shocks are the main drivers of the nominal exchange rate and that nominal rigidity is the key part of the transmission mechanism into the real exchange rate. We suggest an entirely different perspective, which de-emphasizes nominal rigidities and instead shifts focus to the nature of the shock process. We argue that the behavior of the real exchange rate—both in the time series (see, e.g., Blanco and Cravino 2020) and in the cross section (see, e.g., Kehoe and Midrigan 2008)—is evidence neither in favor nor against sticky prices but instead suggests that monetary shocks cannot be the key source of exchange rate fluctuations. We show that financial shocks drive both nominal and real exchange rates in concert, resulting in volatile and persistent behavior of both variables, thus reproducing the PPP puzzle. The only two essential ingredients of the transmission mechanism for this result are the monetary policy rule, which stabilizes domestic inflation, and home bias in consumption, which limits the response of aggregate prices to the exchange rate.[5]

Third, we address the Backus-Smith puzzle—namely, the comovement between consumption and the real exchange rate. Our approach crucially

[4] Intuitively, consider the extreme case of a demand shock for foreign bonds in an economy that cannot trade goods internationally. The full equilibrium adjustment in this case is achieved exclusively by means of exchange rate movements.

[5] Consumer price stabilization can account for the PPP puzzle even in response to productivity shocks (see Eichenbaum, Johannsen, and Rebelo 2021); however, this results in counterfactual predictions for alternative measures of the real exchange rate, in particular for those based on relative wages as well as in the other exchange rate puzzles.

shifts focus from risk sharing (in the financial market) to expenditure switching (in the goods market) as the key force shaping this comovement. We show that expenditure switching robustly implies a negative correlation between relative consumption and the real exchange rate, as is the case in the data. An exchange rate depreciation increases global demand for domestic goods, which, in light of home bias, requires a reduction in domestic consumption.[6] Indeed, this force is present in all models with expenditure switching and goods market clearing, yet it is usually dominated by the direct effect of shocks on consumption.[7] With a financial shock as the key source of exchange rate volatility, there is no direct effect, and thus expenditure switching is the only force affecting consumption—and weakly so under home bias—resulting in the empirically relevant comovement properties. Put differently, to reproduce the empirical Backus-Smith comovement, real depreciations must be mostly triggered by relative demand shocks for foreign-currency assets rather than supply shocks of domestically produced goods.

In addition, we show that the model with financial shocks reproduces the comovement properties of the exchange rate with interest rates and in particular the forward premium puzzle. Indeed, a demand shock for foreign-currency bonds is compensated in equilibrium with a lower return (a UIP deviation) owing to both an increase in the relative home interest rate and an expected home-currency appreciation. This leads to a negative Fama coefficient in the regression of exchange rate changes on interest rate differentials, albeit with a vanishingly small R^2 as financial shocks become more persistent and the exchange rate becomes closer to a random walk. The disconnect mechanism further ensures that interest rates, just like consumption, are an order of magnitude less volatile than the exchange rate.[8]

The rest of the paper is organized as follows. In section II, we describe our baseline modeling framework and in particular the model of the financial sector, which is our only departure from a conventional international business cycle environment. Section III explores the disconnect

[6] Perhaps more intuitively, the same general equilibrium mechanism can be restated as follows: financial shocks that lead home households to delay their consumption, which is biased toward domestically produced goods, require an exchange rate depreciation to shift global expenditure toward these goods in order to clear the goods market.

[7] For example, productivity shocks (or also expansionary monetary shocks) increase the supply of domestic goods, reducing their prices (hence depreciating the real exchange rate) and increasing consumption, which induces a counterfactual correlation pattern. Alternative mechanisms in the literature (see, e.g., Kocherlakota and Pistaferri 2007; Benigno and Thoenissen 2008; Corsetti, Dedola, and Leduc 2008; Colacito and Croce 2013; Karabarbounis 2014) either mute the direct effect of productivity shocks on consumption or reverse the sign of the exchange rate response, as we discuss further below.

[8] While the fact that a financial shock can match the forward premium moments is perhaps least surprising, the contribution of the paper is to show how the same shock simultaneously accounts for the other exchange rate puzzles, which the literature has typically viewed as distinct and often unrelated.

mechanism with a sequence of analytical results, addressing each of the exchange rate puzzles. Section IV presents the quantitative results, emphasizing the fit of both exchange rate moments and conventional international business cycle moments. This section starts with the outline of the full quantitative environment and our calibration strategy and concludes with the additional analysis of incomplete exchange rate pass-through and small open economies. Section V offers closing remarks, and the online appendix provides detailed derivations and proofs.

II. Modeling Framework

We build on a standard international real business cycle (IRBC) model with home bias in consumption and productivity shocks and without capital in the simple baseline model. Monetary policy is conducted according to a conventional Taylor rule targeting inflation, resulting in a floating nominal exchange rate. The baseline specification features no nominal rigidities—all prices and wages are flexible. The only departure from a conventional IRBC model is a segmented international financial market, which features noise traders and risk-averse arbitrageurs, who intermediate the bond holdings of the households by taking carry trade positions. Online appendix A.2 sets up our general quantitative model, which additionally features capital and investment with adjustment costs, domestic and foreign intermediate inputs, Kimball (1995) demand resulting in variable markups and pricing to market, and sticky wages and prices in either producer, destination, or dominant currency.

A. Model Setup

There are two symmetric countries—home (Europe) and foreign (United States, denoted with an asterisk)—each with its own nominal unit of account in which the local prices are quoted; for example, the home wage rate is W_t euros and the foreign is W_t^* dollars. The nominal exchange rate $\mathcal{E}_t$ is the price of dollars in terms of euros; hence, an increase in $\mathcal{E}_t$ signifies a nominal devaluation of the euro (the home currency). In our description, we focus on the home country. In section IV.D, we extend the analysis to accommodate asymmetric large and small open economies.

Households.—A representative home household maximizes the discounted expected utility over consumption and labor:

$$\mathbb{E}_0\sum_{t=0}^{\infty}\beta^t\left(\frac{1}{1-\sigma}C_t^{1-\sigma}-\frac{1}{1+\varphi}L_t^{1+\varphi}\right),$$

where σ represents the relative risk aversion and $1/\varphi$ represents the Frisch elasticity of labor supply (the results are robust to alternative utility specifications, e.g., Greenwood-Hercowitz-Huffman preferences). The flow budget constraint is given by

$$P_t C_t + \frac{B_{t+1}}{R_t} \leq W_t L_t + B_t + \Pi_t, \tag{1}$$

where P_t represents the consumer price index, W_t represents the nominal wage rate, B_t represents the quantity of the local-currency bond paying out one unit of the home currency next period, R_t represents the gross nominal interest rate (and thus $1/R_t$ represents the price of the bond), and Π_t represents dividends from domestic firms. Household optimization results in the standard labor supply condition and Euler equation for bonds:

$$C_t^{\sigma} L_t^{1/\varphi} = W_t/P_t, \tag{2}$$

$$1 = \beta R_t \mathbb{E}_t\{(C_{t+1}/C_t)^{-\sigma} P_t/P_{t+1}\}. \tag{3}$$

We assume that households trade only local-currency bonds, as well as own home firms.

The foreign households are symmetric, with their behavior characterized by parallel optimality conditions. In particular, they trade only foreign-currency bonds B_{t+1}^*, which pay nominal interest R_t^* in foreign currency, and own foreign firms, which pay Π_t^* as dividends.

The domestic households allocate their within-period consumption expenditure $P_t C_t$ between home and foreign varieties of the final good C_t, defined by a constant elasticity of substitution (CES) aggregator featuring home bias:

$$C_t = \left(\int_0^1 \left[(1-\gamma)^{1/\theta} C_{Ht}(i)^{(\theta-1)/\theta} + \gamma^{1/\theta} C_{Ft}(i)^{(\theta-1)/\theta} \right] \mathrm{d}i \right)^{\theta/(\theta-1)},$$

where $\theta > 1$ represents the elasticity of substitution and $\gamma \in [0, 1/2)$ represents the trade openness parameter, which can be due to a combination of home bias in preferences, trade costs, and nontradable goods (see Obstfeld and Rogoff 2001).[9] The households minimize expenditure, $P_t C_t = \int_0^1 [P_{Ht}(i) C_{Ht}(i) + P_{Ft}(i) C_{Ft}(i)]\, \mathrm{d}i$, resulting in the conventional constant elasticity demand schedules:

$$C_{Ht}(i) = (1-\gamma)\left(\frac{P_{Ht}(i)}{P_t}\right)^{-\theta} C_t \quad \text{and} \quad C_{Ft}(j) = \gamma\left(\frac{P_{Ft}(j)}{P_t}\right)^{-\theta} C_t, \tag{4}$$

[9] The aggregate implications of the model do not depend on whether home bias emerges on the extensive margin because of nontradables or on the intensive margin because of trade costs or preferences; hence, we do not explicitly introduce nontradables.

where the consumer price level is given by $P_t = (\int_0^1[(1-\gamma)P_{Ht}(i)^{1-\theta} + \gamma P_{Ft}(i)^{1-\theta}]\,\mathrm{d}i)^{1/(1-\theta)}$.

The expenditure allocation of the foreign households is characterized by a symmetric demand system. In particular, the demand for home and foreign goods by foreign households is given by

$$C^*_{Ht}(i) = \gamma\left(\frac{P^*_{Ht}(i)}{P^*_t}\right)^{-\theta} C^*_t \quad \text{and} \quad C^*_{Ft}(j) = (1-\gamma)\left(\frac{P^*_{Ft}(j)}{P^*_t}\right)^{-\theta} C^*_t, \tag{5}$$

where $P^*_{Ht}(i)$ and $P^*_{Ft}(j)$ represent the foreign-currency prices of the home and foreign goods in the foreign market and P^*_t represents the foreign consumer price level with a respective home bias.

The real exchange rate, $\mathcal{Q}_t \equiv (P^*_t\mathcal{E}_t)/P_t$, is the relative consumer price level in the two countries. An increase in $\mathcal{Q}_t$ corresponds to a real depreciation—that is, a decrease in the relative price of the home consumption basket.

Producers.—Home output is produced by a given pool of identical firms (hence, we omit indicator i) using a linear technology in labor:

$$Y_t = e^{a_t}L_t, \quad \text{with} \quad a_t = \rho_a a_{t-1} + \sigma_a\varepsilon^a_t, \tag{6}$$

where a_t represents the log total factor productivity following an AR(1) process with persistence $\rho_a \in [0,1]$ and volatility of the innovation $\sigma_a \geq 0$. Given the wage rate W_t, the associated marginal cost of production is $MC_t = e^{-a_t}W_t$. Our results below do not depend on constant returns to scale, a constant elasticity production function, or a single production input, which we adopt solely to simplify exposition.

Every firm faces a downward-sloping demand for its variety in each market. The firm maximizes profits from serving the home and foreign markets,

$$\Pi_t(i) = (P_{Ht}(i) - MC_t)C_{Ht}(i) + \big(P^*_{Ht}(i)\mathcal{E}_t - MC_t\big)C^*_{Ht}(i), \tag{7}$$

by setting $P_{Ht}(i)$ and $P^*_{Ht}(i)$, expressed in home and foreign currency, respectively, and producing $Y_t = C_{Ht}(i) + C^*_{Ht}(i)$ to accommodate the resulting demand (4) and (5) in the two markets. The aggregate profits of the domestic firms, $\Pi_t = \int_0^1\Pi_t(i)\,\mathrm{d}i$, are then distributed to the domestic households. We assume no entry or exit of firms, and therefore our model captures the short and the medium run—namely, the horizons from 1 month up to 5 years, where empirically extensive margins of firm entry and exit play a negligible role in the aggregate (see, e.g., Bernard et al. 2009).

The firms set prices $P_{Ht}(i)$ and $P^*_{Ht}(i)$ flexibly by maximizing profits in (7) state by state. With CES demand, this results in constant-markup pricing with a common price across all domestic firms and the law of one price (LOP) holding across the two markets:

$$P_{Ht}(i) = P_{Ht} = \frac{\theta}{\theta - 1} e^{-a_t} W_t \quad \text{and} \quad P^*_{Ht}(i) = P^*_{Ht} = P_{Ht}/\mathcal{E}_t, \tag{8}$$

for all $i \in [0, 1]$. An equivalent price-setting problem characterizes the behavior of the foreign firms:

$$P^*_{Ft}(i) = P^*_{Ft} = \frac{\theta}{\theta - 1} e^{-a^*_t} W^*_t \quad \text{and} \quad P_{Ft}(i) = P_{Ft} = P^*_{Ft}\mathcal{E}_t, \tag{9}$$

in the foreign and home markets, respectively. Price setting in (8) and (9) features complete pass-through of shocks and no pricing to market—assumptions that we relax in our quantitative analysis.

Market clearing.—The labor market clearing requires that L_t equals simultaneously the labor supply of the households in (2) and the labor demand of the firms in (6), and equivalently for L^*_t in foreign. The wage rates, W_t and W^*_t, adjust to clear this market.

Goods market clearing requires that total production by the home firms is split between supply to the home and foreign markets, respectively, and satisfies the local demand in each market:

$$Y_t = C_{Ht} + C^*_{Ht} = (1 - \gamma)\left(\frac{P_{Ht}}{P_t}\right)^{-\theta} C_t + \gamma\left(\frac{P^*_{Ht}}{P^*_t}\right)^{-\theta} C^*_t, \tag{10}$$

where Y_t represents the aggregate home production and $C_{Jt}(i) = C_{Jt}$ for all $i \in [0, 1]$ and $J \in \{H, F\}$, owing to symmetry in price setting across firms. A symmetric condition holds for the foreign production Y^*_t.

Last, we combine the household budget constraint (1) with profits (7), aggregated across all home firms, as well as the market clearing conditions above, to obtain the home country budget constraint:

$$\frac{B_{t+1}}{R_t} - B_t = NX_t, \quad \text{with} \quad NX_t = \mathcal{E}_t P^*_{Ht} C^*_{Ht} - P_{Ft} C_{Ft}, \tag{11}$$

where NX_t denotes net exports expressed in units of the home currency. The relative price of imports, $\mathcal{S}_t \equiv P_{Ft}/(\mathcal{E}_t P^*_{Ht})$, is the terms of trade. The foreign country faces a symmetric budget constraint, which is redundant by Walras's law.

Monetary policy.—The government is present in the economy only by means of the monetary policy rule, as the fiscal authority is fully passive. This is without loss of generality, as, in view of Ricardian equivalence, the net foreign asset position of the country B_{t+1} should be regarded as the consolidated position of the public and the private sectors. The monetary policy in both countries is implemented via a conventional Taylor rule. In the baseline model, which features no nominal rigidities, we consider the limiting case with fully stable consumer prices, or zero inflation: $\pi_t \equiv \Delta \log P_t = 0$ and $\pi^*_t = 0$ for all t. While this offers a useful simplification for the analytical analysis, we also view it as a reasonable point of approximation to a low-inflation environment in the developed countries.

B. Segmented Financial Market

The remaining block of the model concerns the international financial market and the resulting equilibrium risk-sharing between home and foreign households, which constitutes the only departure from an otherwise conventional IRBC model. The financial market is incomplete and segmented, as the home and foreign households cannot directly trade any assets with each other, and their international asset positions are intermediated by the financial sector. The equilibrium in the financial market results in a modified interest rate parity condition, which is subject to financial shocks, as we now describe.

Our model of the financial sector builds on Jeanne and Rose (2002) and Gabaix and Maggiori (2015) and features three types of agents: households, noise traders, and professional intermediaries.[10] The home and foreign households trade the local-currency bonds only and hence cannot directly trade assets with each other. In particular, the home households demand a quantity B_{t+1} of the home-currency bond at time t, while the foreign households demand a quantity B^*_{t+1} of the foreign-currency bond. Both B_{t+1} and B^*_{t+1} can take positive or negative values depending on whether the households save or borrow.

In addition to the household fundamental demand for currency (bonds), the financial market features a liquidity currency demand—independent of the expected currency return and the other macroeconomic fundamentals—from a measure n of symmetric noise traders. In particular, noise traders follow a zero-capital strategy by taking a long position in the foreign currency and shorting equal value in the home currency, or vice versa if they have an excess demand for the home currency. The overall position of the noise traders is N^*_{t+1}/R^*_t dollars invested in the foreign-currency bond, matched by $N_{t+1}/R_t = -\mathcal{E}_t N^*_{t+1}/R^*_t$ euros invested in the home-currency bond, and we model it as an exogenous process:

$$\frac{N^*_{t+1}}{R^*_t} = n\left(e^{\psi_t} - 1\right), \quad \text{with} \quad \psi_t = \rho_\psi \psi_{t-1} + \sigma_\psi \varepsilon^\psi_t. \tag{12}$$

[10] We follow Jeanne and Rose (2002) in modeling the financial intermediaries, who take limited asset positions because of exposure to the exchange rate risk, rather than because of financial constraints as in Gabaix and Maggiori (2015). In contrast, we follow Gabaix and Maggiori (2015) in modeling the segmented participation of the households. Last, the exogenous liquidity needs of the noise trader are akin to the exogenous "portfolio flows" in Gabaix and Maggiori (2015) but can equally emerge from biased expectations about the exchange rate, $\mathbb{E}^n_t \mathcal{E}_{t+1} \neq \mathbb{E}_t \mathcal{E}_{t+1}$, as in Jeanne and Rose (2002).

We refer to the noise-trader demand shock ψ_t as the financial shock, with $\rho_\psi \in [0, 1]$ and $\sigma_\psi \geq 0$ parameterizing its persistence and volatility, respectively.

The trades of the households and the noise traders are intermediated by a measure m of symmetric risk-averse arbitrageurs, or market makers. These intermediaries adopt a zero-capital carry trade strategy by taking a long position in the foreign-currency bond and a short position of equal value in the home-currency bond or vice versa. The return on the carry trade is given by

$$\tilde{R}^*_{t+1} = R^*_t - R_t \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} \tag{13}$$

per dollar invested in the foreign-currency bond and $\mathcal{E}_t$ euros sold of the home-currency bond at time t. We denote the size of individual position by d^*_{t+1}, which may take positive or negative values, and assume that intermediaries maximize the constant absolute risk aversion (CARA) utility of the real return in units of the foreign good:

$$\max_{d^*_{t+1}} \mathbb{E}_t\left\{ -\frac{1}{\omega} \exp\left(-\omega \frac{\tilde{R}^*_{t+1}}{P^*_{t+1}} \frac{d^*_{t+1}}{R^*_t} \right) \right\}, \tag{14}$$

where $\omega \geq 0$ is the risk-aversion parameter.[11] In aggregate, all m intermediaries invest $D^*_{t+1}/R^*_t = md^*_{t+1}/R^*_t$ dollars in foreign-currency bond and take an offsetting position of $D_{t+1}/R_t = -\mathcal{E}_t D^*_{t+1}/R^*_t$ euros in home-currency bond, resulting in a zero-capital portfolio at time t.

Both currency bonds are in zero net supply, and therefore financial market clearing requires that the positions of the households, noise traders, and intermediaries balance out:

$$B_{t+1} + N_{t+1} + D_{t+1} = 0 \quad \text{and} \quad B^*_{t+1} + N^*_{t+1} + D^*_{t+1} = 0. \tag{15}$$

In equilibrium, the intermediaries absorb the demand for home and foreign currency of both households and noise traders. If intermediaries were risk neutral ($\omega = 0$), they would do so without a risk premium, resulting in the UIP, or equivalently a zero expected real return, $\mathbb{E}_t\{\tilde{R}^*_{t+1}/P^*_{t+1}\} = 0$. Risk-averse intermediaries, however, require an appropriate compensation for taking a risky carry trade, which results in equilibrium risk premia and deviations from the UIP.

[11] CARA utility provides tractability, as it results in a portfolio choice that does not depend on the level of wealth of the intermediaries, thus avoiding the need to carry it as an additional state variable; the trade-off of working with CARA utility, however, is that intermediaries need to be short-lived, maximizing the 1-period return on their investment.

LEMMA 1. The equilibrium condition in the financial market, log linearized around a symmetric steady state with $\bar{B} = \bar{B}^* = 0, \bar{R} = \bar{R}^* = 1/\beta$, $\overline{\mathcal{Q}} = 1$, and a finite nonzero $\omega\sigma_e^2/m$, is given by

$$i_t - i_t^* - \mathbb{E}_t\Delta e_{t+1} = \chi_1\psi_t - \chi_2 b_{t+1}, \tag{16}$$

where $i_t - i_t^* \equiv \log(R_t/R_t^*)$, $b_{t+1} \equiv B_{t+1}/\bar{Y}$, and the coefficients $\chi_1 \equiv (n/\beta)(\omega\sigma_e^2/m)$ and $\chi_2 \equiv \bar{Y}(\omega\sigma_e^2/m)$, with $\sigma_e^2 \equiv \text{var}_t(\Delta e_{t+1})$ denoting the volatility of the log nominal exchange rate, $e_t \equiv \log\mathcal{E}_t$.

The equilibrium condition (16) is the modified UIP in our model with imperfect financial intermediation, where the right-hand side corresponds to the departures from the UIP. Condition (16) arises from the combination of the financial market clearing (15) with the solution to the portfolio choice problem of the intermediaries (14), as we formally show in online appendix A.4. Intuitively, the optimal portfolio of the intermediaries D_{t+1}^* is proportional to the expected log return on the carry trade, $i_t - i_t^* - \mathbb{E}_t\Delta e_{t+1}$, scaled by the risk absorption capacity of the intermediary sector, $\omega\sigma_e^2/m$—that is, the product of their effective risk aversion (ω/m, the price of risk) and the volatility of the carry trade return (σ_e^2, the exchange rate risk). As $\omega\sigma_e^2/m \to 0$, the risk absorption capacity of the intermediaries increases and the UIP deviations disappear in the limit, $\chi_1, \chi_2 \to 0$. With $\omega\sigma_e^2/m > 0$, the UIP deviations remain first order and hence affect the first-order equilibrium dynamics. Note that both $\psi_t > 0$ and $b_{t+1} < 0$ correspond to the excess demand for the foreign-currency bond—by noise traders and households, respectively—resulting in a negative expected return on the foreign currency bond.

International risk sharing.—What are the implications of this financial market equilibrium for the risk sharing between the home and foreign households? First, as both noise traders and intermediaries hold zero-capital positions, financial market clearing (15) implies a balanced position for the home and foreign households combined, $B_{t+1}/R_t + \mathcal{E}_t B_{t+1}^*/R_t^* = 0$. In other words, even though the home and foreign households do not trade any assets directly, the financial market acts to intermediate the intertemporal borrowing between them. However, this intermediation is frictional, as there is a wedge between the interest rates faced by the home and foreign households, R_t and R_t^*, namely, the (expected) departures from the UIP in (16). If interest rate parity held, the equilibrium would correspond to a conventional bonds-only incomplete-market IRBC model. The UIP wedge further limits the extent of international risk sharing.[12] The exogenous noise-trade shock ψ_t plays the key role as the driver

[12] The positions of intermediaries and noise traders also generate income (or losses), which for concreteness we assume is returned to the foreign households at the end of each trading period, as a lump sum payment. This, however, is inconsequential for the first-order dynamics of the model, as this transfer is second order (see online app. A.4).

of the deviations from the interest rate parity and international risk sharing. The specific nature of this shock, however, is less important for the resulting macroeconomic and exchange rate dynamics.[13]

Covered interest parity.—We briefly consider the equilibrium pricing of the currency forwards by the financial sector and the resulting CIP. Consider a period t forward price $\mathcal{F}_t$ of one unit of foreign currency at $t+1$ in units of home currency. The financial sector prices it at $\mathcal{F}_t = \mathcal{E}_t R_t / R_t^*$, as any other price would lead the intermediaries to take unbounded positions buying or selling such forwards (see online app. A.4). Therefore, CIP holds in equilibrium, even though UIP is generally violated, as the imperfection in the financial market is due to market segmentation and limited risk absorption by the risk-averse intermediaries. Profiting from the UIP deviations requires taking a carry-trade risk, which commands an equilibrium risk premium, while the departures from CIP generate riskless arbitrage opportunities. This is in contrast with models of financial constraints, where the departures from both UIP and CIP are due to binding constraints on the balance sheet of the financial intermediaries. We opt in favor of the former modeling approach, as empirically the size of the CIP deviations is at least an order of magnitude smaller than the expected departures from the UIP.[14]

III. The Disconnect Mechanism

In this section, we explore the baseline model, which admits a tractable analytical solution without compromising the exchange rate disconnect mechanism of the more general framework. This allows us to fully dissect the mechanism and show in particular that two ingredients play the central role in the model's ability to explain the exchange rate puzzles—namely, the financial shock ψ_t as the leading driver of the exchange rates and the low trade openness γ, which ensures a muted pass-through of the exchange rate volatility into the macro aggregates. Section IV confirms that the same two features of the model remain key in a full quantitative

[13] In Itskhoki and Mukhin (2017), we discuss various alternative microfoundations for the UIP shock ψ_t, ranging from complete-market models of risk premia (e.g., Verdelhan 2010; Colacito and Croce 2013; Farhi and Gabaix 2016) to models of heterogeneous beliefs and expectational errors (e.g., Evans and Lyons 2002; Gourinchas and Tornell 2004; Bacchetta and van Wincoop 2006). All models resulting in a variant of (16) with $\chi_1 > 0$ (and $\chi_2 \geq 0$) produce similar equilibrium exchange rate dynamics and can be differentiated only by additional financial moments (e.g., covered interest parity, comovement of exchange rates with additional asset classes). Consistent with the recent work of Lustig and Verdelhan (2019), we emphasize the importance of financial frictions in explaining exchange rates and in particular focus on the role of segmented markets.

[14] Du, Tepper, and Verdelhan (2018) document that the average annualized CIP deviations were a negligible two basis points before 2007 and since then increased 10-fold to 20 basis points, yet this is still an order of magnitude smaller than the expected UIP deviations, which are around 200 basis points, or 2%.

environment, which additionally features domestic and imported intermediate inputs, pricing to market, and nominal rigidities. These additional ingredients reinforce home bias to further mute the exchange rate transmission, helping to quantitatively match a rich set of moments describing the comovement between exchange rates and macro variables, given the empirical degree of openness of various countries, as we explore in section IV.D.

For concreteness, we focus here on just two shocks—the relative productivity shock $\tilde{a}_t \equiv a_t - a_t^*$ and the financial shock ψ_t—with the same persistence parameter ρ. Yet our results generalize for a variety of macrofundamental shocks following general statistical processes, including monetary, government spending, price markup, and labor wedge shocks, so long as this set features the financial shock ψ_t, as we show in Itskhoki and Mukhin (2017). To further streamline exposition, we consider the limiting case with $\chi_2 = 0$ and a normalization $\chi_1 = 1$ in the modified UIP condition (16), which simplifies the dynamic roots of the equilibrium system without changing its quantitative properties.[15]

We solve the model by log linearization and write all expressions in terms of log deviations from a symmetric steady state, denoted with corresponding lowercase letters (e.g., $y_t \equiv \log Y_t - \log \bar{Y}$ is the log deviation of GDP). The model admits a block-recursive structure, which allows for a sequential analysis of its equilibrium properties. We begin here by postulating the equilibrium near-random-walk property of the nominal exchange rate. We then proceed sequentially with the analysis of the PPP puzzle (the price block), the Backus-Smith puzzle (the quantity block), and the forward premium puzzle (the intertemporal block). Finally, we conclude with the general equilibrium properties of the model and in particular the Meese-Rogoff disconnect puzzle, circling back to the result that we now introduce:

PROPOSITION 1. The equilibrium nominal exchange rate, $e_t \equiv \log \mathcal{E}_t$, follows a volatile near-random-walk process; in particular, when both discount factor β and shock persistence $\rho \approx 1$, then $\text{corr}(\Delta e_t, \Delta e_{t+1}) \approx 0$.

An important property for our analysis is that the exchange rate follows a volatile and persistent process, as it does in the data. We take this general equilibrium result as given in section III.A–III.C and return to its detailed analysis in section III.D, where we focus on both the near-random-walk properties of the exchange rate and its excess volatility relative to fundamental macroeconomic variables, such as GDP, for realistic values of the model parameters.

[15] We present the general analytical solution with endogenous $\chi_1, \chi_2 > 0$ in online app. A.6. From lemma 1, the limit with $\chi_1 > 0$ and $\chi_2 \to 0$ emerges when $\bar{Y}/m \to 0$ as n/m stays bounded away from zero—i.e., when the size of the financial sector (number of both noise traders n and arbitrageurs m) increases relative to the size of the real economy. The further normalization of $\chi_1 = 1$ is simply a rescaling of the volatility units of the shock ψ_t.

A. The Purchasing Power Parity Puzzle

We start our analysis with the equilibrium relationship between real and nominal exchange rates and the associated PPP puzzle, which we broadly interpret as the close comovement between the nominal and the real exchange rates. In the data, all notions of the real exchange rate—consumer price, producer price, and wage based—closely comove with the nominal exchange rate, exhibiting strong persistence with very long half-lives. The close comovement involves both nearly perfect correlations at various horizons and nearly equal volatilities for all exchange rate series, as we illustrate in figure 1. Such properties may perhaps be expected of the nominal exchange rate if it is viewed as a financial variable; they are, however, puzzling from the point of the real exchange rate—a key international relative price with an important role in the product market, especially in light of the relative stability of the macro aggregates, including price levels, consumption, and output.

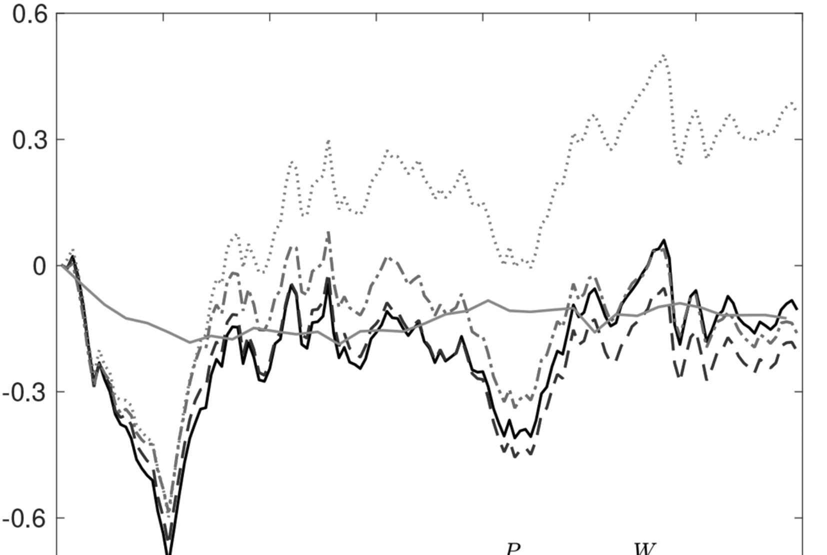

FIG. 1.—Nominal and real exchange rates. This figure plots quarterly NER e_t, CPI-based RER q_t, PPI-based RER q_t^P, and wage-based RER q_t^W for the United States against the PPP-weighted sum of France, Germany, and the United Kingdom, as well as the annual terms of trade s_t for the United States against the rest of the world (see online app. A.1). All series are in logs and normalized to zero in 1980:Q1. A color version of this figure is available online.

Our disconnect mechanism immediately delivers a close comovement between nominal and real exchange rates. A monetary policy that ensures stable price levels, or $p_t = p_t^* \equiv 0$ in log deviation terms, implies the identical dynamics for the real and nominal exchange rates:

$$q_t \equiv p_t^* + e_t - p_t = e_t, \tag{17}$$

where $q_t \equiv \log \mathcal{Q}_t$. In the absence of nominal frictions, the monetary policy rule simply selects a path of the nominal exchange rate, which tracks the real exchange rate by keeping the consumer price levels stable. In other words, if the monetary authority is successful at stabilizing consumer prices, as is the case in developed countries, this immediately explains the comovement between the nominal and the real exchange rates. It remains to show how in general equilibrium both exchange rates follow a volatile and persistent near-random-walk process, as predicted by proposition 1 (see sec. III.D).[16]

Next we explore the properties of the other real exchange rates. Combining the price setting equations (8) and (9) with the log-linearized expression for the price level P_t, we solve for the real wage rate:[17]

$$w_t - p_t = a_t - \frac{\gamma}{1-2\gamma} q_t. \tag{18}$$

The real wage increases with the productivity of the economy a_t and with its relative purchasing power, captured by the real exchange rate in proportion with the openness of the economy γ. This allows us to characterize the producer-price and the wage-based real exchange rates as follows:

$$q_t^P \equiv p_{Ft}^* + e_t - p_{Ht} = \frac{1}{1-2\gamma} q_t, \tag{19}$$

$$q_t^W \equiv w_t^* + e_t - w_t = \frac{1}{1-2\gamma} q_t - (a_t - a_t^*). \tag{20}$$

From (19), which holds independently of the source of the shocks, we immediately see that the model reproduces a close comovement between consumer and producer relative prices. Furthermore, as openness γ decreases, q_t and q_t^P are not only tightly correlated but also have approximately the same volatility. Intuitively, a monetary policy that stabilizes

[16] In particular, if one were to fit an AR(1) process for the real exchange rate in our model, as is conventionally done in the PPP puzzle literature (see Rogoff 1996), one would be challenged to find evidence of mean reversion and would infer very long half-lives in finite samples (see online app. A.6), quantitatively consistent with the 3–5-year empirical range.

[17] The log deviation of the price index P_t around a symmetric equilibrium is given by $p_t = (1-\gamma)p_{Ht} + \gamma p_{Ft}$, with $p_{Ht} = w_t - a_t$ and $p_{Ft} = w_t^* + e_t - a_t^*$, and symmetric expressions holding in foreign.

domestic consumer prices also stabilizes domestic producer prices, as the difference between the two is small in economies with home bias.

This logic does not hold for the wage-based real exchange rate q_t^W in (20). In particular, productivity shocks a_t and a_t^* drive a wedge between price and wage inflation. In other words, a monetary policy that stabilizes prices in response to productivity shocks results in volatile wages, as real wages (18) reflect productivity.[18] This trade-off is not present, however, if financial shocks are the key drivers of the exchange rates. Indeed, financial shocks generate a volatile and persistent nominal exchange rate, which—under a monetary policy that stabilizes price levels—translates into equally volatile and persistent real exchange rates, independently of whether they are measured using consumer prices, producer prices, or wages. We summarize these results in the following:

LEMMA 2. Home bias and monetary policy that stabilizes consumer prices ensure a near-perfect comovement between e_t, q_t, and q_t^P. Financial shocks, in addition, result in a near-perfect comovement between q_t and q_t^W. Lemma 2, combined with proposition 1, has the following equilibrium implication:

PROPOSITION 2. With financial shocks, home bias, and β, $\rho \approx 1$, all real exchange rates exhibit a volatile near-random-walk behavior, with arbitrarily large half-lives, closely tracking the nominal exchange rate.

In other words, the combination of (i) a conventional monetary policy, (ii) significant home bias, and (iii) financial shocks allows the model to reproduce the empirical behavior of all exchange rate series. The absence of the direct effect of the financial shock on the product and labor markets translates price stability into both nominal and real wage stability. As a result, the international relative prices and wages comove closely with the nominal exchange rate, exhibiting a high degree of persistence. Greater openness of the economies leads to larger feedback effects of the exchange rate into domestic relative prices, as the foreign value added plays a larger role in the domestic consumption basket (see [18]). Importantly, these properties of the model arise under flexible prices and wages and hence do not rely on nominal rigidities. While wage and price stickiness is arguably a salient feature of the real world, proposition 2 shows that the empirical behavior of exchange rates is well captured to a first order by a flexible-price model, provided that financial shocks account for a considerable portion of exchange rate volatility.

Relationship to the PPP puzzle literature.—In view of this result, a natural question is why the PPP puzzle posed such a challenge to the literature,

[18] Empirically, in fig. 1, while q_t^W and q_t are highly correlated in changes, their low-frequency movements differ, reflecting the differential productivity and real-wage growth in the United States and Europe, consistent with the role of $(a_t - a_t^*)$ in (20).

as summarized in a seminal survey by Rogoff (1996). From the definition of the real exchange rate, the close comovement between q_t and e_t implies that price levels p_t and p_t^* must in turn move little with the nominal exchange rate e_t. The PPP puzzle literature has largely focused on one conceptual possibility, namely, that price levels move little due to nominal rigidities, assuming that monetary shocks are the main drivers of the nominal exchange rate. The issue with this approach is that monetary shocks necessarily imply cointegration between relative nominal variables—$(w_t - w_t^*)$, $(p_t - p_t^*)$, and e_t—resulting in mean reversion in the real exchange rate q_t. The speed of this mean reversion is directly controlled by the duration of nominal stickiness, which is empirically insufficient to generate long half-lives, characteristic of the real exchange rate (see, e.g., Chari, Kehoe, and McGrattan 2002).

We focus on the other conceptual possibility, namely, that prices are largely disconnected from exchange rates, or in other words, the low exchange rate pass-through into consumer price index (CPI) inflation, even in the long run, due to substantial home bias (small γ). Importantly, this mechanism requires that the main drivers of the exchange rate are not productivity or monetary shocks, which introduce a wedge between nominal and real exchange rates independently of the extent of the home bias. In contrast, financial shocks do not drive a wedge between nominal and real exchange rates, even in the long run, and thus our mechanism does not need to rely on short-run nominal rigidities to induce their comovement.[19]

B. *The Backus-Smith Puzzle*

We now study the relationship between aggregate consumption and the real exchange rate, emphasizing the role of expenditure switching in the product market, as opposed to international risk sharing in the financial market (the Backus-Smith condition).[20] The expenditure switching mechanism relies on the standard equilibrium conditions in international macro models—namely, the labor and product market clearing, which

[19] As a result, our model is consistent with the recent cross-sectional and time-series evidence, which poses a challenge for the conventional monetary model: Kehoe and Midrigan (2008) show a missing correlation between price durations and the volatility and persistence of the sectoral real exchange rates (see also Imbs et al. 2005; Carvalho and Nechio 2011), while Blanco and Cravino (2020) show that reset-price real exchange ratio (RER) is as volatile and persistent as the conventional RER. Neither of this is evidence against price stickiness per se, but rather it is evidence against monetary shocks as the key driver of the nominal exchange rate. Furthermore, our model is also in line with the empirical findings in Engel (1999) and Betts and Kehoe (2008), as it is the tradable component that drives the volatility of the overall RER (see online app. A.6).

[20] With complete markets, the efficient international risk sharing requires that $\sigma(c_t - c_t^*) = q_t$, implying a perfect positive correlation between relative consumption and RER. Our model instead features incomplete markets and a shock to risk sharing ψ_t, resulting in $\mathbb{E}_t\{\sigma(\Delta c_{t+1} - \Delta c_{t+1}^*) - \Delta q_{t+1}\} = \psi_t$, which does not impose a particular correlation pattern.

derive from (2), (6), and (10). We rewrite these conditions in log deviation terms:

$$\sigma c_t + \varphi \ell_t = w_t - p_t,$$
$$y_t = a_t + \ell_t,$$
$$y_t = (1-\gamma)[-\theta(p_{Ht} - p_t) + c_t] + \gamma[-\theta(p^*_{Ht} - p^*_t) + c^*_t].$$

Using the solution for prices and wages from the previous subsection, and solving out equilibrium employment ℓ_t, we arrive at the two equilibrium loci for the labor and product markets, respectively:

$$\sigma c_t + \varphi y_t = (1+\varphi) a_t - \frac{\gamma}{1-2\gamma} q_t, \tag{21}$$

$$y_t = (1-\gamma) c_t + \gamma c^*_t + 2\theta \frac{\gamma(1-\gamma)}{1-2\gamma} q_t. \tag{22}$$

Consider first the labor market clearing condition (21). A real depreciation (an increase in q_t) reduces the real wage (recall [18]) and hence labor supply, resulting in lower output y_t. In turn, higher productivity increases output both directly and indirectly (due to increased labor supply), while higher consumption reduces labor supply via the income effect. We turn next to the goods market clearing condition (22), which in the closed economy with $\gamma = 0$ reduced to $y_t = c_t$. In an open economy, home production y_t is split between domestic and foreign consumption of the home good, which increases with overall consumption levels in the two countries (c_t and c^*_t), as well as with the real depreciation of the home currency. This latter force is the expenditure switching effect that we emphasize in our analysis, and its quantitative magnitude is proportional to $\gamma\theta$—a product of the economy's openness γ and the elasticity of substitution between home and foreign goods θ.

Combining (21) and (22) with their foreign counterparts, we obtain the equilibrium relationship between relative consumption and the real exchange rate, implied by the labor and product market clearing:

$$c_t - c^*_t = \kappa_a(a_t - a^*_t) - \gamma\kappa_q q_t, \tag{23}$$

where the derived parameters $\kappa_a \equiv (1+\varphi)/(\sigma + \varphi(1-2\gamma))$ and $\gamma\kappa_q \equiv (2\gamma/(1-2\gamma))(1+2\theta\varphi(1-\gamma))/(\sigma+\varphi(1-2\gamma))$ are both positive. This relationship immediately implies the following:

Proposition 3. An equilibrium response to a financial shock ψ_t implies a negative comovement between the real exchange rate q_t and relative consumption $c_t - c^*_t$, with the relative volatility of the consumption response, $\mathrm{var}_t(\Delta c_{t+1} - \Delta c^*_{t+1})/\mathrm{var}_t(\Delta q_{t+1})$, declining to zero as $\gamma \to 0$.

Proposition 3 emphasizes two important properties of the financial shocks. First, they result in a negative correlation between relative consumption and the real exchange rate, both in levels and in growth rates. In other words, consumption is low when prices are low, in relative terms across countries. This violates the pattern of efficient international risk sharing predicted by the Backus-Smith condition, yet it is in line with the robust empirical patterns observed in the data for rich countries—the Backus-Smith puzzle. Second, the proposition also shows that in economies with home bias, the relative volatility of the consumption response to financial shocks can be an order of magnitude smaller than the response of the real exchange rate—an essential property for the model to be consistent with the empirical exchange rate disconnect.

What is most striking about this simple resolution of the celebrated Backus-Smith puzzle is that it derives from conventional labor and product market clearing conditions, which are ubiquitous in international general equilibrium models. Indeed, the negative relationship between consumption and the real exchange rate is a robust feature of the expenditure switching mechanism. A real exchange rate depreciation switches expenditure toward home goods, and to clear the markets, home output needs to rise and home consumption needs to fall because of the home bias.[21] Furthermore, this effect persists regardless of the other parameters of the model, including the relative risk aversion σ and the inverse Frisch elasticity of labor supply φ.

Relationship to the conventional models.—We have just argued that the expenditure switching effect is a robust property of nearly every international macro model. Why is it, then, that the Backus-Smith puzzle proved to be such a challenge for both the productivity-driven IRBC models and the monetary New Keynesian models, even when these models feature incomplete asset markets? Equilibrium condition (23) sheds light on this question as well. It implies the following variance decomposition:

$$\frac{\operatorname{cov}(\Delta c_t - \Delta c_t^*, \Delta q_t)}{\operatorname{var}(\Delta q_t)} = -\gamma\kappa_q + \kappa_a \frac{\operatorname{cov}(\Delta a_t - \Delta a_t^*, \Delta q_t)}{\operatorname{var}(\Delta q_t)}, \qquad (24)$$

where the last term is the contribution of the product-market shocks to the overall equilibrium volatility of the real exchange rate.[22] While the expenditure switching force is generally present, its effect on aggregate

[21] This equilibrium logic can be traced backward as well: a financial shock that makes home households postpone their consumption and results in a lower relative demand for home goods, which requires an exchange rate depreciation to shift relative demand toward the home good worldwide to clear the market—a version of Keynes's transfer effect (see, e.g., Caballero, Farhi, and Gourinchas 2008; Pavlova and Rigobon 2008).

[22] Here we focus on the productivity shock as the only product-market shock, yet the results generalize to other shocks, including shifts in markups induced by monetary shocks under sticky prices. One way to see this is to use the product market clearing condition (22) directly, without specifying the supply side. Combining it with its foreign counterpart yields $c_t - c_t^* = (1/(1-2\gamma))(y_t - y_t^*) - 2\theta(2\gamma(1-\gamma)/(1-2\gamma))q_t$, where $y_t - y_t^*$ represents the equilibrium relative supply of the home and foreign goods.

consumption is weak because of home bias (small γ). In contrast, the direct effect of domestic goods supply on domestic consumption is strong, particularly so under home bias, and generally produces a counterfactual comovement between the relative consumption and the real exchange rate.

In other words, models in which real depreciations are mostly driven by product market expansions—whether due to a positive productivity shock or an expansionary monetary shock—generally predict a simultaneous expansion in consumption, resulting in the Backus-Smith puzzle independently of the asset market completeness. In contrast, financial shocks that cause a real depreciation and have no direct effect on the supply of goods exert only an indirect expenditure switching effect on the real economy, which results in lower consumption consistent with the empirical patterns. Therefore, a successful resolution of the Backus-Smith puzzle must limit the role of product-market shocks in the unconditional variance of the real exchange rate (the last term in [24]).

Simply put, real depreciations must largely reflect an increased demand for foreign assets rather than an increased supply of home goods. Note that the mechanism arises under the news shocks about future productivity or the long-run risk shocks, as in Colacito and Croce (2013). Such shocks, just like a financial shock ψ_t, trigger large exchange rate movements without significantly affecting the contemporaneous supply and consumption of domestic output. Similarly, persistent productivity growth coupled with increased investment demand, as in Corsetti, Dedola, and Leduc (2008), can also generate increased demand for foreign financing and a currency appreciation, akin to a financial shock, without a significant direct effect on output available for current domestic consumption.[23]

C. *The Forward Premium Puzzle*

We now turn to the equilibrium properties of the interest rates and their comovement with the nominal exchange rate. Log linearization of the home household Euler equation (3) leads to a conventional relationship for the nominal interest rate, $i_t = \mathbb{E}_t\{\sigma\Delta c_{t+1} + \pi_{t+1}\}$. Combining it with the foreign counterpart and our assumption on monetary policy stabilizing consumer prices $\pi_{t+1} = \pi^*_{t+1} = 0$, which results in $\Delta e_t = \Delta q_t$, we can write the interest rate differential as

$$i_t - i^*_t = \sigma\mathbb{E}_t\left\{\Delta c_{t+1} - \Delta c^*_{t+1}\right\} = \sigma\kappa_a\mathbb{E}_t\Delta\tilde{a}_{t+1} - \gamma\sigma\kappa_q\mathbb{E}_t\Delta e_{t+1}, \qquad (25)$$

[23] Alternatively, the Backus-Smith puzzle can be resolved if the real exchange rate appreciates with a positive productivity shock, either due to Balassa-Samuelson forces, as in Benigno and Thoenissen (2008), or due to a low elasticity of substitution between home and foreign goods ($\theta < 1$), as in the second mechanism considered by Corsetti, Dedola, and Leduc (2008). These alternative mechanisms, however, are at odds with the other exchange rate puzzles, including Meese-Rogoff and PPP.

where the second equality substitutes in the relationship between consumption and the exchange rate (23). The interest rate differential reflects the intertemporal substitution in consumption, which is in part due to the expected depreciation and in part due to the mean reversion in productivity shocks.

In turn, the modified UIP condition (16) ensures equilibrium in the international financial market. In particular, it implies that a financial shock ψ_t—a relative demand shock for foreign currency—must be accommodated by some combination of a positive interest rate differential for home-currency bonds and an expected appreciation of the home currency. Both of these effects make holding foreign-currency bonds less attractive, returning the financial market to equilibrium.

We now combine (25) with the modified UIP condition (16) under our simplifying assumption $\chi_2 = 0$ to solve for the equilibrium interest rate differential and the expected nominal depreciation:

$$i_t - i_t^* = -\frac{\sigma\kappa_a}{1 + \gamma\sigma\kappa_q}(1 - \rho)(a_t - a_t^*) + \frac{\gamma\sigma\kappa_q}{1 + \gamma\sigma\kappa_q}\psi_t, \tag{26}$$

$$\mathbb{E}_t\Delta e_{t+1} = -\frac{\sigma\kappa_a}{1 + \gamma\sigma\kappa_q}(1 - \rho)(a_t - a_t^*) - \frac{1}{1 + \gamma\sigma\kappa_q}\psi_t, \tag{27}$$

where we expressed $\mathbb{E}_t\Delta\tilde{a}_{t+1} = -(1 - \rho)(a_t - a_t^*)$. Note that these relationships imply that both $i_t - i_t^*$ and $\mathbb{E}_t\Delta e_{t+1}$ follow AR(1) processes with persistence ρ.

Using these results, we can now characterize the joint properties of the interest rates and the nominal exchange rate, and in particular the Fama regression, $\mathbb{E}\{\Delta e_{t+1}|i_t - i_t^*\} = \hat{\beta}_F(i_t - i_t^*)$. We prove the following:

PROPOSITION 4. (*a*) Conditional on a productivity shock, the Fama coefficient $\hat{\beta}_{F|a} = 1$. Conditional on a financial shock, the Fama coefficient is negative, $\hat{\beta}_{F|\psi} = -1/(\gamma\sigma\kappa_q) < 0$. (*b*) Unconditionally, as $\beta\rho \to 1$:

i. $\hat{\beta}_F \to -1/(\gamma\sigma\kappa_q) < 0$ and the R^2 in the Fama regression becomes arbitrarily small;
ii. the volatility (persistence) of $(i_t - i_t^*)$ relative to Δe_{t+1} becomes arbitrarily small (large); and
iii. the Sharpe ratio of the carry trade becomes arbitrarily small.

Note that the first part of proposition 4 follows immediately from (26) and (27), while the second part also relies on the equilibrium properties of the nominal exchange rate (proposition 1 and lemma 3 below). We provide a formal proof in online appendix A.6 and offer here an intuitive discussion of the results.

Conditional on a financial shock, positive interest rate differentials predict expected exchange rate appreciations—a pattern of UIP deviations known as the forward premium puzzle (Fama 1984). The reason for this is increased demand for foreign-currency bonds, resulting in an equilibrium positive expected return on home-currency bonds.[24] The productivity shocks are unable to reproduce this empirical pattern, implying a Fama coefficient of one. However, if financial shocks play an important role in the dynamics of the exchange rate, the model reproduces a negative unconditional Fama coefficient. At the same time, the predictive ability of the interest rate differential for future exchange rate changes is very weak in the data (see, e.g., Valchev 2020), and our model captures this with a vanishingly small R^2 in the Fama regression, as shocks become more persistent and the exchange rate becomes closer to a pure random walk. The model also captures the pronounced differences in the statistical properties of $i_t - i_t^*$ and Δe_{t+1}, with the former following a smooth and persistent process and the latter being close to a volatile white noise. Importantly, the financial shock in our model does not produce expected UIP deviations with counterfactually large associated carry trade returns, which allows the quantitative model in the next section to match the size of its Sharpe ratio.

The presence of a UIP shock ψ_t makes it perhaps unsurprising that the model can match the empirical patterns of the UIP deviations. Nonetheless, we point out that the rich patterns of comovement between interest rates and the exchange rate, summarized in proposition 4, are reproduced in the model using a single-parameter AR(1) process for ψ_t. Our main emphasis, however, is that a simple financial shock, disciplined with the properties of the UIP deviations in the data, accounts for the other exchange rate puzzles, which the literature conventionally viewed as not directly related with each other.

D. *Equilibrium Exchange Rate Dynamics*

We now provide a complete analytical characterization of equilibrium exchange rate dynamics, which are shaped by the interplay between financial and macroeconomic forces. The equilibrium in the financial market requires that the modified UIP condition (16) holds, which in turn results in (27) and imposes discipline on the expected future appreciations and depreciations of the nominal exchange rate. Indeed, the equilibrium in the financial market is not affected by the level of the exchange rate but only by its expected changes. This can be seen formally by solving (27) forward to express the exchange rate e_t as a function of the expected future shocks and its long-run expectation $\mathbb{E}_t e_\infty$, which remains indeterminate from the perspective of the financial market alone.

[24] In contrast with the macrofinance literature, surveyed in Engel (2014), our mechanism is not a partial asset-pricing result but a general equilibrium outcome of joint interest rate and exchange rate determination to clear product and asset markets.

In contrast to the financial market, the product market equilibrium depends on the level of the exchange rate. In particular, a depreciated (real) exchange rate causes expenditure switching toward home-produced goods, as we have seen in section III.B. To characterize the equilibrium level of the exchange rate, we need to appeal to the country's intertemporal budget constraint (11), which upon log linearization can be written as[25]

$$\beta b_{t+1} - b_t = nx_t = \gamma[\lambda q_t - \kappa_a \tilde{a}_t], \tag{28}$$

where $\lambda \equiv (2\theta(1-\gamma)-1)/(1-2\gamma)+\gamma\kappa_q > 0$, and κ_q and κ_a are defined in (23). The left-hand side of (28) is the evolution of the net foreign assets (NFAs), while the right-hand side is equilibrium net exports, which decrease with relative domestic demand $c_t - c_t^*$ and hence $\tilde{a}_t$, which increases imports. Net exports increase with the expenditure switching toward home goods induced by a real devaluation (higher q_t).

The intertemporal budget constraint, $b_t + \Sigma_{j=0}^{\infty}\beta^j nx_{t+j} = 0$, is obtained from (28) by rolling it forward and imposing the no-Ponzi-game condition (NPGC), $\lim_T \beta^T b_{t+T} \geq 0$, which holds with equality in equilibrium. Given the expected path of future exchange rate changes, which equilibrate the financial market, the intertemporal budget constraint pins down the equilibrium level of the exchange rate. Finally, note that net exports nx_t depend on the real exchange rate q_t, while monetary policy, which stabilizes domestic price levels in (17), ties together the nominal and the real exchange rates, $e_t = q_t$.

Formally, the interplay between the two dynamic conditions, (27) and (28), shapes the equilibrium dynamics of both exchange rates. In particular, the unique solution to this dynamic system implies the following equilibrium relationship between the exchange rate e_t and the state variable b_t (NFA):[26]

$$e_t = -\frac{1-\beta}{\gamma\lambda} b_t + \frac{1}{1+\gamma\sigma\kappa_q}\frac{\beta}{1-\beta\rho}\left[\psi_t + \left((1-\rho) + \frac{1+\gamma\sigma\kappa_q}{\sigma\lambda}\frac{1-\beta}{\beta}\right)\sigma\kappa_a\tilde{a}_t\right]. \tag{29}$$

[25] Net exports, like net foreign assets, are zero in a symmetric steady state, and we denote $nx_t \equiv NX_t/\bar{Y}$, in parallel with b_t introduced in lemma 1. It follows from (11) that $nx_t = \gamma[c_{Ht}^* - c_{Ft} - s_t] = \gamma[\theta q_t + (\theta-1)s_t - (c_t - c_t^*)]$, where terms of trade $s_t = q_t^P = q_t/(1-2\gamma)$ (from [19]); solving out relative consumption using (23) yields (28). Also note that $\lambda > 0$ in (28) is the general equilibrium version of the Marshall-Lerner condition, which holds in the model, as $\theta > 1$.

[26] Solving (27) and (28) forward and using the fact that shocks are AR(1) results in $e_t = \mathbb{E}_t e_\infty + (1/(1+\gamma\sigma\kappa_q))[\psi_t/(1-\rho) + \sigma\kappa_a\tilde{a}_t]$ and $b_t + \gamma\lambda\Sigma_{j=0}^{\infty}\beta^j\mathbb{E}_t e_{t+j} - (\gamma\kappa_a/(1-\beta\rho))\tilde{a}_t = 0$, which together yield (29). Online app. A.6 offers an alternative derivation, using the Blanchard and Kahn (1980) technique, for the general case with $\chi_1, \chi_2 \geq 0$ that are endogenously determined in equilibrium; with $\chi_2 > 0$, the equilibrium process becomes a stationary mean-reverting ARMA(2,1) instead of an integrated ARIMA(1,1,1), yet the two have indistinguishable finite-sample properties for small $\chi_2 > 0$.

Intuitively, the exchange rate is stronger (lower e_t) the greater the net foreign assets b_t are, and it depreciates with the financial shock ψ_t, which shifts demand to the foreign currency, as well as with the relative productivity shock $\tilde{a}_t$, which results in additional supply of home goods. This pins down the unique equilibrium path of the exchange rate, as deviations from (29) shift the entire expected path of the exchange rate and hence all expected trade balances nx_{t+j}, violating the intertemporal budget constraint. Combining (29) with (28), we can solve for the equilibrium dynamic process for e_t:

LEMMA 3. The equilibrium exchange rate e_t follows an ARIMA(1,1,1) process, or equivalently Δe_t follows an ARMA(1,1), with the autoregressive root ρ, given by

$$\Delta e_t = \frac{1}{1+\gamma\sigma\kappa_q}\frac{\beta}{1-\beta\rho}\left[(1-\frac{1}{\beta}L)\psi_t + [(1-\rho)(1-\frac{1}{\beta}L) + \frac{1+\gamma\sigma\kappa_q}{\sigma\lambda}\frac{1-\beta}{\beta}(1-\rho L)]\sigma\kappa_a\tilde{a}_t\right], \tag{30}$$

where L is the lag operator such that $L\psi_t = \psi_{t-1}$ and $L\tilde{a}_t = \tilde{a}_{t-1}$.

Lemma 3 is the basis for proposition 1, which postulates the equilibrium properties of the exchange rate. In particular, the lemma shows that the dynamics of the exchange rate are shaped by the parameters β and ρ, which determine the ARMA roots in (30), while the other parameters of the model affect the proportional volatility scalers of the shocks. Interestingly, the exchange rate volatility is higher in more closed economies and is maximized in the autarky limit, as $\gamma \to 0$ (see fig. A1*A*). This is in line with the data, where the more open economies have indeed less volatile exchange rates, even after controlling for country size and other characteristics (see, e.g., Hau 2002). Intuitively, a more open economy cannot sustain the same amount of equilibrium exchange rate volatility without it causing more volatile behavior of the macro variables, as we discuss further in section IV.D.

We now focus on the two essential equilibrium properties of the nominal exchange rate:[27]

PROPOSITION 5. As $\beta\rho \to 1$: (i) the exchange rate process (30) becomes indistinguishable from a random walk, with $\mathbb{E}_t\Delta e_{t+1} \to 0$ and $\mathrm{corr}(\Delta e_t, \Delta e_{t-1}) \to 0$, and (ii) the volatility of the exchange rate becomes unboundedly large relative to the volatility of the financial shock, $\mathrm{var}(\Delta e_t)/\mathrm{var}(\psi_t) \to \infty$, with the contribution of ψ_t (relative to $\tilde{a}_t$) dominating the variance of the exchange rate; furthermore, under strong home bias ($\gamma \approx 0$), the relative

[27] The results in proposition 5 follow from the exchange rate process in lemma 3, combined with the equilibrium solution for GDP, $y_t = ((1+\varphi)/(\sigma+\varphi))[a_t - (2\gamma\sigma/(\sigma+\varphi(1-2\gamma)))\tilde{a}_t] + (\gamma/(1-2\gamma))((2\sigma\theta(1-\gamma)-(1-2\gamma))/(\sigma+\varphi(1-2\gamma)))q_t$, which follows from the equilibrium conditions in sec. III.B.

volatility of macroeconomic aggregates, such as GDP, is arbitrarily small $(\text{var}(\Delta y_t)/\text{var}(\Delta e_t) \approx 0)$.

Proposition 5 describes the qualitative order-of-magnitude properties of the nominal exchange rate—namely, that it can follow a process arbitrarily close to a random walk and with an arbitrarily large volatility relative to fundamental macroeconomic variables, such as GDP. Figure 2 illustrates these properties quantitatively for the empirically relevant values of β, ρ, and γ (see calibration in sec. IV).

Figure 2*A* plots the impulse response of the exchange rate to the financial shock ψ_t. A shift in demand toward the foreign currency, $\psi_t > 0$, results in an instantaneous depreciation of the home currency, while also predicting an expected appreciation, consistent with (27), akin to the celebrated overshooting dynamics in Dornbusch (1976). This exchange rate path ensures both equilibrium in the financial market (via expected appreciation) and a balanced country budget (via instantaneous depreciation). The impulse response to the relative productivity shock $\tilde{a}_t$ is quantitatively similar (see fig. A1*B*).[28] In both cases, a large instantaneous depreciation is followed by small but persistent expected future appreciations. Furthermore, as shocks become more persistent, the impulse response of e_t becomes closer to a step function of a random walk for both types of shocks. Thus, the financial shock is not unique in delivering near-random-walk behavior for the exchange rate; in fact, any persistent fundamental shock achieves this.[29]

The essential difference between financial and productivity shocks is emphasized in the second part of proposition 5 and concerns the relative volatility implications for the equilibrium exchange rate. As shocks become more persistent, the effect of the financial shock on the exchange rate increases without bound, while the effect of the productivity shock remains bounded.[30] The differential implications of the two types of shocks become increasingly apparent when we consider the comovement between the exchange rate and macro variables, such as GDP (earlier subsections address the comovement with other macro variables). In response to a financial shock, the volatility of the exchange rate relative to that of GDP is arbitrarily large provided the economy is sufficiently

[28] An increase in productivity and resulting supply of home goods lead to an instantaneous depreciation needed to equilibrate the intertemporal budget constraint (in view of the increased domestic production and consumption), with the currency gradually appreciating thereafter as the productivity shock wears out.

[29] This is reminiscent of the Engel and West (2005) result, which, however, derives from the partial equilibrium in the financial market. In contrast, our solution relies on the full general equilibrium and in particular endogenizes the real exchange rate; thus, our results are not nested by their theorem (for details, see the earlier draft, Itskhoki and Mukhin 2017).

[30] Formally, this is the case because random-walk productivity shocks have no direct effect on the intertemporal optimality condition (25) and thus on the expected exchange rate changes (27). In contrast, rare-disaster, long-run-risk, or productivity-news shocks are more similar in their properties to the financial shock ψ_t from the point of intertemporal optimality.

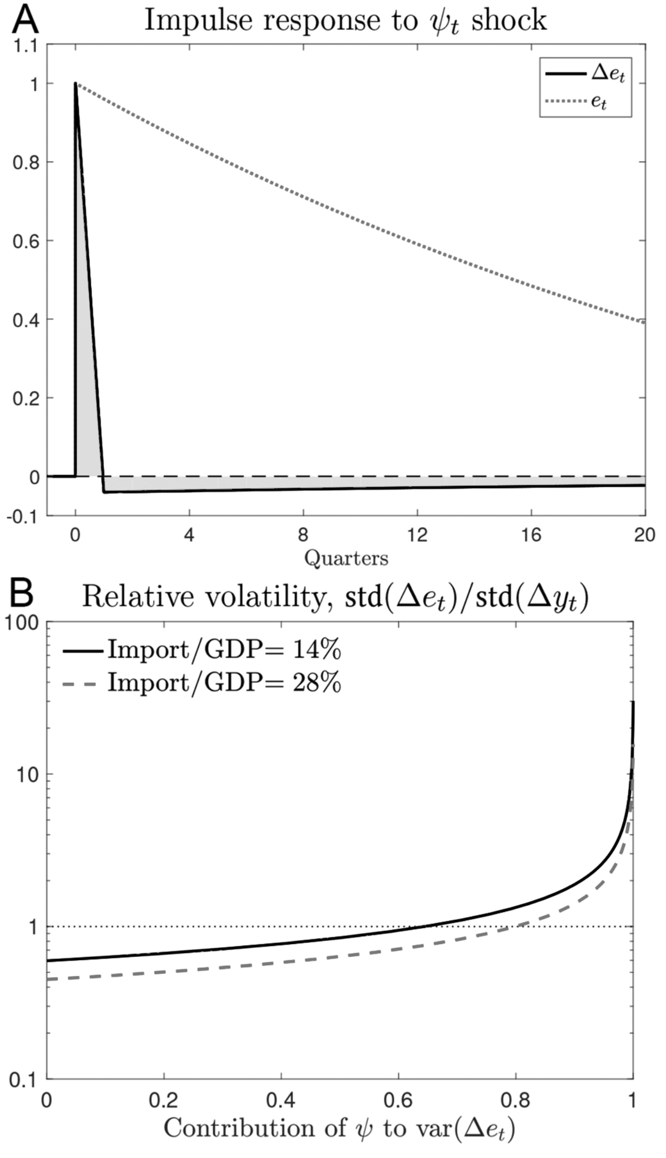

FIG. 2.—Properties of the equilibrium exchange rate process. Calibrated IRBC model (see sec. IV). *A*, Impulse response of Δe_t and e_t to a ψ_t-shock innovation (see fig. A1*B* for $\tilde{a}_t$ shock). *B*, Ratio of the unconditional standard deviations, $\text{std}(\Delta e_t)/\text{std}(\Delta y_t)$, on a logarithmic scale, against the variance contribution (share) of the financial shock, $\text{var}(\Delta e_t|\psi_t)/\text{var}(\Delta e_t)$, plotted by varying the volatility of the financial shock, $\sigma_\psi \in [0, \infty)$; the two curves correspond to different values of γ (matching the indicated import-to-GDP ratios). A color version of this figure is available online.

closed. Formally, this means that $\text{std}(\Delta y_t)/\text{std}(\Delta e_t)$ has the order of magnitude of γ, when γ is small. In contrast, conditional on a productivity shock a_t, the volatility of GDP is of the same order of magnitude as that of the exchange rate, independently of γ; for example, around $\gamma \approx 0$ and with persistent shocks $\rho \approx 1$, we have $\text{std}(\Delta y_t)/\text{std}(\Delta e_t) \approx (2\theta - 1) > 1$. That is, in response to productivity shocks, GDP is counterfactually more volatile than the exchange rate. This is a stark negative result for product-market shocks, which generally cannot deliver exchange rate disconnect in volatilities, even in limiting economies.

Figure 2*B* provides a quantitative illustration of both the negative result for product-market shocks and the positive result for the financial shock, using our calibrated model. In particular, we plot the equilibrium volatility of the exchange rate relative to GDP, $\text{std}(\Delta e_t)/\text{std}(\Delta y_t)$, as a function of the share of the exchange rate volatility, $\text{var}(\Delta e_t)$, explained by the financial shock (with the remaining accounted for by the productivity shocks). We do so for two values of openness, γ—one typical of large, relatively closed economies, such as the United States, Japan, and the European Union, and the other typical of smaller, open economies, such as the United Kingdom, South Korea, and New Zealand. The figure illustrates how the model reproduces the significantly greater volatility of the exchange rate relative to GDP, but only when financial shocks dominate the variance decomposition of the exchange rate. This gap in volatility is indeed greater in less open economies, a pattern that we document in the data in section IV.D.

Predictability.—Equation (27) suggests departures from martingale behavior and implies predictability of the nominal exchange rate. Indeed, there exists empirical evidence on the departure of the exchange rate process from a pure random walk (see, e.g., Bacchetta and van Wincoop 2006; Engel 2016; Lustig, Stathopoulos, and Verdelhan 2019). In a recent paper, Eichenbaum, Johannsen, and Rebelo (2021) emphasize the predictability of future nominal exchange rate changes with the current value of the real exchange rate, $\mathbb{E}\{e_{t+h} - e_t | q_t\} = \alpha_h + \beta_h q_t$, which becomes stronger with the horizon h. We now explore the properties of our model for this predictive regression. In figure A1*C*, we plot the projection coefficients $\hat{\beta}_h$ and the corresponding R^2 values from the simulated paths of exchange rates in our baseline model, closely reproducing the empirical findings of Eichenbaum, Johannsen, and Rebelo (2021): (i) the projection coefficients $\hat{\beta}_h$ are about zero for small h and become increasingly more negative as h increases, crossing -1 after about 6 years, and (ii) R_h^2 also starts around zero and increases toward 0.6 for large h. This pattern holds similarly for financial and productivity shocks and does not rely on stationarity of the nominal or real exchange rate. Therefore, our model reproduces simultaneously the near-random-walk behavior and the subtle departures from a pure random walk in the nominal exchange rate observed in the data.

IV. Quantitative Analysis

In this section, we turn to the full model to study its quantitative properties. The goal is threefold. First, we show that our baseline exchange rate disconnect results in section III are robust to the introduction of capital, nominal rigidities, and a conventional Taylor rule monetary policy. Second, we show that a multishock version of the model matches not only the relative volatilities but also the empirical correlations between exchange rates and macro variables. Finally, we show that matching the exchange rate moments comes at no cost in terms of the model's ability to match the standard international business cycle moments. In particular, while financial shocks account for much of the exchange rate volatility, standard productivity and monetary shocks remain the key drivers of consumption, investment, and output. As a result, the relative volatilities and correlations of macro aggregates in our model are similar to those in the international business cycle literature following Backus, Kehoe, and Kydland (1992). We first focus on large open economies, such as the United States and the euro area, and then consider small open economies in section IV.D.

A. *Full Quantitative Model and Calibration*

We first outline five additional ingredients of our quantitative model relative to the baseline model presented in section II. The full model setup can be found in online appendix A.2. The production function now additionally features capital K_t and intermediate inputs X_t:

$$Y_t = \left(e^{a_t} K_t^{\vartheta} L_t^{1-\vartheta}\right)^{1-\phi} X_t^{\phi}, \tag{31}$$

where ϑ represents the elasticity of the value added with respect to capital and ϕ represents the elasticity of output with respect to intermediates, which determines the equilibrium expenditure share on intermediate goods. Capital is accumulated according to $K_{t+1} = (1-\delta)K_t + [Z_t - (\kappa/2)((\Delta K_{t+1})^2/K_t)]$, where the term in square brackets is investment Z_t net of quadratic adjustment costs. Both intermediate inputs X_t and investment goods Z_t are bundles of domestic and foreign varieties, in parallel with finite consumption C_t.

Monetary policy is now implemented by means of a Taylor rule for the nominal interest rate:

$$i_t = \rho_m i_{t-1} + (1-\rho_m)\phi_\pi \pi_t + \sigma_m \varepsilon_t^m, \tag{32}$$

where $\pi_t = \Delta \log P_t$ represents the inflation rate and ε_t^m represents the monetary shock. Parameters $\sigma_m \geq 0$ and $\rho_m \in [0, 1)$ characterize the volatility of monetary shocks and the persistence of the monetary policy rule, while $\phi_\pi > 1$ is the Taylor rule coefficient, which ensures that the Taylor principle is satisfied.

The final two ingredients are variable markups, arising from Kimball (1995) demand, and sticky wages and prices following Calvo (1983). The desired price of the firm depends on both its marginal cost and the average price of its local competitors, reflecting strategic complementarities in price setting. In particular, the home- and foreign-market desired prices of the home firm are given by

$$p_{Ht} = (1-\alpha)mc_t + \alpha p_t \quad \text{and} \quad p_{Ht}^* = (1-\alpha)(mc_t - e_t) + \alpha p_t^*, \qquad (33)$$

where $\alpha \in [0,1)$ represents the elasticity of strategic complementarities and $(1-\alpha)$ represents the (incomplete) cost pass-through elasticity, both arising from variable markups (see Amiti, Itskhoki, and Konings 2019). Desired prices of the foreign firms are defined by symmetric equations. Last, we introduce wage and price stickiness in a conventional way, as described in Galí (2008) and online appendix A.7. We denote with λ_p and λ_w the Calvo probabilities of price and wage nonadjustment, respectively, and we assume that the prices are sticky in the destination (local) currency (local currency price [LCP], as in Chari, Kehoe, and McGrattan 2002). Therefore, the model features both sources of the LOP deviations—due to variable markups and pricing to market (PTM) and due to LCP stickiness—which we explore in detail below, in section IV.C.

Empirical moments.—Column 1 of table 1 shows the empirical moments that are the focus of our quantitative analysis. For comparability, we follow Chari, Kehoe, and McGrattan (2002) and estimate the moments for the United States relative to the PPP-weighted sum of France, Germany, Italy, and the United Kingdom, using quarterly data from 1973–94. The empirical moments are similar for the longer period that we extend to 2017 (see online data app. A.1). Additionally, for the moments that involve interest rates, we rely on the estimates in Hassan and Mano (2014) and Valchev (2020). Finally, because of the high variability of the Backus-Smith correlation across countries and periods, we use the average estimate from Corsetti, Dedola, and Leduc (2008), which is representative of the conventional value in the literature.

Calibration.—Our calibration, for the most part, does not target the empirical moments in table 1 and instead adopts conventional values for the model parameters following the broader macro literature, as summarized in table A1. In particular, we set the imports-in-expenditure ratio $\gamma = 0.07$, to be consistent with the 0.28 trade-to-GDP ratio of the United States, provided the intermediate input share $\phi = 0.5$.[31] This value of the

[31] In a symmetric steady state, imports are half of trade (imports + exports) and GDP (final consumption) is roughly half of expenditure in the data, with the other half allocated to

trade-to-GDP ratio is also characteristic of the other large developed economies (Japan and the euro area), and we explore a small-open-economy calibration in section IV.D.

We use the estimate of Amiti, Itskhoki, and Konings (2019) for the elasticity of strategic complementarities, $\alpha = 0.4$, which is in line with the exchange rate pass-through literature, corresponding to the pass-through elasticity of $1 - \alpha = 0.6$ (see survey in Gopinath and Itskhoki 2011). We follow the estimates of Feenstra et al. (2018) and set the elasticity of substitution $\theta = 1.5$, which is also the number used in the original calibrations of Backus, Kehoe, and Kydland (1994) and Chari, Kehoe, and McGrattan (2002).[32]

For the other parameters, we use conventional values of the relative risk aversion $\sigma = 2$, the Frisch elasticity of labor supply $1/\varphi = 1$, the quarterly discount factor $\beta = 0.99$, the capital share in value added $\vartheta = 0.3$, and the quarterly capital depreciation rate $\delta = 0.02$. For each specification of the model, we calibrate the capital adjustment cost parameter κ to match the relative volatility of investment, $\text{std}(\Delta z_t)/\text{std}(\Delta gdp_t) = 2.5$. We set the Taylor rule parameter $\phi_\pi = 2.15$ and the interest rate smoothness parameter $\rho_m = 0.95$, following the estimates in Clarida, Galí, and Gertler (2000). In the sticky-price version of the model, we assume that prices adjust on average once a year and thus set $\lambda_p = 0.75$, while wages adjust on average every six quarters, $\lambda_w = 0.85$, following standard calibrations in the literature (Galí 2008). Thus, the range of the models that we consider includes both the flexible-price benchmark and specifications with a considerable extent of price and wage stickiness.

Finally, we discuss the calibration of the shock processes. The model features three exogenous shocks—two country-specific productivity shocks (a_t, a_t^*) and a financial shock ψ_t—for which we need to calibrate the covariance matrix. We assume that ψ_t is orthogonal to (a_t, a_t^*), while a_t and a_t^* are correlated and have a common variance. We choose the relative volatility of the productivity shock, σ_a/σ_ψ, to match the Backus-Smith correlation, $\text{corr}(\Delta q_t, \Delta c_t - \Delta c_t^*) = -0.4$, while the cross-country correlation of productivity shocks is calibrated to match $\text{corr}(\Delta gdp_t, \Delta gdp_t^*) = 0.35$. In addition, we consider a version of the sticky-price model with monetary shocks $(\varepsilon_t^m, \varepsilon_t^{m*})$ instead of productivity shocks, and we discipline their relative volatility σ_m/σ_ψ and cross-country correlation in the same way. Last, we assume that all shocks follow AR(1) processes with the same autoregressive coefficient $\rho = 0.97$, which is consistent with the observed persistence of both

intermediate inputs. The US trade-to-GDP ratio increased from 20% in 1980 to 28% in 2018, corresponding to an increase in γ from 0.05 to 0.07 (see table 4 for further details).

[32] The estimates of the micro elasticity at more disaggregated levels are typically larger, around 3 or 4, yet it is the macro elasticity of substitution between the aggregates of home and foreign goods that is the relevant elasticity for our analysis.

macroeconomic variables, such as GDP and interest rates, as well as risk premia in international financial markets.[33]

B. Main Quantitative Results

Before studying the full quantitative model, we start by evaluating partial single-shock specifications to dissect how individual shocks account for the fit of specific moments in the full model. Our quantitative results are reported in table 1, with the moments related to exchange rate summarized in panels A–C and the international business cycle moments in panel D.

Single-shock models.—Columns 2–5 of table 1 report the results from four single-shock specifications of the model: a financial shock under both flexible and sticky prices; productivity shocks in a standard flexible-price IRBC model; and monetary shocks in a new Keynesian open economy (NKOE) model with sticky prices and wages. We start with the exchange rate moments, which confirm the various analytical results of section III.

First, all four single-shock specifications match the near-random-walk behavior of the nominal exchange rate. Consistent with proposition 5, it is the persistence of the shock rather than its type that ensures that the exchange rate is a near martingale. At the same time, it is only the financial shock that has the ability to replicate the empirical disconnect in volatilities of the exchange rate and the macro variables. In the data, exchange rates are about five times more volatile than GDP and six times more volatile than consumption. Both versions of the model with the ψ_t shock consistently reproduce this gap in the volatility. In fact, they predict that macro variables are an order of magnitude less volatile than exchange rates. As we explain in section III, home bias in the goods market allows us to sustain large equilibrium exchange rate swings without passing excessive volatility through to the macro variables. In contrast, the effect of productivity and monetary shocks on macro aggregates is of the same order of magnitude as on the exchange rates, inconsistent with the disconnect in volatilities.

[33] The ex ante risk premium ψ_t is not directly observable in the data and hence cannot be readily used to calibrate the volatility and persistence of the financial shock. Our calibration is nonetheless consistent with the statistical properties of the estimated $\hat{\psi}_t = i_t - i_t^* - \widehat{\mathbb{E}}_t\Delta e_{t+1}$ using the econometric forecasts of $\widehat{\mathbb{E}}_t\Delta e_{t+1}$ (see, e.g., Bekaert 1995; Kollmann 2005). We also note that the relative volatilities of the shocks could be calibrated to match the relative volatilities of exchange rates and macro variables, instead of targeting the negative Backus-Smith correlation. As we show below, our model can fit these moments without targeting them directly, suggesting that there is no conflict between these alternative calibration targets. Finally, when we calibrate the level of volatility in the model to match the 10% annualized standard deviation of the nominal exchange rate, the implied volatility of the total factor productivity innovations is 1.4% annually, consistent with the Chari, Kehoe, and McGrattan (2002) calibration.

TABLE 1

QUANTITATIVE MODELS

		Single-Type Shocks				Multishock Models		
	Data	Financial Shock		IRBC	NKOE	IRBC	IRBC$^+$	NKOE
Moments	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Exchange rate disconnect:								
$\rho(\Delta e)$	≈0	−.02	−.03	.01	−.06	−.02	−.03	−.03
		(.09)	(.09)	(.09)	(.09)	(.09)	(.09)	(.09)
$\sigma(\Delta e)/\sigma(\Delta gdp)$	5.2	17.7	9.8	.58	1.31	2.9	3.4	3.8
$\sigma(\Delta e)/\sigma(\Delta c)$	6.3	7.5	17.5	.96	2.18	3.9	5.8	6.6
B. Real exchange rate and the PPP:								
$\rho(q)$	.94	.93	.91	.94	.82	.93	.91	.90
		(.04)	(.05)	(.04)	(.06)	(.04)	(.05)	(.04)
$\sigma(\Delta q)/\sigma(\Delta e)$	.99	.74	.98	1.40	.95	.83	.98	.97
$\mathrm{corr}(\Delta q, \Delta e)$	.99	1.00	1.00	1.00	.99	.99	1.00	1.00
$\sigma(\Delta q^W)/\sigma(\Delta e)$	1.01	1.04	1.00	.56	.95	1.07	1.00	1.00
$\mathrm{corr}(\Delta q^W, \Delta e)$	.99	1.00	1.00	−.99	.99	.96	1.00	1.00
C. Backus-Smith and forward premium:								
$\mathrm{corr}(\Delta q, \Delta c - \Delta c^*)$	−.40	−1.00	−.95	1.00	1.00	−.40	−.40	−.40
			(.01)			(.08)	(.08)	(.08)
Fama β	<0	−2.0	−3.4	1.6	1.4	−1.7	−2.2	−1.9
		(1.4)	(2.7)	(.8)	(.8)	(1.5)	(2.1)	(1.3)
Fama R^2	.02	.03	.03	.08	.03	.02	.02	.02
		(.02)	(.02)	(.03)	(.02)	(.02)	(.02)	(.02)
Carry trade *SR*	.20	.23	.22	.01	−.03	.23	.22	.22
		(.04)	(.04)	(.10)	(.09)	(.04)	(.04)	(.04)
$\sigma(i - i^*)/\sigma(\Delta e)$	.06	.08	.05	.17	.12	.08	.06	.06
$\rho(i - i^*)$	.90	.93	.98	.95	.82	.94	.98	.94
$\rho(i)$	.97	.93	.98	.95	.83	.94	.98	.89
D. International business cycle moments:								
$\sigma(\Delta c)/\sigma(\Delta gdp)$	.82	2.37	.56	.60	.60	.74	.59	.57
$\mathrm{corr}(\Delta c, \Delta gdp)$	.64	−1.00	−.82	1.00	1.00	.85	.80	.75
$\mathrm{corr}(\Delta z, \Delta gdp)$	.81	−1.00	−.20	1.00	1.00	.81	.86	.86
$\mathrm{corr}(\Delta gdp, \Delta gdp^*)$	.35	−1.00	−1.00	.35	.35	.35	.35	.35
$\mathrm{corr}(\Delta c, \Delta c^*)$	.30	−1.00	−1.00	.40	.38	.14	.39	.40
$\mathrm{corr}(\Delta z, \Delta z^*)$	.27	−1.00	−1.00	.45	.39	.10	.54	.55
$\sigma_a/\chi_1\sigma_\psi$ or $\sigma_m/\chi_1\sigma_\psi$						3.3	2.5	.38
ρ_{a,a^*} or ρ_{m,m^*}				.28	.34	.30	.37	.56
Nominal rigidities			✓		✓		✓	✓

NOTE.—Panels A–D report the simulation results, where each entry is the median value of moments across 10,000 simulations of 120 quarters and brackets report (when relevant) the standard deviations across simulations. The bottom panel describes the model specifications. Columns 2, 4, and 6 feature flexible prices and wages; cols. 3, 5, 7, and 8 feature both sticky wages and LCP sticky prices. Shocks: financial ψ_t in cols. 2, 3, and 6–8; productivity (a_t, a_t^*) in cols. 4, 6, and 7; monetary $(\varepsilon_t^m, \varepsilon_t^{m*})$ in cols. 5 and 8. In cols. 4–8, correlation of shocks matches $\mathrm{corr}(\Delta gdp, \Delta gdp^*) = 0.35$; in cols. 6–8, in addition, the relative volatility of shocks matches $\mathrm{corr}(\Delta q, \Delta c - \Delta c^*) = -0.4$ (see bottom panel). See data description in the main text.

Second, we consider the properties of the real exchange rate. Note that the Taylor rule that targets inflation ensures a close comovement of the CPI-based real exchange rate with the nominal exchange rate, independently from the type of the shock or price stickiness. However, in line with proposition 2, only the models with the financial shock are consistent with a broader set of the PPP moments. In particular, consistent with the PPP puzzle literature, the monetary model (NKOE) cannot match the persistence of the real exchange rate—predicting a short half-life under 1 year, considerably below the empirical estimates of about 3 years. While this is not an issue for the IRBC model, this model produces a wedge between the CPI-based and the wage-based real exchange rates, which moves with the productivity shocks. Specifically, the IRBC model predicts a negative correlation between the nominal and the wage-based real exchange rates, in contrast with the data (recall fig. 1). The models with the ψ_t shock, on the other hand, have no difficulty in simultaneously matching the persistence of the real exchange rate and nearly perfect comovement between both measures of the real exchange rate and the nominal exchange rate. In contrast to the conventional wisdom, price stickiness is not crucial to resolve the PPP puzzle, but it does help to increase the relative volatility of the real exchange rate toward one.

Third, as anticipated by propositions 3 and 4, only the financial shock models are consistent with a negative Backus-Smith correlation and a negative Fama regression coefficient, again independently of the presence of nominal rigidities. In contrast and despite the segmented asset market, the correlation between relative consumption and the real exchange rate and the Fama coefficient are both close to one for productivity and monetary shocks alike. These properties again favor the models with financial shocks, which additionally have a good fit of the other financial moments—the positive but small Sharpe ratio of the carry trade, the low volatility and high persistence of the interest rates, and the close-to-zero R^2 in the Fama regression.[34]

While the financial shock model is highly successful in matching exchange rate moments, it is clearly dominated by the productivity and monetary shock models in terms of the standard international business cycle moments, as we report in panel D of table 1. In particular, financial shocks counterfactually induce negative correlations between GDP and

[34] We follow Lustig and Verdelhan (2011) in specifying the carry trade strategy (see online app. A.6). Its unconditional Sharpe ratio in the data is about 0.5, but at least half of it is due to the cross-sectional country fixed effects, not modeled in our framework, which focuses on the time-series properties. Our empirical target for the Sharpe ratio of 0.2 corresponds to the "forward premium trade" in Hassan and Mano (2014). In an earlier draft (Itskhoki and Mukhin 2017), we also show how a multishock version of the model matches the additional moments on the intertemporal comovement of interest rates and exchange rates documented by Bacchetta and van Wincoop (2010), Engel (2016), and Valchev (2020).

its domestic components (consumption and investment), as well as negative correlations between macro variables across countries. In contrast and consistent with the earlier literature, this is not an issue for either IRBC or NKOE models, which reproduce the empirical positive comovement of macro aggregates within and across countries.

The full model.—We finally turn to the full quantitative model. In column 6 of table 1, we report the results for the IRBC model with productivity and financial shocks and no nominal rigidities. Column 7 adds sticky wages and sticky prices to the same specification, and we label it IRBC$^+$. Finally, column 8 replaces productivity shocks with monetary shocks, keeping nominal rigidities as in column 7. The bottom line is that all three specifications are successful at simultaneously matching the exchange rate moments in panels A–C and the international business cycle moments in panel D.

Indeed, multishock models inherit the ability of the financial shock model to match the exchange rate moments and the capacity of standard IRBC and NKOE models in matching the international business cycle moments. In particular, multishock models generate volatile and persistent nominal and real exchange rates, which all comove nearly perfectly together, a negative Backus-Smith correlation, and a negative Fama coefficient, while still allowing the main macro aggregates (GDP, consumption, and investment) to be positively correlated with each other and across countries. Therefore, the multishock model faces no trade-off in matching the exchange rate and business cycle moments simultaneously, despite the failure of all single-shock models in one or the other task.[35] Recall that our only explicit calibration target is the negative Backus-Smith correlation, which identifies the relative contribution of the financial and macrofundamental shocks (see eq. [24] in sec. III.B).

To provide an intuitive explanation for these—perhaps surprising—findings, table 2 describes the variance contribution of the shocks to various macroeconomic variables. In particular, the table reports the contribution of the financial shock to the unconditional variance of the exchange rates, consumption, and GDP, while the remaining shares are accounted for by the other shocks. Across specifications, financial shocks account for almost all of the nominal exchange rate volatility and about 90% of the real exchange rate volatility. At the same time, these shocks account for around 10% of the consumption and output volatility. Home bias in the goods market, coupled with incomplete pass-through and low substitutability of home and foreign products, limits the transmission

[35] Note also that the presence of the segmented financial market allows our multishock model to resolve two prominent international business cycle puzzles—the weak cross-country correlation of consumption (Obstfeld and Rogoff 2001) and the positive cross-correlation of investment (Kehoe and Perri 2002)—without targeting these moments in the calibration.

TABLE 2
CONTRIBUTION OF ψ_t TO MACROECONOMIC VOLATILITY

	IRBC (1)	IRBC$^+$ (2)	NKOE (3)
Nominal exchange rate, var(Δe) (%)	96	98	94
Real exchange rate, var(Δq) (%)	87	97	94
Consumption, var(Δc) (%)	20	10	12
GDP, var(Δgdp) (%)	1	11	14

NOTE.—Variance decompositions (cols. 1–3) respectively correspond to the quantitative models in cols. 6–8 of table 1. The entries are the percent contributions of the financial shock ψ_t to the unconditional variances of the macro variables, with the remaining shares accounted for by the other shocks in each model specification.

of large exchange rate fluctuations into the macro variables. As a result, the macro variables are both stable in comparison with exchange rates and are primarily driven by productivity and monetary shocks, which exert strong direct effects on these variables yet contribute relatively little to the exchange rate volatility.

Returning to the main quantitative results in columns 6–8 in table 1, what we find particularly surprising is that the quantitative success of the model is not sensitive, to a first approximation, to the presence or absence of nominal rigidities and to the nature of the shocks, provided that the financial shock is included in the mix. This emphasizes the robustness of the disconnect mechanism laid out in section III, as well as the reason why the earlier literature was unable to explain the equilibrium behavior of exchange rates. Specifically, it is not the failures of the flexible-price or sticky-price transmission mechanisms but rather the focus on productivity and monetary shocks as the key drivers of exchange rates. Instead, we argue that these shocks are fundamentally inconsistent with the disconnect, which calls for the financial shock as the key ingredient in a model of exchange rates.

C. The Role of Incomplete Pass-Through

So far, we have emphasized the role of the financial shock and home bias as the two main ingredients of the disconnect mechanism. Home bias alone goes a long way in muting the transmission of exchange rate volatility into the macro aggregates. Nonetheless, incomplete exchange rate pass-through at the border—due to both variable markups and foreign-currency price stickiness—acts to reinforce home bias in limiting the transmission of exchange rate volatility into macroeconomic prices and quantities. We now evaluate the quantitative contribution of incomplete pass-through to the disconnect mechanism, focusing on the exchange rate transmission via the terms of trade and net exports.

Variable-markup price setting in (33) results in deviations from the LOP—that is, $p^*_{Ht} + e_t - p_{Ht} = \alpha q_t \neq 0$ whenever $q_t \neq 0$ and strategic complementarity elasticity $\alpha > 0$ and similarly for foreign goods. Therefore, if prices are flexible, the terms of trade (TOT), which measure the relative price of imports and exports $s_t = p_{Ft} - p^*_{Ht} - e_t$, are related to RER as follows:[36]

$$s_t = \frac{1 - 2\alpha(1 - \gamma)}{1 - 2\gamma} q_t. \tag{34}$$

Without strategic complementarities ($\alpha = 0$), the TOT are more volatile than the consumer-price RER, $s_t = q_t/(1 - 2\gamma)$, as consumption bundles are more similar across countries than exported production bundles. This is empirically counterfactual, since in the data TOT are substantially more stable than RER (see fig. 1; table 3). PTM, when $\alpha > 0$, mutes the transmission of RER into the TOT, thus reconciling the model with the data (see Atkeson and Burstein 2008).

When prices are sticky, relationship (34) no longer holds in the short run, when the transmission from RER into TOT is instead shaped by the specific pattern of border price stickiness. In particular, when prices are sticky in the producer currency (PCP), TOT depreciate together with RER, as foreign imports become cheaper. In contrast, under local currency price stickiness (LCP), TOT appreciate with a real depreciation, as home export prices increase (Obstfeld and Rogoff 2000). In fact, both of these patterns are at odds with the data, where the correlation between TOT and RER is weak, even if slightly positive (Gopinath et al. 2020). Instead, under dominant currency pricing (DCP), whereby a single currency is used in pricing both exports and imports, TOT are uncorrelated with RER in the short run.

We now contrast the quantitative implications of various pricing assumptions in the context of our calibrated model. In particular, we compare a flexible-price model with PTM against the three alternative versions of the sticky-price model—namely, PCP, LCP, and DCP. In all these cases, we still let the PTM mechanism operate in the background, along with sticky wages, which improve the quantitative fit of the sticky price specifications. We consider both the IRBC$^+$ model with productivity shocks and the NKOE model with monetary shocks, as in table 1. While all versions of the model are comparable in their fit of the exchange rate and business cycle moments in table 1, their ability to match the behavior of the terms of trade and net exports varies across specifications.

[36] This equation results from two relationships: (i) $q_t = (1 - \gamma)q^P_t - \gamma s_t$ states that the relative consumer prices q_t differ from the relative producer prices q^P_t by the relative price of imports s_t, and (ii) $s_t = q^P_t - 2\alpha q_t$ states that TOT reflect the relative producer prices adjusted for the law of one-price deviations, generalizing our analysis in sec. III.A with $\alpha = 0$.

TABLE 3
Terms of Trade and Net Exports

Moments	Data (1)	IRBC (2)	IRBC$^+$ PCP (3)	IRBC$^+$ LCP (4)	IRBC$^+$ DCP (5)	NKOE PCP (6)	NKOE LCP (7)	NKOE DCP (8)
$\sigma(\Delta q)/\sigma(\Delta e)$	.99	.83	.85	.98	.91	.83	.97	.90
$\sigma(\Delta s)/\sigma(\Delta e)$	.25	.22	.86	.81	.08	.85	.81	.06
corr$(\Delta s, \Delta e)$	≈.20	.98	.98	−.94	.59	.97	−.94	.63
$\sigma(\Delta nx)/\sigma(\Delta q)$	.10	.26	.27	.17	.22	.25	.16	.20
corr$(\Delta nx, \Delta q)$	≈0	.97	.99	.99	.99	.97	.97	.97

Note.—Additional moments and model specifications; IRBC and the two LCP columns correspond to cols. 6–8 in table 1.

We report the results in table 3, which identifies the two PCP specifications as clear losers, as they lag in matching all three types of moments—the volatility of the real exchange rate and the behavior of the terms of trade and the net exports. The flexible-price IRBC model comes in second to last, with a good fit of the terms of trade volatility due to the pricing-to-market mechanism. The LCP and DCP specifications compete for first place, with LCP being more successful in matching the volatility of the real exchange rate and net exports, while DCP has a clear lead in its ability to match the behavior of the terms of trade.[37] The DCP mechanism captures both the stability of the terms of trade and their imperfect correlation with the real exchange rate—properties that both PCP and LCP lack. This, however, leads the DCP specification to yield volatile relative prices of imported to domestically produced goods, resulting in an insufficiently volatile real exchange rate and excessively volatile net exports. Both of these issues are addressed under LCP, which produces stable relative prices of imported and domestically produced goods and thus stable import demand. To match all these moments simultaneously, it is likely necessary to generalize the model with either mixed-currency pricing at the border (see Amiti, Itskhoki, and Konings 2020) or combine DCP at the border with local distribution margin and LCP retail-price stickiness for imported goods (see Auer, Burstein, and Lein 2021).

D. *Small Open Economy*

While all large developed economies—the United States, Japan, and the euro area—exhibit a strong home bias, it is much less pronounced in other

[37] Note that all specifications imply a counterfactually high correlation between the real exchange rate and net exports, which is nearly zero in the data, suggesting the need for either additional home-bias or trade-cost shocks or slow adjustment in the trade quantities (the J-curve; see, e.g., Fitzgerald, Yedid-Levi, and Haller 2019), as net exports are more closely correlated with the real exchange rate over the long run (see Alessandria and Choi 2019).

countries, especially small open economies. What are the implications of greater trade openness for the exchange rate disconnect mechanism proposed in this paper? We now study the data from six developed countries of very different size and openness—the United States, Japan, the United Kingdom, South Korea, Sweden, and New Zealand—and show how our model, calibrated to match the size and openness of individual countries, captures both the differences and the similarities in the exchange rate moments observed across these countries in the data.

Even the United States, with the largest economy in the world, still represents less than one-quarter of the world economy. Therefore, the baseline assumption that US openness to imports from the rest of the world, γ, equals the openness of the rest of the world to imports from the United States, γ^*, is a stretch; in reality, $\gamma^* < \gamma$ and is roughly in proportion to the relative size of the United States and the rest of the world. For all other countries, this gap is even larger, and for the truly small open economies, such as New Zealand, an accurate approximation requires a high γ and $\gamma^* \approx 0$, as such countries are open, yet account for a negligible share of global trade. Our two-country model can be readily adjusted to accommodate small open economies by breaking the implicitly imposed symmetry between γ and γ^* and allowing for $\gamma > \gamma^*$, as is consistent with the data on size and openness of individual countries.[38]

The left portion of table 4 describes the empirical patterns we observe across countries, ranked by their size from the United States to New Zealand. Smaller countries are systematically more open, with a larger share of imports in their final expenditure (GDP). For example, according to this measure, South Korea and Sweden are three times more open than the United States, which is about 20 times larger than these countries. New Zealand is 100 times smaller than the United States and about 2.5 times more open (on par with the much larger United Kingdom), reflecting its relative remoteness. We now explore how such vast differences in country size and openness are reflected in exchange rate moments across these countries.

Perhaps surprisingly, there is no systematic relationship between country openness and the time-series comovement between the nominal and real exchange rates. In particular, table 4 shows that the persistence of the real exchange rate and its volatility relative to the nominal exchange rate are essentially the same across the six countries that we study, and the same applies to a nearly perfect correlation between RER and nominal exchange rate (NER; not reported). In this sense, the PPP puzzle is

[38] That is, we still consider a country vs. the rest of the world and treat the moments in the data accordingly. The log-linearized equilibrium system remains the same, only with an added asymmetry in market clearing (10), which now features γ at home and γ^* abroad, with $\gamma^*/(\gamma + \gamma^*)$ equal to the steady-state share of the home economy in world GDP, and the consumer price indexes p_t and p_t^* reflect these changes accordingly.

TABLE 4
SMALL OPEN ECONOMY

Moments	Data						Model (IRBC$^+$)	
	United States (1)	Japan (2)	United Kingdom (3)	Korea (4)	Sweden (5)	New Zealand (6)	United States (7)	New Zealand (8)
Size (% world GDP), $\gamma^*/(\gamma+\gamma^*)$	23.7	10.5	4.1	1.3	.8	.2		
Imp/GDP (%), 2γ	12.1	11.5	24.4	33.4	33.0	22.8	12.1	22.8
Exp/GDP* (%), $2\gamma^*$	2.9	1.2	1.0	.5	.3	.1	2.9	.1
$\rho(q)$	.96	.96	.93	.92	.97	.96	.92	.91
$\sigma(\Delta q)/\sigma(\Delta e)$	.97	1.03	1.04	.95	.99	1.01	.99	.99
$\text{corr}(\Delta q, \Delta c - \Delta c^*)$	−.22	.12	−.03	−.50	−.17	.01	−.40	−.40
$\sigma(\Delta e)/\sigma(\Delta gdp)$	4.5	4.5	4.9	3.3	2.9	2.1	5.3	3.6
$\sigma(\Delta nx)/\sigma(\Delta q)$	.06	.09	.16	.24	.25	.26	.15	.28

NOTE.—Empirical moments calculated using quarterly data for 1981–2017 from the World Bank's World Integrated Trade Solution database; exchange rates are trade-weighted bilateral exchange rates with major trading partners (see online app. A.1). Exp = export; Imp = import.

equally pronounced in large closed and small open economies. The same is true of the Backus-Smith puzzle, in the sense that there is no systematic relationship between country openness and the sign or the magnitude of the correlation between RER and relative consumption growth, which is small for all countries and typically negative.[39]

The only two exchange rate moments that are clearly sensitive to the openness of the economy are the volatility of the nominal exchange rate relative to macroeconomic aggregates and the volatility of net exports relative to the real exchange rate. While net exports are relatively more volatile, the nominal exchange rate is relatively less volatile in more open economies. Note that this is driven not by the changing volatility of GDP, which is somewhat larger in small open economies, but instead by lower volatility of exchange rate and greater volatility of net exports.

We now verify how our model accommodates these empirical patterns. To this end, we focus on our preferred IRBC$^+$ version of the quantitative model with nominal rigidities (as in col. 7 of table 1) and recalibrate it to feature $\gamma > \gamma^*$. In particular, we consider two calibrations—to the size and openness of the United States and New Zealand, which lie at the two extremes. For transparency of the comparison, we keep all other

[39] Our results in sec. III.B—in particular the variance decomposition (24)—provide insight as to why this is likely the case. While the relationship between relative consumption and RER depends on openness γ, the contribution of RER to the overall volatility of consumption is not very large, even as γ increases. Therefore, the variation in the Backus-Smith correlation across countries largely reflects the composition of shocks over a given time interval, rather than the degree of country openness.

parameters unchanged and adjust the relative volatility of shocks to keep the Backus-Smith correlation and the cross-country GDP correlation unchanged, as we described above.[40]

Columns 7 and 8 of table 4 show that in the model, significant differences in the openness of the economies do not change the time-series comovement between the real and nominal exchange rates, reproducing the "PPP puzzle" moments observed in the data. While the exchange rate pass-through into domestic CPI inflation increases because of a higher openness of the economy γ, consistent with empirical evidence, the pass-through into foreign prices falls because of a correspondingly lower γ^*. As a result, the effect of the nominal exchange rate on the relative prices across countries remains largely unchanged, and so does the comovement between the nominal and real exchange rates.

The changing openness of the economy, however, affects the equilibrium relative volatility of the exchange rates and macroeconomic aggregates. Indeed, a small open economy with a high γ features a smaller volatility of the exchange rates and a greater volatility of net exports, relative to the volatility of GDP. Intuitively, the transmission of exchange rate volatility into domestic output and net exports depends primarily on the home import share γ and hence is significantly higher under the small open economy calibration. In general equilibrium, this results in a mildly higher GDP volatility (with GDP, as before, largely determined by domestic productivity), a notably lower exchange rate volatility (recall the role of γ in [30]), and a substantially higher volatility of net exports, consistent with the empirical patterns we document in table 4.

Developing countries.—In our analysis, we target the moments from developed Organization for Economic Cooperation and Development (OECD) countries under floating exchange rate regimes. In non-OECD countries, the volatility contribution of monetary, productivity, and commodity-price shocks is arguably more pronounced (see e.g. Aguiar and Gopinath 2007) and, in addition, pegs and partial pegs are more ubiquitous (see, e.g., Reinhart and Rogoff 2004).[41] In the model, this makes the exchange rate puzzles less pronounced, as it reduces the relative role of the financial shock in shaping the dynamics of the exchange rate. This is in line with the empirical evidence that the Meese-Rogoff disconnect, the PPP, the Backus-Smith, and the UIP conditions fare less badly in developing

[40] This constitutes a conservative approach, as the composition of shocks and business cycle moments are somewhat different in small open economies, which allows us to further improve the fit of the exchange rate moments in these economies, as we discuss at the end of this section. Also recall that we target a negative value of the Backus-Smith correlation, which is conventional in the literature; our results change little when we target a lower absolute value for this correlation (e.g., -0.2).

[41] On the role of commodity prices in shaping the exchange rates, see, e.g., Chen and Rogoff (2003), Ayres, Hevia, and Nicolini (2020), and Gopinath et al. (2020).

countries (see, e.g., Rogoff 1996; Bansal and Dahlquist 2000) and under pegged regimes (for the analysis of a peg, see Itskhoki and Mukhin 2019). Therefore, accommodating these differences in the combination of shocks and in the exchange rate policies allows our quantitative model to capture the properties of exchange rates in rich and developing countries of different sizes and openness.

V. Conclusion

We propose a parsimonious general equilibrium model of exchange rate determination, which offers a unifying resolution to the main exchange rate puzzles in international macroeconomics. In particular, we show that introducing a financial shock into an otherwise standard international business cycle model allows it to match a rich set of moments describing the comovement between exchange rates and macro variables without compromising the model's ability to explain the main international business cycle properties. We take advantage of the analytical tractability of the model to dissect the underlying exchange rate disconnect mechanism, which we show is robust and requires only an empirically relevant degree of home bias in consumption. Additional sources of incomplete pass-through, including pricing to market and foreign-currency price stickiness, improve the quantitative fit of the model without changing its qualitative properties.

With this general equilibrium model, one can reconsider the conclusions in the broad international macro literature, which has been plagued by exchange rate puzzles. In particular, our analysis shows that these puzzles do not necessarily invalidate the standard international transmission mechanism for monetary and productivity shocks, including international spillovers from monetary policy (see, e.g., Corsetti, Dedola, and Leduc 2010; Egorov and Mukhin 2020). We emphasize instead that these conventional shocks cannot be the main drivers of the unconditional behavior of exchange rates. In contrast, our findings likely challenge the conventional normative analysis in open economies and in particular the studies of the optimal exchange rate regimes and capital controls. Pegging the exchange rate may simultaneously reduce monetary policy flexibility (Friedman 1953) yet improve international risk sharing by offsetting the noise-trader risk (Jeanne and Rose 2002; Devereux and Engel 2003). Furthermore, a microfoundation of financial shocks is essential, as they may endogenously interact with or arise from monetary policy (see Alvarez, Atkeson, and Kehoe 2007; Itskhoki and Mukhin 2019).

In addition, our framework can be used as a theoretical foundation for the vast empirical literature that relies on exchange rate variation for identification (see, e.g., Burstein and Gopinath 2012). Similarly, it can serve as a point of departure for the equilibrium analysis of the international price system (Gopinath 2016; Mukhin 2017) and the global financial cycle (Rey 2013). The model also offers a simple general equilibrium framework for nesting the financial sector in an open economy environment. This may prove particularly useful for future explorations into the nature of financial shocks, which can be disciplined by additional comovement properties between exchange rates and financial variables (e.g., see recent work by Jiang, Krishnamurthy, and Lustig 2018; Engel and Wu 2019).

Appendix

Additional Figures and Tables

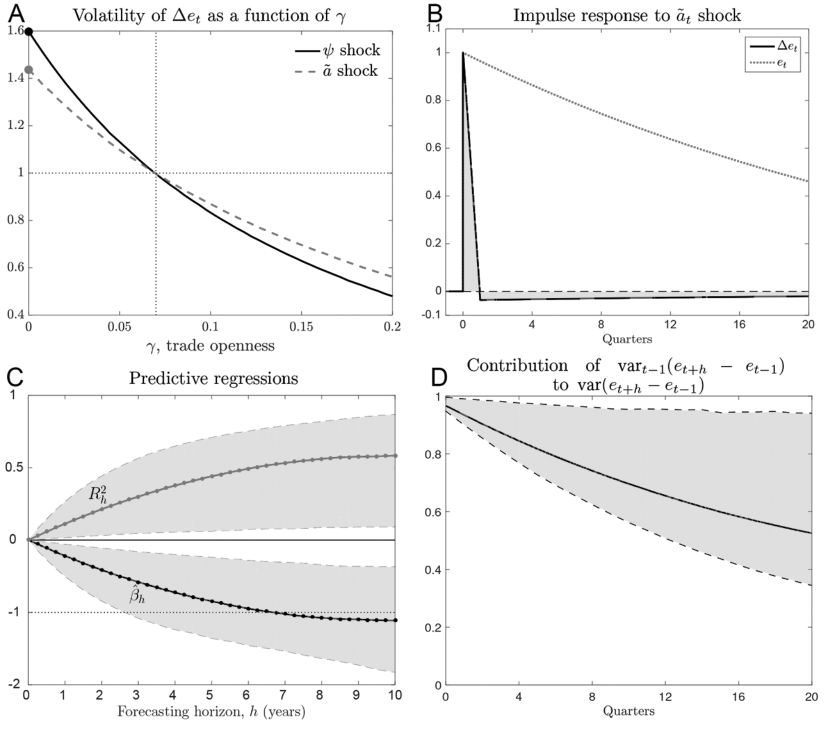

Fig. A1.—Additional properties of the equilibrium exchange rate process. *A*, Plot of std(Δe_t) as a function of openness γ, conditional on ψ_t and $\tilde{a}_t$ shocks, normalizing to one the calibrated value of std(Δe_t) for $\gamma = 0.07$. *B*, Impulse response of Δe_t and e_t to a productivity shock $\tilde{a}_t$ innovation (cf. fig. 2*A*). *C*, $\hat{\beta}_h$ and R_h^2 from the predictive regression $\mathbb{E}\{e_{t+h} - e_t | q_t\} = \alpha_h + \beta_h q_t$, at different horizons $h \geq 1$. *D*, Variance contribution of the unexpected component, $e_{t+h} - \mathbb{E}_{t-1} e_{t+h}$, to the overall variance of $e_{t+h} - e_{t-1}$ for different horizons $h \geq 0$. Lines in *C* and *D* plot medians across 10,000 simulations with 120 quarters each, and shaded areas provide the 5%–95% range across simulations. A color version of this figure is available online.

TABLE A1
MODEL PARAMETERS

Parameter	Variable	Value	Comment
Conventional parameters:			
Discount factor, quarterly	β	.99	
Relative risk aversion	σ	2	
Macro Frisch elasticity	$\nu = 1/\varphi$	1	
Intermediate share	ϕ	.5	
Capital share in value added	ϑ	.3	
Depreciation rate, quarterly	δ	.02	
CES parameter for labor (sticky wages)	ϵ	4	
Transmission mechanism:			
Trade openness	γ	.07	Trade-to-GDP ratio = .28
Elasticity of substitution	θ	1.5	Feenstra et al. 2018
Strategic complementarity	α	.4	Amiti et al. 2019
Monetary parameters:			
Taylor rule coefficient	ϕ_π	2.15	Clarida, Galí, and Gertler 2000
Interest rate smoothing	ρ_m	.95	$\rho(i_t)$, $\rho(i_t - i_t^*) \approx .95$
Calvo probability for prices	λ_p	.75	Duration of four quarters
Calvo probability for wages	λ_w	.85	Duration of six quarters
Calibrated parameters:			
Persistence of shocks	ρ	.97	$\rho(gdp_t)$, $\rho(i_t)$, $\rho(\psi_t)$
Coefficient on NFA in UIP (16)	χ_2	.001	$\rho(\Delta b_t) \approx .95$
Standard deviation of the UIP shock	$\chi_1\sigma_\psi$	1	Normalization
Standard deviation of productivity (monetary) shocks	σ_a (σ_m)	$\rightarrow$	$\text{corr}(\Delta c_t - \Delta c_t^*, \Delta q_t) = -.4$
Correlation of productivity (monetary) shocks	ϱ_{a,a^*} (ϱ_{m,m^*})	$\rightarrow$	$\text{corr}(\Delta gdp_t, \Delta gdp_t^*) = .35$
Capital adjustment cost parameter	κ	$\rightarrow$	$\text{std}(\Delta z_t)\ /\ \text{std}(\Delta gdp_t) = 2.5$

NOTE.—See calibration details in sec. IV. The values of κ, σ_a, σ_m, ϱ_{a,a^*}, and ϱ_{m,m^*} vary across specifications to keep the targeted moments unchanged. We normalize the effective volatility of the financial shock $\chi_1\sigma_\psi = 1$, as our results focus on the relative volatilities of the variables; scaling σ_a and $\chi_1\sigma_\psi$ proportionally does not affect the results reported in table 1 and allows us to match the volatility of the nominal exchange rate in any specification of the model. In addition, we use a small positive $\chi_2 = 0.001$ in the modified UIP (16), which endogenously ensures long-run stationarity of the model (cf. Schmitt-Grohé and Uribe 2003) and is also consistent with the high persistence of the US current account Δb_t in the data.

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