A QUANTITY-DRIVEN THEORY OF TERM PREMIA AND EXCHANGE RATES*

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We develop a model in which specialized bond investors must absorb shocks to the supply and demand for long-term bonds in two currencies. Since long-term bonds and foreign exchange are both exposed to unexpected movements in short-term interest rates, a shift in the supply of long-term bonds in one currency influences the foreign exchange rate between the two currencies, as well as bond term premia in both currencies. Our model matches several important empirical patterns, including the comovement between exchange rates and term premia, and the finding that central banks' quantitative easing policies affect exchange rates. An extension of our model links spot exchange rates to the persistent deviations from covered interest rate parity that have emerged since 2008. *JEL codes:* E43, E52, F31, G12.

I. Introduction

There is a growing recognition that financial intermediaries play an important role in determining foreign exchange (FX) rates (Kouri 1976; Evans and Lyons 2002; Froot and Ramadorai 2005; Gabaix and Maggiori 2015; Itskhoki and Mukhin 2021). When there are frictions in financial intermediation, exchange rates move in response to shifts in the supply and demand for assets in different currencies, which intermediaries must absorb. Since the wealth of intermediaries in FX markets need not be closely tied to aggregate consumption or conditions in broader financial markets, this approach can explain the disconnect of exchange rates from macroeconomic fundamentals (Obstfeld and Rogoff 2001) and the predictability of currency returns (Fama 1984).

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In this article, we provide a framework for understanding how the structure of financial intermediation affects FX rates and show that this approach can shed light on numerous puzzles in the exchange rate literature. We start by assuming that global bond and FX markets are integrated with one another but segmented from other financial markets. We make this assumption for two reasons. First, FX is conceptually similar to long-term bonds in that both are "interest-rate sensitive" assets: they are heavily exposed to news about future short-term interest rates. Thus, the physical and human capital needed to trade long-term bonds can also be used to trade FX. Indeed, at most major dealer-banks and hedge funds, interest rate and FX trading are tightly integrated.

Second, concrete motivation for this assumption comes from recent work showing that quantitative easing (QE) policies—that is, large-scale purchases of long-term bonds by central banks—significantly affected foreign exchange rates and not just long-term bond yields, suggesting important linkages between the two markets. For example, Bauer and Neely (2014), Neely (2015), Swanson (2017), and Bhattarai and Neely (2022) show that the Fed's long-term bond purchases were associated with a large depreciation of the U.S. dollar vis-à-vis other major currencies.

A quantity-driven, supply-and-demand approach in the spirit of Tobin (1958, 1969) provides a natural explanation for bond price movements stemming from QE.[1] According to this "portfolio balance" view, holding fixed the expected path of future short-term rates, a reduction in the supply of long-term bonds—such as QE—leads to a fall in long-term bond yields because it reduces the total amount of interest rate risk borne by specialized financial intermediaries. Since the fixed-income market is assumed to be partially segmented from other parts of the broader capital markets, these intermediaries cannot diversify away the interest rate risk they bear and must be paid to absorb shocks to the supply and demand for long-term bonds. This segmentation explains why QE policies—which, while large relative to national bond markets, are small relative to global markets for all financial assets—have a large effect on long-term yields.

1. See Hamilton and Wu (2012), D'Amico and King (2013), Greenwood and Vayanos (2014), Greenwood, Hanson, and Vayanos (2016), and Vayanos and Vila (2021).

Our article shows that this same quantity-driven, supply and demand approach can also explain many empirical facts about exchange rates, including their response to QE. The key insight is that FX and long-term U.S. bonds are exposed to the same primary risk factor—unexpected movements in short-term U.S. interest rates. Thus, if the global bond and FX markets are integrated with one another, a shift in the supply of long-term U.S. bonds like QE affects the risk premium on both types of assets.

Our baseline model is a straightforward generalization of the Vayanos and Vila (2021) term structure model to a setting with two currencies. Specifically, we consider a model with short-term and long-term bonds in two currencies, which we label the U.S. dollar (USD) and the euro (EUR). Short-term interest rates in each currency are exogenous and evolve stochastically over time. We assume that short rates in the two currencies are positively but imperfectly correlated.

The key friction in the model is that the marginal investors in global bond and FX markets—whom we call "global bond investors"—are specialized. These investors must absorb exogenous shocks to the supply and demand for long-term bonds in both currencies, as well as demand shocks in the FX market. Because these specialists have limited risk-bearing capacity, they will only absorb these shocks if the expected returns on long-term bonds in both currencies, as well as FX, adjust in response.

To solve the model, we must pin down three equilibrium prices: the long-term yield in each currency and the exchange rate between the currencies—the number of dollars per euro. Equivalently, we need to determine the equilibrium expected returns on three long-short trades: a "yield curve trade" in each currency—which borrows short-term and lends long-term—and an "FX trade"—which borrows short-term in dollars and lends short-term in euros.

This baseline model predicts that shifts in the supply of long-term bonds affect not only term premia but also the expected returns on the FX trade and hence exchange rates. For instance, an increase in the supply of long-term U.S. bonds raises the expected excess return on long-term U.S. bonds and the expected return on the borrow-in-dollar lend-in-euro FX trade, leading to a depreciation of the euro versus the dollar.

The key intuition is that the U.S. yield curve trade and the borrow-in-dollar lend-in-euro FX trade have similar exposures to U.S. short-rate risk. First, when the U.S. short rate rises unexpectedly, long-term U.S. yields also rise through an expectations hypothesis channel: the expected path of U.S. short rates is now higher, so long-term U.S. yields must rise for long-term U.S. bonds to remain attractive to investors. As a result, the price of long-term U.S. bonds falls, so investors in the U.S. yield curve trade lose money. The borrow-in-dollar lend-in-euro FX trade is also exposed to U.S. short-rate risk. When the U.S. short rate rises unexpectedly, the euro depreciates through an uncovered-interest-rate-parity (UIP) channel: since future short rates are now expected to be higher in the United States than in Europe, the euro must fall and then be expected to appreciate for short-term euro bonds to remain attractive. Thus, the FX trade suffers losses at the same time as the U.S. yield curve trade.

Now consider the effect of an increase in the supply of long-term U.S. bonds—for example, because the Federal Reserve announces it is going to unwind its QE policies. Following this outward supply shift, global bond investors will be more exposed to future shocks to short-term U.S. interest rates. As a result, the price of bearing U.S. short-rate risk must rise. Because long-term U.S. bonds are exposed to U.S. short-rate risk, this leads to a rise in the term premium component of long-term U.S. yields. It also leads to a rise in the risk premium on the borrow-in-dollar lend-in-euro FX trade, which is similarly exposed to U.S. short-rate risk. As a result, the euro must depreciate against the dollar and will be expected to appreciate going forward.[2]

The baseline model makes several additional predictions. First, we show that bond supply shocks should have a larger effect on the bilateral exchange rate when the correlation between the countries' short rates is lower. For example, the JPY-USD exchange rate should be more responsive to U.S. QE than the EUR-USD exchange rate because Japanese short rates are less correlated with U.S. short rates than are euro short rates. Second, our model matches the otherwise puzzling finding in Lustig, Stathopoulos, and Verdelhan (2019) that the return to the FX trade declines if one borrows long-term in one currency to lend long-term in the other. In our model, this pattern arises because the "long-term" FX trade has offsetting exposures to short-rate shocks, making it less risky for global bond investors than the

2. We discuss these effects in terms of U.S. short-rate risk, but they apply symmetrically to euro short-rate risk. The supply of long-term euro bonds has the opposite effect on the EUR-USD exchange rate as that of U.S. bonds.

standard FX trade involving short-term bonds. Third, if we assume that the net supply of each risky asset is increasing in its price, our model offers a unified explanation that links the predictability of FX returns documented by Fama (1984) with the predictability of long-term bond returns documented by Fama and Bliss (1987) and Campbell and Shiller (1991).

After fleshing out these basic predictions, we extend the model in several ways to explore how the detailed structure of financial intermediation affects foreign exchange rates. We first explore what happens if intermediation is further segmented in global bond and FX markets. Specifically, we replace some of our flexible global bond investors with local-currency bond specialists, who can only trade short- and long-term bonds in their local currency, as well as with specialists who only conduct the FX trade. Introducing this specialization delivers two additional effects relative to the baseline model. First, shocks to the supply of long-term bonds trigger FX trading flows between different investor types. In this way, we endogenize the FX flows in Gabaix and Maggiori (2015), ascribing them to broader capital market forces, and these flows in turn affect exchange rates. Second, shocks to the supply of long-term bonds in either currency generally have a larger impact on the exchange rate than in the baseline model. This effect arises because further segmentation effectively reduces bond investors' collective risk-bearing capacity.

In our next extension, we add non-risk-based bank balance sheet constraints to our model, which Du, Tepper, and Verdelhan (2018) show are critical for explaining the post-2008 violations of covered interest rate parity (CIP). We show that doing so provides a simple and plausible explanation for the fact that CIP deviations comove with spot exchange rates, as documented by Avdjiev et al. (2019) and Jiang, Krishnamurthy, and Lustig (2021). The intuition is that a positive U.S. bond supply shock generates demand from euro investors to buy long-term U.S. bonds and hedge the associated FX risk. Doing so consumes scarce balance-sheet capacity, so banks will only accommodate this hedging demand if there are deviations from CIP, leading to comovement between CIP deviations and spot FX rates.

A key implication of this extension is that CIP deviations are informative about the supply shocks that global bond investors must absorb, which are otherwise difficult to observe. Thus one might say that, through the lens of our model, the strong empirical relationship between CIP deviations and spot exchange rates suggests that an important fraction of the variation in the latter is due to supply and demand factors, rather than the changes in macro fundamentals that drive conventional models of exchange rate fluctuations.

This article is most closely related to work studying portfolio balance effects in currency markets (e.g., Kouri 1976; Evans and Lyons 2002; Froot and Ramadorai 2005; Gabaix and Maggiori 2015). In these models, the disconnect between exchange rates and macroeconomic fundamentals is explained by a disconnect between intermediaries in currency markets and the broader economy. A related literature in international economics, including Farhi and Werning (2012) and Itskhoki and Mukhin (2021), features reduced-form UIP shocks, which similarly disconnect exchange rates from macro fundamentals. Our article is also closely related to papers studying portfolio balance effects in bond markets.[3] Our key contribution is to show that the structure of financial intermediation, which links shocks hitting the intermediaries in FX markets to shocks in the bond market, helps explain several important empirical patterns.

The closest work to ours is independent work by Gourinchas, Ray, and Vayanos (2022; GRV). GRV also study a two-currency generalization of the Vayanos and Vila (2021) term structure model. While we work in discrete time with two bonds in each currency, GRV work in continuous time and consider a continuum of zero-coupon bonds in each currency. The tractability afforded by our simpler model allows us to analytically derive a broader and more general set of results. Despite these technical differences, our baseline results in Section III have close analogs in their setting. Nevertheless, there are a number of important differences between the papers, and we believe they are complementary. GRV numerically estimate their model using data on the EUR-USD exchange rate and the U.S. and German yield curves, show that the estimated model can match a variety of stylized facts, and use the estimated model to conduct numerical policy experiments. In contrast, we theoretically explore the role of additional segmentation in the global bond market and CIP violations. We also establish a number of empirical results that support the key predictions of our baseline model. In summary, while the results in Section III

3. See Greenwood and Vayanos (2014), Hanson (2014), Hanson and Stein (2015), Malkhozov et al. (2016), Haddad and Sraer (2020), Hanson, Lucca, and Wright (2021), and Albagli et al. (2022).

are similar in spirit to those in GRV, the results in Sections II and IV are entirely distinct.

This study is also related to the vast literature taking a consumption-based, representative-agent approach to exchange rates.[4] In contrast to our quantity-driven, segmented markets model, these traditional asset pricing theories struggle to explain why supply shocks—for example, central bank QE policies—affect foreign exchange rates and other asset prices. As Woodford (2012) emphasizes, this is because a "mere reshuffling" of assets between households and the central bank does not change how risk is priced in standard theories.[5] Furthermore, consumption-based models generally imply different relationships between exchange rates and interest rates than our model. For instance, in consumption-based models, the expected return on the borrow-in-dollar lend-in-euro FX trade is negatively correlated with the difference between U.S. and euro term premia. By contrast, in our model, the correlation is positive.

The remainder of the article is organized as follows. In Section II, we present some empirical evidence that motivates our theoretical analysis. Section III presents the baseline model. Section IV extends the model in several ways to explore how the structure of financial intermediation affects FX rates, including by allowing for further segmentation in the global bond and FX markets and for deviations from CIP. Section V concludes.

II. Motivating Evidence

To motivate our theoretical analysis, we present evidence for three related propositions. First, exchange rates appear to be about as sensitive to changes in long-term interest rate differentials as to changes in short-term interest rate differentials.

4. Contributions to this literature include Backus, Kehoe, and Kydland (1992), Backus and Smith (1993), Backus, Foresi, and Telmer (2001), Verdelhan (2010), Colacito and Croce (2011, 2013), Bansal and Shaliastovich (2013), Lustig, Roussanov, and Verdelhan (2014), Farhi and Gabaix (2016), and many others.

5. If one consolidates a country's fiscal authority and its central bank, then QE policies replace long-term government liabilities (bonds) with short-term ones (reserves) and are isomorphic to changing the maturity structure of government debt. In standard frictionless models, Ricardian equivalence holds and the maturity structure of government debt is irrelevant because it does not change the total amount of interest rate risk that is borne by households; it simply shifts risk from households' asset holdings to their tax liabilities.

Second, the component of long-term rate differentials that matters for exchange rates appears to be a forecastable term premium differential, rather than the future path of short rates. Third, differences in term premia that move exchange rates appear to be partially quantity driven, as they are responsive to central bank announcements about large-scale purchases of long-term bonds—that is, QE.

The motivating evidence we develop here echoes findings from the recent literature exploring linkages between foreign exchange and bond markets. Ang and Chen (2010), Lustig, Stathopoulos, and Verdelhan (2019), Lloyd and Marin (2020), and Chernov and Creal (2023) find that variables that predict long-term bond returns—for example, the differences in term spreads between currencies—are also useful for forecasting FX returns. The common finding, which we reproduce below, is that expected returns are lower on currencies that appear to have higher bond term premia. As pointed out by Lustig, Stathopoulos, and Verdelhan (2019), this joint predictability of FX and bond returns implies that the returns on currency carry trades are higher when they are implemented with shorter-term bonds than when implemented with longer-term bonds. Second, Chinn and Meredith (2004), Bacchetta and van Wincoop (2010), Boudoukh, Richardson, and Whitelaw (2016), Engel (2016), and Chernov and Creal (2023) all find evidence that UIP holds better at long horizons than at short horizons, a finding that is also tightly linked to the logic in Lustig, Stathopoulos, and Verdelhan (2019). Third, Bauer and Neely (2014), Neely (2015), Swanson (2017), and Bhattarai and Neely (2022) find that the U.S. dollar has tended to depreciate when the Federal Reserve announces that it is going to expand its purchases of U.S. long-term bonds.

II.A. Data

We obtain data on nominal exchange rates from Bloomberg. We obtain estimates of the nominal zero-coupon government yield curve for each currency from each country's central bank or finance ministry. For example, our data on U.S. Treasury zero-coupon yields is from Gürkaynak, Sack, and Wright (2007). Many of these data sets lack estimates for three-month government bill yields, so we obtain data on three-month government bill yields from Global Financial Data. Online Appendix A provides additional details on our data sources and variable definitions.

Our theory is intended as a description of the exchange rates of major developed economies that have floating (or lightly managed) currencies, independently set their own monetary policy, and play an important role in international financial markets. Thus, our analysis uses data for six major currencies, each quoted versus the U.S. dollar: the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British pound (GBP), and Japanese yen (JPY).

As discussed shortly, our theory characterizes the behavior of real yields and real exchange rates. However, due to the lack of comprehensive international data on inflation-indexed bonds, our motivating evidence here exploits data on nominal exchange rates and nominal bond yields, introducing measurement error from the perspective of our theory. Thus, it makes sense to focus on a period when inflation expectations were relatively stable and hence the use of nominal data introduces little measurement error. Motivated by this consideration, our baseline sample includes monthly observations from 2001 and 2021. In addition, bond and FX markets have arguably become more tightly integrated in recent decades, especially after the introduction of the euro in 1999 (Schulz and Wolff 2008; Mylonidis and Kollias 2010; Ehrmann et al. 2011; Pozzi and Wolswijk 2012). Since our theory hinges on the idea that bond and FX markets are tightly integrated, this argues in favor of looking at more recent data. See Online Appendix A for additional discussion.

II.B. Contemporaneous Movements in FX Rates

Table I shows monthly panel regressions of the form

$$\Delta_H q_{c,t} = A_c + B \cdot \Delta_H \left(i^*_{c,t} - i_t\right) + D \cdot \Delta_H \left(y^*_{c,t} - y_t\right) + \Delta_H \varepsilon_{c,t}, \tag{1}$$

where $\Delta_H q_{c,t}$ is the quarterly ($H = 3$) or annual ($H = 12$) log change in currency c vis-à-vis the U.S. dollar, $i^*_{c,t}$ and i_t denote the foreign and U.S. short-term interest rates, and $y^*_{c,t}$ and y_t are the foreign and U.S. long-term interest rates. Positive values of $\Delta_H q_{c,t}$ denote appreciation of the foreign currency versus the dollar. The regressions include currency fixed effects and thus exploit within-currency time-series variation. We measure the short-term rate as the 1-year government bond yield and the long-term rate as the 10-year zero-coupon government bond yield.

Because these regressions use overlapping changes, the residuals will be mechanically autocorrelated in a given currency

TABLE I

CONTEMPORANEOUS RELATIONSHIP BETWEEN MOVEMENTS IN FOREIGN EXCHANGE, SHORT-TERM INTEREST RATES, AND LONG-TERM INTEREST RATES

	H = 3-month changes				H = 12-month changes			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\Delta_H(i^*_{c,t} - i_t)$	4.27	3.22			2.77	1.26		
	(1.37)***	(1.47)**			(1.44)*	(1.64)		
$\Delta_H(y^*_{c,t} - y_t)$		3.13				5.13		
		(1.26)**				(1.88)**		
$\Delta_H i^*_{c,t}$			6.69	5.16			6.00	3.10
			(1.23)***	(1.11)***			(1.15)***	(1.40)*
$\Delta_H i_t$			−3.10	−1.67			−2.14	−0.21
			(0.84)***	(0.84)*			(0.93)**	(1.08)
$\Delta_H y^*_{c,t}$				4.94				9.07
				(1.39)***				(1.63)***
$\Delta_H y_t$				−3.98				−5.77
				(1.06)***				(1.61)***
DK lags	18	18	18	18	29	29	29	29
N	1,512	1,512	1,512	1,512	1,512	1,512	1,512	1,512
R^2 (within)	0.12	0.14	0.18	0.22	0.10	0.14	0.20	0.27

Notes. This table presents monthly panel regressions of the form:

$$\Delta_H q_{c,t} = A_c + B \times \Delta_H(i^*_{c,t} - i_t) + D \times \Delta_H(y^*_{c,t} - y_t) + \Delta_H \varepsilon_{c,t},$$

and

$$\Delta_H q_{c,t} = A_c + B_1 \times \Delta_H i^*_{c,t} + B_2 \times \Delta_H i_t + D_1 \times \Delta_H y^*_{c,t} + D_2 \times \Delta_H y_t + \Delta_H \varepsilon_{c,t}.$$

We regress H-month changes in the foreign exchange rate on H-month changes in short-term interest rates and in long-term yields in both the foreign currency and in U.S. dollars. All regressions include currency fixed effects. The sample runs from 2001m1 to 2021m12 and includes six currency pairs: AUD-USD, CAD-USD, CHF-USD, EUR-USD, GBP-USD, and JPY-USD (a higher value of $q_{c,t}$ means that currency c is stronger against the USD). Our proxy for the short-term interest rate is the one-year government yield. Our proxy for the long-term interest rate is the ten-year government bond yield. We report Driscoll-Kraay (1998) standard errors allowing for serial correlation up to a lag parameter that is chosen using a data-dependent approach based on Lazarus et al. (2018). Statistical significance is assessed using the fixed-b asymptotic theory of Kiefer and Vogelsang (2005). * $p < .10$, ** $p < .05$, *** $p < .01$.

over time. Furthermore, the residuals may be contemporaneously correlated across currencies at a given time. To draw proper inferences, we compute Driscoll-Kraay (1998) standard errors—that is, the panel data analog of Newey-West (1987) time-series standard errors. We assess statistical significance using the fixed-b asymptotic theory of Kiefer and Vogelsang (2005), which yields more conservative p-values and has better finite-sample properties than traditional Gaussian asymptotic theory. As detailed in Online Appendix A.3, our standard errors allow for serial correlation up to a lag parameter that we choose using the data-dependent approach of Lazarus et al. (2018).

Table I, columns (1)–(4) consider quarterly changes ($H = 3$ months). Column (1) shows the well-known result, consistent with standard UIP logic, that the foreign currency appreciates in response to an increase in the foreign-minus-dollar short-rate differential. Column (2) shows a more novel result: currencies appear to be nearly as responsive to changes in long-term interest rates as they are to changes in short-term rates. Columns (3) and (4) present specifications that break the rate differentials into their foreign and dollar components:

$$\Delta_H q_{c,t} = A_c + B_1 \cdot \Delta_H i^*_{c,t} + B_2 \cdot \Delta_H i_t + D_1 \cdot \Delta_H y^*_{c,t} + D_2 \cdot \Delta_H y_{c,t} + \Delta_H \varepsilon_{c,t}. \quad (2)$$

Foreign and U.S. short-term rates enter with opposite signs in column (3). Similarly, the foreign and U.S. long-term yields enter with coefficients of 4.94 and −3.98 in column (4), consistent with the idea that changes in the term premium differential impact the exchange rate.

Columns (5)–(8) repeat this analysis using annual changes ($H = 12$ months). Compared with the specifications using quarterly changes, the coefficient on the foreign-minus-U.S. short-rate differential is smaller in magnitude, but the coefficient on the long-rate differential is larger.

The evidence in Table I suggests that exchange rates react to movements in bond term premia. However, the change in the 10-year bond yield is not a very clean measure of changes in term premia: it reflects changes in term premia and changes in expected future short-term interest rates. A potentially cleaner, but still imperfect, measure of movements in term premia is the change in forward interest rates at a distant horizon. Distant forward rates reflect expectations of short-term interest rates in the distant future plus a term premium component. A range of evidence suggests that there is typically relatively little news about short-term rates in the distant future, so changes in distant forward rates primarily reflect movements in term premia (Campbell and Ammer 1993; Hanson and Stein 2015; Cieslak and Pang 2021). Moreover, there is a large literature showing that forward rates strongly predict the excess returns on long-term bonds (Fama and Bliss 1987; Cochrane and Piazzesi 2005). Of course,

TABLE II

CONTEMPORANEOUS RELATIONSHIP BETWEEN MOVEMENTS IN FOREIGN EXCHANGE, SHORT-TERM INTEREST RATES, AND LONG-TERM FORWARD RATES

	$H = 3$-month changes				$H = 12$-month changes			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\Delta_H(i^*_{c,t} - i_t)$	4.27	4.15			2.77	2.70		
	(1.37)***	(1.38)***			(1.44)*	(1.42)*		
$\Delta_H(f^*_{c,t} - f_t)$		1.72				2.50		
		(1.21)				(1.13)*		
$\Delta_H i^*_{c,t}$			6.69	6.53			6.00	5.54
			(1.23)***	(1.21)***			(1.15)***	(1.12)***
$\Delta_H i_t$			−3.10	−2.92			−2.14	−1.72
			(0.84)***	(0.87)***			(0.93)**	(0.87)*
$\Delta_H f^*_{c,t}$				2.41				5.38
				(0.99)**				(0.84)***
$\Delta_H f_t$				−1.95				−2.79
				(1.01)*				(0.83)***
DK lags	18	18	18	18	29	29	29	29
N	1,512	1,512	1,512	1,512	1,512	1,512	1,512	1,512
R^2 (within)	0.12	0.13	0.18	0.20	0.10	0.11	0.20	0.25

Notes. This table presents monthly panel regressions of the form:

$$\Delta_H q_{c,t} = A_c + B \times \Delta_H(i^*_{c,t} - i_t) + D \times \Delta_H(f^*_{c,t} - f_t) + \Delta_H \varepsilon_{c,t},$$

and

$$\Delta_H q_{c,t} = A_c + B_1 \times \Delta_H i^*_{c,t} + B_2 \times \Delta_H i_t + D_1 \times \Delta_H f^*_{c,t} + D_2 \times \Delta_H f_t + \Delta_H \varepsilon_{c,t}.$$

We regress H-month changes in the foreign exchange rate on H-month changes in short-term interest rates and in distant forward rates in both the foreign currency and in U.S. dollars. All regressions include currency fixed effects. The sample runs from 2001m1 to 2021m12 and includes six currency pairs: AUD-USD, CAD-USD, CHF-USD, EUR-USD, GBP-USD, and JPY-USD. Our proxy for the short-term interest rate is the one-year government bond yield. Our proxy for the distant forward rate is the three-year, seven-year forward government bond yield. We report Driscoll-Kraay (1998) standard errors allowing for serial correlation up to a lag parameter that is chosen using a data-dependent approach based on Lazarus et al. (2018). Statistical significance is assessed using the fixed-b asymptotic theory of Kiefer and Vogelsang (2005). * $p < .10$, ** $p < .05$, *** $p < .01$.

movements in distant forward rates may still reflect some news about future short rates, so changes in distant forward rates are still an imperfect proxy for movements in bond term premia.

Table II presents regressions of the same form as in Table I using distant forward rates ($f^*_{c,t}$ and f_t) instead of long-term yields ($y^*_{c,t}$ and y_t) as our proxy for term premia. The distant forward we use is the three-year seven-year forward government bond yield—that is, the rate one can currently lock in on a three-year loan

TABLE III

FORECASTING FOREIGN MINUS DOMESTIC BOND EXCESS RETURNS USING SHORT-TERM INTEREST RATES AND LONG-TERM FORWARD RATES

	H = 3-month excess returns				H = 12-month excess returns			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$i^*_{c,t} - i_t$	−0.05	−0.21			0.11	−0.27		
	(0.14)	(0.13)			(0.45)	(0.39)		
$f^*_{c,t} - f_t$		1.74				4.31		
		(0.22)***				(0.33)***		
$i^*_{c,t}$			−0.17	−0.23			−0.37	−0.51
			(0.16)	(0.16)			(0.49)	(0.42)
i_t			−0.08	0.08			−0.60	−0.21
			(0.17)	(0.14)			(0.53)	(0.37)
$f^*_{c,t}$				1.62				3.94
				(0.21)***				(0.55)***
f_t				−1.71				−4.12
				(0.25)***				(0.38)***
DK lags	17	17	17	17	28	28	28	28
N	1,494	1,494	1,494	1,494	1,440	1,440	1,440	1,440
R^2 (within)	0.00	0.10	0.02	0.11	0.00	0.22	0.08	0.28

Notes. This table presents monthly panel forecasting regressions of the form:

$$rx^{y*}_{c,t\to t+H} - rx^{y}_{c,t\to t+H} = A_c + B \times (i^*_{c,t} - i_t) + D \times (f^*_{c,t} - f_t) + \varepsilon_{c,t\to t+H},$$

and

$$rx^{y*}_{c,t\to t+H} - rx^{y}_{c,t\to t+H} = A_c + B_1 \times i^*_{c,t} + B_2 \times i_t + D_1 \times f^*_{c,t} + D_2 \times f_t + \varepsilon_{c,t\to t+H}.$$

We forecast the difference between foreign and domestic H-month bond returns using short-term interest rates and distant forward rates in both the foreign currency and in U.S. dollars. All regressions include currency fixed effects. The sample runs from 2001m1 to 2021m12 and includes six currency pairs: AUD-USD, CAD-USD, CHF-USD, EUR-USD, GBP-USD, and JPY-USD. Our proxy for the short-term interest rate is the one-year government bond yield. Our proxy for the distant forward rate is the three-year, seven-year forward government bond yield. $rx^{y*}_{c,t\to t+H} - rx^{y}_{c,t\to t+H}$ is the difference between the H-month log excess returns on 10-year foreign bonds and those on 10-year domestic bonds—that is, the difference between the returns on two yield-curve carry trades that borrow short- and lend long-term. We report Driscoll-Kraay (1998) standard errors allowing for serial correlation up to a lag parameter that is chosen using a data-dependent approach based on Lazarus et al. (2018). Statistical significance is assessed using the fixed-b asymptotic theory of Kiefer and Vogelsang (2005). * $p < .10$, ** $p < .05$, *** $p < .01$.

in seven years' time. Compared with Table I, the coefficients on the short-rate variables are slightly larger in magnitude and the coefficients on the long-rate variables are slightly smaller in magnitude, but the latter generally remain economically and statistically significant. Thus, Table II reinforces the idea that changes in the term premium component of long-term yields are associated with movements in foreign exchange rates.

II.C. Forecasting Bond and FX Returns

In Tables I and II, we provided suggestive evidence of a relationship between term premia and exchange rates. We now provide more direct evidence, showing that forward rates forecast returns on both long-term bonds and foreign currency. Table III starts with long-term bonds, running monthly panel regressions of the form

$$rx^{y*}_{c,t\to t+H} - rx^{y}_{t\to t+H} = A_c + B\cdot\left(i^*_{c,t} - i_t\right) + D\cdot\left(f^*_{c,t} - f_t\right) + \varepsilon_{c,t\to t+H}, \tag{3}$$

and

$$rx^{y*}_{c,t\to t+H} - rx^{y}_{t\to t+H} = A_c + B_1\cdot i^*_{c,t} + B_2\cdot i_t + D_1\cdot f^*_{c,t} + D_2\cdot f^*_t + \varepsilon_{c,t\to t+H}. \tag{4}$$

Here $rx^{y*}_{c,t\to t+H}$ denotes H-month log returns on long-term bonds in country c in excess of the H-month short-term interest rate in that country. $rx^{y}_{t\to t+H}$ denotes H-month log excess returns on long-term bonds in the United States. As in Tables I and II, the sample period runs from 2001 to 2021 and includes six major currency pairs. (For simplicity, the short-term interest rates on the right side in these regressions are the one-year government bond yields we have been using throughout.) The table shows that distant forward rates strongly predict future excess bond returns at 3- and 12-month horizons. For example, column (6) shows that if the foreign distant forward rate is 1 percentage point higher than the U.S. distant forward rate, then, over the next 12 months, excess returns (in foreign currency) on long-term foreign bonds exceed excess returns (in dollars) on long-term U.S. bonds by 4.31 percentage points on average. Similar results obtain at a quarterly forecasting horizon.

In Table IV, we forecast excess returns on foreign currency investments. The specifications parallel those in Table III, but the dependent variable is now the log excess return on an investment in foreign currency that borrows for H-months at the H-month U.S. short-term rate $i_t^{\left(\frac{H}{12}\right)}$ and invests at the foreign short-term rate $i_{c,t}^{*\left(\frac{H}{12}\right)}$. In other words, the regressions take the form:

$$rx^{q}_{c,t\to t+H} = A_c + B\cdot\left(i^*_{c,t} - i_t\right) + D\cdot\left(f^*_{c,t} - f_t\right) + \varepsilon_{c,t\to t+H}, \tag{5}$$

and

$$rx^{q}_{c,t\to t+H} = A_c + B_1\cdot i^*_{c,t} + B_2\cdot i_t + D_1\cdot f^*_{c,t} + D_2\cdot f_t + \varepsilon_{c,t\to t+H}, \tag{6}$$

TABLE IV

FORECASTING FOREIGN EXCHANGE EXCESS RETURNS USING SHORT-TERM INTEREST RATES AND LONG-TERM FORWARD RATES

	$H = 3$-month excess returns				$H = 12$-month excess returns			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$i^*_{c,t} - i_t$	0.21	0.29			0.65	0.96		
	(0.36)	(0.37)			(1.31)	(1.34)		
$f^*_{c,t} - f_t$		−0.83				−3.59		
		(0.39)*				(1.03)***		
$i^*_{c,t}$			0.31	−0.13			1.23	0.11
			(0.43)	(0.60)			(1.44)	(1.76)
i_t			−0.10	−0.06			−0.05	−0.02
			(0.33)	(0.36)			(1.16)	(1.22)
$f^*_{c,t}$				−0.27				−1.86
				(0.37)				(0.84)*
f_t				0.88				3.51
				(0.42)*				(1.09)***
DK lags	17	17	17	17	28	28	28	28
N	1,494	1,494	1,494	1,494	1,440	1,440	1,440	1,440
R^2 (within)	0.00	0.01	0.01	0.03	0.01	0.04	0.03	0.09

Notes. This table presents monthly panel forecasting regressions of the form:

$$rx^q_{c,t\to t+H} = A_c + B \times (i^*_{c,t} - i_t) + D \times (f^*_{c,t} - f_t) + \varepsilon_{c,t\to t+H},$$

and

$$rx^q_{c,t\to t+H} = A_c + B_1 \times i^*_{c,t} + B_2 \times i_t + D_1 \times f^*_{c,t} + D_2 \times f_t + \varepsilon_{c,t\to t+H}.$$

We forecast H-month foreign exchange excess returns using short-term interest rates and distant forward rates in both the foreign currency and in U.S. dollars. All regressions include currency fixed effects. The sample runs from 2001m1 to 2021m12 and includes six currency pairs: AUD-USD, CAD-USD, CHF-USD, EUR-USD, GBP-USD, and JPY-USD. For simplicity, the short-term interest rates on the right side in these regressions are one-year government bond yields. Our proxy for the distant forward rate is the three-year, seven-year forward government bond yield. $rx^q_{c,t\to t+H}$ is the H-month log excess return on the FX carry trade strategy that borrows short-term in U.S. dollars and lends short-term in currency c and is defined as $rx^q_{c,t\to t+H} \equiv (q_{c,t+H} - q_{c,t}) + (\frac{H}{12})(i_t^{*(\frac{H}{12})} - i_t^{(\frac{H}{12})})$ where $i_t^{*(\frac{H}{12})}$ and $i_t^{(\frac{H}{12})}$ denote the $(\frac{H}{12})$ −year short-term interest rates in foreign currency c and U.S. dollars, respectively. We report Driscoll-Kraay (1998) standard errors allowing for serial correlation up to a lag parameter that is chosen using a data-dependent approach based on Lazarus et al. (2018). Statistical significance is assessed using the fixed-b asymptotic theory of Kiefer and Vogelsang (2005). * $p < .10$, ** $p < .05$, *** $p < .01$.

where $rx^q_{c,t\to t+H} \equiv (q_{c,t+H} - q_{c,t}) + \left(\frac{H}{12}\right) \cdot \left(i_{c,t}^{*(\frac{H}{12})} - i_t^{(\frac{H}{12})}\right)$ is the H-month excess return (in dollars) on foreign currency c. The results in Table IV are consistent with a risk premium interpretation of our earlier results. For example, in column (6), an increase in the foreign-minus-U.S. distant forward rate differential negatively predicts 12-month currency returns with a coefficient of

−3.59 (p-value < .01). This means that if the foreign distant forward rate rises by 1 percentage point relative to the U.S. distant forward rate, investors can expect a 3.59 percentage point lower return on the trade that borrows in dollars and lends in foreign currency over the next three months. This is consistent with our results in Tables I and II. For instance, Table II shows that increases in the foreign-minus-U.S. distant forward differential are associated with a contemporaneous appreciation of the foreign currency. Table IV shows that this increase in distant forward rate differentials is associated with a subsequent depreciation of foreign currency and thus low foreign currency returns.

1. *Robustness* In Online Appendix A, we conduct a battery of robustness checks on our baseline results in Tables I, II, III, and IV. First, one might be concerned about our use of overlapping changes and returns in our baseline regressions. Our results are quite similar if we simply use nonoverlapping H-month changes or returns.

Second, the panel data estimates in Tables I–IV are a weighted average of currency-level time-series estimates. Although pooling data across currencies generates additional statistical power and is standard practice in empirical asset pricing, it is natural to examine the results for the six currencies separately. Broadly speaking, our results are strong for AUD, CHF, GBP, EUR, and JPY when considered in isolation, but our results for CAD are not.

Third, EUR, GBP, and JPY are the three currencies that, alongside the USD, arguably play the most significant role in international financial markets and thus most clearly satisfy the conditions of our theory. Thus, it is comforting that our results are similar if we restrict our sample to EUR, GBP, and JPY.

Fourth, in light of the growing literature that emphasizes the special role of the USD in international financial markets, it is natural to ask whether our results are driven by the decision to use USD as the base currency. The short answer is no: we obtain broadly similar results if, instead of using USD as the base currency, we use other currencies.

Finally, our baseline results focus on the 2001 to 2021 period. As explained, we focus on recent data for two main reasons. First, we are using data on nominal rates to test a theory that makes predictions about real rates. As a result, we expect the patterns predicted by our theory to emerge most strongly in nominal data during periods when expected inflation is stable. Second, our theory hinges on the idea that bond and FX markets are tightly integrated and these markets have arguably become more integrated in recent decades. However, neither consideration offers a strong justification for beginning the analysis in precisely 2001: we do not think there was a structural break in the stability of inflation expectations or the integration of markets in 2000. The Online Appendix shows that our results hold over the longer 1994–2021 sample which is as far back as we have zero-coupon yields for all currencies in our sample. To be sure, if we were to extend our sample back to the 1980s or 1970s—which is possible for some of the currencies we consider—our results become weaker. However, this is consistent with the notion that our theory's predictions should emerge less strongly during these earlier decades, especially when working with nominal data.

II.D. Central Bank QE Announcements

Our results so far are consistent with the idea that bond term premia play a role in driving the FX risk premium. That said, our prior results do not tell us precisely what drives bond term premia in the first place and thus do not necessarily single out a supply-and-demand approach to risk premium determination. As a final piece of more direct motivating evidence for our quantity-driven approach, we turn our attention to central bank announcements about changes in the net supply of long-term bonds. As noted earlier, many studies have documented the effect of central bank QE announcements on long-term bond yields (Gagnon et al. 2011; Krishnamurthy and Vissing-Jorgensen 2011; Greenwood, Hanson, and Vayanos 2016). Drawing on these previous studies, we isolate periods in which there is news about quantities and show that changes in distant forward rates—our proxy for movements in term premia—typically occur alongside changes in exchange rates at these times.[6]

Figure I illustrates our approach. We construct a list of large-scale asset purchase announcements by the U.S. Federal Reserve,

6. Even this evidence from QE announcements is not uniquely consistent with a term premium interpretation. According to the "signaling" view, QE also influences long-term rates through an expectations hypothesis channel by signaling a central bank's intention to keep short rates low for a long period of time. See Eggertsson and Woodford (2003), Bauer and Rudebusch (2014), and Bhattarai, Eggertsson, and Gafarov (forthcoming).

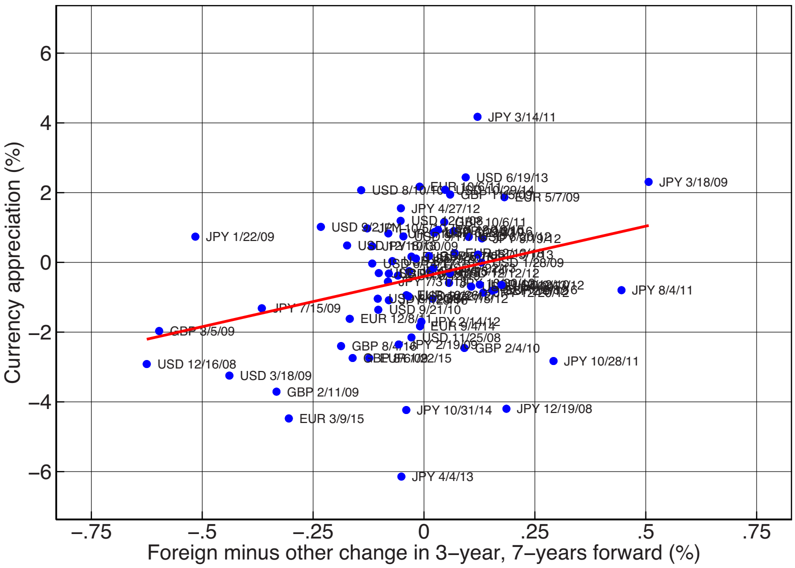

FIGURE I

Movements in Exchange Rates versus Differential Movements in Forward Rates on QE Announcement Dates

The figure shows the movement in foreign exchange rates versus movements in the difference between foreign and domestic long-term forward rates around quantitative easing (QE) announcement dates by the U.S. Federal Reserve, the European Central Bank, the Bank of England, and the Bank of Japan from 2008 to 2019. For an announcement on date t, we show the change in the foreign exchange rate and the movement in foreign minus domestic long-term rates from day $t-2$ to day $t+2$. The long-term forward rate is the three-year yield, seven-years forward. For the U.S. announcements, we plot the average appreciation of the dollar relative to euro, pound, and yen versus the movement in U.S. long-term forward rates minus the average movement in forward rates for the euro, pound, and yen. For the other three currencies, we plot their appreciation relative to the dollar versus the movement in the local currency forward rate minus the dollar forward rate. To form our list of QE announcement dates, we begin with Fawley and Neely's (2013) list of unconventional policy announcements by these four central banks. We update this list through 2019 and then focus on the subset of the announcement that contain news about central bank purchases of long-term bonds (either sovereign or private-sector).

the European Central Bank, the Bank of England, and the Bank of Japan from 2008 to 2019.[7] Since the Reserve Bank of Australia,

7. We end this analysis in 2019, thereby excluding the asset purchase announcements associated with the onset of the COVID-19 pandemic in March 2020, for two reasons. First, central banks began purchasing long-term bonds in March

the Bank of Canada, and the Swiss National Bank did not undertake large-scale purchases of long-term bonds from 2008 to 2019, we drop AUD, CAD, and CHF and focus solely on EUR, GBP, JPY, and USD. To form our list of asset purchase announcement dates, we begin with Fawley and Neely's (2013) list of unconventional policy announcements by these four central banks. We update this list through 2019 and focus on the subset of announcements that contain news about large-scale purchases of long-term bonds (either sovereign or private-sector), including announcements about "tapering" or "balance sheet normalization"—a.k.a. "quantitative tightening."

For an asset purchase announcement on date t, we show the appreciation of the FX rate and the movement in foreign-minus-U.S. distant forward rates from day $t-2$ to day $t+2$. For the U.S. announcements, we plot the average appreciation of USD relative to EUR, GBP, and JPY versus the movement in U.S. long-term forward rates minus the average movement in forward rates for EUR, GBP, and JPY. For the other three currencies, we plot their appreciation relative to USD versus the movement in the local-currency forward interest rate minus the USD forward interest rate.

Consider the Fed's announcement on March 18, 2009, that it would expand its purchases of long-term U.S. bonds to \$1.75 trillion from a previously announced \$600 billion. As can be seen in Figure I, distant U.S. forward interest rates fell by more than 40 basis points relative to those in other countries in the days surrounding this announcement, and the USD depreciated by approximately 3% vis-à-vis the EUR, GBP, and JPY basket. Conversely, when the Fed announced it was planning to slow or "taper" its long-term bond purchases on June 19, 2013, distant U.S. forward rates rose by roughly 10 basis points relative to foreign forwards and the USD appreciated by roughly 2.5%. For many announcements, neither distant forwards nor currencies

2020, in part due to a desire to counteract the widespread institutional bond sales associated with the COVID-induced "dash for cash." Thus, the sign of the initial combined shock to net bond supply—institutional sales minus central bank purchases—is unclear. Second, our theory emphasizes that exchange rates depend on term premia differentials and, hence, the differential net supply of long-term bonds in different currencies. Since the major central banks announced large-scale bond purchases in rapid succession (most in a few days after March 15, 2020), these events do not represent clean shocks to cross-currency differences in net supply.

move by much, perhaps because the announcements were largely anticipated. However, Figure I shows that announcements that were associated with significant relative movements in distant forward rates were typically associated with sizable currency movements.[8]

In Table V, we focus our attention on these asset purchase announcement dates and estimate the regressions akin to those in Table II, namely:

$$\Delta_4 q_{c,t+2} = A + B \cdot \Delta_4 \left(i^*_{c,t+2} - i_{t+2}\right) + D \cdot \Delta_4 \left(f^*_{c,t+2} - f_{t+2}\right) + \Delta_4 \varepsilon_{c,t+2}, \quad (7)$$

and

$$\Delta_4 q_{c,t+2} = A + B_1 \cdot \Delta_4 i^*_{c,t+2} + B_2 \cdot \Delta_4 i_{t_{t+2}} + D_1 \cdot \Delta_4 f^*_{c,t+2} + D_2 \cdot \Delta_4 f_{t+2} + \Delta_4 \varepsilon_{c,t+2}. \quad (8)$$

Whereas in Tables I and II we studied quarterly and annual changes, here we restrict attention to the 73 QE-related announcements in the United States, Eurozone, United Kingdom, and Japan. The regressions have more than 73 observations because for the 28 U.S. QE announcements, we include data points for each of the euro, pound, and yen responses; this is similar to looking at the average change in the dollar relative to these three currencies. To avoid double-counting events from a statistical perspective, we cluster our standard errors by announcement date. As in Figure I, $\Delta_4 q_{c,t+2}$ is the four-day change in the exchange

8. A potential alternative interpretation is that long-term yields and FX rates reflect movements in convenience or safety premia. However, fluctuations in safety premia should generate the opposite relationship between contemporaneous changes in FX rates and long-term yields. To see why, suppose U.S. QE leads to a reduction in the supply of safe dollar assets. If the demand for safe assets is downward sloping, QE should raise the dollar safety premium, pushing down long-term Treasury yields (Krishnamurthy and Vissing-Jorgensen 2011, 2012). If foreign investors derive greater convenience services from holding safe dollars assets than U.S. investors, the decline in the supply of safe dollar assets should also lead the dollar to appreciate against foreign currencies (Jiang, Krishnamurthy, and Lustig 2021). Alternately, if central bank reserves are safer than the long-term assets the Fed is purchasing, then U.S. QE would expand the supply of dollar safe assets, which should push up long-term U.S. yields and lead the dollar to depreciate (Jiang, Krishnamurthy, and Lustig 2020). Either way, movements in the U.S. dollar safety premium should lead to a negative, not positive, correlation between U.S. Treasury yields and the strength of the dollar.

TABLE V

DAILY MOVEMENTS IN FOREIGN EXCHANGE, SHORT-TERM INTEREST RATES, AND LONG-TERM FORWARD RATES ON QE ANNOUNCEMENT DATES

	(1)	(2)	(3)	(4)
$\Delta_4(i^*_{c,t+2} - i_{t+2})$	8.26	9.67		
	(3.33)**	(2.12)***		
$\Delta_4(f^*_{c,t+2} - f_{t+2})$		4.04		
		(1.26)***		
$\Delta_4 i^*_{c,t+2}$			7.53	8.82
			(3.26)**	(2.25)***
$\Delta_4 i_{t+2}$			−17.01	−13.45
			(6.89)**	(5.67)**
$\Delta_4 f^*_{c,t+2}$				4.33
				(1.41)***
$\Delta_4 f_{t+2}$				−3.59
				(1.41)**
N	128	128	128	128
R-squared	0.10	0.26	0.14	0.27

Notes. This table presents daily panel regressions of the form:

$$\Delta_4 q_{c,t+2} = A + B \times \Delta_4(i^*_{c,t+2} - i_{t+2}) + D \times \Delta_4(f^*_{c,t+2} - f_{t+2}) + \Delta_4 \varepsilon_{c,t+2},$$

and

$$\Delta_4 q_{c,t+2} = A + B_1 \times \Delta_4 i^*_{c,t+2} + B_2 \times \Delta_4 i_{t+2} + D_1 \times \Delta_4 f^*_{c,t+2} + D_2 \times \Delta_4 f_{t+2} + \Delta_4 \varepsilon_{c,t+2}.$$

on days with major QE news announcements by the U.S. Federal Reserve, the European Central Bank, the Bank of England, and the Bank of Japan from 2008 to 2019. We regress four-day changes in the foreign exchange rate on four-day changes in short-term interest rates and in distant forward rates in the foreign currency and in U.S. dollars. For an announcement on date t, we look at changes from date $t-2$ to $t+2$. We show results for EUR-USD, GBP-USD, and JPY-USD where a higher value of $q_{c,t}$ means that currency c is stronger versus the dollar. Our proxy for the short-term interest rate in each currency is the one-year government bond yield. Our proxy for the distant forward rate is the three-year, seven-year forward government bond yield. To form our list of QE announcement dates, we begin with Fawley and Neely's (2013) list of unconventional policy announcements by these four central banks. We update this list through 2019 and then focus on the subset of the announcements that contain news about central bank purchases of long-term bonds (either sovereign or private-sector). Standard errors are clustered by announcement date in these specifications. * $p < .10$, ** $p < .05$, *** $p < .01$.

rate, from two days before the announcement to the close two days after; all other variables are measured over the same period.

Column (2) shows the main result. Both changes in short-term interest rate differentials and changes in long-term forward rate differentials measured around QE-news dates are positively related to movements in exchange rates. Column (4) shows that the effects of foreign and U.S. term premia on exchange rate movements are approximately symmetric and of opposite sign, attracting coefficients of 4.3 and −3.6, respectively.

In sum, the evidence suggests that not only is there a close connection between bond term premia and FX risk premia, both premia are partially driven by shocks to bond supply. These stylized facts are the motivation for the model that we turn to next.

III. Baseline Model

Our baseline model generalizes the Vayanos and Vila (2021) term structure model to a setting with two currencies, say, the U.S. dollar and the euro. We consider a model with short- and long-term bonds in domestic currency (dollars) and foreign currency (euros). There is an exogenously given short-term interest rate in each currency. The key friction is that the global bond market is partially segmented from the broader capital market: we assume the marginal investors in the global bond market—whom we call "global bond investors"—are specialized investors. These bond investors must absorb exogenous shocks to the supply and demand for long-term bonds in both currencies, as well as shocks in the foreign exchange market. Because they are concerned about the risk of near-term losses on their imperfectly diversified portfolios, specialists will only absorb these shocks if the expected returns on bonds and FX adjust in response.

III.A. Model Setup

The model is set in discrete time. To maintain tractability, we assume that asset prices (or yields) and expected returns are linear functions of a vector of state variables. To model fixed income assets, we (i) substitute log returns for simple returns throughout and (ii) use Campbell and Shiller (1988) linearizations of log returns. We view (i) and (ii) as linearity-generating modeling devices that do not qualitatively affect our conclusions.

1. *Financial Assets.* There are four assets in the model: short- and long-term bonds in both domestic (dollars) and foreign (euros) currency. We then describe the foreign exchange market.

i. *Short-Term Domestic Bonds.* The log short-term interest rate in domestic currency between time t and $t+1$, denoted i_t, is known at time t and follows an exogenous stochastic process described below. We assume short-term domestic bonds are available in perfectly elastic supply: investors can borrow or lend any desired quantity in domestic currency from t to $t+1$ at i_t.

ii. *Long-Term Domestic Bonds.* The long-term domestic bond is a default-free perpetuity with geometrically declining payments. At time t, long-term domestic bonds are available in a given net supply s_t^y which follows an exogenous stochastic process. As shown in Online Appendix B, the log return in domestic currency on long-term domestic bonds from t to $t+1$ is approximately:

$$r_{t+1}^y = \frac{1}{1-\delta} y_t - \frac{\delta}{1-\delta} y_{t+1} = y_t - \frac{\delta}{1-\delta}(y_{t+1} - y_t), \quad (9)$$

where y_t is the log yield-to-maturity on domestic bonds, $\delta \in (0, 1)$, and $D = \frac{1}{1-\delta}$ is the duration of the long-term bond, that is, the sensitivity of the bond's price to its yield. The parameter $\delta = 1 - \frac{1}{D}$ is governed by the rate at which the bond's payments decline over time, and a larger δ corresponds to an economy with longer-term bonds. Naturally, the return on long-term bonds is the sum of a "carry" component, y_t, which investors earn if yields do not change and a capital gain component, $-(\frac{\delta}{1-\delta})(y_{t+1} - y_t)$, due to changes in yields.

Iterating equation (9) forward and taking expectations, the domestic long-term yield can be decomposed into an expectations hypothesis component and a term premium component:

$$y_t = (1-\delta) \sum_{j=0}^{\infty} \delta^j E_t\left[i_{t+j} + rx_{t+j+1}^y\right], \quad (10)$$

where $rx_{t+1}^y \equiv r_{t+1}^y - i_t$ is the excess return on domestic long-term bonds over the domestic short rate. In other words, rx_{t+1}^y is the log excess return on the domestic "yield curve trade," the trade that borrows short-term and lends long-term in domestic currency.

iii. *Short-Term Foreign Bonds.* Short-term foreign bonds mirror short-term domestic bonds. The log short-term riskless rate in foreign currency between time t and $t+1$ is denoted i_t^*.

iv. *Long-Term Foreign Bonds.* Long-term foreign bonds mirror long-term domestic bonds. Specifically, long-term foreign bonds have the same duration $D = \frac{1}{1-\delta}$ as long-term domestic bonds and are available in an exogenous, time-varying net supply s_t^{y*}. The log return in foreign currency on long-term foreign bonds is given by the analog of equation (9), and the log yield-to-maturity on foreign bonds, y_t^*, is given by the analog of equation (10). $rx_{t+1}^{y^*} \equiv r_{t+1}^{y^*} - i_t^*$ denotes the excess return on the yield curve trade in foreign currency.

v. *Foreign Exchange.* Let Q_t denote the foreign exchange rate defined as units of domestic currency per unit of foreign currency—that is, an investor can exchange foreign short-term bonds with a market value of one unit in foreign currency for domestic short-term bonds with a market value of Q_t in domestic currency. Thus, a rise in Q_t corresponds to an appreciation of the foreign currency relative to the domestic currency. Let q_t denote the log exchange rate.

Consider the excess return on foreign currency from time t to $t+1$, the FX trade that borrows short-term in domestic currency and lends short-term in foreign currency. The log excess return on foreign currency is approximately:

$$rx^q_{t+1} = (q_{t+1} - q_t) + (i^*_t - i_t). \tag{11}$$

Thus, the excess return on foreign currency is the sum of the interest rate differential, $i^*_t - i_t$, and the change in exchange rates, $(q_{t+1} - q_t)$. Assuming the exchange rate is stationary with a steady-state level of zero (i.e., that purchasing power parity holds in the long run), we can iterate forward and take expectations to obtain:

$$q_t = \sum_{j=0}^{\infty} E_t\left[(i^*_{t+j} - i_{t+j}) - rx^q_{t+j+1}\right], \tag{12}$$

as in Froot and Ramadorai (2005). Thus, the exchange rate is the sum of a UIP component and an FX risk premium component. Equation (12) is consistent with the evidence in Dahlquist and Pénasse (2022) who show that the level of the real exchange rate is a robust negative predictor of the future excess returns on foreign exchange.[9]

9. Our assumption that the exchange rate is stationary is made purely for simplicity. Virtually all of our results carry through trivially if the exchange rate is nonstationary. Specifically, we could instead assume that $q_t = q^{\infty}_t + \sum_{j=0}^{\infty} E_t[(i^*_{t+j} - i_{t+j}) - rx^q_{t+j+1}]$, where $q^{\infty}_t \equiv \lim_{T\to\infty} E_t\left[q_{t+T}\right]$ follows an exogenous random walk $q^{\infty}_{t+1} = q^{\infty}_t + \varepsilon_{q^{\infty},t+1}$, $\varepsilon_{q^{\infty},t+1}$ is orthogonal to the other shocks and $Var_t\left[\varepsilon_{q^{\infty},t+1}\right] = \sigma^2_{q^{\infty}} > 0$. Relative to the expressions we present, which assume $\sigma^2_{q^{\infty}} = 0$, allowing for this random walk component of exchange rates means that we simply need to add $\sigma^2_{q^{\infty}} > 0$ to the fundamental component of $V_q \equiv Var_t[rx^q_{t+1}]$. For instance, in Proposition 1 we would replace $V_q = \frac{2(1-\rho)\sigma^2_i}{(1-\phi_i)^2}$ with $V_q = \sigma^2_{q^{\infty}} + \frac{2(1-\rho)\sigma^2_i}{(1-\phi_i)^2}$.

vi. *Real versus Nominal Rates.* Since our theory hinges on the comovement between exchange rates and short-term interest rates, it makes sense to think of all of the interest rates in our model as real interest rates and the exchange rate as the real exchange rate.[10] This is a key reason we focused on data from 2001–2021 in the prior section: this was a time when inflation expectations were firmly anchored and where movements in nominal interest rates largely corresponded to movements in real rates.

2. *Risk Factors.* Investors face two types of risk in our model: interest rate risk and supply risk. First, long-term bonds and FX positions are exposed to interest rate risk. For example, both long-term domestic bonds and foreign currency will suffer unexpected losses if short-term domestic rates rise unexpectedly. Second, long-term bonds and FX positions are exposed to supply risk: stochastic supply shocks affect equilibrium bond yields and exchange rates, holding fixed the expected future path of short rates.

i. *Short-Term Interest Rates.* We think of monetary policy as determining short-term rates outside of the model. The domestic and foreign central banks independently pursue monetary policy in their currencies by posting an interest rate and then elastically borrowing and lending at that rate. Formally, we assume

10. To see why, note that if short-term nominal interest rates move one-for-one with changes in expected inflation, then news about future inflation will not impact real exchange rates. What is more, pure news about future inflation will not lead to unexpected changes in nominal exchange rates and will only lead to expected future movements in nominal exchange rates (see Krugman, Obstfeld, and Melitz 2022, chap. 16). Only news about future short-term real rates leads to unexpected changes in both real and nominal exchange rates. Turning to bonds, although both real and nominal long-term bonds are exposed to news about future short-term real rates, only long-term nominal bonds are directly exposed to news about future inflation. These ideas are detailed in Online Appendix B, where we extend our model to include shocks to both real interest rates and expected inflation. The upshot is that the comovement patterns between long-term bonds and exchange rates that we emphasize should be strongest when looking at real bonds. Similarly, the FX return predictability we emphasize should be strongest when looking at real rates: looking at nominal rates simply adds measurement error to the independent variables, biasing the results toward zero. Alternately, if one is forced to use data on nominal bonds to test our theory (e.g., due to a lack of data on real bonds), then we would expect our predictions to emerge most strongly in periods where inflation expectations are stable and the resulting measurement error is small.

short-term interest rates in domestic and foreign currencies follow exogenous and symmetric AR(1) processes with correlated shocks:

$$i_{t+1} = \bar{\imath} + \phi_i(i_t - \bar{\imath}) + \varepsilon_{i_{t+1}}, \tag{13a}$$

$$i^*_{t+1} = \bar{\imath} + \phi_i(i^*_t - \bar{\imath}) + \varepsilon_{i^*_{t+1}}, \tag{13b}$$

where $\bar{\imath} > 0$, $\phi_i \in (0, 1)$, $Var_t[\varepsilon_{i_{t+1}}] = Var_t[\varepsilon_{i^*_{t+1}}] = \sigma_i^2 > 0$, and $\rho = Corr[\varepsilon_{i_{t+1}}, \varepsilon_{i^*_{t+1}}] \in [0, 1]$.

ii. *Net Bond Supplies.* We assume the net supplies of long-term domestic bonds (s_t^y) and long-term foreign bonds (s_t^{y*}) follow symmetric AR(1) processes. These net bond supplies are the market value of long-term domestic and foreign bonds, denominated in units of domestic currency, that arbitrageurs must hold in equilibrium. Specifically, we assume:

$$s^y_{t+1} = \bar{s}^y + \phi_{s^y}\left(s^y_t - \bar{s}^y\right) + \varepsilon_{s^y_{t+1}}, \tag{14a}$$

$$s^{y*}_{t+1} = \bar{s}^y + \phi_{s^y}\left(s^{y*}_t - \bar{s}^y\right) + \varepsilon_{s^{y*}_{t+1}}, \tag{14b}$$

where $\bar{s}^y > 0$, $\phi_{s^y} \in [0, 1)$, and $Var_t[\varepsilon_{s^y_{t+1}}] = Var_t[\varepsilon_{s^{y*}_{t+1}}] = \sigma^2_{s^y} \geqslant 0$.[11]

As in Vayanos and Vila (2021), these net bond supplies should be viewed as the gross supply of long-term bonds minus the demand of any inelastic "preferred habitat" investors—that is, they reflect the combined supply and demand shocks that global bond investors must absorb in equilibrium. This means that from the vantage point of our global bond investors, there are two potential sources of variation in the net supply of long-term bonds. First, there are true shocks to the gross supply of long-term bonds that all private investors must collectively hold. These gross supply shocks could either stem from the issuance of long-term government bonds or from QE policies by central

11. Online Appendix B explores the effect of relaxing our symmetry assumptions on short rates and bond supply. Our baseline results carry through qualitatively so long as the asymmetries are moderate. However, our model has qualitatively different implications for the comovement between foreign exchange and bond returns if the short-rate processes become highly asymmetric—say, if the foreign country's short rate tends to move more than one-for-one with the home country's short rate. Thus, our baseline results apply most naturally to major currencies whose central banks pursue an independent monetary policy.

banks. Second, there are inelastic demand shocks from other unmodeled investors that our global bond investors must accommodate. For instance, if pension fund or insurance companies exogenously decided to sell their holdings of long-term bonds, that would be a positive net supply shock from the standpoint of our global bond investors.[12] With this broader view of net supply in mind, it is plausible that there are sufficient fluctuations in net supply to explain a meaningful fraction of the variation in FX rates and long-term bond yields.

iii. *Net FX Supply.* We assume that global bond investors must engage in a borrow-domestic and lend-foreign FX trade in time-varying market value (in domestic currency units) s_t^q to accommodate the opposing demand of other unmodeled agents. For example, if nonfinancial firms have an inelastic demand to exchange foreign currency for domestic currency, global bond investors must take the other side, going long foreign currency and short domestic currency. We assume

$$s_{t+1}^q = \phi_{s^q} s_t^q + \varepsilon_{s_{t+1}^q}, \quad (15)$$

where $Var_t[\varepsilon_{s_{t+1}^q}] = \sigma_{s^q}^2 \geqslant 0$ and $\phi_{s^q} \in [0, 1)$. Of course, if we consider all agents in the global economy, then FX must be in zero net supply: if some agent is exchanging dollars for euros, then some other agent must be exchanging euros for dollars. However, the specialized bond investors in our model are only a subset of all actors in global financial markets, so they need not have zero FX exposure.

Collecting terms, let $\varepsilon_{t+1} \equiv [\varepsilon_{i_{t+1}}, \varepsilon_{i_{t+1}^*}, \varepsilon_{s_{t+1}^y}, \varepsilon_{s_{t+1}^{y*}}, \varepsilon_{s_{t+1}^q}]'$ and $\mathbf{\Sigma} \equiv Var_t[\boldsymbol{\varepsilon}_{t+1}]$. For simplicity, we assume the three supply shocks are independent of each other and of both short-rate shocks.

3. *Global Bond Investors.* The global bond investors in our model are specialized investors who choose portfolios consisting of short- and long-term bonds in the two currencies. They have mean-variance preferences over next-period wealth with risk

12. For recent work along these lines, see Greenwood and Vayanos (2010) for bond demand from pension funds, Hanson (2014) and Malkhozov et al. (2016) for bond demand linked to mortgage hedging, and Hanson, Lucca, and Wright (2021) for demand from extrapolative investors. Indeed, using their demand system approach, Koijen and Yogo (2020) argue that portfolio rebalancing by institutional investors can explain 50% to 60% of the variation in long-term bond yields and exchange rates.

tolerance τ. Let d_t^y (d_t^{y*}) denote the market value of bond investors' holdings of long-term domestic (foreign) bonds and let d_t^q denote the value of investors' position in the borrow-domestic and lend-foreign FX trade, all denominated in domestic currency. Defining $\mathbf{d}_t \equiv [d_t^y,\ d_t^{y*},\ d_t^q]'$ and $\mathbf{rx}_{t+1} \equiv [rx_{t+1}^y,\ rx_{t+1}^{y*},\ rx_{t+1}^q]'$, investors choose their holdings to solve:[13]

$$\max_{\mathbf{d}_t} \left\{ \mathbf{d}_t' E_t \left[\mathbf{rx}_{t+1}\right] - \frac{1}{2\tau} \mathbf{d}_t' Var_t \left[\mathbf{rx}_{t+1}\right] \mathbf{d}_t \right\}. \tag{16}$$

Thus, their demands must satisfy:

$$E_t \left[\mathbf{rx}_{t+1}\right] = \tau^{-1} Var_t \left[\mathbf{rx}_{t+1}\right] \mathbf{d}_t. \tag{17}$$

These preferences are similar to assuming that investors manage their overall risk exposure using value-at-risk or other standard risk management techniques.

In practice, we associate the global bond investors in our model with market players such as fixed-income divisions at global broker-dealers and global macro hedge funds. Relative to more broadly diversified players in global capital markets, risk factors related to movements in interest rates loom large for these imperfectly diversified investors. Indeed, the particular form of segmentation that we assume is quite natural since both government bonds and foreign exchange are interest rate sensitive assets. Any specialized human capital, physical infrastructure, or organizational infrastructure that is useful for managing interest rate sensitive assets can be readily applied to both bonds and FX.[14]

13. Global bond investors solve expression (16) irrespective of whether they are domestic- or foreign-based. This is because we can represent an investor's positions in any asset other than short-term bonds in her local currency as a linear combination of three long-short trades: the yield curve trade in each currency and the FX trade. Assuming all investors have the same risk tolerance in domestic currency terms (i.e., the risk tolerance of any foreign-based investors is $\frac{\tau}{Q_t}$ in foreign-currency terms) and hold the same beliefs, all will choose the same exposures to these three trades in domestic-currency terms regardless of where they are based.

14. Our view is that at its core, market segmentation is driven by the gains from investor specialization and the informational frictions specialization engenders. Different assets are exposed to different kinds of economic risk factors, and understanding different kinds of risk factors requires specialized human capital. Although specialization is valuable, it inevitably creates informational problems between specialized investors and outside capital providers. Because of these

III.B. Equilibrium

1. *Conjecture and Solution.* We need to pin down three equilibrium prices: y_t, y_t^*, and q_t. To solve the model, we conjecture that prices are linear functions of a 5×1 state vector $\mathbf{z}_t = [i_t, i_t^*, s_t^y, s_t^{y*}, s_t^q]'$. As shown in the Online Appendix, a rational expectations equilibrium is a fixed point of an operator involving the "price-impact" coefficients that govern how the supplies $\mathbf{s}_t = [s_t^y, s_t^{y*}, s_t^q]'$ affect y_t, y_t^*, and q_t. Specifically, the market-clearing condition $\mathbf{d}_t = \mathbf{s}_t$ implicitly defines an operator that gives the expected returns—and hence the price-impact coefficients—that will clear markets when investors believe that the risk of holding assets is determined by some initial set of price-impact coefficients. A rational expectations equilibrium of our model is a fixed point of this operator.

In the absence of supply risk ($\sigma_{s_y}^2 = \sigma_{s_q}^2 = 0$), this fixed-point problem is degenerate, and there is a straightforward, unique equilibrium. However, when asset supply is stochastic, the fixed-point problem is nondegenerate: the risk of holding assets depends on how prices react to supply shocks. For example, if investors believe that supply shocks will have a large effect on prices, they perceive assets as being highly risky. As a result, investors will only absorb supply shocks if they are compensated by large price declines and high future expected returns, making the initial belief self-fulfilling. This logic means that (i) a linear equilibrium only exists when investors' risk tolerance τ is sufficiently large relative to the volatility of supply shocks and (ii) the model admits multiple equilibria. However, there is at most one equilibrium that is stable in the sense that it is robust to a small perturbation in investors' beliefs regarding equilibrium price

informational problems, the specialized investors who are the marginal price setters in the short run are not fully diversified and have outsized economic exposures to the specific assets they intermediate. A key implication of this human-capital-centric approach to market segmentation is that there is a crucial distinction between the economic and statistical similarity of different risk factors. For example, U.S. and Japanese short-term rates are not highly correlated, implying that U.S. and Japanese bonds face very different statistical risks. However, the underlying human capital needed to analyze and manage short-rate risk is quite similar in both currencies. As a result, global bond investors may have an edge in both bond markets even though the underlying short rates are far from perfectly correlated.

impact.[15] We focus on this unique stable equilibrium in our analysis.

2. *Equilibrium Expected Returns and Prices.* We characterize equilibrium expected returns and prices. Market clearing implies that $\mathbf{d}_t = \mathbf{s}_t$. Thus, using equation (17), equilibrium expected returns must satisfy:

$$E_t\left[\mathbf{rx}_{t+1}\right] = \tau^{-1} Var_t\left[\mathbf{rx}_{t+1}\right]\mathbf{s}_t = \tau^{-1}\mathbf{V}\mathbf{s}_t, \tag{18}$$

where $\mathbf{V} = Var_t[\mathbf{rx}_{t+1}]$ is constant in equilibrium. Writing out equation (18) and making use of the symmetry between long-term domestic and foreign bonds in equations (13) and (14), we have:

$$E_t\left[rx^y_{t+1}\right] = \frac{1}{\tau}\left[V_y \cdot s^y_t + C_{y,y*} \cdot s^{y*}_t + C_{y,q} \cdot s^q_t\right] \tag{19a}$$

$$E_t\left[rx^{y*}_{t+1}\right] = \frac{1}{\tau}\left[C_{y*,y} \cdot s^y_t + V_y \cdot s^{y*}_t - C_{y,q} \cdot s^q_t\right] \tag{19b}$$

$$E_t\left[rx^q_{t+1}\right] = \frac{1}{\tau}\left[C_{y,q} \cdot \left(s^y_t - s^{y*}_t\right) + V_q \cdot s^q_t\right], \tag{19c}$$

where $V_y \equiv Var_t[rx^y_{t+1}] = Var_t[rx^{y*}_{t+1}]$, $V_q \equiv Var_t[rx^q_{t+1}]$, $C_{y*,y} \equiv Cov_t[rx^y_{t+1}, rx^{y*}_{t+1}]$, and $C_{y,q} \equiv Cov_t[rx^y_{t+1}, rx^q_{t+1}] = -Cov_t[rx^{y*}_{t+1}, rx^q_{t+1}]$. These variances and covariances are equilibrium objects: they depend on shocks to short-term interest rates and on the equilibrium price impact of supply shocks.

Making use of equations (10) and (12) and the AR(1) dynamics for i_t, i^*_t, s^y_t, s^{y*}_t, and s^q_t, we can characterize equilibrium yields

15. Equilibrium nonexistence and multiplicity are common in models like ours where short-lived investors absorb shocks to the supply of infinitely lived assets. Consistent with Samuelson's (1947) "correspondence principle," the unique stable equilibrium has comparative statics that accord with standard intuition. By contrast, the comparative statics of the unstable equilibria are counterintuitive. For previous treatments of these issues, see Spiegel (1998), Watanabe (2008), Banerjee (2011), and Greenwood, Hanson, and Liao (2018).

and the exchange rate. The long-term domestic yield is:

$$y_t = \overbrace{\left\{\bar{\imath} + \frac{1-\delta}{1-\delta\phi_i}\cdot(i_t - \bar{\imath})\right\}}^{\text{Expectations hypothesis}} + \overbrace{\left\{\tau^{-1}\left(V_y + C_{y,y^*}\right)\cdot \bar{s}^y\right\}}^{\text{Steady-state term premium}}$$
$$+\underbrace{\left\{\tau^{-1}\frac{1-\delta}{1-\delta\phi_{s^y}}\left[V_y\cdot\left(s_t^y - \bar{s}^y\right) + C_{y,y^*}\cdot\left(s_t^{y*} - \bar{s}^y\right)\right] + \tau^{-1}\frac{1-\delta}{1-\delta\phi_{s^q}}C_{y,q}\cdot s_t^q\right\}}_{\text{Time-varying term premium}};$$

(20a)

the long-term foreign yield is:

$$y_t^* = \overbrace{\left\{\bar{\imath} + \frac{1-\delta}{1-\delta\phi_i}\cdot\left(i_t^* - \bar{\imath}\right)\right\}}^{\text{Expectations hypothesis}} + \overbrace{\left\{\tau^{-1}\left(V_y + C_{y,y^*}\right)\cdot \bar{s}^y\right\}}^{\text{Steady-state term premium}}$$
$$+\underbrace{\left\{\tau^{-1}\frac{1-\delta}{1-\delta\phi_{s^y}}\left[C_{y,y^*}\cdot\left(s_t^y - \bar{s}^y\right) + V_y\cdot\left(s_t^{y*} - \bar{s}^y\right)\right] - \tau^{-1}\frac{1-\delta}{1-\delta\phi_{s^q}}C_{y,q}\cdot s_t^q\right\}}_{\text{Time-varying term premium}};$$

(20b)

and the FX rate is

$$q_t = \overbrace{\left\{\frac{1}{1-\phi_i}\cdot\left(i_t^* - i_t\right)\right\}}^{\text{Uncovered interest rate parity}} - \overbrace{\left\{\tau^{-1}\frac{1}{1-\phi_{s^y}}C_{y,q}\cdot\left(s_t^y - s_t^{y*}\right) + \tau^{-1}\frac{1}{1-\phi_{s^q}}V_q\cdot s_t^q\right\}}^{\text{FX risk premium}}.$$

(20c)

Equations (20a) and (20b) say that long-term domestic and foreign yields are the sum of an expectations hypothesis component that reflects expected future short-term rates and a term premium component that reflects expected future bond risk premia. The expectations hypothesis component for domestic long-term bonds, for example, depends on the current deviation of short-term domestic rates from their steady-state level $(i_t - \bar{\imath})$ and the persistence of short-term rates (ϕ_i). Similarly, the domestic term premium depends on the current deviation of asset supplies from their steady-state levels and the persistence of those asset supplies. Equation (20c) says that the FX rate consists of a UIP term, reflecting expected future foreign-minus-domestic short-rate differentials, minus a risk-premium term that reflects expected future excess returns on the borrow-domestic lend-foreign FX trade.

3. *Understanding Equilibrium Expected Returns.* We can understand expected returns in terms of exposures to the five risk factors in our model. Formally, the time t conditional expected return on any asset $a \in \{y, y^{*}, q\}$ satisfies:

$$E_t[rx^a_{t+1}] = \beta^a_i \lambda_{i,t} + \beta^a_{i^*} \lambda_{i^*,t} + \beta^a_{s^y} \lambda_{s^y,t} + \beta^a_{s^{y*}} \lambda_{s^{y*},t} + \beta^a_{s^q} \lambda_{s^q,t}, \tag{21}$$

where, for factors $f \in \{i, i^{*}, s^y, s^{y^*}, s^q\}$, β^a_f is the constant loading of asset a's returns on factor innovation $\varepsilon_{f_{t+1}}$ and $\lambda_{f,t}$ is the time-varying equilibrium price of bearing $\varepsilon_{f_{t+1}}$ risk. Formally, β^a_f is the coefficient on $\varepsilon_{f_{t+1}}$from a multivariate regression of $-(rx^a_{t+1} - E_t[rx^a_{t+1}])$ on the innovations to the five risk factors. For instance, long-term domestic bonds have a positive loading on $\varepsilon_{i_{t+1}}$ and no loading on $\varepsilon_{i^*_{t+1}}$. At time t, the prices of domestic and foreign short-rate risk are:

$$\lambda_{i,t} = \tau^{-1}\sigma_i^2 \cdot \sum_a \left[\left(\beta^a_i + \rho\beta^a_{i^*}\right) \cdot s^a_t\right], \tag{22a}$$

$$\lambda_{i^*,t} = \tau^{-1}\sigma_i^2 \cdot \sum_a \left[\left(\rho\beta^a_i + \beta^a_{i^*}\right) \cdot s^a_t\right], \tag{22b}$$

and, for $f \in \{s^y, s^{y^*}, s^q\}$, the prices of supply risk are:

$$\lambda_{f,t} = \tau^{-1}\sigma_f^2 \cdot \sum_a [\beta^a_f \cdot s^a_t]. \tag{22c}$$

Expected returns can also be written using a conditional-capital-asset-pricing-model (CAPM)-like representation. Letting $rx^{s_t}_{t+1} = \mathbf{s}_t'\mathbf{rx}_{t+1}$ denote the excess return on global bond investors' portfolio from t to $t+1$, the conditional expected return on any risky asset $a \in \{y, y^{*}, q\}$ is:

$$E_t\left[rx^a_{t+1}\right] = \frac{Cov_t\left[rx^a_{t+1}, rx^{s_t}_{t+1}\right]}{Var_t\left[rx^{s_t}_{t+1}\right]} \cdot E_t\left[rx^{s_t}_{t+1}\right]. \tag{23}$$

The expected return on each asset equals its conditional β with respect to the portfolio held by bond investors times the conditional expected return on that portfolio. Relatedly, the stochastic discount factor that prices risky assets—that is, the random variable m_{t+1} that satisfies $E_t[rx^a_{t+1}] = -Cov_t[rx^a_{t+1}, m_{t+1}]$ for all a—is $m_{t+1} = -i_t - (rx^{s_t}_{t+1} - E_t[rx^{s_t}_{t+1}]) \cdot (\frac{E_t[rx^{s_t}_{t+1}]}{Var_t[rx^{s_t}_{t+1}]})$. In other words, "bad times" in our model—states of the world where m_{t+1} is unexpectedly high—are states where the excess return on global bond investors' portfolio ($rx^{s_t}_{t+1}$) is unexpectedly low.

Equation (23) is superficially similar to the pricing condition that would obtain if the true conditional-CAPM held in fully integrated global capital markets. However, in our model, the portfolio return that prices risky assets is the return on the portfolio held by specialized bond investors. By contrast, in fully integrated markets, the portfolio return that prices all financial assets is the market portfolio consisting of all global financial wealth.

If global bond investors' portfolios were readily observable, equation (23) would be directly testable. Currently, however, there are (at least) two main hurdles to observing the portfolios of the marginal intermediaries in the global bond market. First, we think that global macro hedge funds play an important role in bond and FX markets. Data on these funds' positions are unavailable to the best of our knowledge. Second, some data are available on the portfolios of the large dealer banks through the Federal Reserve's Primary Dealer Statistical Release. However, these data only cover primary dealers' positions in cash securities, not derivatives. Conceptually, the relevant object in our model is global bond investors' total exposure to interest rate risk, whether it comes through securities or derivatives. Given that intermediaries' portfolios are not readily observable, precisely quantifying the magnitude of the effects in our model is challenging. Thus, our main goal is to trace out the qualitative implications of this quantity-driven view of bond term premia and exchange rates.[16]

III.C. Bond Term Premia and Exchange Rates

The major payoff from our baseline model is that we are able to study the simultaneous determination of domestic term premia, foreign term premia, and FX risk premia. Specifically, we can ask how a shift in the supply of any of these three assets

16. Gourinchas, Ray, and Vayanos (2022) take a complementary approach. Treating the net supplies held by global bond investors as unobservable, they estimate the unknown parameters of their model using an indirect inference aproach: they choose parameters to match a set of empirical statistics summarizing the volatilities of and covariances between equilibrium prices. They estimate this model using monthly data on U.S. and German bonds and the EUR-USD exchange rate from 1986 to 2021. They show that this estimated model can match a range of stylized facts and use the model to conduct a set of numerical policy experiments. We believe their multimaturity model is a more natural setting for quantitative estimation of this sort. By contrast, the tractability of our two-bond model means we are able to analytically derive a broader and more general set of qualitative results. Our simpler model is better suited to considering extensions as we do in Section IV.

affects the equilibrium expected returns on the two other assets using equation (19).

1. *Limiting Case with No Supply Risk.* Many of the core results of the model can be illustrated using the limiting case in which asset supplies are constant over time, leaving only short-rate risk, that is, where $\sigma_{s^y}^2 = \sigma_{s^q}^2 = 0$.

PROPOSITION 1. *Equilibrium without supply shocks.* If $\sigma_{s^y}^2 = \sigma_{s^q}^2 = 0$ and $\rho \in (0, 1)$, then

$$V_y = \left(\frac{\delta}{1-\delta\phi_i}\right)^2 \sigma_i^2 > 0 \quad \text{and} \quad V_q = 2\left(\frac{1}{1-\phi_i}\right)^2 (1-\rho)\sigma_i^2 > 0, \tag{24a}$$

$$C_{y,y*} = \rho\left(\frac{\delta}{1-\delta\phi_i}\right)^2 \sigma_i^2 > 0 \text{ and } C_{y,q} = (1-\rho)\frac{\delta}{1-\delta\phi_i}\frac{1}{1-\phi_i}\sigma_i^2 > 0. \tag{24b}$$

Thus, $\frac{\partial E_t[rx_{t+1}^q]}{\partial s_t^y} = \tau^{-1}C_{y,q}$ is decreasing in the correlation between domestic and foreign short rates, ρ, whereas $\frac{\partial E_t[rx_{t+1}^{y*}]}{\partial s_t^y} = \tau^{-1}C_{y,y*}$ is increasing in ρ.

Proof. All proofs are in the Online Appendix.

Proposition 1 provides guidance about how shifts in long-term bond supply—for example, due to QE policies—should affect exchange rates and term premia. There are three key takeaways.

First, Proposition 1 shows that a shift in domestic bond supply affects the domestic term premium, the foreign term premium, and the FX risk premium. For example, suppose there is an increase in the supply of dollar long-term bonds. This increase in dollar bond supply raises the price of bearing dollar short-rate risk in equation (22a), lifting the expected returns on the dollar yield curve trade and long-term dollar yields as in Vayanos and Vila (2021). When dollar and euro short rates are correlated ($\rho > 0$), the increase in dollar bond supply also raises the price of euro short-rate risk in equation (22b), pushing up the euro term premium and long-term euro yields.

Turning to exchange rates, equation (20c) shows that the borrow-in-dollars to lend-in-euros FX trade is also exposed to dollar short-rate risk: the euro depreciates when dollar short rates rise through the standard UIP channel. Because the price of bearing dollar short-rate risk rises following an increase in the supply of dollar long-term bonds, the expected returns on the FX trade must also rise. Thus, an increase in the supply of long-term dollar bonds leads the euro to depreciate; it is then expected to appreciate going forward. More precisely, when $\rho > 0$, an increase in the supply of long-term dollar bonds raises the prices of both dollar and euro short-rate risk per equations (22a) and (22b). As shown in equation (20c), the FX trade has offsetting exposures to dollar and euro short rates. However, as long as $\rho < 1$, the increase in the supply of long-term dollar bonds has a larger effect on the price of dollar short-rate risk, so $\frac{\partial E_t[rx_{t+1}^q]}{\partial s_t^y} = \tau^{-1}C_{y,q} > 0$.

Second, Proposition 1 shows that the effects of a shift in domestic bond supply depend on the correlation ρ between domestic and foreign short rates. When ρ is higher, the domestic bond supply shift has a larger effect on the price of foreign short-rate risk. As a result, more of the effect appears in long-term foreign yields and less shows up in the exchange rate. For instance, U.S. short-term rates are more highly correlated with euro short rates than with Japanese yen short rates. Thus, Proposition 1 suggests we should expect U.S. QE—a reduction in dollar bond supply—to lead to a larger depreciation of the dollar versus the yen than versus the euro. At the same time, U.S. QE should lead to a larger reduction in euro term premia than yen term premia. Intuitively, if foreign and domestic short rates are highly correlated, the UIP component of the exchange rate will not be very volatile; if domestic short rates rise, foreign short rates are also likely to rise, leaving the UIP component of the exchange rate largely unchanged. This means that the FX trade is not very exposed to interest rate risk, and therefore its expected return should not move much in response to bond supply shifts.[17]

Corollary 1 details the limiting case where $\delta \to 1$, and therefore the duration of long-term bonds $D = \frac{1}{1-\delta}$ goes to infinity.

17. We find some suggestive evidence in favor of this prediction in Online Appendix A. Specifically, if we add interaction terms involving an estimate of each currency's ρ to the regressions in Tables II and IV, the coefficient on the interaction with distant forward rates goes in the predicted direction and is marginally significant.

COROLLARY 1. *Limit where the duration of long-term bonds becomes infinite*. Suppose $\sigma_{s^y}^2 = \sigma_{s^q}^2 = 0$ and consider the limit where $\delta \to 1$. In this limit, we have

$$V_y = \left(\frac{1}{1-\phi_i}\right)^2 \sigma_i^2 > 0, V_q = 2(1-\rho)V_y, C_{y,y*} = \rho V_y, \text{ and } C_{y,q} = (1-\rho)V_y, \tag{25}$$

so $Var_t\left[rx_{t+1}^q + \left(rx_{t+1}^{y*} - rx_{t+1}^y\right)\right] = V_q + 2V_y - 2C_{y,y*} - 4C_{y,q} = 0$, that is, the long-term FX carry trade is riskless. Thus, long-term UIP must hold state-by-state and hence also in expectation (i.e., $rx_{t+1}^q + \left(rx_{t+1}^{y*} - rx_{t+1}^y\right) = E_t\left[rx_{t+1}^q + \left(rx_{t+1}^{y*} - rx_{t+1}^y\right)\right] = 0$). As a result, $\frac{\partial E_t[rx_{t+1}^y]}{\partial s_t^y} = \tau^{-1}V_y$ equals the sum of $\frac{\partial E_t[rx_{t+1}^{y*}]}{\partial s_t^y} = \tau^{-1}\rho V_y$ and $\frac{\partial E_t[rx_{t+1}^q]}{\partial s_t^y} = \tau^{-1}(1-\rho)V_y$.

In the $\delta \to 1$ limit where the duration of long-term bonds becomes infinite, the long-term FX carry trade that borrows long-term in dollars and lends long-term in euros becomes riskless. As a result, the return on the long-term carry trade must be zero by the absence of arbitrage—that is, we must have $\lim_{\delta\to 1}\left[rx_{t+1}^q + \left(rx_{t+1}^{y*} - rx_{t+1}^y\right)\right] = 0$ state-by-state.[18] Even though long-term UIP holds in this limit, our model still pins down the precise mix of equilibrium adjustments that ensure it holds following a change in asset supply. For instance, suppose there is an increase in dollar bond supply s_t^y. This bond supply shock raises the term premium on long-term U.S. bonds, $E_t[rx_{t+1}^y]$. Long-term UIP implies that some combination of the term premium on euro bonds ($E_t[rx_{t+1}^{y*}]$) and the FX premium ($E_t[rx_{t+1}^q]$) must adjust in response. What Corollary 1 shows is that the correlation between domestic and foreign short rates, ρ, governs whether the adjustment comes through the foreign term premium or the FX risk premium. Specifically, when the correlation ρ is higher, more of the adjustment comes through a rise in the foreign term premium and less comes through a rise in the FX premium.

18. If the exchange rate is stationary, the fact that $\lim_{\delta\to 1} Var_t[rx_{t+1}^q + (rx_{t+1}^{y*} - rx_{t+1}^y)] = \lim_{\delta\to 1} E_t[rx_{t+1}^q + (rx_{t+1}^{y*} - rx_{t+1}^y)] = 0$ still holds once we introduce stochastic supply shocks. Of course, $\lim_{\delta\to 1} Var_t[rx_{t+1}^q + (rx_{t+1}^{y*} - rx_{t+1}^y)] > 0$ if the exchange rate contains a random-walk component.

2. *Adding Supply Shocks.* We show that these results generalize once we add stochastic shocks to the net supplies of domestic and foreign long-term bonds and to FX.[19]

PROPOSITION 2. *Equilibrium with supply shocks*. If $0 \leq \rho < 1$, $\sigma_{s^y}^2 \geqslant 0$, $\sigma_{s^q}^2 \geqslant 0$, then in any stable equilibrium we have $\frac{\partial E_t[rx_{t+1}^q]}{\partial s_t^y} = \tau^{-1}C_{y,q} > 0$. If in addition $\rho > 0$ and $\sigma_{s^q}^2 = 0$, then in any stable equilibrium we have $\frac{\partial E_t[rx_{t+1}^{y*}]}{\partial s_t^y} = \tau^{-1}C_{y,y*} > 0$. Thus, by continuity of the stable equilibrium in the model's underlying parameters, we have $\frac{\partial E_t[rx_{t+1}^{y*}]}{\partial s_t^y} > 0$ unless foreign exchange supply shocks are volatile and ρ is near zero.

Proposition 2 shows that once we allow supply to be stochastic, shifts in bond supply continue to affect bond yields and foreign exchange rates as they did in Proposition 1, where supply was fixed. Shifts in supply tend to amplify the comovement between long-term bonds and foreign exchange that is attributable to shifts in short-term interest rates.

The exception is when FX supply shocks are volatile ($\sigma_{s^q}^2$ is large) and the correlation of short rates ρ is low. Because FX supply shocks push domestic and foreign long-term yields in opposite directions by equation (20), if these shocks are highly volatile they can result in a negative equilibrium correlation between domestic and foreign bond returns, $C_{y,\,y^*}$, even if the underlying short rates are positively correlated. However, in the empirically relevant case where ρ is meaningfully positive, we have $C_{y,\,y^*} > 0$ and bond yields behave as in Proposition 1.

3. *Empirical Implications of the Baseline Model.* In Section II, we presented evidence for three propositions. First, exchange rates appear to be about as sensitive to changes in long-term interest rate differentials as they are to changes in short-term interest rate differentials. Second, the component of long-rate differentials that matters for exchange rates appears to be a term premium differential. Third, the term premium differentials that move exchange rates appear to be, at least

19. As shown in the Online Appendix, when $\sigma_{s^y}^2 > 0$ and $\sigma_{s^q}^2 > 0$, solving the model involves characterizing the stable solution to a system of four quadratic equations in four unknowns. When $\sigma_{s^y}^2 > 0$ and $\sigma_{s^q}^2 = 0$, the model can be solved analytically: we simply need to solve two quadratics and a linear equation.

partly, quantity driven. Using our baseline model, we can formally motivate these empirical results. We can also match the finding in Lustig, Stathopoulos, and Verdelhan (2019).

We begin with our third fact: the term premium differentials that move exchange rates are partially quantity driven. To see this, we focus for simplicity on the case where FX supply shocks are small—that is, the limit where $s_t^q = 0$ and $\sigma^2_{s^q} = 0$. (The Online Appendix shows that a similar set of results obtains when $\sigma^2_{s_q} > 0$ and $s_t^q \neq 0$.) In this case, the FX risk premium is decreasing in the difference between foreign and domestic bond supply $(s_t^{y*} - s_t^y)$,

$$E_t\left[rx^q_{t+1}\right] = \overbrace{\left[-\tau^{-1}C_{y,q}\right]}^{<0} \cdot \left(s_t^{y*} - s_t^y\right), \tag{26}$$

and the difference between foreign and domestic bond risk premia is increasing in $s_t^{y*} - s_t^y$:

$$E_t\left[rx^{y*}_{t+1} - rx^y_{t+1}\right] = \overbrace{\left[\tau^{-1}\left(V_y - C_{y,y^*}\right)\right]}^{>0} \cdot \left(s_t^{y*} - s_t^y\right). \tag{27}$$

Equations (26) and (27) motivate our regressions examining QE announcement dates in Section II. In the context of the model, we think of a euro QE announcement as news indicating that the supply of euro long-term bonds s_t^{y*} will be low. Equation (27) shows that this decline in euro bond supply should reduce euro term premia relative to dollar term premia. Equation (26) shows that this decline in s_t^{y*} should increase the risk premium on the borrow-in-dollar lend-in-euros FX trade, leading the euro to depreciate relative to the dollar. By symmetry, U.S. QE announcements—that is, news that s_t^y will be low—will have the opposite effects.

To understand our second fact, we combine equations (26) and (27). We find that the FX risk premium is negatively related to the difference between foreign and domestic bond term premia:

$$E_t\left[rx^q_{t+1}\right] = \overbrace{\left[-\frac{C_{y,q}}{V_y - C_{y,y^*}}\right]}^{<-1} \cdot E_t\left[rx^{y*}_{t+1} - rx^y_{t+1}\right]. \tag{28}$$

Equation (28) motivates Table IV where we forecast FX returns using the difference in (proxies for) foreign and domestic term premia. When euro bond supply is high, the euro term premium is high and the risk premium on the borrow-in-dollars lend-in-euros FX trade is low. Thus, the FX risk premium moves inversely with the foreign term premium. The same argument applies to the domestic term premium with the opposite sign—the FX risk premium moves proportionately with the domestic term premium.[20]

To understand our first fact, we combine equations (12) and (28). The exchange rate reflects the sum of expected (i) foreign-minus-domestic short-rate differentials and (ii) foreign-minus-domestic bond risk-premium differentials:

(29)

$$q_t = \sum_{j=0}^{\infty} E_t[i^*_{t+j} - i_{t+j}] + \overbrace{\left[\frac{C_{y,q}}{V_y - C_{y,y^*}}\right]}^{>1} \cdot \sum_{j=0}^{\infty} E_t\left[rx^{y*}_{t+j+1} - rx^{y}_{t+j+1}\right].$$

This result motivates Tables I and II, where we regress changes in exchange rates on changes in short-rate differentials and changes in (proxies for) term premium differentials. When foreign bond supply is high, the foreign term premium is high and the risk premium on the borrow-at-home to lend-abroad FX trade is low. For investors to earn low returns on foreign currency, foreign currency must be strong—q_t must be high—and must be expected to depreciate.

Last, our model can match the otherwise puzzling finding in Lustig, Stathopoulos, and Verdelhan (2019) that the return to the FX trade—conventionally implemented by borrowing and lending short-term in different currencies—declines if one borrows long-term and lends long-term. To see this, note that the return on a long-term FX trade that borrows long-term at home to lend long-term abroad is just a combination of our three long-short returns. Specifically, the return on this long-term FX trade equals (i) the return to borrowing long to lend short domestically ($-rx^y_{t+1}$), plus (ii) the return to borrowing short domestically to lend short in the foreign currency (rx^q_{t+1}), plus (iii) the return to borrowing short to lend long in the foreign currency (rx^{y*}_{t+1}). Thus, the expected

20. The constant of proportionality in equation (28), $-\frac{C_{y,q}}{V_y - C_{y,y^*}}$, is less than -1 because FX is effectively a "longer duration" asset than long-term bonds when $\delta < 1$. This fact follows from the expressions in equation (24) in the limit where $\sigma^2_{sy} = \sigma^2_{sq} = 0$ and is proved in Online Appendix D for the general case where $\sigma^2_{sy}, \sigma^2_{sq} \geqslant 0$.

return on the long-term FX trade is:

$$(30)\quad E_t\left[rx^q_{t+1} + \left(rx^{y*}_{t+1} - rx^y_{t+1}\right)\right] = \overbrace{\left[1 - \frac{V_y - C_{y,y^*}}{C_{y,q}}\right]}^{\in(0,1)} \cdot E_t\left[rx^q_{t+1}\right].$$

Equation (30) shows that the expected return on the long-term FX trade is smaller in absolute magnitude—and hence less volatile over time—than that on the standard short-term FX trade. The intuition is that the long-term FX trade has offsetting exposures that reduce its riskiness for global bond investors compared with the standard FX trade. For instance, the standard FX trade (rx^q_{t+1}) will suffer when there is an unexpected increase in domestic short rates. However, borrowing long to lend short in domestic currency (i.e., $-rx^y_{t+1}$) will profit when there is an unexpected rise in domestic short rates. Thus, the long-term FX trade is less exposed to interest rate risk than the standard short-term FX trade. As a result, the expected return on the long-term FX trade moves less than one-for-one with the return on the standard short-term FX trade.[21]

We collect these four observations in the following proposition.

PROPOSITION 3. *Empirical implications*. Suppose $\rho \in [0, 1)$, $\sigma^2_{s^y} > 0$, and $\sigma^2_{s^q} = 0$. Then:

- The FX risk premium ($E_t[rx^q_{t+1}]$) is decreasing in the difference in net long-term bond supply between foreign and domestic currency ($s^{y*}_t - s^y_t$). The difference between foreign and domestic bond risk premia, $E_t\left[rx^{y*}_{t+1} - rx^y_{t+1}\right]$, is increasing in $s^{y*}_t - s^y_t$.
- $E_t\left[rx^q_{t+1}\right]$ is negatively related to $E_t\left[rx^{y*}_{t+1} - rx^y_{t+1}\right]$.
- The FX rate (q_t) is the sum of expected future foreign-minus-domestic short-rate differentials and a term that is proportional to expected future foreign-minus-domestic bond risk premium differentials.
- The expected return on the borrow long in domestic to lend long in foreign FX trade ($E_t[rx^q_{t+1} + (rx^{y*}_{t+1} - rx^y_{t+1})]$)

21. This result goes through unchanged if we allow the exchange rate to be nonstationary by adding a random-walk component. Thus, the ability of our model to match the Lustig, Stathopoulos, and Verdelhan (2019) result does not simply follow from our simplifying assumption that the exchange rate is stationary.

is smaller in magnitude than that on the standard borrow-short-in-domestic to lend-short-in-foreign FX trade, ($E_t[rx^q_{t+1}]$).

This logic, which implies that bond supply shocks should affect FX risk premium, also implies that FX supply shocks should affect bond risk premium. For instance, suppose the foreign central bank conducts a sterilized FX intervention to depress its currency, selling some of its holdings of short-term foreign bonds to purchase short-term domestic bonds. By FX market clearing, this FX intervention is associated with an increase in the net supply of foreign currency that global bond investors must absorb—that is, a rise in s^q_t. Naturally, our model predicts that this FX intervention will raise the risk premium on investments in foreign currency ($E_t[rx^q_{t+1}]$), leading foreign currency to depreciate versus the domestic currency. However, since $C_{y,q} > 0$, our model also predicts that this FX intervention will lead to a decline in foreign term premia and a rise in domestic term premia (see equations (20a) and (20b)). Some suggestive evidence in favor of this prediction comes from Christensen and Krogstrup (2019), who find that Swiss term premia fell in August 2011 when the Swiss National Bank first hinted that it might intervene in FX markets to hold down the value of the franc.

III.D. A Unified Approach to Carry Trade Returns

In this section, we show that our model can deliver a unified explanation that links return predictability in FX and long-term bond markets to the levels of domestic and foreign short-term interest rates. For foreign exchange, Fama (1984) showed that the expected return on the borrow-in-dollar to lend-in-euro FX trade is increasing in the euro-minus-dollar short-rate differential, $i^*_t - i_t$, a well-known failure of UIP. For long-term bonds, Fama and Bliss (1987) and Campbell and Shiller (1991) showed that the expected return on the borrow short to lend long yield curve trade is increasing in the slope of the yield curve, $y_t - i_t$, a well-known and highly robust failure of the expectations hypothesis of the term structure.

The baseline model we developed above does not generate either of these predictability results. In our baseline model, shocks to short-term interest rates make FX and long-term bonds risky investments for global bond investors. As a result, supply shocks affect the expected excess returns on foreign exchange and long-term bonds. But the levels of domestic and foreign short rates do not affect the relevant supplies and, hence, expected excess returns.

However, as detailed in Online Appendix B, a straightforward extension of our model can simultaneously match these two return predictability results: we simply need to assume that the net supply of each risky asset is endogenously increasing its price. For instance, first assume that global bond investors' exposure to the FX trade is endogenously increasing in the spot exchange rate due to balance-of-trade-driven flows. The idea is that when the euro is strong, U.S. net exports to Europe rise. This in turn creates higher demand from U.S. exporters to swap the euros they receive from their European sales into dollars, which global bond investors must accommodate.

This assumption, which is needed in Gabaix and Maggiori (2015) to match the Fama (1984) result, naturally delivers the Campbell-Shiller (1991) result in our model for the yield curve trades in both currencies. When the euro short rate is higher than the U.S. short rate, the euro will be strong relative to the dollar by standard UIP logic. Trade flows then mean that global bond investors must bear greater euro exposure to borrow-in-dollar lend-in-euro FX trade when the euro is strong. This raises the expected returns on that trade. As a result, the expected return on the FX trade is increasing in the difference between euro and U.S. short rates as in Fama (1984). This is the logic of Gabaix and Maggiori (2015). In our model, greater exposure to borrow-in-dollar lend-in-euro FX trade means greater exposure to U.S. short-rate risk, and thus the equilibrium expected returns on the U.S. yield curve trade must simultaneously rise. At the same time, the yield curve will be steeper in the United States than the euro area because U.S. short rates are lower and expected to mean revert. Thus, our model will also match Campbell and Shiller's (1991) finding that a steep yield curve predicts high excess returns on long-term bonds.

In this way, our model suggests that it is possible to theoretically "kill two birds with one stone." Specifically, the assumption that the supply of FX exposure is increasing in the exchange rate, which delivers the Fama (1984) result for FX, simultaneously generates the Campbell-Shiller (1991) result for bonds. Conversely, the assumption that the net supply of long-term bonds is increasing in the bond price, which generates the Campbell-Shiller (1991) result for bonds, simultaneously delivers the Fama (1984) result for FX.[22] In practice, both supply-driven mechanisms (and potentially other mechanisms as well) are likely needed to realistically generate the observed magnitude of the Fama (1984) and Campbell-Shiller (1991) results. Our more modest conclusion here is simply that the two supply-driven mechanisms are mutually reinforcing.

III.E. Relationship to Consumption-Based Models

Our quantity-driven, segmented markets model provides a unified way to understand term premia and exchange rates. In Online Appendix B, we compare our model's implications with those of frictionless, consumption-based asset pricing models. Our model is able to simultaneously match many important stylized facts about long-term bonds and foreign exchange rates. By contrast, leading consumption-based models struggle to simultaneously match these empirical patterns in a unified way. The key driver of these differences is our assumption that the global bond and FX markets are partially segmented from financial markets more broadly. In other words, "bad times" for the marginal investors in global bond markets need not coincide with "bad times" for more broadly diversified investors or for the representative households in, say, the United States and Europe.

IV. Model Extensions

In this section, we consider a series of extensions that explore how introducing additional intermediation frictions alter the predictions of our baseline model.

IV.A. Further Segmenting the Global Bond Market

In our first extension, we enrich the structure of intermediation in our model to capture two significant, real-world features of global bond and FX markets. First, real-world markets feature a variety of different investor types—each facing a different set of constraints—opening the door for meaningful segmentation within global bond and FX markets. Second, real-world bond

22. Relatedly, once we endogenize supply, changes in conventional monetary policy in the eurozone (i_t^*) will impact U.S. term premia ($E_t[rx_{t+1}^y]$) and vice versa. As a result, the Friedman-Obstfeld-Taylor trilemma fails: foreign monetary policy impacts domestic financial conditions (and vice versa) even though exchange rates are floating.

and FX markets involve substantial trading flows between different investor types (Evans and Lyons 2002; Froot and Ramadorai 2005).

We further segment the global bond market as in Gromb and Vayanos (2002), assuming some bond investors cannot trade short- and long-term bonds in both currencies. A first take-away is that with further segmentation exogenous bond supply shocks give rise to endogenous FX trading flows that affect exchange rates. A second is that a small amount of additional segmentation increases the effect of bond supply shocks on exchange rates.

Our extended model features four types of bond investors. All types have mean variance preferences over one-period-ahead wealth and a risk tolerance of τ in domestic currency terms. Types only differ in their ability to trade different assets. Specifically:

- *Domestic bond specialists*, present in mass $\mu\pi$, can only choose between short- and long-term domestic bonds—that is, they can only engage in the domestic yield curve trade.
- *Foreign bond specialists*, also present in mass $\mu\pi$, can only choose between short- and long-term foreign bonds—that is, they can only engage in the foreign yield curve trade.
- *FX specialists*, present in mass $\mu(1-2\pi)$, can only choose between short-term domestic and foreign bonds—that is, they can only engage in the FX trade.
- *Global bond investors*, present in mass $(1-\mu)$, can hold short- and long-term bonds in both currencies and can engage in all three long-short trades.

We assume $\mu \in [0, 1]$ and $\pi \in \left(0, \frac{1}{2}\right)$. Increasing the combined mass of specialist types, μ, is equivalent to introducing greater segmentation in the global bond market. Thus, our baseline model corresponds to the limiting case where $\mu = 0$. At the other extreme, markets are fully segmented when $\mu = 1$. When $\mu \in (0, 1)$ markets are partially segmented.

Our domestic bond specialists are reminiscent of the specialized bond investors in Vayanos and Vila (2021) in the sense that their positions in long-term domestic bonds are a sufficient statistic for the expected returns on the domestic yield curve trade. Our FX specialists are similar to the FX intermediaries in Gabaix and Maggiori (2015): their FX positions are a sufficient statistic for the expected returns on the FX trade. In practice, we associate the domestic and foreign bond specialists with market participants who, for institutional reasons, exhibit significant home bias and are essentially unwilling to substitute between bonds in different currencies.

In the Online Appendix, we derive the following results:

PROPOSITION 4. *Further segmenting the bond market*. Suppose $\rho \in (0, 1)$ and that fraction μ of investors are specialists. We have the following results:

(i) **Price impact.** Suppose $\sigma^2_{s^y} = \sigma^2_{s^q} = 0$. **(a) Greater segmentation increases own-market price impact.** Formally, for any $a \in \{y, y^*, q\}$, $\frac{\partial^2 E_t[rx^a_{t+1}]}{\partial s^a_t \partial \mu} > 0$. **(b) Segmentation has a hump-shaped effect on cross-market price impact.** For any $a_1 \in \{y, y^*, q\}$ and $a_2 \neq a_1$, $\left|\frac{\partial E_t[rx^{a_1}_{t+1}]}{\partial s^{a_2}_t}\right|$ is a hump-shaped function of μ with $\left|\frac{\partial E_t[rx^{a_1}_{t+1}]}{\partial s^{a_2}_t}\right| > 0$ when $\mu = 0$ and $\frac{\partial E_t[rx^{a_1}_{t+1}]}{\partial s^{a_2}_t} = 0$ when $\mu = 1$. **(c) Greater segmentation increases bond market–wide price impact.** For any supply $\mathbf{s}_t \neq \mathbf{0}$, the expected return on the global bond market portfolio $rx^{s_t}_{t+1} = \mathbf{s}'_t \mathbf{rx}_{t+1}$ is increasing in μ: $\frac{\partial E_t[rx^{s_t}_{t+1}]}{\partial \mu} > 0$.

(ii) **Segmentation leads to endogenous trading flows.** Suppose $\sigma^2_{s^y} \geqslant 0$, $\sigma^2_{s^q} \geqslant 0$. For any $\mu \in (0, 1)$, a shock to the supply of any asset $a \in \{y, y^*, q\}$ triggers trading in all assets $a' \neq a$ between global bond investors and specialist investors.

Further segmenting the global bond market has three effects. First, as we increase μ, there is an "inefficient risk-sharing" effect because fewer investors can absorb a given supply shock. This effect tends to increase the price impact of all supply shocks. Second, there is a "width-of-the-pipe" effect because we increase the mass of specialist investors who do not alter their demand for their asset in response to shocks in other markets. This effect tends to diminish the impact of a supply shock in one market on prices in other markets because price impact is only transmitted across markets by global bond investors—"the pipe"—whose demands for each asset are affected by shocks to other markets. Finally, there is an "endogenous risk" effect. To the extent that greater segmentation directly alters the price impact of supply shocks, greater segmentation affects equilibrium return volatility, further altering equilibrium price impact.

Part (i) of Proposition 4 characterizes equilibrium price impact as a function of μ in the limit where supply risk vanishes.[23] In this limit, the endogenous risk effect disappears, leaving only the inefficient risk-sharing and width-of-the-pipe effects. As we raise μ, these two effects always increase the impact of a supply shock in market a on expected returns in that market: $\frac{\partial^2 E_t[rx^a_{t+1}]}{\partial s^a_t \partial \mu} > 0$ for any $a \in \{y, y^*, q\}$. Cross-market price impact under partial segmentation is more complicated. Consider how the FX risk premium responds to domestic bond supply, $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t}$, as a function of μ. When there are only global bond investors ($\mu = 0$), a shock to domestic bond supply raises expected returns on the FX trade: $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t} > 0$. This is the key result from the baseline model. By contrast, when markets are fully segmented and there are no global bond investors, bond supply shocks have no effect on FX—that is, $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t} = 0$ when $\mu = 1$. In between, μ has a hump-shaped effect on cross-market price impact. This hump shape reflects the combination of the inefficient risk-sharing effect, which typically leads $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t}$ to rise with μ and dominates when μ is near zero, and the width-of-the-pipe effect, which typically leads $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t}$ to fall with μ and dominates when μ is near one.

When we introduce stochastic supply shocks, the endogenous risk effect comes into play. By continuity of the stable equilibrium in the model's underlying parameters, the results in part (i) of Proposition 4 continue to hold when supply risk is small. More generally, the endogenous risk effect typically amplifies the sum of the inefficient risk-sharing and width-of-the-pipe effects, so the hump-shaped profile of $\left|\frac{\partial E_t[rx^{a_1}_{t+1}]}{\partial s^{a_2}_t}\right|$ becomes more pronounced in the presence of supply risk. In addition, when asset supply is stochastic, greater segmentation typically increases equilibrium market volatility. Furthermore, the

23. To prove part (i) of the proposition and draw Figure II, we assume there is some FX-specific fundamental risk. Specifically, we assume $\lim_{T\to\infty} E_t[q_{t+T}] = q^\infty_t$ follows a random walk $q^\infty_{t+1} = q^\infty_t + \varepsilon_{q^\infty,t+1}$ with $Var_t[\varepsilon_{q^\infty,t+1}] = \sigma^2_{q^\infty} > 0$. If $\sigma^2_{q^\infty} = 0$, then in the absence of supply risk, FX is a redundant asset whose returns are a linear combination of those on domestic and foreign bonds. However, if $\sigma^2_{s^q}, \sigma^2_{s^y} > 0$, FX is not redundant and cross-market impact is still hump-shaped.

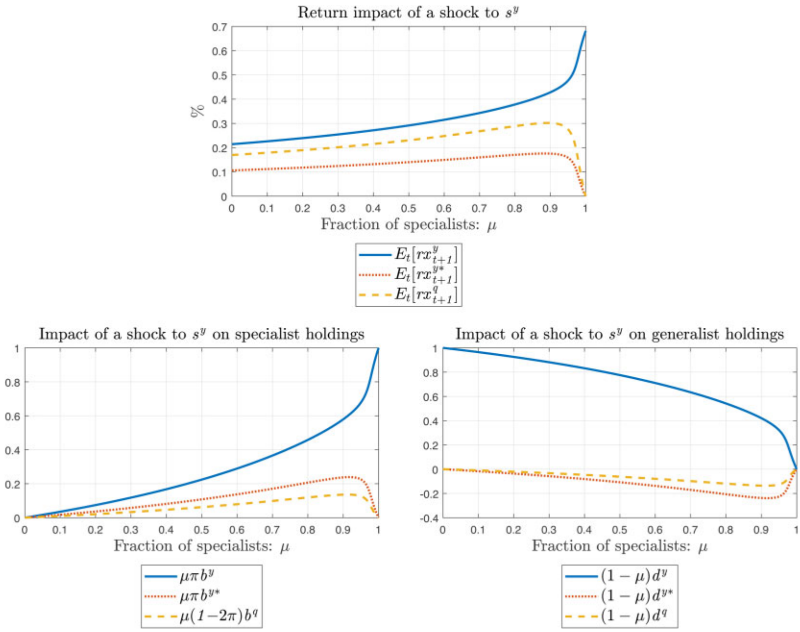

FIGURE II

Further Segmenting the Global Bond Markets

This figure illustrates the model with further segmentation from Section IV.A. The figure shows the impact of a shock to the domestic bond supply on expected returns (top panel) and investor holdings (bottom two panels) as a function of the fraction of specialists, μ. The figure assumes $\pi = \frac{1}{3}$, so specialists are evenly split between domestic bonds, foreign bonds, and foreign exchange. We chose the other parameters so each period represents one month. We assume $\sigma_i = 0.25\%$, $\phi_i = 0.985$, $\rho = 0.5$, $\sigma_{s^y} = 1$, $\phi_{s^y} = 0.95$, $\sigma_{s^q} = 1$, $\phi_{s^q} = 0.95$, $\sigma_{q^\infty} = 0.5\%$, $\delta = \frac{119}{120}$ (i.e., the long-term bond has a duration of 120 months or 10 years), and $\tau = 1.80$. These parameter choices are illustrative. See Online Appendix C for additional details.

endogenous risk effect typically steepens the relationship between segmentation μ and the expected return on the global bond market portfolio.[24]

24. Formally, for any bond portfolio $\mathbf{p}_t \neq \mathbf{0}$ with returns $rx^{p_t}_{t+1} = \mathbf{p}_t' \mathbf{rx}_{t+1}$, we typically have $\frac{\partial Var_t[rx^{p_t}_{t+1}]}{\partial \mu} > 0$. When the endogenous risk effect is positive in this portfolio sense, then for any set of supply shocks $\mathbf{s}_t \neq \mathbf{0}$, the expected return on the global bond market portfolio $rx^{s_t}_{t+1} = \mathbf{s}_t' \mathbf{rx}_{t+1}$ rises more steeply with μ—that is, the endogenous risk effect raises $\frac{\partial E_t[rx^{s_t}_{t+1}]}{\partial \mu} > 0$.

The results in Proposition 4 are illustrated in Figure II. The top panel plots the impact of a domestic bond supply shock on expected returns as a function of μ. The plot shows that while $\frac{\partial E_t[rx^y_{t+1}]}{\partial s^y_t}$ is always increasing in μ, segmentation has a hump-shaped effect on $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t}$. Unless μ is near one and global bond markets are highly segmented, the effect of bond supply shocks on foreign exchange exceeds that in our baseline model where $\mu = 0$. Thus, one might conjecture that the effect of bond supply shocks on foreign exchange markets has risen in recent decades because μ has fallen over time. In other words, relative to earlier periods when markets were highly segmented ($\mu \approx 1$), the global bond market has become more integrated, raising $\frac{\partial E_t[rx^q_{t+1}]}{\partial s^y_t}$ (Mylonidis and Kollias 2010; Pozzi and Wolswijk 2012).

The next two plots in Figure II show the trading response to a unit domestic bond supply shock as a function of μ. When $\mu \in (0, 1)$, markets are partially segmented, global bond investors and the three specialist types disagree on the appropriate compensation for bearing factor risk exposure. Thus, as shown in part (ii) of Proposition 4, following a supply shock to any one asset, global bond investors trade across markets to align—but not equalize—how factor risk is priced in different markets. For instance, a shock to the supply of domestic bonds leads to FX trading between global bond investors and FX specialists. Specifically, following a positive shock to domestic bond supply, global bond investors want to increase their exposure to domestic bonds and reduce their exposure to the FX trade. FX specialists must take the other side, increasing their exposure to the FX trade. These endogenous FX trading flows are associated with an increase in FX risk premia and a depreciation of foreign currency. In this way, our extension with additional bond market segmentation endogenizes the kinds of capital market driven FX flows considered in Gabaix and Maggiori (2015). Rather than being exogenous quantities that specialist FX investors are required to absorb, these endogenous FX flows are tied to supply-and-demand shocks for long-term bonds.[25]

25. In Online Appendix C, we show that similar results to Proposition 4 obtain if we instead add bond investors who cannot hedge FX risk—that is, investors who cannot separately manage the FX exposure resulting from investments they make in nonlocal, long-term bonds.

IV.B. Deviations from Covered Interest Rate Parity

We combine our model with bank balance sheet constraints, which Du, Tepper, and Verdelhan (2018) show are critical for explaining post-2008 violations of CIP. We show that doing so provides a simple and plausible explanation for the fact that CIP deviations comove with spot exchange rates. This suggests that CIP deviations are informative about the supply shocks that global bond investors must absorb, which are otherwise very difficult to observe.

To model deviations from CIP and their connection to spot FX rates, we first introduce one-period FX forward contracts, which allow investors to lock in the next period's exchange rate. When CIP holds, the "cash" domestic short-term rate equals its "synthetic" counterpart, which is obtained by investing in short-term foreign bonds and hedging the associated FX risk using FX forwards. Because CIP violations imply the existence of riskless profits, CIP violations cannot be explained by the limited investor risk-bearing capacity we assume in the baseline model. We therefore make three changes to our baseline model. First, we split our global bond investors, so half are domiciled in the domestic country and half are domiciled in the foreign country. Second, we assume that the only market participants who can engage in riskless CIP arbitrage trades—borrowing at the synthetic domestic short rate to lend at the cash domestic short rate—are a set of global banks who face non-risk-based balance sheet constraints. Third, we assume bond investors must use FX forwards if they want to hedge the currency risk stemming from any investments in nonlocal long-term bonds.[26]

In this setting, we show that deviations from CIP comove with spot exchange rates as recently documented in Avdjiev et al. (2019) and Jiang, Krishnamurthy, and Lustig (2021). The intuition is that bond supply shocks generate investor demand to hedge foreign currency risk, which in turn generates demand for FX forward transactions. When banks accommodate this demand, they engage in riskless CIP arbitrage trades. These trades

26. This is equivalent to saying that bond investors cannot directly borrow (or obtain "cash" funding) in nonlocal currency. Of course, they can convert their local currency to nonlocal currency in the spot FX market to purchase nonlocal assets. But if they wish to obtain leverage in nonlocal currency, they must use "synthetic" funding, which is constructed by borrowing in local currency, converting the proceeds to nonlocal currency in the spot market, and then forward selling nonlocal currency in the forward market.

consume scarce bank balance sheet capacity, so banks are only willing to accommodate FX forward demand if they earn positive profits doing so, that is, only if there are deviations from CIP.

To illustrate, suppose that there is an increase in the supply of long-term domestic bonds. As in our baseline model, this supply shock raises the domestic term premium and the FX risk premium, leading the domestic currency to appreciate. To take advantage of the elevated domestic term premium, foreign bond investors want to buy long-term domestic bonds. They want do so on an FX-hedged basis to isolate the elevated domestic term premium component of the investment. This puts pressure on the market for FX forwards, generating deviations from CIP. Thus, deviations from CIP are driven by supply-and-demand shocks in the global bond market.

Once we allow for CIP deviations, domestic investors acquire an endogenous comparative advantage at absorbing domestic bond supply shocks relative to foreign investors. Intuitively, domestic investors can hold long-term domestic bonds without bearing currency risk or paying the costs of hedging currency risk with FX forwards, and foreign investors cannot. As a result, the failure of CIP leads bond supply shocks to have a larger effect on bond risk premia and FX risk premia than in our baseline model where CIP holds.

1. *Forward Foreign Exchange Rates.* Let F_t^Q denote the one-period forward exchange rate at time t, that is, the amount of domestic currency per unit of foreign currency that investors can lock in at t to exchange at $t+1$. Once we introduce forwards, there are two ways to earn a riskless return in domestic currency between t and $t+1$. First, investors can hold short-term domestic bonds, earning the gross "cash" rate of I_t. Second, investors can convert domestic currency into $\frac{1}{Q_t}$ units of foreign currency, invest that foreign currency in short-term foreign bonds at rate I_t^*, and enter into an forward contact to exchange foreign for domestic currency at $t+1$, obtaining the gross "synthetic" domestic rate of $\frac{F_t^q I_t^*}{Q_t}$. Under CIP, the cash (I_t) and synthetic ($\frac{F_t^q I_t^*}{Q_t}$) domestic short rates must be equal, implying $F_t^q = \frac{Q_t I_t}{I_t^*}$ or $f_t^q = q_t - (i_t^* - i_t)$ in logs.

By contrast, if CIP fails, the "cross-currency basis," x_t^{cip}, given by

$$x_t^{cip} = i_t - \left(i_t^* + f_t^q - q_t\right), \tag{31}$$

is nonzero. The cross-currency basis, x_t^{cip}, is the return on a riskless CIP arbitrage trade that borrows short-term in domestic currency on a synthetic basis at rate $(i_t^* + f_t^q - q_t)$ and lends short-term in domestic currency on a cash basis at rate i_t. Alternately, we have:

$$f_t^q = q_t - \left(i_t^* - i_t\right) - x_t^{cip}. \tag{32}$$

Thus, x_t^{cip} is positive when the forward FX rate is lower than it would be if CIP held.

2. *Positions Involving FX Forwards.* We introduce three positions that involve FX forwards.

i. *Forward FX Investments.* The excess return in domestic currency on a position in foreign currency that is obtained through a forward purchase of foreign currency is:

$$q_{t+1} - f_t^q = \left[\left(q_{t+1} - q_t\right) + \left(i_t^* - i_t\right)\right] + x_t^{cip} = rx_{t+1}^q + x_t^{cip}, \tag{33}$$

which follows from equation (32) and $rx_{t+1}^q \equiv (q_{t+1} - q_t) + \left(i_t^* - i_t\right)$. A forward investment in foreign currency is equivalent to "stapling" together a standard FX trade, which earns rx_{t+1}^q, and a long position in the CIP arbitrage trade, which earns x_t^{cip}. Using FX forwards in this way is a synthetic way of obtaining funding or leverage for a standard FX trade. An investor in FX uses little of their own capital up front when they use forwards, just as they use little of their own capital up front when they use leverage.

In our baseline model where CIP held, it did not matter where our global bond investors were domiciled. However, once CIP fails, investor domiciles matter. For instance, movements in the cross-currency basis change the attractiveness of investing in long-term foreign bonds for domestic bond investors because they must either (i) not hedge the FX risk stemming from their foreign bond holdings or (ii) hedge this risk at cost of x_t^{cip}. Thus, we must distinguish between foreign and domestic investors when considering FX-hedged investments in long-term bonds.

ii. *FX-Hedged Investments in Long-Term Foreign Bonds by Domestic Investors.* To obtain this return from t to $t+1$, a domestic investor exchanges domestic for foreign currency in the spot market at time t, invests that foreign currency in long-term foreign bonds from t to $t + 1$, and then exchanges foreign for domestic currency at $t + 1$ at the predetermined forward rate F_t^Q. The log excess return on this position is approximately:

$$\left(r_{t+1}^{y^*} + f_t^q - q_t\right) - i_t = rx_{t+1}^{y^*} - x_t^{cip}, \tag{34}$$

which follows from equation (32) and $rx_{t+1}^{y^*} \equiv r_{t+1}^{y^*} - i_t^*$. Thus, an FX-hedged investment in long-term foreign bonds is akin to "stapling" together the foreign yield curve trade, which earns rx_{t+1}^{y*}, and a short position in the CIP arbitrage trade, which earns $-x_t^{cip}$. Using forwards to hedge FX risk in this way is a way of converting domestic currency funding into foreign currency funding. [27]

iii. *FX-Hedged Investments in Long-Term Domestic Bonds by Foreign Investors.* Symmetrically, the log excess return foreign investors earn buying domestic long-term bonds and hedging the FX risk is approximately:

$$\left(r_{t+1}^{y} + q_t - f_t^q\right) - i_t^* = rx_{t+1}^{y} + x_t^{cip}. \tag{35}$$

This expression is consistent with recent evidence from Tabova and Warnock (2021) who show that foreign holdings of Treasuries tend to rise when the CIP basis (x_t^{cip}) is high.

3. *Investor Types.* We assume that half of all bond investors are domiciled in the domestic country and half are domiciled in the foreign country. Both domestic and foreign investors have mean-variance preferences over one-period-ahead wealth and a risk tolerance of τ in domestic currency terms. Investors differ only in terms of the returns they can earn because of CIP violations.

Domestic bond investors are present in mass $\frac{1}{2}$. They can obtain a riskless return of i_t from t to $t + 1$. They can also (i) buy long-term domestic bonds, earning an excess return of rx_{t+1}^{y}; (ii) take FX-hedged positions in long-term foreign bonds, generating

27. FX-hedged positions in foreign risky assets do not completely eliminate the exchange rate risk that investors must bear because the size of the hedge cannot be made contingent on the foreign asset's subsequent return. Thus, the full FX-hedged return includes a second-order interaction between the local currency excess return on the foreign asset and the excess return on foreign currency. For simplicity, we omit this second-order term, which converges to a constant when investors continuously rebalance their hedges, from our analysis.

an excess return of $rx_{t+1}^{y^*} - x_t^{cip}$; and (iii) make forward investments in foreign currency, earning an excess return of $rx_{t+1}^{q} + x_t^{cip}$. In effect, domestic investors only have access to excess returns $[rx_{t+1}^{y}, rx_{t+1}^{y^*} - x_t^{cip}, rx_{t+1}^{q} + x_t^{cip}]'$.[28] Foreign bond investors are present in mass $\frac{1}{2}$ and are the mirror image of domestic investors, with access to excess returns $[rx_{t+1}^{y} + x_t^{cip}, rx_{t+1}^{y^*}, rx_{t+1}^{q} + x_t^{cip}]'$.

While domestic and foreign bond investors may transact in FX forwards, they cannot engage in the riskless CIP arbitrage trade in isolation. To the extent that these investors transact in FX forwards, they "staple" the returns on a riskless CIP arbitrage trade together with those on other risky trades. This assumption is crucial for preventing bond investors, who are risk averse but are not subject to other constraints, from arbitraging away deviations from CIP. This is equivalent to assuming that bond investors cannot obtain leverage in nonlocal currency; they can only obtain synthetic nonlocal currency funding, which embeds a spread (x_t^{cip}) that reflects banks' balance sheet costs.

We assume that the only players who can engage in the riskless CIP arbitrage are a set of balance sheet constrained banks. These banks choose the value of their positions in the CIP arbitrage trade, $d_{B,t}^{cip}$, to solve $\max_{d_{B,t}^{cip}}\{x_t^{cip} d_{B,t}^{cip} - \left(\frac{\kappa}{2}\right)(d_{B,t}^{cip})^2\}$, where $\kappa \geq 0$. Here $(\frac{\kappa}{2})(d_{B,t}^{cip})^2$ captures non-risk-based balance sheet costs faced by banks. These costs arise because equity capital is costly and banks are subject to non-risk-based equity capital requirements. Thus, banks take a position in the CIP arbitrage trade equal to $d_{B,t}^{cip} = \kappa^{-1} x_t^{cip}$.

These assumptions are purposely stark and highlight the key mechanisms. In particular, our results would be qualitatively unchanged if some bond investors could engage in the CIP arbitrage trade in limited size. Similarly, we are assuming that banks have zero risk-bearing capacity, so that anytime they transact in the forward market, it is as part of a CIP arbitrage trade. However, we would obtain qualitatively similar results if we assumed that banks had finite risk-bearing capacity and thus could also take on risky FX positions.

28. Domestic investors can make unhedged investments in long-term foreign bonds. By combining FX-hedged investments in long-term foreign bonds with forward FX investments, they earn $rx_{t+1}^{y^*} + rx_{t+1}^{q}$ which is independent of x_t^{cip}. However, if they want FX-hedged exposure to long-term foreign bonds, they must pay x_t^{cip}.

4. *Market Equilibrium.* We need to clear four markets at time t: the markets for (i) long-term domestic bonds; (ii) long-term foreign bonds; (iii) forward FX exposure, which we assume is in net supply s_t^q; and (iv) the CIP arbitrage trade.[29] Because forwards and the CIP arbitrage trade span the spot market, (iii) and (iv) are equivalent to clearing the forward and spot FX markets.

To clear the market for forward FX exposure at time t, investors must be willing to make a forward FX investment with a domestic notional value of s_t^q. Turning to the CIP arbitrage market, recall that the CIP arbitrage trade exchanges currency at the time t spot rate and then reverses that exchange at $t+1$ at the forward FX rate f_t^Q. For simplicity, we assume that the CIP arbitrage trade is in zero net supply ($s_t^{cip} \equiv 0$), implying that banks must take the opposite side of bond investors' trades.

PROPOSITION 5. *Allowing for CIP deviations*. Consider the extended model where the banks are potentially balance sheet constrained. We have the following results:

- In the limiting case where banks are not balance sheet constrained—that is, where $\kappa \to 0$, CIP holds ($x_t^{cip} \to 0$) and the extended model converges to the baseline model in Section III.
- If banks are balance sheet constrained ($\kappa > 0$), we have

$$\text{(36a)}\quad E_t\left[rx_{t+1}^y\right] = \tau^{-1}\left[V_y \cdot s_t^y + C_{y,y*} \cdot s_t^{y*} + C_{y,q} \cdot s_t^q\right] - \frac{x_t^{cip}}{2},$$

$$\text{(36b)}\quad E_t\left[rx_{t+1}^{y*}\right] = \tau^{-1}\left[C_{y,y*} \cdot s_t^y + V_y \cdot s_t^{y*} - C_{y,q} \cdot s_t^q\right] + \frac{x_t^{cip}}{2},$$

$$\text{(36c)}\quad E_t\left[rx_{t+1}^q\right] = \tau^{-1}\left[C_{y,q} \cdot \left(s_t^y - s_t^{y*}\right) + V_q \cdot s_t^q\right] - x_t^{cip},$$

$$\text{(36d)}\qquad x_t^{cip} = \underbrace{-\kappa \frac{V_y + C_{y,y*}}{2\left(V_y + C_{y,y*}\right) + \tau\kappa}}_{<0} \cdot \left(s_t^y - s_t^{y*}\right).$$

29. To clearly separate the amount of risky FX exposure and the amount of balance sheet–intensive riskless funding that bond investors and banks must intermediate, we assume here that s_t^q is the net supply of risky FX exposure on a forward basis. Since bond investors can accommodate shocks to the supply of forward FX exposure without using scarce bank balance sheet capacity, s_t^q does not impact x_t^{cip}. By contrast, if s_t^q were instead the supply of risky FX exposure on a spot basis, then a rise in s_t^q would be associated with a decline in x_t^{cip}.

- Bond supply shocks s_t^y and s_t^{y*} push $E_t[rx_{t+1}^q]$ and x_t^{cip} in opposite directions; as a result, these shocks push q_t and x_t^{cip} in the same direction. Indeed, when there are no FX supply shocks, we have $E_t[rx_{t+1}^q] = -K_q \cdot (E_t[rx_{t+1}^{y*}] - E_t[rx_{t+1}^y])$ and $x_t^{cip} = K_{cip} \cdot (E_t[rx_{t+1}^{y*}] - E_t[rx_{t+1}^y])$, where K_q and K_{cip} are positive constants given in the Online Appendix.
- A rise in bank balance sheet costs raises the effect of domestic bond supply shocks on domestic bond risk premia and FX risk premia ($\frac{\partial^2 E_t[rx_{t+1}^y]}{\partial s_t^y \partial \kappa} > 0$, $\frac{\partial^2 E_t[rx_{t+1}^q]}{\partial s_t^y \partial \kappa} > 0$), but reduces the effect of these shocks on foreign bond risk premia ($\frac{\partial^2 E_t[rx_{t+1}^{y*}]}{\partial s_t^y \partial \kappa} < 0$).

In the limiting case where banks' balance sheet costs vanish ($\kappa \to 0$), CIP holds, and equilibrium bond yields and exchange rates behave exactly as they did in the baseline model in Section III. This limit arguably approximates the pre-2008 era, when CIP held and banks did not face binding non-risk-based equity capital constraints.

Next consider the case where bank balance sheet costs are positive ($\kappa > 0$). In this case, risk premia are given by equation (36), and the cross-currency basis x_t^{cip} is given by equation (36d). To understand the intuition for equation (36d), suppose there is an increase in the supply of long-term domestic bonds, s_t^y. As in the baseline model, this supply shock raises the domestic term premium and the FX risk premium, leading domestic currency to appreciate against foreign. Foreign bond investors then want to buy long-term domestic bonds, but they want to hedge the associated FX risk to isolate the elevated domestic term premium. Hedging the FX risk involves forward-selling domestic currency. Because banks are balance sheet constrained, they are only willing to accommodate investor demand for FX hedges if domestic currency is weaker than CIP would imply in the forward market, meaning that the forward exchange rate f_t^q rises and the basis x_t^{cip} declines. Equivalently, the domestic bond supply shock boosts foreign bond investors' demand for short-term synthetic funding in domestic currency. Because banks are balance sheet constrained, this shift in funding demand pushes up the synthetic domestic short rate ($i_t^* + f_t^q - q_t$) relative to its cash counterpart (i_t), thereby driving down the basis.

Equations (36c) and (36d) show that bond supply shocks (s_t^y or s_t^{y*}) push x_t^{cip} and $E_t[rx_{t+1}^q]$ in opposite directions. Thus, these supply shocks induce a positive time series correlation between the basis x_t^{cip} and the spot exchange rate q_t, consistent with the recent findings of Avdjiev et al. (2019) and Jiang, Krishnamurthy, and Lustig (2021). Intuitively, in our model, demand to buy domestic currency in the spot market, which drives down q_t, is linked with hedging demand to sell domestic currency in the forward market, which drives down x_t^{cip}. Since risk premia are not directly observable but CIP deviations are, the CIP basis is an informative signal about the underlying supply-and-demand shocks that drive UIP failures. Relatedly, our model suggests that the CIP basis should be higher when foreign term premia are higher, that is, we have $x_t^{cip} = K_{cip} \cdot (E_t[rx_{t+1}^{y*}] - E_t[rx_{t+1}^y])$ when there are no FX supply shocks. This prediction is loosely consistent with the evidence in Du, Tepper, and Verdelhan (2018), who find that CIP bases are increasing in the level of foreign interest rates, in the cross section of currencies and in the time series for a given currency.

Through the lens of our model, the strong correlation between CIP bases and spot FX rates suggests that an important fraction of the variation in FX rates may be due to supply-and-demand shocks, as opposed to the macro fundamentals that drive FX rates in more conventional models. The CIP basis has a fundamental value of zero, so its movements can only reflect supply-and-demand imbalances. Thus, if the basis moves strongly with the level of the currency, this would seem to indicate that the latter is also heavily influenced by these imbalances. In any event, this is the mechanism in our model.

Finally, our model suggests that allowing for CIP deviations ($\kappa > 0$) puts foreign investors at an endogenous comparative disadvantage relative to domestic investors when it comes to absorbing domestic supply shocks (and vice versa). If they hold long-term domestic bonds, foreigners must either bear currency risk or pay the cost ($-x_t^{cip}$) of hedging the associated currency risk with FX forwards. Since these FX hedging costs rise with the level of domestic bond supply (s_t^y), foreigners play a smaller role than domestic investors in absorbing domestic bond supply shocks. As a result, a rise in bank balance sheet costs (κ) raises the effect of domestic bond supply shocks on domestic term premia ($E_t[rx_{t+1}^y]$) and FX premia ($E_t[rx_{t+1}^q]$) but reduces the effect of domestic bond supply shocks on foreign term premia ($E_t[rx^{y*}_{t+1}]$).[30]

IV.C. Interest Rate Insensitive Assets

In a final extension, we introduce interest rate insensitive assets that are not exposed to movements in interest rates. In our baseline model, shocks to the supply-and-demand for rate-insensitive assets have no effect on exchange rates because they do not change the amount of interest rate risk borne by global bond investors. However, in the presence of deviations from CIP, these shocks can affect exchange rates because they generate demands for different currencies, which global bond investors must accommodate. In other words, the CIP deviations that have emerged since 2008 significantly increase the set of capital market flows that can affect exchange rates. See Online Appendix C.

V. Conclusion

We develop a workhorse model in which the limited risk-bearing capacity of global bond market investors plays a central role in determining foreign exchange rates. In the baseline model, specialized bond investors must accommodate supply-and-demand shocks in the markets for foreign and domestic long-term bonds and in the foreign exchange market.

This simple model captures many features of the data, including (i) correlations between realized excess returns on foreign currency and long-term bonds, (ii) the relationship between the FX risk premium and bond term premia, (iii) the effects of quantitative easing policies on exchange rates, and (iv) the fact that currency trades are more profitable when implemented using short-term bonds than when using long-term bonds.

30. Our results here connect to those in He, Nagel, and Song (2022). Motivated by the sharp rise in long-term interest rates and the rise in Treasury yields relative to those on overnight-index swaps (OIS) during the COVID-19-induced “dash for cash” in March 2020, these authors add non-risk-based dealer balance sheet costs to an otherwise standard Vayanos and Vila (2021) term structure model. Shocks to the net supply of long-term bonds push term premia and the spread between Treasury and OIS yields—a failure of the law of one price that reflects dealer balance sheet costs—in the same direction. The presence of these balance sheet costs steepens the aggregate-demand curve for interest rate risk, amplifying the effect of bond supply shocks on term premia.

We enrich the structure of intermediation in our model in two ways. First, we further segment the bond market, introducing investors who cannot flexibly trade bonds of any maturity in both currencies. This segmentation leads to endogenous trading flows in currency markets that are associated with movements in the exchange rate. Second, we add balance sheet constrained banks, which allows us to study CIP deviations. Overall, our article shows that the structure of financial intermediation in bond and currency markets helps explain a number of empirical regularities in these markets.

From a policy perspective, our model shows that the ability to influence exchange rates—and hence presumably trade flows—remains a potentially important channel for monetary policy transmission even when central banks are pinned against the zero lower bound and must rely on quantitative easing to provide monetary accommodation. Indeed, our analysis leaves open the interesting possibility that when other conventional channels of transmission are compromised by low rates (Brunnermeier and Koby 2018), this QE-exchange-rate channel may become a relatively more important part of the overall monetary transmission mechanism. If so, and given the zero-sum nature of this channel across countries, arguments for monetary-policy coordination (Rajan 2016) may gather more force near the zero lower bound. To be clear, neither our model nor any of the evidence that we have presented gives decisive guidance on this point. But the model does provide a framework in which questions of this sort can be pursued more rigorously.

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Supplementary Material

An Online Appendix for this article can be found at *The Quarterly Journal of Economics* online.

Data Availability

The data underlying this article are available in the Harvard Dataverse, https://doi.org/10.7910/DVN/LUSR9I (Greenwood et al. 2023).

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