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# EXCHANGE RATES, NATURAL RATES, AND THE PRICE OF RISK

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**ABSTRACT**

We study the source of exchange rate fluctuations using a general equilibrium model accommodating shocks in goods and financial markets. These shocks differ in their induced comovements between exchange rates, interest rates, and quantities. A calibration matching data from the U.S. and G10 currency countries implies that persistent shocks to relative demand, reflected in persistent interest rate differentials, account for 75% of the variance in the dollar/G10 exchange rate. Shocks to currency intermediation are important, however, in generating deviations from uncovered interest parity at high frequencies and explaining the dollar appreciation in crises.

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A data appendix is available at http://www.nber.org/data-appendix/w32976

# 1 Introduction

What drives exchange rates? This question is particularly challenging because exchange rates are very difficult to predict (Meese and Rogoff (1983)); appear inconsistent with uncovered interest parity, at least at short horizons (Hansen and Hodrick (1980), Fama (1984)); and are inconsistent with standard macroeconomic models with complete markets (Backus and Smith (1993)). In this context, recent advances in international macroeconomics and finance have identified shocks to intermediary constraints, "noise trader" demand, and convenience yields, all ultimately entering as wedges in the uncovered interest parity (UIP) condition, as possibly important drivers of exchange rates, and have made tractable their study in general equilibrium.

In this paper, we investigate the source of exchange rate fluctuations using a general equilibrium model accommodating shocks to currency intermediation as well as shocks to demand and supply in each country. The key distinction between currency intermediation shocks and other shocks is the induced comovement between interest rate differentials and the exchange rate. The distinction between supply shocks and other shocks is the induced comovement between relative consumption and the exchange rate. Between the U.S. and G10 currency countries over 1991-2020, U.S. interest rates and relative U.S. consumption have been high when the dollar is strong, suggesting an important role for demand shocks. In a calibration disciplining demand shocks using bond yields, we find that these shocks indeed account for roughly 75% of the variance in the dollar/G10 exchange rate and generate the observed comovements. Demand shocks generate much larger volatility of exchange rates than macroeconomic aggregates because they are persistent, reflected in persistent yield differentials, and exchange rates are forward-looking. While demand shocks have a predominant role in accounting for the dollar/G10 exchange rate, we also find currency intermediation shocks are important to account for UIP deviations at high frequencies, and to explain the dollar appreciation in crises when the yield on dollar bonds is relatively low.

We study these questions using a two-country exchange economy. We build on the recent literature studying exchange rates in segmented markets in which U.S. households trade a bond denominated in their own consumption bundle (a "dollar bond"), Foreign households trade a bond denominated in their consumption bundle, and arbitrageurs with limited risk-bearing capacity trade with both groups of households. Demand shocks are shocks to the discount factors of households, supply shocks are shocks to endowments, and currency intermediation shocks are shocks to the risk tolerance of arbitrageurs. In terms of their macroeconomic implications, currency intermediation shocks can equivalently be modeled as shocks to the demand for foreign currency assets (on the part of "noise traders", or from households as reflected in convenience yields);[1] they are distinguished by shocks to discount factors because the latter affect the demand of households in a given country for *all* assets.

We first analytically clarify how the shocks in our model generate distinct comovements between exchange rates, interest rates, and macroeconomic aggregates. The key distinction between currency intermediation shocks and other shocks is the induced comovement between the real exchange rate and real interest rates. An intermediation shock that causes the dollar to appreciate also causes a relative increase in the Foreign interest rate, while the other shocks do the opposite. The key distinction between supply shocks and other shocks is the induced comovement between the real exchange rate and relative consumption. A supply shock that causes the dollar to appreciate also causes a relative increase in Foreign consumption, while demand and intermediation shocks do the opposite. It follows that demand shocks are the only ones which simultaneously imply that a strong dollar is associated with a relatively high U.S. interest rate and relatively high U.S. consumption.

We also characterize the role of persistence in shaping the exchange rate effects of demand shocks, anticipating their important role in the quantitative analysis which follows. Consider the comparative statics with respect to more persistent relative demand. In this case, an innovation in relative demand will imply more persistent interest rate differentials going forward. Since exchange rates are forward-looking, this increases the impact effect on the exchange rate provided that deviations from UIP are small, which will be the case when steady-state currency intermediation frictions are small. This generates larger volatility in exchange rates than interest rates and macroeconomic quantities. At the same time, since innovations in the expected change in the exchange rate are simply equal to the innovations in interest rates, its variance falls relative to the overall variance of the change in the exchange rate. This generates a lower $R^2$ in regressions of future changes in exchange rates on interest rates or other macroeconomic aggregates. The role of persistence in delivering

[1] The only distinction between shocks to risk tolerance and shocks to the demand for foreign currency assets is in the volume of intermediation done by arbitrageurs. The effects on exchange rates, interest rates, and aggregate consumption are qualitatively the same.

these results relies on incomplete markets: if instead risk sharing was efficient across countries, the persistence of demand shocks would be irrelevant in determining their impact effect on the exchange rate.

We next measure comovements of the dollar/G10 exchange rate in the data over the 1991-2020 period. We measure nominal yields in each currency and interpret these yield differences as counterparts to real yield differences in our model, given relatively low and stable expected inflation for the countries in our sample over this period. Higher U.S. yields than G10 yields are associated with a stronger dollar, both in changes and in levels. These comovements hold across tenors, which range from three months to 10 years in our data, and are statistically significantly different from zero using longer tenors. The explanatory power of yield differentials is especially strong when we condition on proxies for risk or convenience yields, such as the excess bond premium of Gilchrist and Zakrajsek (2012). We also measure real consumption per capita in each country. Higher real consumption per capita in the U.S. than G10 countries is statistically significantly associated with a stronger dollar, both in changes and in levels. Despite the strong contemporaneous comovements with yield differentials and relative consumption, these variables have much lower explanatory power for changes in exchange rates in the future. In light of our analytical results, we conclude from these empirical findings that persistent shocks to relative demand may be an important driver of exchange rates.

We turn to formally quantifying the model to see how far it can go in accounting for the dollar/G10 exchange rate. We discipline demand and supply shocks to match the stochastic properties of 10-year yields and output per capita in the data. Consistent with the dollar funding among financial institutions in practice, steady-state discount factors are such that currency arbitrageurs are net short the dollar. We discipline currency intermediation shocks by assuming that the excess bond premium is a direct measure of arbitrageur risk aversion, up to scale. We discipline the volatility of these shocks so that the model generates the same volatility of real exchange rate changes as in the data. We discipline the steady-state degree of currency intermediation frictions to match the volatility of trade flows (as, by the balance of payments, these flows in goods correspond to flows in financial assets). An important implication is that demand shocks require high persistence of 0.98 at a quarterly frequency to match the autocorrelation of the 10-year yield differential of 0.93 in the data.

The calibrated model implies that shocks to relative demand and thus interest rate differentials account for most of the variation in the dollar/G10 exchange rate. Demand shocks generate roughly 75% of the variance in the exchange rate. The comovements between the real exchange rate, yield differentials, and relative consumption are all within the 90% confidence intervals in the data; in particular, the model-implied dollar is strong when U.S. yields and U.S. consumption are relatively high. The $R^2$ in regressions predicting changes in the exchange rate are much lower, consistent with the weak predictability of the exchange rate in the data. Indeed, the exchange rate exhibits near random walk behavior, with a high autocorrelation in levels (0.91) and close to zero autocorrelation in levels (-0.04) comparable to their values in the data (0.94 and 0.04, respectively). We also invert the sequence of shocks required by our model to rationalize the exact path of 10-year yields, output per capita, and excess bond premium in the data over 1991-2020. Simulating the resulting real exchange rate reveals that the model accounts for both the trend and cycles in the observed exchange rate, and most of this is due to relative demand shocks.

At the same time, because currency intermediation shocks induce the opposite comovement of exchange rates and yield differentials as demand shocks, they play a complementary role in matching the data. First, intermediation shocks reduce the explanatory power of yield differentials for exchange rates to be comparable with the data; in their absence, yield differentials would account for a counterfactually high share of contemporaneous exchange rate fluctuations. Second, they allow the model to match deviations from UIP at short horizons, especially because they are more transitory than persistent demand shocks and thus account for half of the variance in the exchange rate in quarterly changes. Third, in the model simulation over 1991-2020, these shocks explain why the dollar appreciated in crises (the early 2000s, 2008, and 2020) even though U.S. interest rates were relatively low.

We conclude with an interpretation of our findings and directions for future work. First, to the extent that persistent shocks to relative demand, reflected in persistent differences in real interest rates and thus natural rates of interest across countries, are a primary driver of exchange rates, it begs the question of where these shocks come from. In richer economies, changes in credit conditions, demographics, or uncertainty would propagate like discount factor shocks in our reduced form exchange economy. Persistent shocks to growth rates would also generate movements in relative demand and natural rates. Using additional moments in the data to identify the relative importance of these shocks seems a fruitful avenue for future work. Second, there is heterogeneity along the cross-section of currencies to explore. When we extend our empirical investigation to emerging markets, we in fact find that their yields tend to be relatively *low* when their currencies are strong versus the dollar. This suggests that intermediation shocks may play a more important role in driving the dollar/EM exchange rate. More broadly, an interesting question is whether heterogeneous exposures to demand and intermediation shocks can account for the factor structure in bilateral exchange rates documented in the asset pricing literature.

**Related literature** Our paper contributes to an active literature studying exchange rates in segmented financial markets. We build most directly on the work of Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021), who demonstrate that shocks to currency intermediation can generate volatile exchange rates and predictable deviations from UIP.[2] We argue that, while these shocks play a meaningful role at high frequencies, the comovements between interest rates, consumption, and exchange rates call for a predominant role for demand shocks in driving the dollar/G10 exchange rate.[3] In this sense, our analysis harkens back to an earlier literature emphasizing the propagation of conventional "macroeconomic" shocks for exchange rates in segmented markets, as in Alvarez, Atkeson, and Kehoe (2002, 2009) and Heathcote and Perri (2002), though the demand shocks which we emphasize are not studied in these papers. Like us, Devereux, Engel, and Wu (2023) study the dollar exchange rate in an environment featuring demand, supply, and intermediation shocks, but they focus on the propagation of these shocks through an endogenous convenience yield. Gourinchas, Ray, and Vayanos (2024) and Greenwood, Hanson, Stein, and Sunderam (2023) share our focus on long term yields and exchange rates. However, they focus on the relationship between term premiums and exchange rates in partial equilibrium settings, whereas we focus on the relationship between persistent interest rate differentials and exchange rates in general equilibrium.

In this respect, our analysis relates this literature to an older one emphasizing the relationship between exchange rates and interest rate differentials. The "asset market view" of exchange rates, reflected for instance in Dornbusch (1976), emphasized the

[2]Related recent models of exchange rates in frictional financial markets include Adrian, Erceg, Linde, Zabczyk, and Zhou (2020), Basu, Boz, Gopinath, Roth, and Unsal (2020), Fanelli and Straub (2021), Akinci, Kalemli-Ozcan, and Queralto (2022), and Fukui, Nakamura, and Steinsson (2023).

[3]The segmentation emphasized by these papers remains crucial because it links the persistence of demand shocks to the exchange rate response, echoing Corsetti, Dedola, and Leduc (2008).

role of expectations regarding future macroeconomic fundamentals as determinants of the exchange rate, and an enormous empirical literature studying exchange rates and interest rates followed.[4] Our empirical work extends this investigation to data over the past 30 years, and our interpretation through the model focuses on shocks to real interest rates arising from non-monetary factors. Our focus on demand shocks in particular allows us to overcome the consumption-real exchange rate anomaly highlighted by Chari, Kehoe, and McGrattan (2002), and builds on the work of Stockman and Tesar (1995) and Pavlova and Rigobon (2007) who find that demand shocks can help account for other features of international business cycles and asset prices. Also in this context, two especially close precursors to our paper are Engel and West (2005) and Engel (2016). The former demonstrates that persistent innovations to fundamentals can generate realistic exchange rate properties; we make use of this insight in the context of shocks to relative demand and thus interest rates in general equilibrium. The latter argues that models of UIP deviations have difficulty in accounting for longer run properties of exchange rates; in our calibrated model, UIP indeed holds better at longer horizons than shorter horizons because risk premia exhibit more transitory fluctuations than interest rate differentials.

Since the shocks in our reduced form exchange economy likely stand in for deeper sources of fluctuations in richer production economies, our analysis also relates to wedge accounting exercises studying properties of exchange rates.[5] Itskhoki and Mukhin (2023) demonstrate that, in the limit of autarky, shocks to the demand for foreign currency assets are the only ones which can simultaneously generate a disconnect between exchange rates and other macroeconomic or financial variables. We argue that the dollar/G10 exchange rate is not disconnected from bond yields or relative consumption, especially at lower frequencies, and that demand shocks reflected in bond yields deliver realistic comovements and volatility in the exchange rate.[6] Chernov, Haddad, and Itskhoki (2024), Jiang, Krishnamurthy, and Lustig (2024b),

[4]See, for instance, Frankel (1979), Campbell and Clarida (1987), Meese and Rogoff (1988), and Clarida and Gali (1994).

[5]These complement wedge accounting in closed economies, as in Chari, Kehoe, and McGrattan (2007) and Berger, Bocola, and Dovis (2023), as well as in open economies not focused on exchange rates, as in Eaton, Kortum, and Neiman (2016a) and Eaton, Kortum, Neiman, and Romalis (2016b).

[6]To be clear, we do not challenge the idea that the exchange rate may have limited effects on the economy due to features such as high home bias, a low trade elasticity, or pricing to market. We do, however, challenge the idea that the exchange rate is driven by shocks disconnected from those driving other asset prices and macroeconomic quantities.

and Jiang, Krishnamurthy, Lustig, and Sun (2024c) study the ability of unspanned risks, cross-bond Euler equation wedges, and convenience yields to make progress on exchange rate puzzles.[7] These are similar to the currency intermediation shocks in our framework. Demand shocks are instead wedges between consumption growth and stochastic discount factors, and are not the focus of these papers.

Finally, our analysis provides a structural counterpart to a growing empirical literature arguing that the dollar exchange rate is in fact not disconnected from other macroeconomic and financial variables. Obstfeld and Zhou (2023) document that yield differentials have substantial explanatory power for the exchange rate between the dollar and advanced economies, and Engel and Wu (2024) demonstrate that macroeconomic fundamentals and proxies for risk and liquidity account for a substantial share of variation in dollar/G10 exchange rates. Our model can make sense of the comovements with the dollar exchange rate uncovered in these papers. Hau and Rey (2006) and Camanho, Hau, and Rey (2022) document that equity returns are related to exchange rates.[8] While we do not price equity claims in the present paper, the link between bond yields and exchange rates which we emphasize echoes their message that the exchange rate is not disconnected from these other asset prices. Chahrour, Cormun, De Leo, Guerron-Quintana, and Valchev (2024) argue using a vector autoregression that the dominant driver of exchange rates are news shocks about future TFP.[9] Since growth shocks would propagate like discount factor shocks in being effective demand shocks, our results are consistent with their findings.

**Outline** In section 2 we outline the model, and in section 3 we analytically characterize the comovements induced by each shock and the role of model ingredients in shaping the propagation of demand shocks. In section 4 we empirically characterize these comovements for the U.S. and G10 currency countries. Motivated by this evidence, in section 5 we calibrate the model to the data and assess its ability to account for exchange rate volatility and comovements. Finally, in section 6 we discuss the

[7] These papers in turn build on a "preference-free" tradition in the determination of exchange rates, as in the work of Brandt, Cochrane, and Santa-Clara (2006) and Lustig and Verdelhan (2019).

[8] Relatedly, using a demand system approach, Koijen and Yogo (2022) argue that most of the variation in the dollar exchange rate is due to macroeconomic and policy variables, and Richmond, Jiang, and Zhang (2024) argue that exchange rate movements are linked to capital flows. Lilley, Maggiori, Neiman, and Schreger (2020) document an increase in the $R^2$ of the dollar/G10 exchange rate with S&P 500 returns and other measures of risk appetite since the global financial crisis.

[9] Stavrakeva and Tang (2024) argue that, more generally, the response to macroeconomic news announcements accounts for most of the variation in the exchange rate.

interpretation and implications of our findings, and in section 7 we conclude.

# 2 Model

We first outline a two-country economy featuring shocks to demand, supply, and currency intermediation.

## 2.1 Environment

We study an exchange economy, though we accommodate a distinction between intermediate goods (endowments) and final goods to allow for incomplete pass-through of the exchange rate into domestic prices. There are two countries, Home (the U.S.) and Foreign, comprised of a measure 1 and $\zeta^*$ households.

**U.S. households** The U.S. representative household has time separable preferences with flow utility

$$u(c_t) = \frac{(c_t)^{1-1/\psi} - 1}{1 - 1/\psi},$$

discount factor $\beta_t$, and a CES aggregator over bundles of final goods from each country

$$c_t = \left( \left( \frac{1}{1+\zeta^*} + \frac{\zeta^*}{1+\zeta^*} \varsigma \right)^{\frac{1}{\sigma}} (c_{Ht})^{\frac{\sigma-1}{\sigma}} + \left( \frac{\zeta^*}{1+\zeta^*} (1-\varsigma) \right)^{\frac{1}{\sigma}} (c_{Ft})^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}.$$

Here, $\psi$ denotes the household's elasticity of intertemporal substitution, $\sigma > \frac{1}{2}$ denotes its elasticity of substitution across domestic goods and imports,[10] and $\varsigma \in [0, 1)$ indexes the degree of consumption home bias. U.S. households can trade a bond denominated in the U.S. consumption bundle paying a risk-free interest rate $r_t$ at $t + 1$, henceforth referred to as a "dollar bond". They receive an endowment of $z_t$ intermediate goods, transfers $\pi_t$ from domestic firms which they own, and net transfers $\pi^a_t$ from arbitrageurs, described further below. Hence, letting $b_t$ denote the representative household's saving in the dollar bond at $t$, the budget constraint of the

[10] The assumption that $2\sigma > 1$ is referred to as the Marshall-Lerner condition. This assumption is satisfied given most estimates of the trade elasticity $\sigma$ in the literature, so we make it here.

U.S. representative household is

$$p_{Ht}c_{Ht} + p_{Ft}c_{Ft} + \frac{1}{1+r_t}b_t = p_t z_t + \pi_t + \pi_t^a + b_{t-1},$$

where $p_{Ht}$ ($p_{Ft}$) is the price of the domestic (imported) bundle, and $p_t$ the price of its endowment, all relative to its overall consumption bundle.

**Foreign households** Symmetrically, the Foreign representative household has time separable preferences with flow utility

$$u(c_t^*) = \frac{(c_t^*)^{1-1/\psi} - 1}{1 - 1/\psi},$$

discount factor $\beta_t^*$, and a CES aggregator over consumption

$$c_t^* = \left( \left( \frac{1}{1+\zeta^*}(1-\varsigma) \right)^{\frac{1}{\sigma}} (c_{Ht}^*)^{\frac{\sigma-1}{\sigma}} + \left( \frac{\zeta^*}{1+\zeta^*} + \frac{1}{1+\zeta^*}\varsigma \right)^{\frac{1}{\sigma}} (c_{Ft}^*)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}.$$

Denoting $b_t^*$ the household's saving in its domestic bond which pays $r_t^*$ at $t+1$, $z_t^*$ its endowment, and $\pi_t^*$ its transfers from domestic firms, its budget constraint is

$$p_{Ht}^* c_{Ht}^* + p_{Ft}^* c_{Ft}^* + \frac{1}{1+r_t^*} b_t^* = p_t^* z_t^* + \pi_t^* + b_{t-1}^*,$$

where $p_{Ft}^*$ ($p_{Ht}^*$) is the price of the domestic (imported) bundle, and $p_t^*$ the price of its endowment, relative to its overall consumption bundle.

**Arbitrageurs** A third set of agents, arbitrageurs, trade in both dollar and Foreign bonds and transfer their profits or losses to the representative U.S. household. Each period $t$, the representative arbitrageur chooses a portfolio of dollar- and Foreign-denominated bonds $\{b_t^a, b_t^{a*}\}$ to maximize mean-variance preferences

$$\mathbb{E}_t \pi_{t+1}^a - \frac{\gamma_t}{2} Var_t \pi_{t+1}^a,$$

subject to the resource constraint at $t$

$$0 = \frac{1}{1+r_t} b_t^a + q_t^{-1} \frac{1}{1+r_t^*} b_t^{a*}$$

and realized profits/losses at $t+1$

$$\pi^a_{t+1} = b^a_t + q^{-1}_{t+1} b^{a*}_t.$$

Here, $q_t$ is the price of the U.S. consumption bundle relative to the Foreign bundle (the real exchange rate), and $\gamma_t$ denotes arbitrageurs' risk aversion and is time-varying. The fact that arbitrageurs transfer their profits/losses to U.S. rather than Foreign households does not meaningfully change any of the effects of shocks which we characterize later in the paper.

**Final good firms** In each country, a continuum of monopolistically competitive final good firms transform the domestic intermediate good into varieties sold globally. We include these final good firms in our model only to accommodate incomplete pass-through of the exchange rate into prices faced by consumers, as in the data. We follow Alessandria (2009) in capturing pricing to market in reduced form,[11] by assuming that U.S. households' aggregators over domestic and imported varieties are

$$c_{Ht} = \left( \int_0^1 c_{Ht}(i)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

$$c_{Ft} = \left( \int_0^1 c_{Ft}(i^*)^{\frac{\theta_t-1}{\theta_t}} \right)^{\frac{\theta_t}{\theta_t-1}},$$

respectively, where the elasticity of substitution across imported varieties is $\theta_t \equiv \theta(q_t/q)^{-\xi}$ and throughout we denote steady-state values without time subscripts. Analogously, Foreign aggregators over imported and domestic varieties are

$$c^*_{Ht} = \left( \int_0^1 c^*_{Ht}(i)^{\frac{\theta^*_t-1}{\theta^*_t}} \right)^{\frac{\theta^*_t}{\theta^*_t-1}},$$

$$c^*_{Ft} = \left( \int_0^1 c^*_{Ft}(i^*)^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

where the elasticity of substitution across imported varieties is $\theta^*_t \equiv \theta(q_t/q)^{\xi}$. Facing the usual residual demand curves in each country, each U.S. firm $i$ then chooses prices

[11] This can stand in for nominal rigidities together with local currency pricing, as in Devereux and Engel (2002); strategic complementarities with CES demand, as in Atkeson and Burstein (2008); or departures from a CES demand system, as in Gopinath and Itskhoki (2010).

$\{p_{Ht}(i), p^*_{Ht}(i)\}$ to maximize profits

$$\pi_t(i) = (p_{Ht}(i) - p_t)\left(\frac{p_{Ht}(i)}{p_{Ht}}\right)^{-\theta} c_{Ht} + \left(q_t^{-1} p^*_{Ht}(i) - p_t\right)\left(\frac{p^*_{Ht}(i)}{p^*_{Ht}}\right)^{-\theta^*_t} \zeta^* c^*_{Ht}.$$

Each Foreign firm $i^*$ analogously chooses prices $\{p_{Ft}(i^*), p^*_{Ft}(i^*)\}$ to maximize profits

$$\pi^*_t(i^*) = (q_t p_{Ft}(i^*) - p^*_t)\left(\frac{p_{Ft}(i^*)}{p_{Ft}}\right)^{-\theta_t} c_{Ft} + (p^*_{Ft}(i^*) - p^*_t)\left(\frac{p^*_{Ft}(i^*)}{p^*_{Ft}}\right)^{-\theta} \zeta^* c^*_{Ft}.$$

The aggregate profits earned by households per capita in each country are then

$$\pi_t = \int_0^1 \pi_t(i) di,$$
$$\pi^*_t = \frac{1}{\zeta^*}\int_0^1 \pi^*_t(i^*) di^*.$$

**Market clearing and driving forces** The environment is closed with standard market clearing conditions in goods and bonds. The driving variables are discount factors $\{\beta_t, \beta^*_t\}$, endowments $\{z_t, z^*_t\}$, and the risk aversion of arbitrageurs $\gamma_t$. For each driving variable $x_t \in \{\beta_t, \beta^*_t, z_t, z^*_t, \gamma_t\}$, we assume $\log x_t$ follows an AR(1) process around $\log x$ with mean reversion $\rho^x$, standard deviation of shocks $\sigma^x$, and correlation of shocks with another driving variable $x'_t$ denoted $\rho^{xx'}$.

Taken together, this environment builds most closely on that in Gabaix and Maggiori (2015) and Itskhoki and Mukhin (2021). The main innovation is our focus on demand shocks $\{\beta_t, \beta^*_t\}$, which we will argue play an important role in driving the exchange rate in the data.[12]

## 2.2 Equilibrium and solution

The equilibrium has a recursive representation in the endogenous state variable $b^*_t$ and exogenous state variables $\{\beta_t, \beta^*_t, z_t, z^*_t, \gamma_t\}$. The full set of equilibrium conditions is outlined in appendix A.

Following Itskhoki and Mukhin (2021) and Borovicka, Hansen, and Sargent (2023), we study a first-order approximation of the system around a steady-state in which

[12]Demand shocks are not modeled in Itskhoki and Mukhin (2021). Gabaix and Maggiori (2015) accommodate overall demand shocks via innovations in their $\{\theta_t, \theta^*_t\}$, but their analysis focuses on shocks to import demand, currency intermediation, endowments, and monetary policy.

the currency risk premium does not disappear. In particular, consider arbitrageurs' optimal portfolio choice condition

$$\mathbb{E}_t \frac{q_t}{q_{t+1}}(1+r_t^*) - (1+r_t) = \gamma_t \left( q_t^{-1} \frac{1}{1+r_t^*} b_t^{a*} \right) Var_t \frac{q_t}{q_{t+1}}(1+r_t^*).$$

Scaling the volatility of all driving forces by the perturbation parameter $\sigma$, we assume that

$$\gamma_t = \gamma(\sigma) \exp\left(\hat{\gamma}_t\right),$$

where $\gamma(\sigma)\sigma^2$ remains positive and finite as $\sigma \to 0$, and where $\hat{\gamma}_t$, an AR(1) process around zero, also features shocks scaled by $\sigma$. Under this assumption, appendix A shows that the first-order approximation of the above condition in $\sigma$ is

$$\hat{r}_t^* - \mathbb{E}_t \Delta \hat{q}_{t+1} - \hat{r}_t = \frac{q^{-1} b^{a*} \Gamma}{1 - 2q^{-1} b^{a*} \Gamma} \left( \hat{\gamma}_t + \hat{r}_t - \hat{q}_t - \hat{r}_t^* + \frac{1}{b^{a*}} \hat{b}_t^{a*} \right), \tag{1}$$

where $\Gamma \equiv \lim_{\sigma \to 0} \gamma(\sigma) Var \log q_{+1}$, and $\hat{\cdot}$ denotes log deviations from steady-state for all variables except bond positions (which can be negative), in which case it denotes level deviations. The associated steady-state condition is

$$(1+r^*) - (1+r) = q^{-1}(1+r^*) b^{a*} \Gamma,$$

which clarifies that arbitrageurs' limited risk-bearing capacity can sustain a non-zero interest rate differential in steady-state.[13] The first-order approximation to all other equilibrium conditions, and their steady-state implications, remain standard.

Since in particular $1 + r^* = (\beta^*)^{-1}$ and $1 + r = \beta^{-1}$, it is clear that in steady-state arbitrageurs will intermediate capital flows from the U.S. to Foreign ($b^{a*} > 0$) provided $\beta^* < \beta$, that is, Foreign households are more impatient than U.S. households. In this case, arbitrageurs are short the dollar and long Foreign bonds.

We view the idea that arbitrageurs are short the dollar as realistic, given the dominant role of dollar funding among global intermediaries.[14] However, one unrealistic implication in the present model is that this would mean the U.S. has a positive net foreign asset position. This counterfactual implication is easily resolved

[13] As a result, the present environment may be a promising one to account for the patterns in excess currency returns described in Hassan, Mertens, and Wang (2024).

[14] See, for instance, Adrian, Etula, and Shin (2010), Bruno and Shin (2015a,b), and Avdjiev, Du, Koch, and Shin (2019).

by allowing Foreign households to also hold dollar bonds and assuming that they receive a non-pecuniary value of doing so, consistent with the Foreign demand for safe dollar assets.[15] We view this as a promising environment to study the implications of the shocks in this paper for *gross* flows and valuation effects in current account adjustment, since (together with $\beta^* < \beta$) it could be consistent with the U.S. being short dollar bonds, long Foreign bonds, and having a negative net foreign asset position. However, since this would not qualitatively change the comovements of exchange rates, interest rates, and consumption — our primary focus in this paper — we refrain from complicating the model along these dimensions here.

We finally note that the results which follow also do not depend on the specific form of segmented markets we have assumed here. We could alternatively consider an environment without intermediaries and in which households in each country trade a domestic and foreign bond, subject to adjustment costs in the foreign bond.[16] Shocks to these adjustment costs are essentially equivalent to the intermediation shocks in the present environment. Shocks to discount factors and endowments still propagate as they do here. Both our analytical results and quantitative findings are thus unaffected.

# 3 Analytical insights

We now analytically characterize the comovements between exchange rates, interest rates, and macroeconomic aggregates induced by the shocks in our model. We also characterize the role of model ingredients in shaping the effects of relative demand shocks, anticipating their important role in the quantitative analysis which follows.

## 3.1 Parameter space of interest

We characterize these results for high consumption home bias $\varsigma$, a small steady-state price of risk $\Gamma$, and small interest rate $r^*$.[17] These parametric conditions simplify the proofs and are also the relevant cases in our quantitative analysis later in the paper. For some of our analytical results, we follow Itskhoki and Mukhin (2021) in

[15] See, for instance, Eichenbaum, Johannsen, and Rebelo (2021) and Jiang, Krishnamurthy, and Lustig (2021, 2024a).

[16] These costs are consistent with the home currency bias in international portfolios (e.g., Maggiori, Neiman, and Schreger (2020)). In the language of Jiang et al. (2024b), they give rise to cross-bond Euler equation wedges.

[17] We refer to $\Gamma$ as the steady-state price of risk because it depends on the limiting $\gamma(\sigma)$.

considering the autarkic limit ($\varsigma \to 1$). Since the response of the exchange rate to shocks is well defined for any $\varsigma < 1$, it is also well defined in the limit.

To further simplify the proofs without affecting the qualitative results, we also make the following parametric assumptions in this section alone:

**Assumption 1** (A1)**.** *The U.S. and Foreign have the same population ($\zeta^* = 1$), the law of one price holds for each final good ($\xi = 0$), and endowments are such that the steady-state exchange rate is one ($q = 1$).*

## 3.2 Contrasting the comovements induced by shocks

Our first result contrasts the comovements between the exchange rate, interest rate differential, and macroeconomic quantities induced by the shocks in our model:

**Proposition 1.** *Assume A1, $\varsigma$ close to one, and $\Gamma$ and $r^*$ small. Given fluctuations induced by each shock alone, we obtain the following comovements:*

| | $\epsilon_t^\gamma$ *(currency intermediation)* | $\epsilon_t^\beta, \epsilon_t^{\beta^*}$ *(demand)* | $\epsilon_t^z, \epsilon_t^{z^*}$ *(supply)* |
|---|---|---|---|
| $Cov(\hat{q}_t, \hat{r}_t^* - \hat{r}_t)$ | $(+)$ | $(-)$ | $(-)$ |
| $Cov(\Delta\hat{q}_t, \hat{r}_{t-1}^* - \hat{r}_{t-1})$ | $(-)$ | $(+)$ | $(+)$ |
| $Cov(\hat{q}_t, \hat{c}_t^* - \hat{c}_t)$ | $(-)$ | $(-)$ | $(+)$ |

The comovement between the exchange rate and interest rate differential distinguishes currency intermediation shocks from other shocks. In particular, consider an increase in arbitrageur risk aversion in the context of the UIP condition (1). For concreteness, assume $\beta^* < \beta$ in steady-state so that, as discussed in the prior section, arbitrageurs are long Foreign bonds financed by dollar bonds ($b^{a*} > 0$) in steady-state. When they get more risk averse ($\hat{\gamma}_t$ rises), they require higher excess returns on Foreign bonds relative to dollar bonds going forward. This is achieved both by an immediate dollar appreciation and thus expected dollar depreciation ($\mathbb{E}_t\Delta\hat{q}_{t+1}$ falls) and by a rise in the Foreign real interest rate relative to the dollar real interest rate ($\hat{r}_t^* - \hat{r}_t$ rises). This intuition underlies why, given a model with only currency intermediation shocks, a strong dollar is accompanied by a high Foreign interest rate relative to dollar interest rate. It also explains why such shocks are able to rationalize a negative Fama (1984) coefficient: a high Foreign interest rate relative to dollar interest rate forecasts an expected dollar depreciation. We note that these comovements are also obtained in the case when $\beta^* > \beta$ and thus arbitrageurs are long dollar bonds: in this case, an increase in risk aversion would induce a dollar depreciation and increase in the dollar interest rate relative to the Foreign interest rate.

By contrast, consider a relative increase in U.S. demand (decline in $\beta_t$ or rise in $\beta_t^*$) or relative decrease in U.S. supply (decline in $z_t$ or rise in $z_t^*$). Each of these shocks causes a relative increase in the U.S. interest rate on impact ($\hat{r}_t^* - \hat{r}_t$ falls), given the domestic Euler equations in each country. By UIP, this implies an immediate dollar appreciation and thus expected dollar depreciation ($\mathbb{E}_t \Delta \hat{q}_{t+1}$ falls).[18] Hence, given a model with only demand or supply shocks, a strong dollar is accompanied by a *low* Foreign interest rate relative to dollar interest rate, and the Fama (1984) coefficient is consistent with the sign of UIP.

The comovement between the exchange rate and relative quantities distinguishes currency intermediation and demand shocks from supply shocks. In particular, an increase in arbitrageur risk aversion or increase in relative U.S. demand induce capital flows toward the U.S., underpinning an increase in relative U.S. consumption. In the case of currency intermediation, the intuition is because arbitrageurs are less willing to intermediate capital flows to Foreign; in the case of demand shocks, the intuition is because U.S. households wish to borrow from Foreign households. By contrast, a decline in relative U.S. supply which appreciates the dollar is mechanically accompanied by relatively low U.S. consumption, in light of consumption home bias. Thus, a strong dollar is accompanied by relatively low Foreign consumption in the first two cases, but relatively high Foreign consumption in the last case.

Taken together, to the extent a strong dollar is accompanied by a relatively high U.S. interest rate and high U.S. consumption in the data, it suggests an important role for relative demand shocks. Anticipating that this is indeed the case in our empirical and quantitative analysis later in the paper, the next subsection characterizes the role of model features in shaping the effects of demand shocks in particular.

## 3.3 Further understanding relative demand shocks

We focus on the role of two key model features: the persistence of relative demand shocks, and the role of the price of risk $\Gamma$. For these results it is expositionally

[18] There is a complementary intuition focused on the goods market: the relative increase in U.S. demand or decrease in U.S. supply requires that the dollar appreciates to clear the goods market.

convenient to focus on the autarkic limit ($\varsigma \to 1$), though by continuity the insights also apply away from this limit too.

We first clarify the role of persistence, assuming the price of risk $\Gamma \to 0$. We study the magnitude of the impact effects of a demand shock, as well as the $R^2$ of regressions predicting the change in the exchange rate:

**Proposition 2.** *Assume A1, the autarkic limit ($\varsigma \to 1$), and the limit in which the price of risk $\Gamma \to 0$. Then on impact of an increase in U.S. demand ($\hat{\epsilon}_t^\beta < 0$),*

- *the U.S. real interest rate rises by $\hat{r}_t = (-\hat{\epsilon}_t^\beta)$;*
- *the dollar appreciates by $\hat{q}_t = \frac{1}{1+r^*-\rho^\beta}(-\hat{\epsilon}_t^\beta)$;*
- *all other variables are unchanged.*

*Given demand shocks, the $R^2$ of a regression of the change in the exchange rate $\Delta\hat{q}_{t+1}$ on the interest rate differential $\hat{r}_t^* - \hat{r}_t$ is $Var(\mathbb{E}_t\Delta\hat{q}_{t+1})/Var(\Delta\hat{q}_{t+1}) = \frac{1}{1+\frac{1-(\rho^\beta)^2}{(1+r^*-\rho^\beta)^2}}$. If $r^* = 0$, the dollar appreciation becomes infinite and the $R^2$ falls to zero as $\rho^\beta \to 1$.*

As described in the prior subsection, an increase in U.S. demand raises the domestic interest rate (by the Euler equation) and appreciates the dollar (by UIP). In the autarkic limit, these are the only variables which are affected, since consumptions are simply equal to the endowments, there are no capital flows, and Foreign is thus unaffected by the shock. The fact that the exchange rate response is rising in the persistence of the shock reflects that the U.S. interest rate remains persistently high relative to the Foreign interest rate, and the exchange rate is forward-looking.

As relative demand gets more persistent, the effect of future demand innovations on the future exchange rate similarly grow relative to the predictable component of the exchange rate. Provided $r^* = 0$, the $R^2$ of the predictability regression also falls. As relative demand approaches a unit root, the impact effect on the exchange rate grows without bound and the $R^2$ of the predictability regression approaches zero.

These results build on those in Itskhoki and Mukhin (2021), Engel and West (2005), and Corsetti et al. (2008). Itskhoki and Mukhin (2021) provide similar results for the effects of UIP shocks on the exchange rate;[19] we extend them to demand shocks. UIP shocks affect the exchange rate in the autarkic limit purely via the

[19] See their Propositions 1 and 5.

currency risk premium, while demand shocks affect the exchange rate when $\Gamma \to 0$ purely via the interest rate differential. The common ingredient, however, is that persistent shocks can induce a large exchange rate response (and thus low $R^2$ in predictability regressions) because exchange rates are forward-looking. In these respects, we also build directly on Engel and West (2005), who demonstrate that asset prices will exhibit near-random walk behavior if fundamentals are persistent and the discount factor is close to one (mirroring the condition $r^* = 0$ referenced at the end of Proposition 2). The fundamentals which drive exchange rates in the models studied by Engel and West (2005) include money supplies and inflation rates; we instead focus on natural rates in general equilibrium. A critical reason why persistent demand shocks induce large effects on exchange rates is that asset markets are incomplete: given our assumed preferences, the exchange rate response to a demand shock would not depend on its persistence if markets were complete. The important interaction between shock persistence and incomplete markets echoes Corsetti et al. (2008).

We finally clarify the role of the price of risk $\Gamma$ for the propagation of demand shocks. We again study the magnitude of the impact effects of a demand shock as well as the Fama (1984) regression predicting the change in the exchange rate:

**Proposition 3.** *Assume A1, the autarkic limit ($\varsigma \to 1$), $r^*$ small, and $\beta^* < \beta$. Then, at least around $\Gamma = 0$, an increase in $\Gamma$:*

- *dampens the dollar appreciation on impact of an increase in U.S. demand;*
- *reduces the expected dollar depreciation on impact of the same shock;*
- *and, given only demand shocks, lowers the Fama (1984) coefficient $Cov(\Delta \hat{q}_{t+1}, \hat{r}_t^* - \hat{r}_t)/Var(\hat{r}_t^* - \hat{r}_t)$ below one.*

Given a positive price of risk, the currency risk premium on the right-hand side of (1) also responds to demand shocks. In particular, consider an increase in U.S. demand ($\beta_t$ falls) which, as described in the discussion of Proposition 1, induces capital flows to the U.S.[20] Since this reduces arbitrageurs' position in Foreign bonds ($\hat{b}_t^{a*}$ falls), it reduces the risk premium on Foreign bonds. This mitigates the expected dollar depreciation and thus initial appreciation, and generates a deviation from UIP.

[20]The endogenous responses of interest rates and the exchange rate also feed back to the risk premium, evident from the right-hand side of (1). The parametric conditions in the proposition ensure that these effects reinforce or do not overturn the effect via capital flows described here.

These results imply a tension: to the extent the endogenous risk premium response to demand shocks can account for deviations from UIP, it will also dampen the magnitude of exchange rate volatility induced by these shocks. Note that no such tradeoff is present for currency intermediation shocks, for which exchange rate volatility is precisely a consequence of deviations from UIP.

These results generalize to an infinite horizon setting those in Gabaix and Maggiori (2015), who characterize the effects of a non-zero currency risk premium (also controlled by $\Gamma$ in their framework) on deviations from UIP in a three-period model.[21]

**Taking stock** We conclude this section by summarizing the main insights from our analytical results. Shocks to currency intermediation are distinguished from the other shocks by the comovement between the real exchange rate and real interest rates. Shocks to supply are distinguished from the other shocks by the comovement between the real exchange rate and relative consumption. More persistent demand increases the magnitude of the exchange rate response to a demand innovation, and dampens the $R^2$ in predictability regressions. A higher price of risk generates larger endogenous UIP deviations from demand shocks, though this dampens the magnitude of exchange rate fluctuations induced by these shocks.

# 4 Empirical analysis

We now measure comovements of the dollar/G10 exchange rate in the data over the 1991-2020 period. U.S. interest rates and U.S. consumption have been relatively high when the dollar is strong. At the same time, changes in exchange rates are difficult to predict. In light of our analytical results, these patterns are consistent with an important role for persistent demand shocks in driving the exchange rate.

## 4.1 Data

Our data covers the period 1991 Q2 through 2020 Q1.[22] We obtain data for the U.S. and G10 currency countries, which are Australia, Canada, Denmark, the Euro Area

[21] See their Proposition 8.

[22] The start date is dictated by the availability of the Libor-based interest rate data we use. The end date is chosen so that second moments are not driven excessively by the sharp recession during the pandemic, while still capturing the asset price comovements at the start of the crisis.

(aggregated across members), Japan, New Zealand, Norway, Sweden, Switzerland, and the U.K. At the end of the paper we provide a brief discussion of data for emerging market countries as well.

We obtain end-of-quarter nominal yields by currency and tenor from Bloomberg.[23] We map nominal yields in the data to real yields in our model given generally low and stable expected inflation among the countries in our sample over this period. Our primary measure of nominal yields are Libor rates (measured at the three-month tenor) combined with interest rate swaps (to obtain longer tenors) in each currency. We also investigate robustness using the government bond yield curve in each currency.

We obtain end-of-quarter nominal exchange rates, the consumer price index, national accounts, and population from the IMF International Financial Statistics. We construct per capita measures by dividing the relevant series by population.[24] Where relevant, we use seasonally adjusted measures as reported by the IMF.

We compute moments using simple averages across the G10. Since we do not have a balanced panel for some series, we compute these averages by computing quarterly changes at the country level, averaging these changes across countries with available data in each quarter, and cumulating.

## 4.2 Comovements with the real exchange rate

Table 1 reports contemporaneous comovements with the real exchange rate between the U.S. and G10 countries. As in the model, an increase in the real exchange rate corresponds to a real dollar appreciation. For any variable $x_t$, the first three columns report the slope coefficients in regressions of the form

$$\log q_{t+h} - \log q_t = \alpha + \beta(x_{t+h} - x_t) + \epsilon_{t+h},$$

for horizons $h \in \{1, 4, 12\}$ quarters and $q$ denoting the real exchange rate, and the last column reports the slope coefficient in a regression of the form

$$\log q_t = \alpha + \beta x_t + \epsilon_t.$$

[23] In particular, we use data compiled by Wenxin Du and we thank her for sharing it with us.

[24] Since population is reported annually, we linearly interpolate it to obtain a quarterly series. We construct population for the Euro area as the sum of population in Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, and Spain.

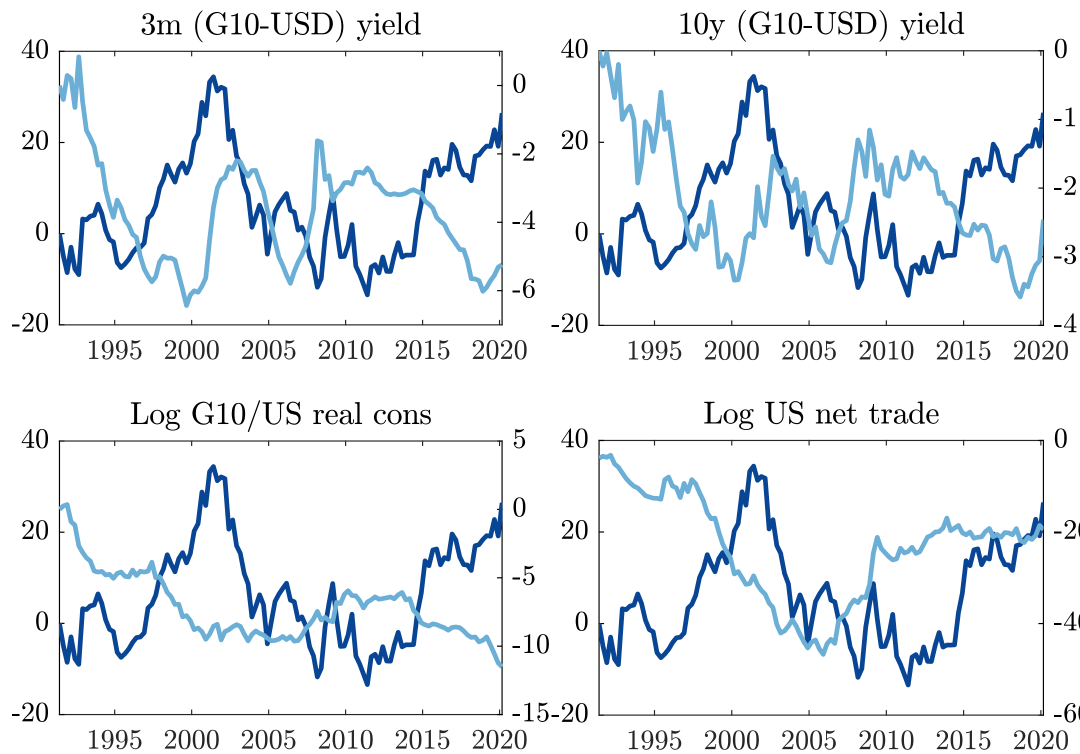


Figure 1: comovements with log real exchange rate between U.S. and G10

Notes: dark blue line in each panel is log real exchange rate, plotted on left axis; light blue line in each panel is series in panel title, plotted on right axis. All series plotted in *pp*. All series except log U.S. net trade are normalized to zero in 1991 Q2. All yields are annualized.

Figure 1 depicts the real exchange rate and other key variables over our sample period, with the former appearing in dark blue in every panel and the latter appearing in light blue and in the panel title.

Since both exchange rates and many of the right-hand side variables are highly persistent, we conduct inference using Newey and West (1987) standard errors with truncation parameter equal to sample size and fixed-$b$ critical values, following Kiefer and Vogelsang (2002a,b). Appendix C demonstrates that this approach yields much more conservative confidence intervals than using Newey and West (1987) standard errors given typical truncation parameters and standard normal critical values, and is comparable to results obtained from bootstrap methods as in Engel (2016).

The dollar is strong when G10 interest rates are relatively low versus U.S. interest rates. These relationships are evident in both changes and levels in the first two panels of Table 1, and especially strong in levels, as is clear from the first two panels of Figure

| | Changes | | | |
|---|---|---|---|---|
| | 1 qtr | 4 qtrs | 12 qtrs | Levels |
| 3m (G10 - USD) yield | -2.17 | -1.40 | -0.64 | -3.28 |
| | [-4.54,0.19] | [-4.03,1.22] | [-2.75,1.46] | [-6.78,0.23] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.05 | 0.03 | -0.00 | 0.20 |
| 10y (G10 - USD) yield | -2.77 | -4.21 | -5.87 | -8.48 |
| | [-6.42,0.87] | [-6.52,-1.89] | [-9.28,-2.46] | [-13.35,-3.61] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.04 | 0.07 | 0.13 | 0.36 |
| Log G10/U.S. real cons. | -1.75 | -3.02 | -3.91 | -2.59 |
| | [-2.70,-0.80] | [-4.23,-1.80] | [-6.25,-1.58] | [-4.61,-0.56] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.03 | 0.13 | 0.27 | 0.29 |
| Log U.S. net trade | -0.08 | -0.10 | -0.26 | -0.21 |
| | [-0.33,0.17] | [-0.51,0.30] | [-0.75,0.24] | [-0.74,0.31] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | -0.01 | -0.01 | 0.02 | 0.04 |

Table 1: comovements with log real exchange rate between U.S. and G10

Notes: columns marked "Changes" regress 1-, 4-, or 12-quarter change in log real exchange rate on 1-, 4-, or 12-quarter change in given variable. Column marked "Levels" regresses log real exchange rate on given variable. Rows in brackets report 90% confidence intervals using Newey and West (1987) standard errors with truncation parameter equal to sample size and fixed-$b$ critical values, following Kiefer and Vogelsang (2002a,b).

1. The point estimates in levels imply that a 1*pp* annualized decline in the G10 yield relative to the dollar yield is associated with a 3–8*pp* stronger dollar, increasing in tenor; the confidence intervals for the 10-year yield differential in particular exclude zero in all cases besides one-quarter changes. Variation in yield differentials account for 20–36% of the variation in the exchange rate, though the bootstrap results in appendix C make clear that the high persistence of these variables implies considerable uncertainty about these $R^2$ values. Figure 1 also shows that the comovement reverses around the onset of recessions, namely the early 2000s, 2008, and 2020, when the dollar appreciates even though G10 interest rates rise versus U.S. interest rates.

For that reason, the explanatory power of yield differentials is especially strong when we also condition on proxies for risk or convenience yields which spike in these periods. The first panel of Table 2 reports the univariate comovement with the excess bond premium of Gilchrist and Zakrajsek (2012). A higher excess bond premium is associated with a stronger dollar. In changes, it accounts for a slightly higher share of the variation in the exchange rate as yield differentials; in levels, it accounts for less of the variation. Notably, however, in a bivariate specification including both yield differentials and the excess bond premium in Table 2, the $R^2$ is greater than the sum of the univariate specifications, consistent with the comovement between the exchange rate and yield differential flipping sign if risk is high. The $R^2$ values in fact exceed 50%; in the bootstrapped confidence intervals for these $R^2$ values reported in appendix C, even the lower bounds reach nearly 30%. Appendix C also demonstrates similar results using yield differentials and other proxies for risk or convenience yields such as the VIX, the global factor in risky asset prices of Miranda-Agrippino and Rey (2020), and the three-month Treasury basis from Du, Im, and Schreger (2018).[25]

Turning from asset prices to quantities, the dollar is also strong when real G10 consumption per capita is relatively low versus its U.S. counterpart. The relationship is significant in both changes and levels in the third panel of Table 1. A 1*pp* decline in G10 consumption per capita relative to the U.S. is associated with a 3*pp* stronger dollar. Variation in relative consumption accounts for 29% of the variation in the exchange rate, though again there is uncertainty about this univariate $R^2$. Unlike with yield differentials, the comovement with relative consumption is not different around the start of recessions, as is evident from the third panel of Figure 1.

Finally, the dollar is only weakly negatively related to U.S. net trade, defined as the ratio of exports to imports.[26] This result is true in both changes and levels in the last panel of Table 1, and evident from the last panel of Figure 1. It is consistent with the weak unconditional comovement of the exchange rate and trade balance documented in the prior literature.

Turning from contemporaneous comovements to predictability, Table 3 reports

[25] We find similar results using convenience yields from Jiang et al. (2021) or Engel and Wu (2023).

[26] We focus on net trade rather than net exports to GDP because the latter also reflects secular trends in the magnitude of exports and imports relative to GDP which are not our focus in this paper (see Alessandria and Choi (2021)). With that said, we obtain similarly weak contemporaneous comovements between the exchange rate and net exports to GDP.

| | Changes | | | |
|---|---|---|---|---|
| | 1 qtr | 4 qtrs | 12 qtrs | Levels |
| EBP | 2.40 | 3.66 | 5.89 | 5.27 |
| | [0.23,4.58] | [2.16,5.15] | [-0.43,12.20] | [-2.83,13.37] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.06 | 0.13 | 0.20 | 0.08 |
| 3m (G10 - USD) yield | -2.28 | -1.90 | -1.62 | -3.70 |
| | [-4.77,0.21] | [-4.87,1.06] | [-3.65,0.41] | [-7.26,-0.15] |
| EBP | 2.51 | 4.07 | 6.76 | 6.66 |
| | [0.38,4.64] | [3.03,5.10] | [1.15,12.37] | [-0.47,13.79] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.11 | 0.18 | 0.25 | 0.33 |
| 10y (G10 - USD) yield | -5.41 | -7.28 | -9.14 | -9.36 |
| | [-6.80,-4.02] | [-10.67,-3.89] | [-13.80,-4.49] | [-16.11,-2.62] |
| EBP | 4.20 | 5.42 | 8.28 | 7.09 |
| | [2.42,5.98] | [4.35,6.50] | [4.22,12.35] | [1.95,12.23] |
| $N$ | 115 | 112 | 104 | 116 |
| Adj $R^2$ | 0.19 | 0.32 | 0.50 | 0.51 |

Table 2: additional comovements using proxy for risk

Notes: columns marked "Changes" regress 1-, 4-, or 12-quarter change in log real exchange rate on 1-, 4-, or 12-quarter change in given variable. Column marked "Levels" regresses log real exchange rate on given variable. EBP refers to excess bond premium from Gilchrist and Zakrajsek (2012) and kept updated by Favara et al. (2016). Rows in brackets report 90% confidence intervals using Newey and West (1987) standard errors with truncation parameter equal to sample size and fixed-$b$ critical values, following Kiefer and Vogelsang (2002a,b).

the slope coefficient from the regression

$$(\log E_{t+h} - \log E_t) = \alpha + \beta \left( i_t^{(h)*} - i_t^{(h)} \right) (h/4) + \epsilon_{t+h},$$

where $E_t$ denotes the nominal exchange rate (foreign currency per dollar) and $i_t^{(h)*}, i_t^{(h)}$ denote annualized $h$-quarter nominal yields abroad and in the U.S., respectively. We use the nominal exchange rate on the left-hand side to be consistent with the large literature following Fama (1984), but very similar results are obtained using the real exchange rate given its tight comovement with the nominal exchange rate.

| | $\log E_{+1} - \log E$ | $\log E_{+4} - \log E$ |
|---|---|---|
| 3m (G10 - USD) yield / 4 | -0.74 | |
| | [-2.73,1.25] | |
| 1y (G10 - USD) yield | | -1.49 |
| | | [-6.71,3.72] |
| $N$ | 115 | 92 |
| Adj $R^2$ | -0.00 | 0.03 |

Table 3: predicting changes in log nominal exchange rate

Notes: yields are annualized (so first row uses quarterly rates). Rows in brackets report 90% confidence intervals using Newey and West (1987) standard errors with truncation parameter equal to sample size and fixed-$b$ critical values, following Kiefer and Vogelsang (2002a,b).

These results indicate that while the evidence against UIP has weakened, what remains the case is that interest rate differentials account for little variation in subsequent exchange rate movements. The negative point estimates imply that higher G10 yields than dollar yields forecast an expected dollar depreciation, inconsistent with UIP. However, the confidence intervals are so wide that we cannot reject UIP (a point estimate of 1) at conventional levels. This is in contrast to earlier sample periods over which there was more precise evidence against UIP (e.g., Lustig, Roussanov, and Verdelhan (2014)). However, what remains the case even in the more recent data is that the $R^2$ in these predictability regressions is low — an order of magnitude lower than in the regressions of exchange rates on contemporaneous yields.

## 4.3 Additional findings

Appendix C reports additional findings in the data which we summarize here.

First, we replace the private sector interest rate differentials in our analysis — constructed from Libor rates and interest rate swaps — with government bond yield differentials. We similarly find that the dollar is strong when G10 government bond yields are low versus U.S. government bond yields, and the share of variation explained by these yield differentials is especially high when also conditioning on proxies for risk.

Second, we study the comovement between bilateral real exchange rates and interest rate differentials for each of the G10 countries versus the U.S. For all currencies except the Japanese yen, a lower foreign yield than the dollar yield is associated with a stronger real dollar. This indicates that the comovement which we document between the broad dollar/G10 exchange rate and yield differential is robust across currencies.

Third, we replace the U.S. with three alternative base currencies and countries: the pound and U.K., the euro and Euro Area, and the yen and Japan. The comovements which we study are not U.S.-specific: when we use the pound as an alternative base currency, we obtain very similar results. Low G10 interest rates (which now includes the U.S. and excludes the U.K.) relative to U.K. interest rates and low G10 consumption per capita relative to its U.K. counterpart are associated with a stronger pound in real terms versus the G10, both in changes and in levels. These results are not as sharp for the Euro area, though this reflects the shorter sample period of available data. They are also again different for Japan in the context of yield differentials.

Fourth, we extract the low frequency components of each time series and focus on the comovements between these, following Müller and Watson (2018). An advantage of their approach is that it is robust to nonstationarity.[27] We still find that the low frequency component of the exchange rate is significantly negatively related to the low frequency component of G10 less U.S. yield differentials, and to the low frequency component of log G10 consumption relative to U.S. consumption. This analysis remains relevant to understand most of the variation in the exchange rate, since 85% (70%) of it is in periodicities above 6 (12) years.

Fifth, we assess the out-of-sample explanatory power of these variables for the exchange rate, following Meese and Rogoff (1983). In contrast to their findings, we find that over the last 30 years, yield differentials, measures of risk, and relative consumption can beat a random walk in accounting for the exchange rate out of sample. This builds on the recent findings of Engel and Wu (2024), who show that the out-of-sample performance of such variables has improved over time.

**Taking stock** We conclude this section by summarizing the takeaways from our empirical analysis. Both in changes and levels, U.S. interest rates and U.S. consumption have been relatively high when the dollar is strong. The explanatory power of yield differentials is especially strong when we also condition on proxies for risk. At the same time, changes in exchange rates remain difficult to predict, at least at short horizons. The comovements with the exchange rate are broadly robust to the defini-

[27] With that said, the recent literature appears to have settled on the real exchange rate in fact being stationary (see for instance Engel (2016) and Engel, Kazakova, Wang, and Xiang (2022)), motivating our baseline empirical specifications.

tion of yields used and the possibility of non-stationarity; they hold across currencies and do not appear U.S.-specific; and they are strong enough to beat a random walk out of sample. In light of our analytical results, we conclude from these empirical findings that persistent innovations in relative demand, reflected in persistent yield and consumption differentials, may be an important driver of exchange rates.

# 5 Quantitative analysis

We now quantify the model's ability to account for the volatility of and comovements with the dollar/G10 exchange rate in the data. Demand shocks account for roughly 75% of the variance in the dollar/G10 exchange rate, and generate contemporaneous comovements between the exchange rate, interest rate differential, and relative consumption as in the data. Currency intermediation shocks are also important, however, to account for deviations from uncovered interest parity at high frequencies, and to explain the dollar appreciation in crises.

## 5.1 Parameterization

We first discuss the parameterization of our model.

We set the IES $\psi$ of households to 1 (log preferences) for simplicity. We also set three parameters which are all normalizations: U.S. steady-state output per capita is $z = 1$, Foreign steady-state output per capita is $z^* = 1$, and the elasticity of substitution across varieties from a given country is $\theta = 4$. The first defines the scale of the economy and the others are without loss of generality because only the ratios $\zeta^* z^*/z$ and $\xi/(\theta - 1)$ are relevant.

We calibrate the remaining parameters to match moments in the data, as summarized in Table 4. We first describe the calibration of stochastic processes, and then describe the few remaining parameters of the model. In all cases we compute moments in the data over our maintained 1991 Q2 - 2020 Q1 sample period. We discuss the moment in the data which most directly informs each parameter, informed by our analytical results from section 3.

In the first panel, we discipline the discount factors in each country to match moments on interest rates. The steady-state U.S. discount factor $\beta$ is set to target an annualized U.S. real interest rate of 0.97%, equal to the average three-month dollar

| | Description | Value | Moment | Target | Model |
|---|---|---|---|---|---|
| $\beta$ | U.S. disc. fact. | 0.99758 | $r^{(1)}$ | 0.97% | 0.97% |
| $\beta^*$ | Foreign disc. fact. | 0.99708 | $r^{(40)*} - r^{(40)}$ | 0.20% | 0.20% |
| $\sigma^\beta, \sigma^{\beta^*}$ | s.d. $\beta, \beta^*$ shocks | 0.002 | $\sigma(r^{(40)*} - r^{(40)})$ | 0.81% | 0.80% |
| $\rho^\beta, \rho^{\beta^*}$ | persistence $\beta, \beta^*$ | 0.98 | $\rho_{-1}(r^{(40)*} - r^{(40)})$ | 0.93 | 0.93 |
| $\rho^{\beta,\beta^*}$ | corr. $\beta, \beta^*$ shocks | 0.84 | $\sigma(\Delta r^{(40)})$ | 0.53% | 0.53% |
| $\sigma^z, \sigma^{z^*}$ | s.d. $z, z^*$ shocks | 0.005 | $\sigma(\log y^* - \log y)$ | 1.73% | 1.76% |
| $\rho^z, \rho^{z^*}$ | persistence $z, z^*$ | 0.95 | $\rho_{-1}(\log y^* - \log y)$ | 0.91 | 0.91 |
| $\rho^{z,z^*}$ | corr. $z, z^*$ shocks | 0.10 | $\sigma(\Delta \log y)$ | 0.49% | 0.51% |
| $\sigma^\gamma$ | s.d. $\gamma$ shocks | 11 | $\sigma(\Delta \log q)$ | 3.91% | 4.00% |
| $\rho^\gamma$ | persistence $\gamma$ | 0.85 | $\rho_{-1}(\log \gamma)$ | 0.80 | 0.82 |
| $\xi$ | pricing to market | 1.3 | $\sigma(\log s)/\sigma(\log q)$ | 0.27 | 0.27 |
| $\Gamma$ | arb risk pricing | $6E-4$ | $\sigma(\log ex/im)$ | 11.41% | 11.88% |
| $\sigma$ | trade elasticity | 0.9 | $\sigma(\log q)$ | 11.48% | 10.39% |
| $\varsigma$ | home bias | 0.8 | $(ex + im)/y$ | 0.25 | 0.23 |
| $\zeta^*$ | rel. population | 1.35 | $\zeta^* q^{-1} y^*/y$ | 1.35 | 1.34 |

Table 4: targeted moments and calibrated parameters

Notes: data moments are estimated over 1991 Q2 – 2020 Q1. Model moments are averages over 1,000 simulations of 116 quarters each using a 1,000 quarter burn-in period. Externally set parameters in model are $\psi = 1$, $z = 1$, $z^* = 1$, and $\theta = 4$, the latter three all normalizations.

yield (2.97%) less expected inflation which we assume to be 2%.[28] The steady-state Foreign discount factor $\beta^*$ is set to target the average 10-year G10/U.S. yield differential of 0.20% over this period.[29] It follows from this that an increase in arbitrageur risk aversion will appreciate the dollar, as discussed in section 3. We assume for simplicity that the volatility of discount factor shocks $\sigma^\beta, \sigma^{\beta^*}$ and the persistence of discount factors $\rho^\beta, \rho^{\beta^*}$ in each country are the same. We jointly discipline these values and the correlation $\rho^{\beta,\beta^*}$ to target the volatility and autocorrelation of the 10-year G10/U.S. yield differential and the volatility of changes in the 10-year U.S.

[28] In keeping with our notation for longer maturity bonds, we denote $r^{(1)}$ as the annualized yield on a one-quarter bond, i.e., $4r$. Analogously, we define $r^{(1)*} \equiv 4r^*$.

[29] We price 10-year bonds in the model by assuming households in each country can trade these bonds with other households in the same country. Because households in each country are identical, there is no trade in these bonds and their presence does not affect the allocation. Under our first-order approximation, the expectations hypothesis holds along each country's yield curve.

yield. We focus on 10-year yields in our baseline calibration as longer tenor bonds are less affected by the short-run interest rate smoothing of central banks which are not likely important drivers of the exchange rate (in light of our analytical results). We note that the persistence of the yield differential, evident from Figure 1, implies a high persistence of $\rho^{\beta} = \rho^{\beta^*} = 0.98$.

In the second panel, we discipline the endowments in each country to match moments on output per capita. In the model, this is the per capita value of final goods expressed in units of consumption in each country:

$$y_t \equiv p_{Ht}c_{Ht} + \zeta^* q_t^{-1} p_{Ht}^* c_{Ht}^*,$$
$$y_t^* \equiv \frac{1}{\zeta^*} q_t p_{Ft} c_{Ft} + p_{Ft}^* c_{Ft}^*.$$

In the data, we analogously define output per capita as nominal GDP less investment and government spending, scaled by the consumption deflator and population.[30] Again for simplicity we assume that the volatility of endowment shocks $\sigma^z, \sigma^{z^*}$ and the persistence of endowments $\rho^z, \rho^{z^*}$ are the same. We jointly discipline these values and the correlation $\rho^{z,z^*}$ to target the volatility and autocorrelation of log relative output per capita and the volatility of changes in log U.S. output per capita.

We note that $\rho^{\beta,\beta^*}$ and $\rho^{z,z^*}$ are the only non-zero correlation coefficients in our model; we assume all others are zero. There are clearly common components of global yields and output, and these correlation parameters allow our model to capture them. We could have equivalently modeled discount factors and endowments in our model as the sum of global and differential components which are independent.

In the third panel, we discipline the risk aversion of arbitrageurs. We treat the excess bond premium as an empirical counterpart of arbitrageurs' log risk aversion, up to scale. We thus discipline the persistence $\rho^{\gamma}$ to match the persistence of the excess bond premium. We note that the persistence of 0.85 implies a half life of the $\log \gamma$ process around one year, much less than the half-life of the $\log \beta - \log \beta^*$ process of more than eight years. Using alternative proxies for $\log \gamma$ such as the VIX, global factor in risky asset prices, or three-month Treasury basis would imply the same result. We then discipline the volatility of arbitrageur risk aversion shocks $\sigma^{\gamma}$

[30] We take out investment and government spending to be consistent between model and data, because our model does not feature these variables. Since some of net exports in the data are also used for investment or government spending, we also take out a share of net exports proportional to the ratio between investment and government spending and these variables plus consumption.

to match the volatility of quarterly changes in the dollar/G10 real exchange rate.

In the final panel, we discipline the remaining five parameters of the model. We set the pricing-to-market coefficient $\xi$ to match the ratio of the volatility of the U.S.' terms of trade to the volatility of the dollar/G10 real exchange rate, where the terms of trade

$$s \equiv q^{-1} p_H^* / p_F$$

is the price of U.S. exports relative to imports. The calibrated value $\xi = 0.27$ is consistent with estimates of long-run exchange rate pass-through.[31] We jointly set the steady-state price of risk $\Gamma$ and trade elasticity $\sigma$ to target the volatility of log U.S. net trade and the dollar/G10 real exchange rate in levels. Recall that net trade is the ratio of exports to imports, where U.S. exports and imports in the model are (in units of the U.S. consumption bundle)

$$ex_t \equiv \zeta^* q_t^{-1} p_{Ht}^* c_{Ht}^*,$$
$$im_t \equiv p_{Ft} c_{Ft}.$$

The price of risk matters for the volatility of net trade because the risk-bearing capacity of arbitrageurs governs the elasticity of capital flows, and thus trade flows, to macroeconomic shocks. The trade elasticity determines how much exchange rate volatility is consistent with the observed trade volatility. The calibrated value $\sigma = 0.9$ is in line with other studies jointly matching aggregate prices and trade volumes.[32] We set the degree of home bias $\varsigma$ to match the average ratio of U.S. exports plus imports relative to output. Finally, we set the relative population of Foreign $\zeta^*$ to match the average ratio of cumulative G10 output to U.S. output.

## 5.2 Exchange rate volatility and comovements

With the calibrated model in hand, we now use it to study the volatility of and comovements with the real exchange rate. A systematic discussion of other untargeted second moments of interest rates and quantities is provided in appendix D.

[31] Firms' optimal price setting implies $\hat{p}_{Ht}^* - \hat{p}_{Ht} = (1 - \xi/(\theta - 1))\,\hat{q}_t$ and $\hat{p}_{Ft} - \hat{p}_{Ft}^* = -(1 - \xi/(\theta - 1))\,\hat{q}_t$. Given $\theta = 4$ and $\xi = 1.3$, exchange rate pass-through is 0.57. By comparison, Burstein and Gopinath (2014) report long-run pass-through into import price indices of 0.51 for the U.S. and 0.71 on average across G10 economies (their Table 7.4).

[32] Backus, Kehoe, and Kydland (1994) propose $\sigma = 1.5$, while Heathcote and Perri (2014) estimate $\sigma = 0.6$ (their Table 9.4) and Alessandria and Choi (2021) estimate $\sigma = 1$ (their Table 1).

| | | $\sigma$ | | $\rho_{-1}$ | |
|---|---|---|---|---|---|
| | Variable | Data | Model | Data | Model |
| $\log q$ | log exchange rate | 11.48% | 10.39% | 0.94 | 0.91 |
| $\Delta \log q$ | $\Delta$ log exchange rate | 3.91% | 4.00% | 0.04 | $-0.04$ |

Table 5: exchange rate volatility and autocorrelation in data and model

Notes: model moments are averages over 1,000 simulations of 116 quarters each using a 1,000 quarter burn-in period.

Table 5 demonstrates that the model accounts well for the volatility and autocorrelation of the log exchange rate both in levels and in one-quarter changes. While the volatility moments were calibration targets, the autocorrelation moments were not, so it is notable that the model implies near random-walk behavior in the exchange rate (a high autocorrelation in levels and close to zero in changes), as in the data.

Figure 2 demonstrates that demand shocks are the predominant driver of exchange rates in the model. It decomposes the variance of changes in the exchange rate at increasing horizons into the contribution from each set of shocks. Demand shocks and intermediation shocks account for comparable shares of the variance in quarterly changes. As the horizon increases, demand shocks account for more and intermediation shocks for less of the variance. In levels, demand shocks account for 77% and intermediation shocks account for 21% of the variance in the exchange rate. At all horizons and in levels, supply shocks account for little of the variance.

Persistence and low steady-state currency intermediation frictions are the key mechanisms generating large exchange rate volatility from demand shocks. Figure 3 depicts the impulse responses to a one standard deviation shock. In response to a $20bp$ decline in the U.S. discount factor, the dollar appreciates by roughly $500bp$, the Foreign interest rate falls by roughly $15bp$ relative to the U.S. interest rate, Foreign consumption falls by roughly $150bp$ relative to U.S. consumption, U.S. net trade falls by nearly $600bp$, and the expected return to Foreign bonds less dollar bonds falls very slightly. These results are consistent with the impact effects of demand shocks characterized in section 3. The exchange rate response is an order of magnitude larger than the response of the interest rate differential because the latter is persistently low and the exchange rate is forward-looking. Indeed, if we lower persistence to $\rho^\beta = 0.9$, the same shock induces a dollar appreciation which is less than a third of that in the baseline calibration, consistent with Proposition 2. The exchange rate response is

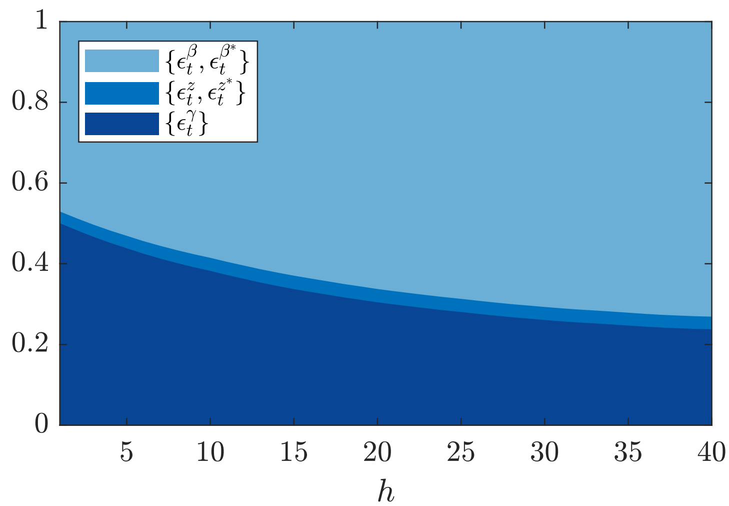


Figure 2: variance decomposition of exchange rate changes over $h$ quarters

Notes: figure depicts, for each $h$, the share of $\sigma^2(\log q_{t+h} - \log q_t)$ in the model due to each set of driving forces alone. Variances are averaged over 1,000 simulations of 116 quarters each using a 1,000 quarter burn-in period.

also large because the steady-state intermediation frictions controlled by the price of risk $\Gamma$ are small, so the decline in the currency risk premium does not dampen much the exchange rate response in (1). If we raise the steady-state price of risk by a factor of 10 to $\Gamma = 6 \times 10^{-3}$, the same shock induces a dollar appreciation which is only two thirds of that in the baseline calibration, consistent with Proposition 3.

Table 6 compares comovements with the exchange rate between data and model, all of which were untargeted in the calibration.[33] The first column reports 90% confidence intervals from the levels specification in Table 1. The second column reports the model-generated comovements, and the remaining columns report comovements eliminating two of the three sets of shocks to focus on each set alone.

The first two panels indicate that the model is successful in accounting for the comovement between the exchange rate and yield differentials. At both tenors, the model-generated regression coefficients are near the center of the empirical confidence intervals, the $R^2$ coefficients are of a similar order of magnitude as the data, and the $R^2$ coefficients are rising in tenor as in the data. Consistent with Proposition 1, demand or supply shocks are necessary to match the sign of the empirical comovements: with only intermediation shocks, the dollar would be strong when U.S. yields are

[33] Appendix D compares the specifications in changes between data and model, as well as the out-of-sample analysis in data and model.

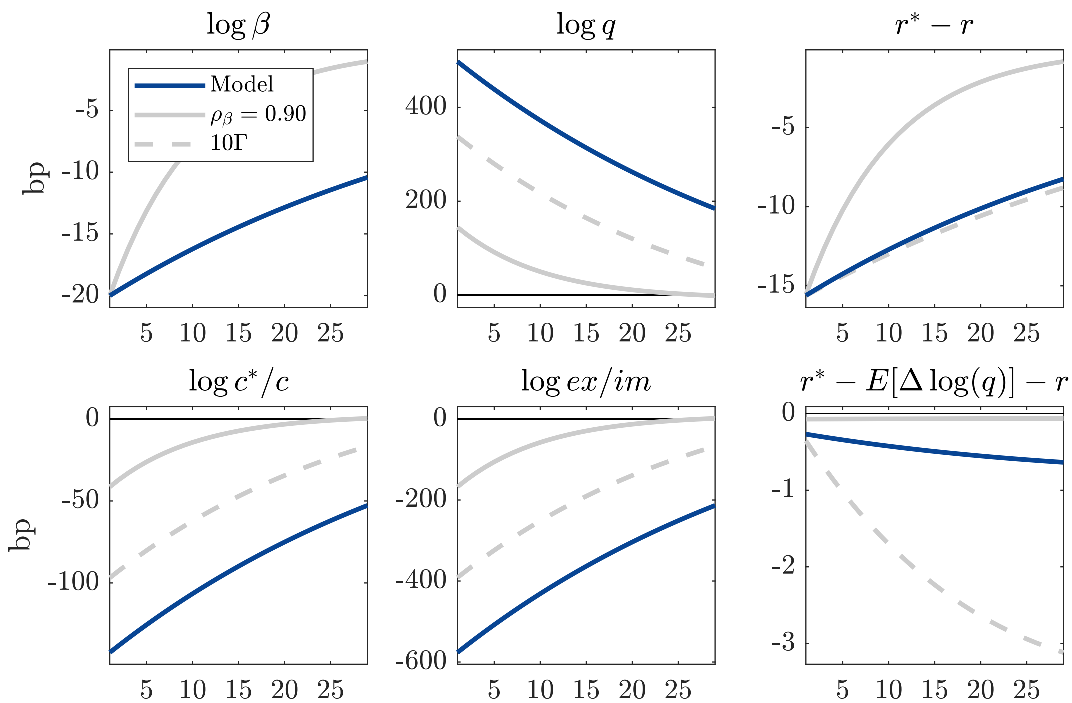


Figure 3: impulse responses to demand shock

relatively low. At the same time, the presence of intermediation shocks is important to explain why the $R^2$ of these regressions is below one: with only demand or supply shocks, the yield differential would account for too much of the exchange rate. Since intermediation shocks are more transitory than demand shocks, they dampen the comovements and $R^2$ for short tenors more so than longer tenors.[34]

The third panel indicates that the model is also successful in accounting for deviations from UIP and weak predictability of the exchange rate at high frequencies. Using the interest rate differential to predict the appreciation of the dollar over the next quarter (similar results are obtained using the one-year yield differential and exchange rate appreciation over the next year), the model implies predictable deviations from UIP, but also that the interest rate differential explains essentially none of the variation in the subsequent change in the exchange rate. Both of these results are consistent with the data. Consistent with Proposition 1, here intermediation shocks are essential because they imply that the dollar would be expected to depreciate when U.S. rates are relatively low. In their absence, a relatively low dollar yield would fore-

[34]The presence of both shocks also implies that exchange rates are not “spanned” by bond returns. In appendix D, we replicate the regressions of Chernov et al. (2024) on model-generated data.

| | Data | Model | Only $\{\epsilon_t^\beta, \epsilon_t^{\beta^*}\}$ | Only $\{\epsilon_t^z, \epsilon_t^{z^*}\}$ | Only $\{\epsilon_t^\gamma\}$ |
|---|---|---|---|---|---|
| $\log q$ on $r^{(1)*} - r^{(1)}$ | | | | | |
| Coefficient | [-6.78,0.23] | $-2.59$ | $-7.36$ | $-5.20$ | 5.56 |
| Adj $R^2$ | 0.20 | 0.20 | 0.88 | 0.99 | 0.99 |
| $\log q$ on $r^{(40)*} - r^{(40)}$ | | | | | |
| Coefficient | [-13.35,-3.61] | $-9.40$ | $-11.06$ | $-11.95$ | 33.66 |
| Adj $R^2$ | 0.36 | 0.52 | 0.87 | 0.99 | 0.99 |
| $\log q_{+1} - \log q$ on $(r^{(1)*} - r^{(1)})/4$ | | | | | |
| Coefficient | [-2.73,1.25] | $-0.29$ | 2.14 | 1.81 | $-4.13$ |
| Adj $R^2$ | $-0.00$ | $-0.00$ | 0.03 | 0.04 | 0.09 |
| $\log q$ on $\log c^* - \log c$ | | | | | |
| Coefficient | [-4.61,-0.56] | $-2.34$ | $-3.49$ | 1.05 | $-3.49$ |
| Adj $R^2$ | 0.29 | 0.58 | 1.00 | 0.99 | 1.00 |
| $\log q$ on $\log ex/im$ | | | | | |
| Coefficient | [-0.74,0.31] | $-0.86$ | $-0.86$ | 5.86 | $-0.86$ |
| Adj $R^2$ | 0.04 | 0.96 | 1.00 | 0.44 | 1.00 |

Table 6: exchange rate comovements and predictability in data and model

Notes: model moments are averages over 1,000 simulations of 116 quarters each using a 1,000 quarter burn-in period.

cast an expected dollar appreciation by an amount which is inconsistent with the data.[35] At the same time, the low $R^2$ in such predictability regressions is not unique to intermediation shocks: even persistent demand shocks imply a lower $R^2$ than in contemporaneous regressions, consistent with Proposition 2.

The fourth panel indicates that the model is again successful in accounting for the comovement between the exchange rate and relative consumption. As in the data, the dollar is strong when Foreign consumption is relatively low versus U.S. consumption. Consistent with Proposition 1, both demand and intermediation shocks deliver this comovement. One shortcoming of the model is that relative consumption explains

[35] Relatedly, because of intermediation shocks, the model generates realistic returns on the dollar carry trade, a strategy paying $\text{sign}(r_t^* - r_t)\,(r_t^* - \Delta \log q_{t+1} - r_t)$ each period $t+1$ (following Lustig et al. (2014)). The annualized average return and Sharpe ratio of this strategy in the model are 1.6% and 0.10, comparable to our estimates of 3.1% and 0.21 in the data and the estimates for the dollar trade in Hassan and Mano (2019).

double the variation in the exchange rate in the model relative to the data.

The fifth panel indicates that the model counterfactually implies a tighter link between the dollar and net trade than exists in the data (though the sign is consistent between data and model). This is because both demand and intermediation shocks imply that a weak dollar induces a contemporaneous expenditure switch toward U.S. goods.[36] Extending the model to feature investment in capital and/or dynamic trade would be one way of weakening the contemporaneous link between the exchange rate and trade balance, as in Backus et al. (1994), Alessandria and Choi (2007), and Drozd and Nosal (2012). Appendix D demonstrates that adding trade shocks along the lines of Alessandria and Choi (2021) and Mac Mullen and Woo (2024) also resolves this model shortcoming. Since these features dampen the comovement between the exchange rate and trade flows, they also dampen the share of exchange rate variation accounted for by relative consumption above. Disciplining the stochastic properties of trade shocks to match these moments, it remains that relative demand shocks account for most of the variation in the exchange rate.

Our conclusion that relative demand shocks account for most of the variation in the exchange rate contrasts with that of Itskhoki and Mukhin (2021). That paper does not include demand shocks and concludes that intermediation shocks drive nearly all the volatility in the exchange rate. Appendix D compares moments generated by our model and that in Itskhoki and Mukhin (2021). While both models generate comparable moments in regards to exchange rate volatility, autocorrelation, predictability (or lack thereof), and comovement with relative consumption, the dominant role of intermediation shocks in Itskhoki and Mukhin (2021) counterfactually implies that the dollar is strong when U.S. yields are relatively low. Figure 4 depicts histograms of these comovements across many simulations from both models, making evident that this difference between models is clear even accounting for sampling uncertainty.[37] By

[36]Supply shocks also induce such an expenditure switch, but there is a countervailing effect operating through incomes: a relative increase in U.S. supply (which depreciates the dollar) raises relative U.S. income and thus import demand. At our calibrated parameter values, this effect dominates. However, because supply shocks are a minor driver of the exchange rate, they do not much affect the unconditional comovement between the dollar and net trade.

[37]These histograms are also useful in addressing the concern that the estimated relationship between the exchange rate and yield differential in the data may reflect a spurious correlation among highly persistent variables. If the true data generating process was one without relative demand shocks, as in Itskhoki and Mukhin (2021), we would expect to estimate a comovement between the exchange rate and three-month yield differential (10-year yield differential) as or more negative than what we estimate in the data only 3% (2%) of the time.

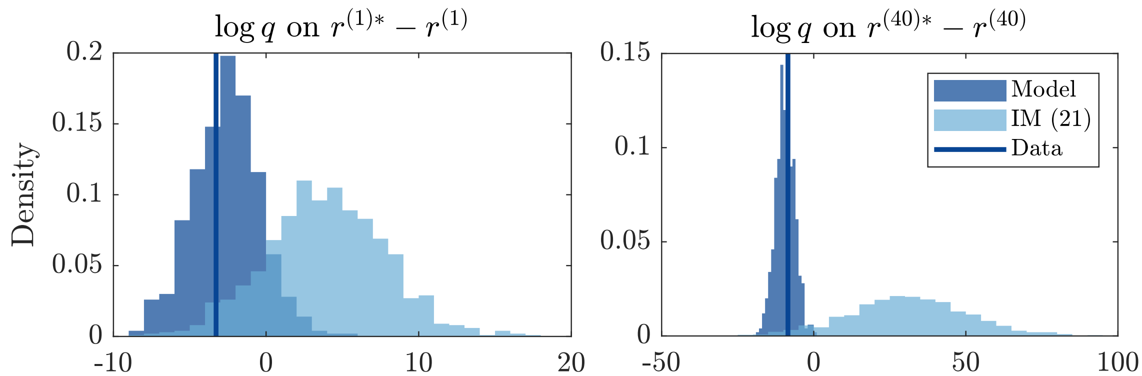


Figure 4: comovement between exchange rate and yield differentials

Notes: for our model and that in Itskhoki and Mukhin (2021), histograms depict estimated coefficients from 1,000 simulations of 116 quarters each using a 1,000 quarter burn-in period. Itskhoki and Mukhin (2021) model simulated using online replication package and calibration "IRBC+" (column 7 of Table 1 in that paper). We price long bonds using expectations hypothesis and we use nominal yield differential for $r_t^{(\tau)} - r_t^{(\tau)*}$, as we do in data. Dark blue lines depict our estimates in data.

adding demand shocks and disciplining them using observed yield differentials, we are able to build on the successes of Itskhoki and Mukhin (2021) while also matching the comovement between the exchange rate and yield differentials in the data.

## 5.3 The exchange rate over 1991-2020

The prior subsection studied model properties using averages over many simulations of 116 quarters each. Here we instead use the model to invert the sequence of shocks required to rationalize the observed sequence of 10-year bond yields, output per capita, and the excess bond premium over 1991-2020, and we ask how the model-implied paths of other variables compare to the data.

We proceed as follows. Since we treat the excess bond premium as our data counterpart to arbitrageur risk aversion up to scale, this series alone delivers the sequence of $\{\epsilon_t^\gamma\}$. The observed sequence of output per capita largely disciplines the sequence of $\{\epsilon_t^z, \epsilon_t^{z^*}\}$.[38] We finally recover $\{\epsilon_t^\beta, \epsilon_t^{\beta^*}\}$ from the observed sequence of 10-year bond yields. We then feed these shocks into our model. In the simulation, we initialize the model's exogenous state variables to be consistent with the 10-year

[38]We detrend output per capita by taking out a linear trend obtained as the weighted average of linear trends in U.S. output per capita and G10 output per capita, with weights equal to the average output shares of the U.S. and G10 (1/2.35 and 1.35/2.35, respectively).

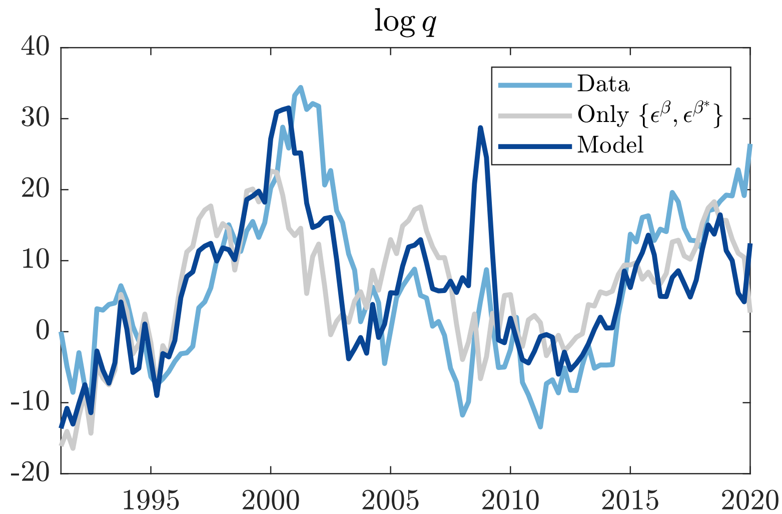


Figure 5: dollar/G10 exchange rate in data and model

Notes: model-implied exchange rate simulated by inverting $\{\beta_t, \beta_t^*, z_t, z_t^*, \gamma_t\}$ to match 10-year yields and output per capita in U.S. and G10, as well as excess bond premium of Gilchrist and Zakrajsek (2012). All series plotted in *pp*. Constant is added to model-generated series to match same average value as data series.

yields, output per capita, and excess bond premium in 1991 Q2, relative to their time-series averages through 2020 Q1. We initialize the model's endogenous state variables to their steady-state values for simplicity and in the absence of a clear alternative.

Figure 5 demonstrates that the simulated model is remarkably successful in accounting for the trend and cycles in the dollar/G10 exchange rate over this period. We emphasize that the exchange rate was not at all used in recovering the model's shocks, except that the intermediation shocks are scaled so that the model's unconditional volatility of exchange rate changes equals that in the data. With only demand shocks, we find that the simulated path continues to account for much of the data, consistent with the variance decomposition in Figure 2. This underscores our finding that demand shocks as reflected in persistent interest rate differentials are the predominant driver of the dollar/G10 exchange rate.

This result may be surprising in light of present value decompositions which typically conclude that expected interest rate differentials account for little of the variation in exchange rates (see, for instance, Froot and Ramadorai (2005)). Appendix D uses our model to clarify that small-sample bias renders the conclusions from such decompositions misleading. In small samples, there is downward bias in the estimated autocorrelation of the interest rate differential, given its high persistence. Vector autoregressions thus interpret too much of the volatility of the exchange rate as "excess volatility" which cannot be explained by expected interest rate differentials.[39]

At the same time, Figure 5 also makes clear that demand shocks alone are unable to explain the dollar appreciation at the onset of recessions: in the early 2000s, 2008, and 2020. As discussed in the context of our empirical results, in these periods, the dollar strengthened even as dollar interest rates fell relative to G10 interest rates. For this reason the full model, which includes positive $\gamma_t$ shocks in these periods disciplined by the excess bond premium, better matches the data in Figure 5.[40]

Appendix D reports model simulations of other variables of interest. The model generates the low-frequency movement in relative consumption observed in the data, though it is more volatile at higher frequencies than the data. The model-implied net trade series is similarly too volatile in changes and appears to lead the data. As discussed in the prior subsection, accounting for endogenous production, dynamic trade, and/or trade shocks would improve the model along these dimensions.[41]

**Taking stock** In summary, our parsimonious model accounts for a substantial share of the volatility in the dollar/G10 exchange rate and its comovements. Demand shocks, reflected in persistent interest rate differentials between the U.S. and G10 economies, are the predominant driver of the exchange rate. These shocks also generate contemporaneous comovements between the exchange rate, interest rate differential, and relative consumption comparable to the data. At the same time, currency intermediation shocks, disciplined by the excess bond premium in our implementation, are also important to account for deviations from uncovered interest parity at high frequencies, and to explain the dollar appreciation in crises.

Appendix D demonstrates that our quantitative conclusions are robust to two alternative calibrations. The first allows relative demand, relative supply, and intermediation shocks to be correlated with one another. This calibration underscores that

[39] This conclusion echoes a point made in Engel et al. (2022). It is also similar to that of Atkeson, Heathcote, and Perri (2024) in the context of news about dividend growth and stock price volatility.

[40] Appendix D indeed depicts a tight comovement between the unexplained component of the exchange rate using only demand shocks and the excess bond premium, VIX, or global factor in risky asset prices of Miranda-Agrippino and Rey (2020), echoing the discussion around Table 2.

[41] The appendix also illustrates that, even when trade shocks are set to exactly rationalize net trade in the data over 1991-2020, it does not much change the model-implied exchange rate series, or the conclusion that most of its variation is driven by demand shocks.

we do not view the shocks in our framework as structural; they are better thought of as wedges which may be correlated because of the propagation of deeper structural shocks.[42] Nonetheless, even in this case demand wedges account for most of the variation in the exchange rate: the implied correlations are not large enough to change our results. The second alternative calibration targets the stochastic properties of the three-month rather than 10-year yield differential. The role of demand shocks again is quite comparable to our baseline, because the calibration implies even more persistent relative demand, but less volatile shocks.

# 6 Interpretation and directions for future work

We conclude with an interpretation of our findings and directions for future work.

**What drives movements in relative demand?** Our analysis implies that persistent shocks to relative demand, reflected in persistent differences in real interest rates and thus natural rates of interest, are a primary driver of exchange rates. This is important because it qualifies the idea of "exchange rate disconnect": while the exchange rate may have limited effects on the economy due to features such as high home bias, a low trade elasticity, or pricing to market, the shocks driving most exchange rate variation are *not* disconnected from those driving other asset prices and macroeconomic quantities. With that said, we have modeled demand shocks in reduced form, and an obvious next question is what exactly such shocks are.

Potential candidates include shocks to credit conditions, demographics, or uncertainty, which generate comovements like discount factor shocks.[43] It may be that nominal rigidities are an important transmission mechanism shaping these comovements. However, we do not interpret monetary shocks themselves as plausible candidates to drive most exchange rate volatility. This is in part because standard estimates of nominal rigidities would imply monetary shocks should not have such persistent effects on real interest rates, but also because monetary shocks induce comovements

[42] For instance, these correlations imply that a country experiencing a fall in its endowment also sees a decline in demand (a higher discount factor), which may arise from nominal rigidities and monetary policy which does not perfectly track the natural rate in the short run.

[43] See, for instance, Gourio (2012), Eggertsson and Krugman (2012), Carvalho, Ferrero, and Nechio (2016), Guerrieri and Lorenzoni (2017), and Mian, Straub, and Sufi (2021) in closed economies, and Gourio, Siemer, and Verdelhan (2013), Kollmann (2016), Auclert, Malmberg, Martenet, and Rognlie (2021), and Carvalho, Ferrero, Mazin, and Nechio (2023) in the open economy context.

like supply shocks: a U.S. monetary easing induces a weak dollar because it generates (temporarily) high U.S. output. Consistent with the conclusions of Chari et al. (2002) as well as our Proposition 1, such shocks cannot account for the comovement between the exchange rate and relative consumption we observe in the data. This distinguishes the perspective of the present paper from the older literature emphasizing monetary shocks as the main drivers of exchange rate volatility, as in Dornbusch (1976).

Persistent shocks to growth rates could also generate persistent movements in relative demand and natural rates which drive the exchange rate. Like a decline in $\beta$, an increase in expected U.S. growth would raise the U.S. interest rate and U.S. consumption, driving a dollar appreciation. Persistent growth rate shocks would again have a large effect on exchange rates in our model because asset markets are incomplete. In fact, it is because markets are incomplete that the transmission of growth rate shocks would differ from their transmission in existing exchange rate models emphasizing "long run risk" with recursive preferences in complete markets.[44] Discount factor and growth shocks would be distinguished by the implied predictive content in exchange rates for future consumption growth, and relatedly by the contemporaneous comovement between the exchange rate and claims on future output (such as equities). Using these features of the data to discriminate between these shocks as drivers of relative demand and natural rates seems a fruitful avenue for future work.

**Heterogeneity across currencies and countries** While we have focused our analysis on the broad dollar/G10 exchange rate, it may be that different economies are subject to a different mix of shocks, another interesting direction for future study.

This idea is particularly relevant when we contrast the comovements obtained between the U.S. and G10 economies with those obtained between the U.S. and emerging markets (EMs).[45] Figure 6 depicts the comovements between the average real exchange rate, average 10-year yield differential, and average measure of relative consumption per capita between the U.S. and EM economies. Unlike the case with the G10 economies, EM yields tend to be relatively *high* when the dollar is strong.

[44]See, for instance, Colacito and Croce (2011, 2013). In these models, an increase in expected U.S. growth which lowers U.S. marginal utility *lowers* U.S. consumption as part of the efficient risk-sharing arrangement and *depreciates* the dollar, while still raising the U.S. interest rate. One implication of this is that the conditional comovement of the interest rate differential and exchange rate is distinct from that induced by growth shocks with incomplete markets.

[45]In our sample these are Brazil, Chile, China, Colombia, Hungary, Indonesia, Israel, India, South Korea, Mexico, Malaysia, Peru, Philippines, Poland, Russia, Thailand, Turkey, and South Africa.

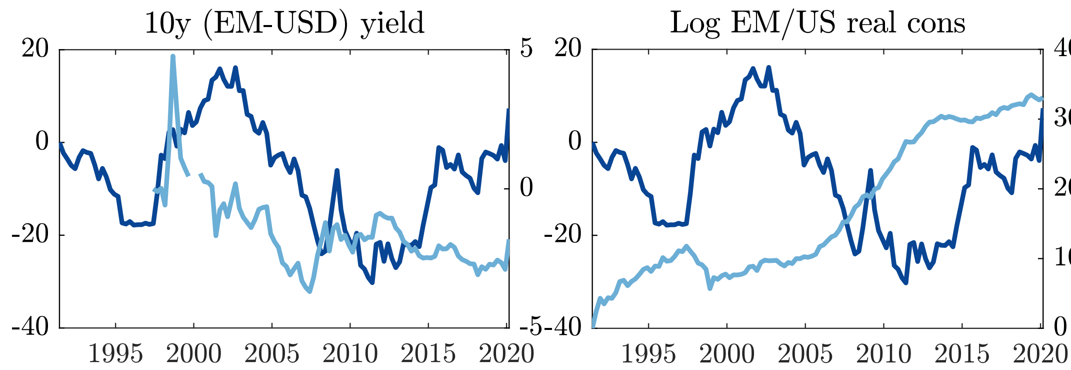


Figure 6: comovements with log real exchange rate between U.S. and EMs

Notes: dark blue line in each panel is log real exchange rate, plotted on left axis; light blue line in each panel is series in panel title, plotted on right axis. All series plotted in *pp*. All series are normalized to zero in first quarter. All yields are annualized.

At the same time, it remains the case that (around a clear trend) EM consumption tends to be relatively low when the dollar is strong. These comovements suggest that shocks to the intermediation of capital flows, as captured by $\gamma_t$ in our framework, may play a more important role in driving EM exchange rates.[46]

More broadly, an interesting question is whether heterogeneous exposures to demand and intermediation shocks can account for the factor structure in bilateral exchange rates documented in the empirical literature. Lustig et al. (2014) demonstrate that there is a carry factor, and Verdelhan (2018) demonstrates there is a dollar factor, priced in the cross-section of excess currency returns. Miranda-Agrippino and Rey (2022) argue that there is also a two-factor structure in global capital flows. Shocks to demand and to the intermediation of capital flows may be promising candidates to account for these risk factors in asset markets.

# 7 Conclusion

We began this paper by outlining a set of exchange rate puzzles: exchange rates are inconsistent with standard macroeconomic models (Backus and Smith (1993)); are very difficult to predict (Meese and Rogoff (1983)); and appear inconsistent with UIP at short horizons (Hansen and Hodrick (1980), Fama (1984)). Our argument is that at

[46]This is consistent with emerging markets' cyclicality of interest rates emphasized by Neumeyer and Perri (2005), and features of their UIP premia documented in Kalemli-Ozcan and Varela (2024).

least between the U.S. and G10 currencies, exchange rates are inconsistent with standard models because they are in fact driven predominantly by relative demand shocks, which imply that a strong currency is associated with relatively high consumption. Exchange rates are difficult to predict because these demand shocks are persistent, as reflected in the persistence of bond yields. And exchange rates are inconsistent with UIP at short horizons because of transitory shocks to currency intermediation, as reflected in financial conditions such as the excess bond premium. Our analysis raises important questions about the sources of persistent demand shocks affecting exchange rates and heterogeneous exposures to demand and intermediation shocks across currencies. We intend to explore these questions in future work.

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