The Hedging Channel of Exchange Rate Determination *

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Abstract

We propose the currency hedging channel that connects countries' external imbalances to their exchange rate behavior. We present a model in which investors increase their currency hedging during periods of financial distress, in proportion to their net foreign asset exposure. This behavior coupled with constrained financial intermediation explains observed relationships between gradually adjusting external imbalances and volatile spot and forward exchange rates. We find empirical support for the hedging channel in both the conditional and unconditional moments of exchange rates, option prices, and countries' uses of Federal Reserve swap lines. Additionally, we forecast currency returns using a hedging demand proxy.

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JEL Classifications:E44, F31, F32, F41, G11, G15, G18, G20

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The disconnect between exchange rates and macroeconomic variables remains one of the most persistent puzzles in international economics. In recent years, a growing body of evidence points to financial intermediary constraints and global imbalances as key drivers of exchange rate dynamics.[1] However, conventional macroeconomic models that match international business cycle moments often generate counterfactual exchange rate dynamics with insufficient volatility. Exchange rate forecasting, particularly in the policy-relevant horizons of one month to one year has been challenging.[2] This paper proposes a mechanism that connects countries' net foreign asset positions to exchange rate markets. We show variation in investors' (and borrowers') desires to hedge exchange rate risks in their net foreign asset positions, coupled with intermediary frictions, explain a number of stylized facts in international financial markets. By centering our channel around a quickly adjusting, countercyclical financial variable— the currency hedge ratio — we link exchange rate movements with country-level external imbalances that adjust gradually.

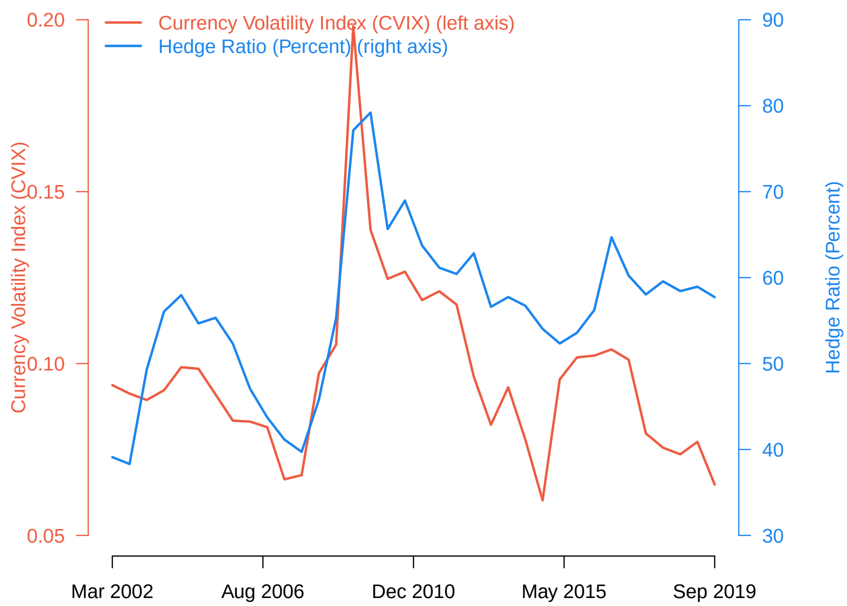
Our proposed channel centers around foreign exchange rate (FX) hedging activities. Figure 1 shows the hedge ratio of nine large Japanese life insurers on their foreign asset holdings and the Currency Volatility Index (CVIX) — a measure of implied exchange rate volatility analogous to the VIX Index. This figure highlights several common trends in the data. Foreign institutional investors have in recent years hedged a large fraction of the currency exposure on their foreign asset holdings through forwards and swaps. Their hedging behavior is time varying, and, moreover, their hedge ratio typically increases with currency volatility.

In this paper, we start by highlighting several facts that are consistent with a hedging channel of exchange rate determination. First, a large set of institutional investors and

[1]For instance, Gabaix and Maggiori (2015) model exchange rate determination under limited financial intermediation; Jiang, Krishnamurthy, and Lustig (2019) emphasize the role of safe asset demand.

[2]See Rogoff and Stavrakeva (2008) for discussion of previous attempts of exchange rate forecasting informed by structural models.

Figure 1: Japanese Life Insurer Hedge Ratio



Notes: The hedge ratio is calculated by dividing the net notional amount of foreign currency forward and swap contracts (sold minus bought) and put options by the foreign currency-denominated asset holdings reported in public disclosures of nine large Japanese insurers. See data appendix for detail.

borrowers hedge a sizable portion of their currency mismatches. This set of participants has a particularly strong presence in the bond market.

Second, in periods of increased market volatility, countries with large positive net U.S. dollar asset holdings, which we term "dollar imbalances,"[3] experience domestic currency appreciation in both spot and forward exchange rate markets whereas countries with negative dollar imbalances experience currency depreciation. Importantly, the changes in forward exchange rates are larger than those of the spot exchange rate after adjusting for interest rate differentials. This difference in exchange rate adjustment between the forward and

[3]Our primary analyses focus on net external U.S. dollar debt asset holdings, because FX hedging is more prevalent for fixed income assets than for equities, as discussed in sections 1 and 4. Results are robust to using alternative measures such as net international investment positions.

spot markets produces an increase in the dispersion of cross-currency bases, in line with the direction and magnitude of the dollar asset imbalances.[4]

Lastly, during market distress, countries with a positive dollar imbalance – those holding a large amount of dollar-denominated assets – draw on the central bank swap line more so than countries that have a little or negative dollar imbalance, in absolute dollar amount and as a fraction of their gross domestic product. This observation provides a more nuanced view on the role of the Federal Reserve as the world's "lender of last resort." The countries that typically are in dollar debt do not utilize the dollar liquidity swap line; rather the "dollar rich" countries with large net dollar asset holdings are the ones that draw on the swap line the most.

To explain these stylized facts, we build a stylized model of currency hedging demand and its impact on exchange rate markets. We consider a foreign country and an associated representative investor who owns a portfolio of U.S. dollar denominated assets. This risk-averse investor chooses to optimally hedge a fraction of her net foreign asset position with forward (or swap [5]) contracts to stabilize the future payoff of her portfolio in domestic currency. The investor's optimal currency hedge ratio increases with the expected exchange rate volatility. If the investor is a net purchaser of foreign assets, then she hedges her exchange rate risk by selling dollars in the forward market. On the other hand, a net borrower hedges exchange rate risk by buying dollars forward. Hence, the quantity of dollar

[4] A non-zero cross-currency basis (or currency basis) indicates a breakdown of the covered interest rate parity condition as previously studied by Du, Tepper, and Verdelhan (2018), among others. In this paper, we emphasize the demand side in explaining the cross-sectional heterogeneity in the currency bases.

[5] A FX swap is composed of a spot and a forward transaction. A swap of yen for dollars is equivalent to a purchase of dollars against yen in the spot market and simultaneous selling of dollars against yen in the forward market.

forwards demanded depends on the product of the country's hedge ratio and net foreign asset position.[6]

To satisfy investors' hedging demands, financial intermediaries produce forwards by trading the spot exchange rate along with the two countries' interest rates. Take, for example, Japan, which has substantial investor holdings of dollar assets and a positive foreign asset position. The representative Japanese investor hedges her exchange rate exposure by selling dollars and buying yen in the forward market with a financial intermediary. Hence, the financial intermediary must supply yen in the forward market, by borrowing in dollars, converting dollars to yen in the spot market, and holding yen deposits until the forward contract's delivery.

The demand to hedge exchange rate risk and the associated intermediation generate price pressure in both the spot and forward exchange rates. The difference in movement between forward and spot exchange rates is particularly informative about the interaction between hedging demand and intermediary constraints. As the intermediary has alternative competing investment opportunities, it therefore charges a spread for providing liquidity in forward markets. In our example, the forward price of the yen becomes elevated and the resulting pricing anomaly is captured by the cross-currency basis.

Investor hedging demand combined with constrained financial intermediation generates predictable movements in forward and spot exchange rates. When expected exchange rate volatility increases, the risk-averse investor optimally chooses to hedge a larger fraction of her dollar imbalance. This rise in a country's hedge ratio increases the magnitude of the investor's demand for forwards in proportion to the country's dollar imbalance. Countries that are net savers should observe a cross-currency basis and spot exchange rate movement

[6] Throughout the paper, we illustrate the demand for forward contracts and intermediaries that deal in forwards. In practice, however, forwards are often packaged and traded as swap contracts.

in the opposite direction of countries that are net borrowers, because their hedging demand differs in direction.

Taking the model predictions to the data, we find empirical support for the hedging channel of exchange rate determination in the behavior of both forward and spot exchange rates. We regress exchange rate returns and changes in currency bases on changes in expected exchange rate volatility interacted with countries' dollar imbalances, and we show there is strong and predictable comovement in forward and spot exchange rates in line with countries' dollar imbalances. Consistent with our model, countries with more positive dollar imbalances have spot and forward exchange rates that systematically appreciate when expected exchange rate volatility increases.

In addition to explaining contemporaneous movements in exchange rates, we show the currency hedging mechanism forecasts exchange rate returns as well. As the optimized hedge ratio follows mean-reverting expected exchange rate volatility[7], our hedging demand measures also predictably reverse. Our proxy for individual currency hedging demand— the interaction of countries' dollar imbalances and expected exchange rate volatility— forecasts conditional exchange rate returns of one quarter to one year horizons in a panel regression with currency fixed effects.

Finally, we show countries' dollar imbalances explain heterogeneity in the usage of dollar swap lines by different central banks during the COVID-19 market distress. Currency regions with large positive dollar investments (e.g. the euro area and Japan) need to borrow in dollars to produce currency forwards to satisfy hedging needs on their dollar investment. As a result, we observe larger draws on the dollar liquidity swap lines in countries with large positive dollar imbalances, whereas regions with negative dollar imbalances had zero or little swap

[7]Volatilities in financial markets are predictably mean reverting and often studied with ARCH models (Engle, 2004)

line usage. Additionally, the maturity of the swap line draws reflects the relative usage of the swap line for hedging versus funding needs. The longer maturity of swap line draws during the COVID-19 pandemic suggests a greater hedging demand compared with the usage of swap lines during the Global Financial Crisis. These results highlight the importance of understanding currency hedging motives when conducting central bank operations.

Related Literature. Our paper is broadly inspired by the exchange rate disconnect literature. Since the influential work of Meese and Rogoff (1983), a large literature has tried to connect economic variables with exchange rates. Recent empirical work has found some predictive power using the cyclical component of net external balances (Gourinchas and Rey, 2007), investor capital flows (Evans and Lyons, 2002; Froot and Ramadorai, 2005; Camanho, Hau, and Rey, 2018), and quanto risk-premia (Kremens and Martin, 2019). More broadly, Lilley, Maggiori, Neiman, and Schreger (2019) and Lilley and Rinaldi (2020) show proxies for global risk appetite and risk premia explain a significant share of currency returns after the Global Financial Crisis.[8] We contribute to this literature by linking the hedged part of investor portfolios to exchange rate dynamics, which helps to explain the reconnect between spot exchange rates and external imbalances in recent years along with several additional facts.

From a theory perspective, our paper is most closely related to the literature studying portfolio balance effects in currency markets (Gabaix and Maggiori, 2015; Greenwood, Hanson, Stein, and Sunderam, 2020; Gourinchas, Ray, and Vayanos, 2020). The portfolio balance view argues for a quantity driven, supply-and-demand approach towards explaining

[8] A related literature on currency risk premia identifies various country-level characteristics that could lead to differences in unconditional exchange rate returns. These characteristics include country size (Hassan, 2013), financial development (Maggiori, 2017), resilience to disaster risk (Farhi and Gabaix, 2016) and location in the trade network (Richmond, 2019). The relationship between overall external imbalances and currency excess returns has been shown previously in Della Corte, Riddiough, and Sarno (2016) and Wiriadinata (2020). See Hassan and Zhang (2021) for a literature review.

asset prices, and has been successful in explaining puzzles in bonds (Vayanos and Vila, 2009; Greenwood and Vayanos, 2010; Krishnamurthy and Vissing-Jorgensen, 2011), swap spreads (Klinger and Sundaresan, 2019), mortgage-backed securities (Hanson, 2014), and equities (Shleifer, 1986). Most relevant to our paper is Gabaix and Maggiori (2015), who highlight the role of financial intermediaries in determining spot exchange rates and Greenwood et al. (2020); Gourinchas et al. (2020), who consider bond term premia and exchange rates jointly through a model of bond investors that operate in multiple markets. Relative to these studies, we highlight the demand-side factor and show the currency hedging channel allows a connection of exchange rates to economic variables.

Finally, our paper relates to the growing body of literature studying persistent violations of covered interest rate parity (CIP). Much this literature shows how regulation and shocks to the supply of dollar funding amplify cross-currency bases (Du et al., 2018; Cenedese, Della Corte, and Wang, 2020).[9] Others have shown the magnitude of CIP violations covary systematically with the broad dollar exchange rate (Avdjiev, Du, Koch, and Shin, 2019; Jiang et al., 2019; Engel and Wu, 2019). Most related to our paper are two recent contributions that also emphasize demand-side factors in driving cross-currency bases. Borio, Iqbal, McCauley, McGuire, and Sushko (2018) provides evidence that exchange rate hedging behavior can drive the cross-currency bases for the euro, yen and Australian dollar. Hazelkorn, Moskowitz, and Vasudevan (2020) study deviations from the law of one price between futures and spot prices in equities and FX with a focus on leverage demand. Relative to these studies, we contribute to the literature by showing both theoretically and empirically how hedging demand connects macroeconomic fundamentals to a much broader set of exchange rate phenomenon and across G-10 currencies.

[9]Other contributions to this strand of literature include Du, Im, and Schreger (2018); Liao (2020); Du, Hebert, and Huber (2019).

1 Currency hedging and institutional details

This section provides additional motivating evidence and institutional details indicating the widespread use of currency hedges in financial markets today.[10] Figure 1 shows large Japanese insurers substantially hedge their foreign asset portfolios against currency risk. This high currency hedge ratio is not unique to Japanese insurers, but rather is the norm among large non-U.S. institutional investors such as pensions and insurers. Many countries have regulations that restrict currency mismatch and encourages currency hedging for foreign assets.[11] Furthermore, the use of currency hedges are not limited to investors. Borrowers such as large global corporate debt issuers also frequently engage in currency-hedged foreign debt issuance in order to obtain cheaper borrowing costs (Liao, 2020; Caramichael, Gopinath, and Liao, 2021).[12] Additionally, the importance of FX hedging on financial intermediation and the real economy can be seen through policy measures that curbed the use of FX derivatives and resulted in unintended consequences on non-financial borrowers (Keller, 2019; Jung, 2020).

Table 1 summarizes regulatory requirements on pension and insurance sectors and estimat FX hedging ratios for the countries associated with our sample of G-10 currencies. The regulations and currency match requirements are mainly applicable to large institutional investors such as pensions and insurers. These two sectors hold relatively large amounts of debt investments and have been documented to have a large impact on yield curve (Greenwood

[10] For additional institutional details discussing the increase in currency hedging over the last two decades, see Appendix A.

[11] For instance, pension investment regulations in Germany, Switzerland, Denmark and Italy each mandate at least 70% to 80% currency matching between assets and liabilities (OECD Survey of investment regulation of pension funds, 2019). Moreover, the Solvency II Directive imposes a capital charge (usually 25%) on currency mismatches of European and U.K. insurers.

[12] Large firms that likely have superior access to currency hedging tend to have less FX exposure in their valuation relative to smaller firms (Dominguez and Tesar, 2006).

and Vissing-Jorgensen, 2018) and swap spreads (Klinger and Sundaresan, 2019). Australia additionally provides country-level surveys of foreign currency exposure and hedging, which shows a much higher level of hedging for debt relative to equities. Even absent of regulations, the high hedging ratio for debt is unsurprising because exchange rate risk is large relative to fixed income returns but small relative to equity returns, and the risk-minimizing currency strategy for a global bond investor is close to a full currency hedge (Campbell, Serfaty-De Medeiros, and Viceira, 2010). Sialm and Zhu (2020), for instance, find that 90% of U.S. international fixed income funds use currency forwards to manage their foreign exchange exposure. Motivated by this evidence, we employ measures of dollar imbalances that exclude equity portfolio holdings to proxy for hedging demand.

2 Theory

We present a model of exchange rate determination that links exchange rate volatility with hedging demand, external imbalances and asset prices. Two time periods exist, $t = 1, 2$. The model consists of N countries, where each country contains a representative investor. A currency trader manufactures forwards by trading the spot exchange rate while borrowing and lending in the associated currencies. The asset space consists of risk-free assets in each of the N countries as well as in the U.S. The risk-free rate in country n is denoted $1 + r^n$, and the U.S. risk-free rate is denoted $1 + r^D$. We let S_t^n denote the spot exchange rate in period t, and we let F^n denote the price of currency forward contract at $t = 1$ that settles at $t = 2$. Both S_t^n and F^n are quoted in terms of foreign currency per dollar.

2.1 Hedging Demand

In period 1, we assume the representative investor in country n has a pre-existing net external position of X^n in U.S. dollar denominated debt that matures in period 2 and earns the return $1+r^D$. In period 2, the country-n investor converts her dollar position into domestic currency for consumption. We assume investors exhibit mean-variance utility:

$$U^n = \mathbb{E}\left[W_2^n\right] - \frac{\gamma}{2}\text{Var}\left[W_2^n\right],$$

where W_2^n is the investor n wealth in domestic currency, and γ is a coefficient of risk aversion.

The country-n investor can hedge her exchange rate exposure by trading dollars in the forward market.[13] She takes the forward exchange rate and interest rates as given, and she chooses her optimal hedge ratio h^n. Her second period wealth given a hedge ratio h^n is

$$W_2^n = \underbrace{h^n(1+r^D)X^nF^n}_{\text{hedged}} + \underbrace{(1-h^n)(1+r^D)X^nS_2^n}_{\text{unhedged}}.$$

Solving the investor's problem shows her optimal hedge ratio is given by

$$h^n = 1 - \frac{\mathbb{E}\left[S_2^n\right] - F^n}{\text{Var}[S_2^n]X^n\gamma(1+r^D)}. \tag{1}$$

Thus, the investor's optimal hedging behavior broadly mimics the hedge ratio shown in Figure 1. The investor increases her hedge ratio in response to higher exchange rate volatility

[13] If the country-n investor has a positive external imbalance in U.S. dollars at the end of period 1 ($X^n > 0$), she receives dollars in period 2 and wants to exchange those dollars into domestic currency. She hedges her exchange rate exposure by selling dollars in the forward market. On the other hand, if the country-n investor has a negative external imbalance ($X^n < 0$), then she owes dollars in period 2 and hedges her exposure by buying dollars in the forward market.

increases. In addition, her optimal hedge ratio is directly proportional to her coefficient of risk aversion and the magnitude of her imbalance.

2.2 Supply of Forwards

A currency forward trader (or equivalently FX swap trader) exists who devotes capital to providing liquidity in forward currency markets and an alternative investment opportunity that provides the profit $G(I)$ for an investment of I. This forward currency trader specializes in producing forwards and does not bear exchange rate risk.

Assumption 1. *For a given positive investment $I > 0$, we assume $G(I) > 0$, $G'(I) > 0$, and $G''(I) < 0$.*

Formally, we assume investments in alternative opportunities lead to positive profits, that these profits are increasing in the size of the investment, and that the investment process exhibits decreasing returns to scale.

Letting q^n denote the trader's position in dollars take in period 1 to provide liquidity for the country-n investor, we can show the the forward trader ultimately earns a profit of

$$b^n = q^n \left((1 + r^D) - \frac{S^n}{F^n}(1 + r^n) \right) \tag{2}$$

from liquidity provision.[14] The term in the parenthesis, b^n, is defined as the cross-currency basis for country-n and reflects the difference between the actual dollar risk-free rate and

[14] If $X^n > 0$, the country-n investor sells dollars and buys currency n in the forward market against the forward trader. To provide liquidity (without incurring currency risk), the forward trader borrows in dollars ($q^n < 0$), and buys currency n in the spot market in period 1 with her borrowed dollars. Her converted cash in currency n then accrues an interest of r^n. In period 2, the trader delivers currency n to the country n investor and receives dollars at the forward price F^n. Finally, the trader pays back her dollar loan: $q^n(1+r^D)$. Ultimately, the trader earns a profit of dollars from this transaction. The case with $X^n < 0$ is analogous.

FX-implied dollar risk-free rate. A profit maximizing forward trader should only provide liquidity in forward markets when doing so is profitable: $q^n b^n \geq 0$. Therefore, an immediate result is that b^n must be negative when X^n is positive, and vice versa, to incentivize the trader to supply liquidity.

Following Gârleanu and Pedersen (2011) and Ivashina, Scharfstein, and Stein (2015), we assume the forward trader must set aside a haircut $\kappa H(q^n)$ when she devotes q^n dollars to providing liquidity for the country-n investor, and κ is a positive constant. Moreover, we assume the trader's total haircut is the sum of the haircuts she sets aside for each position, $\kappa \sum_n H(q^n)$.[15]

Assumption 2. *For a non-zero position q, we assume (1) $H(q) > 0$, (2) $H'(q) > 0$ for $q > 0$, $H'(q) < 0$ for $q < 0$, and (3) $H''(q) > 0$. We also assume $H(0) = H'(0) = H''(0) = 0$.*

Assumption 2 implies the cost of intermediation is increasing and convex in the magnitude of the position. The convex cost function might reflect the cost of holding concentrated position in a single currency. [16]

Finally, we assume the trader has an initial wealth of W dollars. Hence, after providing liquidity to forward markets, the trader is left with $I = W - \kappa \sum_n H(q^n)$ dollars to devote to alternative investments. The trader chooses how much capital to devote to providing

[15] For simplicity, we assume all haircuts are paid in dollars. More generally, the forward trader can end up needing to pay haircuts in multiple currencies, which would make the expectation of $\sum_n H(q^n)$ depend on the covariance matrix of currency returns. For an example of a model with risky exchange rate arbitrage in multiple currencies, see Hau (2014).

[16] Even though the forward trader faces no exchange rate risk in the model, arbitrage in basis trades has known limits (Shleifer and Vishny, 1997).

liquidity for each currency:

$$\max_{q^n} \sum_n b^n q^n + G\left(W - \kappa \sum_n H\left(q^n\right)\right).$$

The trader's first order condition shows the gain from devoting an additional unit of capital to providing liquidity in the forward dollar market is equal to the marginal profitability of the alternative investment:

$$b^n = \kappa G'\left(W - \kappa \sum_k H\left(q^k\right)\right) H'\left(q^n\right)$$

The country-n cross-currency basis b^n is a result of two forces: the country-n investor's hedging demand and the average cost of financial intermediation. If the country-n investor does not demand dollars in the forward market, $q^n = 0$ and the basis reduces to zero. Similarly, if providing liquidity in the forward market is costless, $\kappa = 0$, then the basis reduces to zero as well.

2.3 Spot Exchange Rates

We assume bilateral spot exchange rates in each period clear the market for each currency:

$$\frac{\xi^n}{S^n} - \iota^D - q^n = 0. \tag{3}$$

where ξ^n represents additional demand for dollars from country-n households denominated in the domestic currency. Hence, ξ^n/S^n is accounted for in dollars. ι^n represents the demand for country-n currency from U.S. households. Both ξ^n and ι^n represent demand for foreign currencies from sectors of the economy that are not explicitly modelled. As an example, Gabaix and Maggiori (2015) provide a model of exchange rate determination in which the net demand for dollars is a function of goods traded as well as financial flows. In such a model, $(\xi^n/S^n) - \iota^D$ corresponds with the net exports from the U.S. to the rest of the world. The unmodeled residual net demand can also originate from the financial sector. For instance, ι^D can represent the supply of dollar by a broad set of financial intermediaries that takes on exchange rate risk and engages in fixed income arbitrage activities across global bond markets as modeled in Greenwood et al. (2020).[17]

2.4 Equilibrium

In equilibrium, the forward trader takes the country-n hedging demand as given, and enters into transactions to supply dollars in the forward market:

$$q^n = -h^n X^n. \tag{4}$$

Market clearing conditions in the forward and spot exchange rate markets determine the cross-currency basis b^n, the forward rate F^n, and the spot exchange rate S^n as a function of the hedge ratios h^n, each country's external imbalance X^n, and the demand for foreign exchange from other sectors of the economy, ι^D and ξ^n.

[17] The forward trader modeled above differs in that it only arbitrages CIP deviations and does not take on exchange rate risk. Such specialization can reflect market segmentation in arbitrage activities and differences in the level of risk tolerance, sophistication, and capital cost in providing arbitrage.

Lemma 1. *The equilibrium is described by the following four equations:*

$$h^n = 1 - \frac{\mathbb{E}\left[S_2^n\right] - F^n}{Var[S_2^n]X^n\gamma(1+r^D)}, \tag{5}$$

$$b^n = \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H'\left(-h^n X^n\right), \tag{6}$$

$$S^n = \frac{\xi^n}{\iota^D - h^n X^n}, \tag{7}$$

$$F^n = \frac{\xi^n\left(1 + r^n\right)}{\left(\iota^D - h^n X^n\right)\left(1 + r^D - \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H'\left(-h^n X^n\right)\right)}, \tag{8}$$

2.5 Model Predictions

We use our model to characterize the behavior of cross-currency bases and spot exchange rates with respect to external imbalances and exchange rate volatility. In particular, we show the exchange rates of various countries should load heterogenously on domestic and global exchange rate volatility, and these loadings should be in line with countries' external imbalances.

Our first proposition characterizes the unconditional moments of the cross-currency basis, which have been derived previously in Borio et al. (2018). However, we discuss these results briefly here to build intuition for results in later sections.

Proposition 1. *(Unconditional currency basis)*

A country with a positive external imbalance ($X > 0$) *has a negative basis* ($b < 0$)*, indicating an overvaluation of its currency forward. A country with a negative external imbalance* ($X < 0$) *has a positive basis* ($b > 0$)*, indicating an undervaluation of its currency forward. Countries with larger imbalances are subject to larger cross-currency bases.*

A country's unconditional currency basis is a direct measure of the country's external financial imbalance and its investors' desires to hedge this imbalance.[18] Intuitively, investors in countries with positive external imbalances demand domestic currency in forward markets for hedging purposes, and therefore pay a premium to purchase domestic currency in the forward market because producing currency forward is costly. This premium shows up as a negative currency basis. Conversely, countries with negative external imbalances have forward exchange rates that are unconditionally depressed relative to their spot. Investors in countries with negative external imbalances demand dollars in forward markets, and must pay a premium to exchange domestic currency for forward dollars.

Proposition 2. *(Conditional currency basis)*
The magnitude of the country-n currency basis, $|b^n|$, increases with respect to both its own expected exchange rate volatility, $Var\left[S_2^n\right]$, as well as the expected exchange rate volatility of foreign countries, $Var\left[S_2^m\right]$ for $m \neq n$,

$$sign\left[\frac{\partial b^n}{\partial Var[S_2^n]}\right] = sign\left[\frac{\partial b^n}{\partial Var[S_2^m]}\right] = -sign\left[X^n\right]. \tag{9}$$

Domestic and global exchange rate volatility raise the magnitude of currency bases through two potential channels.[19] First, increases in the exchange rate volatility of a country n incentivizes the country n investor to hedge a greater fraction of her external imbalance. The country n basis therefore increases because the forward trader provides more liquidity to the currency n forward market, which is captured by an increase in the forward trader's country n haircut. In addition, the forward trader faces greater balance sheet constraints

[18]See Appendix B.1 for the proof of Proposition 1.
[19]See Appendix B.2 for the proof of Proposition 2.

overall, because of her limited intermediation capacity. As a result, the currency basis of any single country should also depend on global exchange rate volatility as a result of the exchange rate hedging.[20]

Crucially, Proposition 2 shows a country's external imbalance identifies cross-sectional differences in the loading of currency bases on exchange rate volatility. For countries with positive imbalances, the country's forward exchange rate becomes even more elevated relative to the spot exchange rate (b^n becomes more negative). By contrast, increases in exchange rate volatility further depress the forward rates of countries with negative external imbalances (b^n becomes more positive). Countries with larger external imbalances observe larger movements in their forward exchange rates as the costs of providing additional liquidity in the forward markets grow in proportion to the imbalance. Ultimately, Proposition 2 explains the widening of currency basis spreads during times of financial distress as the currency bases of countries with positive and negative external imbalances diverge.

Next, we turn to the spot exchange rate market. Hedging demand in the forward market affects the spot market, because forward traders transact in spot exchange rate markets to produce forwards.

Proposition 3. *(Spot exchange rate)*

Countries with positive imbalances have home currency that appreciates when expected future exchange rate volatility increases, and countries with negative imbalances have home currency that depreciates when expected exchange rate volatility increases,

$$sign\left[\frac{\partial S^n}{\partial Var[S_2^n]}\right] = -sign\left[X^n\right].$$

[20]Increases in κ can also increase the magnitude of currency bases globally, and can be interpreted as directly capturing increases in balance sheet costs. Du et al. (2018) show currency bases are partially driven by bank balance sheet costs.

As investors increase their hedge ratio in response to increased domestic exchange rate volatility, forward traders transact in spot exchange rate markets to satisfy the additional demand in forward markets.[21] For a country n with a positive imbalance, forward traders use dollars to purchase additional units of country n currency, which leads to currency n appreciation. By similar logic, countries with large negative external imbalances experience domestic currency depreciation.

Proposition 3 shows the magnitude of the hedging effect on spot exchange rate markets is directly proportional to the relative magnitude between the demand for dollars originating from hedging demand, and the demand for dollars from other sectors of the economy. Naturally, as the quantity of dollars required for hedging services increases, increases in the hedge ratio and forward production have larger impacts on the spot exchange rate.

2.6 Term Structure of Currency Basis

Recent work by Du et al. (2019) shows the term structure of cross-currency bases varies systematically over the business cycle. We extend the benchmark model by an additional period and show how hedging demand explains the systematic variation in the term structure of currency bases. We provide the general setup below but leave the model details for interested readers in Appendix B.4. Three time periods exist, $t = 1, 2, 3$. In period 1, the country-n investor still has a net external imbalance of X^n, but she now hedges her period 3 payoff. The country-n investor can either trade dollars two periods forward, or trade dollars one period forward and then roll over her hedge position in period 2. For simplicity, we also take the hedging ratio as exogenous for this subsection.

[21]See Appendix B.3 for the proof of Proposition 3

In period 2, the forward trader faces uncertainty in investors' hedging demands. With probability π, the hedging demand in period 2 equals h_L^n, and with probability $1-\pi$, the hedging demand in period 2 equals h_H^n. $b_1^{n,(2)}$ denotes the cross-currency basis in period 1 on the forward exchange rate two periods ahead (in period 3), b_1^n denotes the one-period currency basis in period 1, $b_{2,k}^n$ denotes the one-period basis in period 2 when the hedging demand equals h_k^n for $k = L, H$, and $1 + r_2^n$ denotes the one-period risk-free rate in period 2.

Solving the trader's profit maximization problem shows the currency basis on the two-period forward is a weighted average of the one-period bases in periods 1 and 2.

Proposition 4. *The period 1 cross-currency basis for the period 3 forward exchange rate is:*

$$b_1^{n,(2)} = \frac{b_1^n(1+r_2^n)}{2} + \frac{\pi b_{2,L}^n + (1-\pi)b_{2,H}^n}{2}. \tag{10}$$

Equation (10) has a very natural interpretation: the two-period cross-currency basis is a weighted average of the expected period 2 basis and the period 1 basis. If, in expectation, the currency basis is expected to increase in magnitude from period 1 to period 2, the two-period basis $b_1^{n,(2)}$ should be larger in magnitude than the period 1 basis b_1^n. Proposition 2 showed currency bases increase in magnitude in response to increases in hedging demand or increases in the costs of financial intermediation. Hence, we should expect currency bases to increase in magnitude with maturity whenever the current magnitude of currency bases is relatively low (and is therefore likely to increase in the future). Conversely, we should expect currency bases to decrease in magnitude with maturity whenever the current magnitude of currency bases is relatively high.

3 Data

We assess the model predictions for the effects of currency hedging on forward and spot exchange rates, focusing on the G-10 currency regions: Australia (AUD), Canada (CAD), Switzerland (CHF), the Euro area (EUR), the United Kingdom (GBP), Japan (JPY), Norway (NOK), New Zealand (NZD), Sweden (SEK) and the United States (USD). These currencies are the most liquid and commonly traded free-floating currencies without significant capital control impediments.[22]

We measure the quantity of dollar imbalances at the country level using data on net U.S. dollar foreign debt holdings obtained from the International Monetary Fund. These measures are provided by Benetrix, Gautam, Juvenal, and Schmitz (2019), and capture the currency composition of countries' international investment positions from 1990 to 2017. Because these positions are relatively stable over time, we forward-fill the data to the present day.

We focus our main analysis on measures of dollar debt holdings for two main reasons. First, we focus on dollar asset position to match to our pricing measures of bilateral exchange rates versus the U.S. dollar. Second, we focus on debt holdings, rather than debt and equity holdings, because the use of currency hedges is more prevalent for debt instruments. Cross-boarder debt investments are dominated by institutional investors that hedge a greater fraction of their currency exposure either due to regulatory mandates or risk constraints, likely because exchange rate risks are larger for debt investments than for equity investments. For instance, Campbell et al. (2010) shows that the risk-minimizing currency strategy for a

[22]The Chinese yuan and Hong Kong dollar are also among the most frequently transacted, but they are actively managed against the U.S. dollar and affected by capital flow restrictions.

global bond investor is close to a full currency hedge, whereas the currency risk is attractive for global equity investors.[23]

We obtain measures of forward-looking currency volatility with at-the-money options implied volatilities of one-year maturity. Alternative maturity choices (e.g. 1 month and 3 month) also yield similar results. The data is from Bloomberg.

To measure the price impact of hedging dollar imbalances, we use Libor-based currency basis defined as the difference between the forward premium and interest rate differential:

$$b_t^n \approx (f_{t,t+1}^n - s_t^n) + (r_t^D - r_t^n), \tag{11}$$

where r_t^D and r_t^n are the Libor interest rates in the U.S. and foreign country n, respectively.[24] As defined here and equivalently in equation (2) in levels, foreign currency appreciation in the forward market is represented by a more negative cross-currency basis b_t^n. We focus on Libor rates and forward rates at the one-year maturity, because forwards with maturities of less than one year are often affected by temporary spikes near quarter-ends and year-ends, due to banks' regulatory window dressing (Du et al., 2018; Correa, Du, and Liao, 2020).[25] We additionally analyze the relative pricing of call and put options as captured by currency risk reversals to provide evidence corroborating our hedging channel. Table 2 provides summary statistics for each of the variables used in our analysis.

[23]To supplement our primary measure of external imbalance based on dollar debt holding positions, we also show results based on the aggregate NIIP, and the net debt and foreign direct investment (FDI) components of NIIP. The net debt component of NIIP comprises both portfolio debt other debt investment. The net FDI component of NIIP comprises both debt and equity FDI. FDIs are investments in which the direct investor owns at least 10% of the voting power in the direct investment enterprise. These results are presented in the appendix, and they support the primary results using the measure on net dollar debt holding. The alternative measures indicate dollar net debt holdings are representative of the overall external imbalance. Furthermore, the disaggregated measures using data that separate debt and equity NIIP positions validates the theoretical insight that, indeed, greater levels of currency hedging occurs in debt than in equities.

[24]All market data are from Bloomberg.

[25]Figure A1 shows the time series of cross-currency bases for G10 currencies since 2000.

4 Empirical Results

In this section, we present evidence for each of our propositions, and characterize the systematic relationship between exchange rate returns, currency bases, and exchange rate volatility. Unfortunately, there is no data set that directly observes hedge ratios across a broad set of countries. Otherwise, we could provide direct evidence on the relationship between exchange rate hedging and asset prices. In lieu of this direct evidence, we instead present a number of empirical results that the systematic relationship between forward and spot exchange rates and exchange rate volatility are consistent with currency hedging behavior.

Consistent with Proposition 1, Figure 2 shows there exists a strong inverse relationship between countries' currency bases and their dollar imbalances both before and after the Global Financial Crisis (GFC) in 2008.[26] To reiterate, a negative basis indicates the currency's forward price is overvalued relative to its spot price after adjusting for the interest rate differentials, while a positive basis indicates an undervaluation of the currency in forward markets. Indeed, Figure 2 shows that investors in countries with more positive dollar debt imbalances must pay a higher currency basis in order to hedge their exchange rate exposure. Comparing the pre- and post- crisis samples (Panel A and B respectively), the slope of the inverse relationship between currency bases and dollar imbalance rose in the post-crisis period, this increase plausibly reflects a stronger hedging demand coupled with more intermediary constraints after the GFC.

Table 3 formally tests for the negative relationship between countries' net dollar imbalances and their cross-currency basis. Columns (1) and (2) focus on the relationship between currency basis and a general measure of imbalance — the NIIP. Columns (3) and (4) show

[26]In earlier work, Borio et al. (2018) showed hedging demand explained the unconditional magnitude of currency bases for Australian dollar, the euro and the Japanese yen.

the inverse relationship between external imbalances and unconditional currency bases is primarily driven by debt imbalances. The point estimate of -29.8 in column (3) indicates that a 10% increase in a country's dollar imbalance coincides with an additional 2.98 bp increase in the country's cross-currency basis. By contrast, the coefficients on equity imbalances in columns (5) and (6) are statistically insignificant. Thus, equity imbalances provide much less explanatory power, which aligns with the theoretical prediction of greater currency hedging in debt instruments (Campbell et al., 2010).

4.1 Dynamics of Forward and Spot Exchange Rates

In the following section, we show the dynamics of spot and forward exchange rates vary systematically with fluctuations in exchange rate volatility and in accordance with their dollar debt imbalances. To evaluate the variation in exchange rates, we run panel regressions of the following form:

$$\Delta y_t^n = \alpha^n + \delta_t + \beta \left(\text{Imbalance}_t^n\right) \times \left(\Delta \text{FX Vol.}_t^n\right) + \Xi_t^n + \varepsilon_t^n, \tag{12}$$

where Δy_t^n captures changes in the variable of interest (i.e., the log spot exchange rate or currency basis), and β^n is the coefficient of interest on the interaction term between the coutry's U.S. dollar imbalance, and changes in expected exchange rate volatility. We include date and currency fixed effects in each of our regressions, and we also double cluster our standard errors by date and currency.

Columns (1) and (2) of Table 4 provide evidence for Proposition 2. The coefficients on the interaction terms between a country's U.S. dollar imbalance and exchange rate volatility are both negative and statistically significant. Thus, a country's currency basis increases in proportion to its dollar imbalance when expected exchange rate volatility increases. For a country with an external USD imbalance equal to its GDP, a one-standard-deviation increase in its expected exchange rate volatility increases its currency basis by 3.19 bps in magnitude. Countries with positive imbalances observe their currency bases become more negative and their currency become more overvalued in forward markets. On the other hand, countries with negative imblances observe their currency bases become more positive, and their currency become more undervalued in forward markets.

The results in columns (1) and (2) show that currency bases appear to respond to measures of both domestic exchange rate volatility, as well as global exchange rate volatility. While this result does align with Proposition 2, expected exchange rate volatility tends to be highly correlated across countries empirically. Thus, it is perhaps less surprising that currency bases respond to both domestic and global volatility.

Columns (3) and (4) of Table 4 provide evidence for Proposition 3. The coeffiecients on the interaction terms between U.S. dollar imbalances and expected exchange rate volatility are negative and statistically significant. Thus, for a country with an external USD imbalance equal to its GDP, a one-standard-deviation increase in its expected exchange rate volatility explains a currency appreciation of 1.27 percent. The currencies of countries with more positive U.S. dollar imbalances appreciate relative to countries with more negative imbalances in response to increases in expected exchange rate volatility. Moreover, even though exchange rates only respond to domestic exchange rate volatility, the results in column (4) are not surprising given that our measure of exchange rate volatility is highly correlated across countries.

While the results in Table 4 are consistent with the hedging rate channel of exchange rate determination, there are indeed other potential explanations for some of the patterns observed in forward and spot exchange rates. However, we want to stress that the strength of the hedging channel lies in the fact that it can explain movements in the full cross-section of currencies. For example, the recent literature on the impact of supply side factors on currency bases shows how time-series variation in balance sheet constraints increases the magnitude of currency bases. These supply-side effects are indeed captured in our model through the $G(\cdot)$ function. Yet, we show that accounting for hedging demand is crucial for explaining the fact that both the forward and spot exchange rates of net debtor countries (e.g., the Australian dollar) move in opposite direction from currencies of net creditor countries (e.g., the Japanese yen).

4.2 Exchange Rate Forecasting

Having shown that hedging behavior explains contemporaneous movements in forward and spot exchange rates, we now show that currency hedging also predicts future exchange rate returns. Exchange rates are predictable in our framework due to the predictability in the reversion of currency hedging demand. Expected exchange rate volatility and the associated response in optimal hedging ratio tend to be mean reverting.[27] During periods of higher expected exchange rate volatility, investors optimally increase their hedge positions, and financial intermediaries produce forward currency to meet this demand. As expected exchange rate volatility declines, investors and financial intermediaries will naturally unwind their positions. More concretely, when expected Japanese yen volatility increases, the Japanese yen appreciates as intermediaries purchase yen to to produce yen forward. However, the high level of yen expected volatility tends to decline over time, which results in future yen depreciation as hedging is reduced and financial intermediaries unwind exposures.

[27] Previous studies such as Engle (2004) have shown that financial market volatilities are mean reverting.

Thus, the hedging channel yields an additional prediction about exchange rate predictability. In a period of above average exchange rate volatility, countries with positive dollar imbalances should depreciate in the future, whereas countries with negative dollar imbalances should appreciate. In order to test this prediction, we run the following panel regression:

$$\Delta s^n_{t,t+\tau} = \alpha^n + \gamma \left(\text{Imbalance}^n_t\right) \times \left(\text{FX Vol}^n_t\right) + \Xi^n_t + \eta^n_t, \tag{13}$$

where $s^n_{t,t+\tau}$ is the log spot exchange rate return between period t and $t+\tau$, α^n continues to capture a currency fixed effect, Ξ^n_t is a vector of controls. Notably, we interact the country n imbalance with the level of the currency n volatility, rather than the change in volatility, because a higher than average exchange rate volatility *level* will likely revert in the future. γ is the coefficient of interest, which should be positive.

Table 5 shows the results of estimating regression 13 for forecast horizions of 3, 6, 9 and 12 months. The top row shows that across all forecast horizions, an above average level of expected exchange rate volatility predicts currency depreciation for countries with positive imbalances, and currency appreciation for currencies with negative imbalances. For country with a positive imbalance equal to its GDP, a one-standard-deviation above-average exchange rate volatility predicts exchange rate depreciation of 1.47 percent over the next 3-months, 3.16 percent over the next 6 months, 4.48 percent overt the next 9 months, and 5.28 percent over the next 12 months. These estimates are both quantitatively large and statistically significant. The magnitude of the currency returns increase over time, which reflects a gradual decline in hedge ratios following a period of high exchange rate volatility.

The exchange rate returns predicted by the interaction of dollar imbalances and expected exchange rate volatility are distinct from the predictive power of each of these covariates alone. We include both dollar imbalances and volatility into the regressions as controls. The negative coefficient estimate on volatility suggests that when volatility is high, the dollar tends to depreciate against all currencies in the next 3 to 12 months. This predicted dollar depreciation corroborates the notion that our regression captures exchange rate behavior in which investors are likely decreasing exchange rate hedges in a period of declining risk and vice versa.

4.3 Carry Trade Returns

These conditional spot exchange rate returns provide an additional explanation for the highly persistent differences in interest rates and currency returns across countries, which capture differences in risk premia (Lustig and Verdelhan, 2007; Lustig, Roussanov, and Verdelhan, 2011). Intuitively, currencies that appreciate in periods of financial distress pay lower unconditional returns, because these currencies provide a hedge against states of the world in which marginal utility is high.

Expanding on this literature, we showed time-varying currency hedging behavior leads to predictable currency returns in both the time series and in the cross-section of countries that are aligned with countries' dollar imbalances. Currencies of countries with positive imbalances appreciate during periods of financial distress as a result of increased hedging demand, and depreciate when risks diminish. These currencies are therefore safer, and investing in currencies of countries with positive imbalances should yield lower returns. On the other hand, currencies of countries with negative imbalances behave in exactly the opposite manner, and thus must reward investors for taking more risk by paying higher returns.

Figure 4 shows the unconditional relationship inverse relationship between average currency excess returns and forward premia against countries' net dollar debt holdings.[28] Cur-

[28] We calculate the log currency excess returns as: $rx_{t+1} = f_t - s_{t+1} = (f_t - s_t) - (s_{t+1} - s_t)$.

rencies with large positive net dollar debt investments typically embed lower currency risk premia and yield lower excess returns. Meanwhile, currencies associated with countries that have large negative net dollar debt yield higher returns. These relationships have been highlighted previously by Della Corte et al. (2016) who attributes to a global imbalance risk factor in explaining this cross-sectional variation in currency excess returns. Relative to earlier work, our exchange rate hedging channel pins down an additional mechanism to explain why countries with positive dollar imbalances have currencies that appreciate in bad times, and thus demand unconditionally lower excess returns.

4.4 The Term Structure of Currency Basis

The demand for hedging instruments can also explain the term premia of the currency basis.[29] In the theory section, Proposition 4 shows the magnitude of longer maturity forwards (and currency bases) should be larger in magnitude to compensate intermediaries for the possibility of financial crises. In other words, longer maturity forwards embed a term premium, and therefore, the term structure of currency basis is typically upward sloping in magnitude.

We test for this systematic variation in the term structure of forward exchange rates formally in Table 6. In the first two columns of Table 6, we regress the level of the 5-year minus 1-year currency basis spread on countries' U.S. dollar imbalances. The estimated coefficient is negative and highly statistically significant, which indicates that countries with negative imbalances have, on average, an upwards sloping basis term structure. By contrast, countries with positive imbalances have a downwards sloping term structure. Thus, the

[29] Recent papers have approached the term structure of currency basis from a perspective of intermediary-based asset pricing (Du et al., 2019; Augustin, Chernov, Schmid, and Song, 2020). Relative to these work, we highlight the demand drivers of the term structure.

results confirm that the unconditional term structure of currency bases is upwards sloping in magnitude.

Columns (3) and (4) show the results of regressing changes in the 5-year minus 1-year basis spread on the interaction between countries' dollar imbalances and changes in exchange rate volatility. The positive and statistically significant coefficients show that during periods of financial distress, the term structures of cross-currency bases systematically invert: the slopes of the term structures of countries with negative dollar imbalances become more negative, and the slopes of the term structure of countries with positive dollar imbalances become more positive.

4.5 Exchange Rate Behavior During the COVID-19 Pandemic

In the previous section, our regression analysis shows countries' dollar imbalances explain systematic variation in their exchange rates in response to changes in exchange rate volatility. We now provide a more concrete example of this behavior by considering the onset of the COVID-19 pandemic as a sharp and unexpected shock to expected exchange rate volatility.[30] Figure 3 shows the level of currency bases (Panel A) and cumulative returns in spot exchange rates (Panel B) from February 1, 2020, to March 13, 2020.[32]

[30] We corroborate our evidence from the COVID-19 crisis by also analyzing exchange rate movements during two additional periods of market turmoil: the GFC and the eurozone crisis. Figure A3 captures changes in currency bases and log exchange rates during the GFC (Panel A) and the Eurozone sovereign crisis (Panel B).[31] Consistent with Propositions 2 and 3, as well as the evidence from the COVID-19 crisis, currencies with more positive dollar imbalances generally observed larger decreases in their cross-currency bases. Currencies with more positive dollar imbalances also experienced domestic currency appreciation.

[32] We end the sample on March 13 because it was the Friday before the Federal Reserve's surprise Sunday announcement of a 100 basis point cut to the Fed Funds rate, and of extensions on central bank swap lines. However, our results are qualitatively similar using a different cutoff date. Various policy measures announced by different central banks in the ensuing weeks influenced exchange rates in channels beyond our model.

The time series shows the large market movements in currency bases and log spot returns were generally consistent with dollar imbalances Panel A shows that while some currencies (e.g., Japanese yen) had bases that became sharply more negative (indicating relative over-valuation of the forward relative to the spot), other currencies (Australian and New Zealand dollars) had bases that became increasingly positive (indicating depressed forward relative to spot). Panel B shows the spot exchange rate returns during this period generally mirrored the movements in the currency basis. Yen spot exchange rates appreciated the most, while the yen had the most overvalued forward relative to spot (negative basis). The Australian dollar depreciated the second-most while experiencing the most positive currency basis, indicating it had the most undervalued forward price relative to spot price. The one notable exception is the Norwegian Krone, which suffered the largest spot price decline among all G10 currencies but had little change in its currency basis. A likely explanation for the Krone's depreciation is that Norway's economy crucially depends on oil exports and the Brent Crude price declined from around \$60 to \$20 in this period.

Figure 5 further illustrates the evolution of the term structure of currency bases during the COVID-19 pandemic follows the intuition from Proposition 4. One month prior to the sudden market distress in March 2020, the term structure of cross-currency bases were indeed upward sloping in magnitude for the Australian dollar and Japanese yen. Longer maturity AUD forwards were more undervalued than shorter maturity forwards, adjusting for interest rates with the respective maturities. By contrast, longer maturity JPY forwards were more over-valued than shorter maturity JPY forwards. During the ensuing period of market distress, the increased hedging demand led shorter maturity AUD forwards to depreciate, and JPY forwards to appreciate, as presented earlier in Figures 3, thus explaining why the term structure of currency bases inverted during the crisis. This term structure inversion is intuitive because large short-term dislocations are expected to normalize over time.

4.6 Central Bank Swap Lines

Up to this point we have focused on how the exchange rate hedging channel explains the stochastic properties of exchange rates. However, our model also identifies unique channels through which central bank swap lines reduce currency bases and affect exchange rate behaviors. The Federal Reserve dollar swap lines lend dollars against foreign currency as collateral with foreign central banks as counterparties. These foreign central banks, in turn, lend dollars from the swap line to their domestic institutions on a collateralized basis. Previous studies have emphasized the use of dollar swap lines to satisfy short-term funding needs of the banking sector (Goldberg, Kennedy, and Miu, 2010; Ivashina et al., 2015) and the role of the Federal Reserve as a "lender of last resort" through the provision of loans to the rest of the world via swap lines (Bahaj and Reis, 2018). Relative to other studies, we emphasize the role of the dollar swap line in fulfilling the hedging demand from non-bank sectors of the economy. Our model also predicts that the dollar swap line is most used by countries that have a surplus of dollar investments rather than dollar debt.

In our framework, central bank swap lines influence exchange rates through two potential channels. In the first channel, the dollar swap line provides funding for intermediaries that produces hedging instruments for non-banks. Thus, central bank swap lines are useful for intermediaries providing liquidity to countries with positive external imbalances, because these intermediaries need to borrow in dollars today to produce foreign currency forward.[33] On the other hand, intermediaries providing hedging services to countries with negative

[33] Intermediaries exchange borrowed dollar for foreign currency that is delivered at maturity to foreign investors that demand exchange rate hedges on their dollar investments.

imbalances would demand foreign currency rather than U.S. dollars.[34] In the second channel, the announcement of swap lines may also affect exchange rate markets by instilling confidence in the financial sector. This channel could lower balance sheet costs and lower institutional hedging demand. The following corollary summarizes these effects:

Corollary 1. *For a country n with a positive external imbalance, swap lines reduce the magnitude of cross-currency bases b^n by funding intermediaries that provide hedging services to non-banks. Swap lines also reduce the magnitude of cross-currency bases by decreasing κ and h^n for all countries n.*

Although central bank swap lines can decrease cross-currency bases globally, Corollary 1 suggests the actual use of central bank swap lines should differ according to countries' external imbalances as a result of differential hedging demands. Countries with positive external imbalances, "dollar-rich" countries, benefit from the dollar swap line through the direct injection of dollar cash that lowers the cost of producing local currency forwards. By contrast, countries with negative external imbalances, "dollar-poor" countries, do not benefit from a direct dollar cash injection, and thus should exhibit little draws on their dollar swap lines. In fact, any draw on the dollar swap line would worsen negative external imbalances, which would widen their cross-currency basis.

Figure 6 provides evidence for this hypothesis by demonstrating the positive relationship between the maximum swap draws outstanding during the weeks following the Fed's swap line expansions, and the the associated countries' net dollar external debt holdings. Countries with low or negative net dollar debt positions made little or no use of the dollar swap line,

[34] To hedge dollar debt, debtor countries need to purchase dollar forwards. Borrowing dollars through the swap line exacerbates rather than reduces this need.

while countries with higher net dollar debt investments had larger draws in absolute amount of dollar swap line.

Even though debtor countries are generally more in need of dollars, the countries with positive dollar fixed income holdings and overall positive net foreign investments drew on the swap line the most. This counterintuitive pattern can be explained through the hedging channel. Exploiting the heterogeneity across maturity in addition to that across currencies, we find the increased demand for longer maturity swap line operations (84-days) during the COVID-19 pandemic, as opposed to the seven-day operations, likely reflect hedging demand in addition to funding demand. Because short-term FX swaps are substitutable with domestic repo funding (Correa et al., 2020), a lower fraction of short-term swap line draws relative to total swap line usage suggests swap lines were used less for funding and more for hedging purposes. At the time of the max swap line usage during the COVID-19 market distress period, the fraction of short-term (seven-day) swap usage was less than 3% of the total, whereas it was more than 40% during the most distressed days of the GFC.[35]

4.7 Hedged Demand and Options Pricing

Finally, we turn our attention to another asset class that is noticeably affected by currency hedging behavior — currency options. The relationship between currency options prices and exchange rate hedging is perhaps natural, because currency options can also be used to hedge against exchange rate risk. Prior studies have used out-of-the-money options to gauge rare disaster risk (Farhi and Gabaix, 2016; Barro and Liao, 2020) and currency crash risks (Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan, 2009; Chernov, Graveline, and

[35]Maximum swap line draws during the COVID-19 financial turmoil was $449 billion on May 27, 2020 ($436 billion for the 84-day operation and $13.3 billion for the 7-day operation). The max swap line draw during the GFC was $586 billion on December 4, 2008 ($345 billion for operations with maturities greater than 30 days and $241 billion for maturities less than 30 days).

Zviadadze, 2018; Jurek, 2014). Our hedging demand channel provides an explanation for the observed heterogeneity in the pricing of out-of-the-money calls and puts for different currencies.

The intuition is that investors in countries with net positive foreign investments can alternatively hedge against the appreciation of home currency (or, equivalently, the devaluation of their foreign currency position) by purchasing calls on their domestic currency instead of buying forwards. Therefore, we would expect hedging demand to elevate (depreciate) both the price of forwards relative to spot and the price of calls relative to puts on the domestic currency when the dollar imbalance is positive (negative).

Consistent with this intuition, we find countries with positive (negative) dollar imbalances have relatively more (less) expensive out-of-the-money call options compared with put options on their currency. This difference in the relative valuation between calls and puts also increases in times of heightened currency volatility. We use risk-reversals, defined as the implied volatility of the out-of-the-money call minus put, as a measure of the relative pricing of calls and puts for a given currency.[36]. Risk-reversals are routinely used by traders to assess the relative valuation of calls and puts and have been used in prior studies on currency options, such as in Farhi and Gabaix (2016).

Figure 7 shows the time series of risk reversals for the sample currencies. The graph highlights a few facts that resemble those of the cross-currency basis as shown in Figure A1. First, options risk reversals increased in magnitude starting in 2008, a fact highlighted in Farhi et al. (2009). Second, the figure shows substantial cross-sectional heterogeneity be-

[36]Our primary measure is the one-year 25-delta risk-reversal, defined as the implied volatility of on the call options with 25-delta minus the implied volatility of the put option with 25-delta, both of one-year maturity. The delta of the option is used in the currency market to denote an option's moneyness. The price of a 25-delta option changes by one-quarter of a unit for every one unit of change in the underlying currency price. The 25-delta risk reversal is the most frequent indicator of option skewness used in practice. We also show similar results with three month maturity options in the appendix.

tween currencies. Currency regions that have large negative dollar imbalances, for example, Australia, typically have the most negative risk-reversal, indicating a premium for put options over call options.[37] Currencies with more positive dollar imbalance (e.g., Japan), have more expensive calls relative to puts, as indicated by positive risk reversals. This positive risk-reversal indicates a more expensive hedging cost for currency appreciation than a depreciation. Lastly, the risk-reversals widen in times of crisis in directions that are aligned with the hedging demand of dollar imbalances. This dispersion indicates that a single dollar factor is unlikely to explain the dynamics of option skew.

Table 7 formally tests for the systematic relationship between currency options prices and dollar imbalances. Similar to earlier results, columns (1) and (2) show variation in U.S. dollar debt imbalances explains the unconditional variation in risk-reversals across countries. The positive and statistically significant coefficients show countries with more positive U.S. dollar imbalances indeed have more expensive calls relative to puts.

Columns (3) and (4) of Table 7 show the results of regressing changes in risk-reversals on the interaction between countries' dollar imbalances and changes in exchange rate volatility. Analogous to our earlier analysis of currency bases, we show that the magnitude of the costs of hedging exchange rate risk increases with expected exchange rate volatility. As expected exchange rate volatility increases, call options on domestic currency become relatively more expensive for countries with positive imbalances, and put options become relatively more expensive for countries with negative imbalances.

Taken together, the cross-sectional and across-time variations in currency option prices provide another piece of evidence in support of our hedging demand framework. Additionally,

[37] A negative risk-reversal also translates into a left-skewness in the option-implied asset return distribution, as it is typical with equity index options.

the results on currency options also provide a unique empirical assessment of the demand-based option pricing as postulated in Garleanu, Pedersen, and Poteshman (2008).[38]

5 Conclusion

In this paper, we presented a novel hedging channel of exchange rate determination. Recent evidence shows the use of currency forwards and swaps to hedge exchange rate risk is a common phenomenon around the world. We argued this hedging behavior generates predictable movements in both spot and forward exchange rate markets that are also intimately linked to countries' external balances. Using data from the G10 currencies, we found evidence in support of the hedging channel of exchange rate determination in both conditional and unconditional moments of spot and forward exchange rate markets. Moreover, we showed our hedging channel explains the stochastic properties of spot and forward exchange rates that result in observed systematic variation in currency excess returns, term premia, and out-of-the-money options on currencies. Our model also explains the relative take-ups of central bank swap lines during periods of liquidity shortage.

[38] Demand drivers for option prices have similarly been shown to have an impact in equities (Celerier, Liao, and Vallee, 2021).

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6 Figures and Tables

Figure 2: Dollar Imbalances and Unconditional Cross-Currency Bases

This figure presents the relationship between average cross-currency bases and dollar imbalances pre- and post- 2008. Panel A shows the post-crisis sample from January 2008 to December 2020. The slope of the regression line is -40.91 (s.e. = 18.58). Panel B shows the pre-crisis sample from January 2000 to December 2007. The slope of the regression line is -6.54 (s.e. = 6.62). A regression of average cross-currency bases on countries' dollar debt imbalances over the full sample yields a slope coefficient of -33.93 (s.e. = 13.93).

Panel A. Post-Crisis (2008 to 2020) Panel B. Pre-Crisis (2000 to 2007)

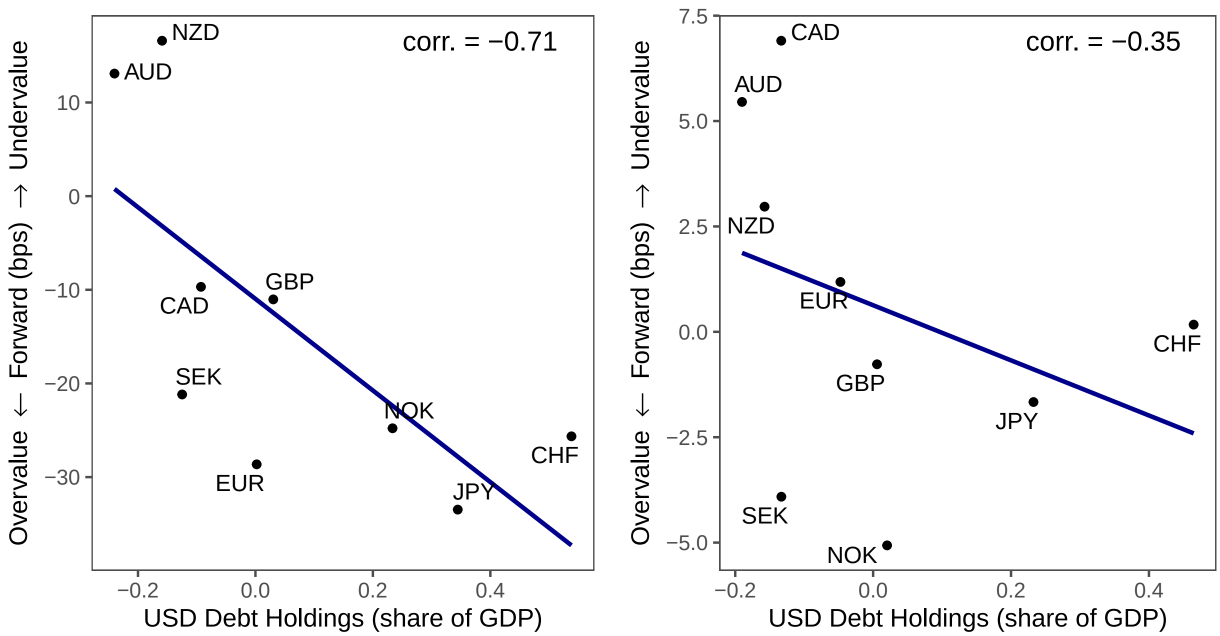
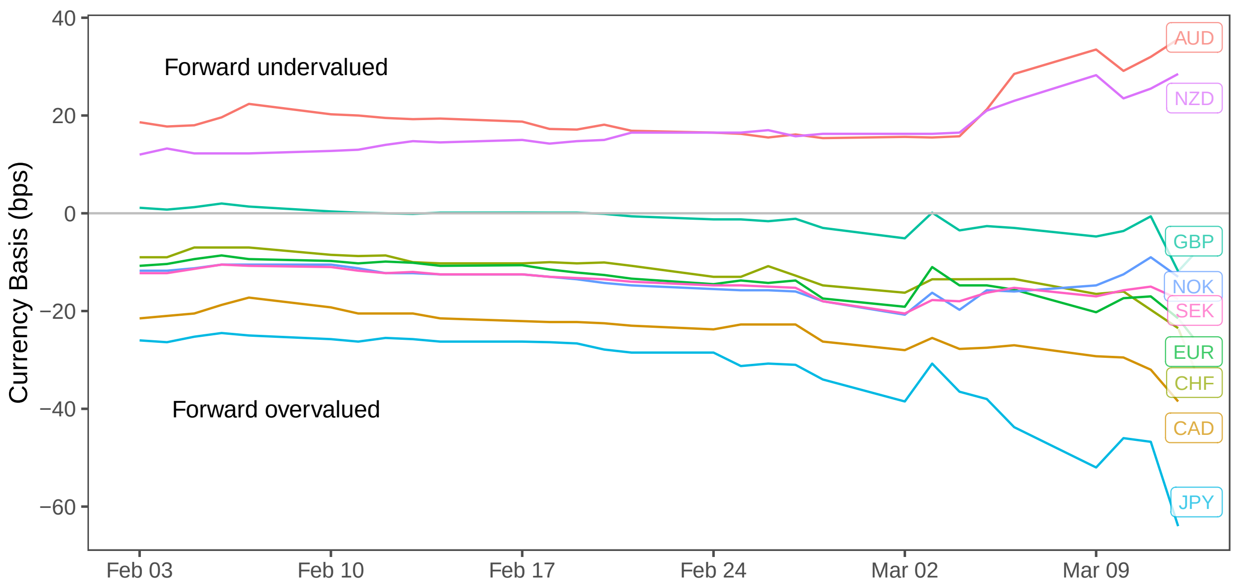


Figure 3: Cross-currency bases and spot exchange rates during Covid-19 crisis

This figure presents time series of cross-currency bases and spot exchange rates during the Covid-19 global pandemic. Panel A plots the time series of currency basis from February 1, 2020 to Friday March 13, 2020. We end the sample on March 13, 2020, the Friday before the Federal Reserve cut the federal funds rate by 100 basis points and extended central bank swap line provision on Sunday March 15, 2020. Panel B plots the times series of cumulative returns in log spot exchange rates from February 1, 2020 to March 13, 2020.

Panel A. Currency Bases



Panel B. Spot Exchange Rates (Cumulative Returns)

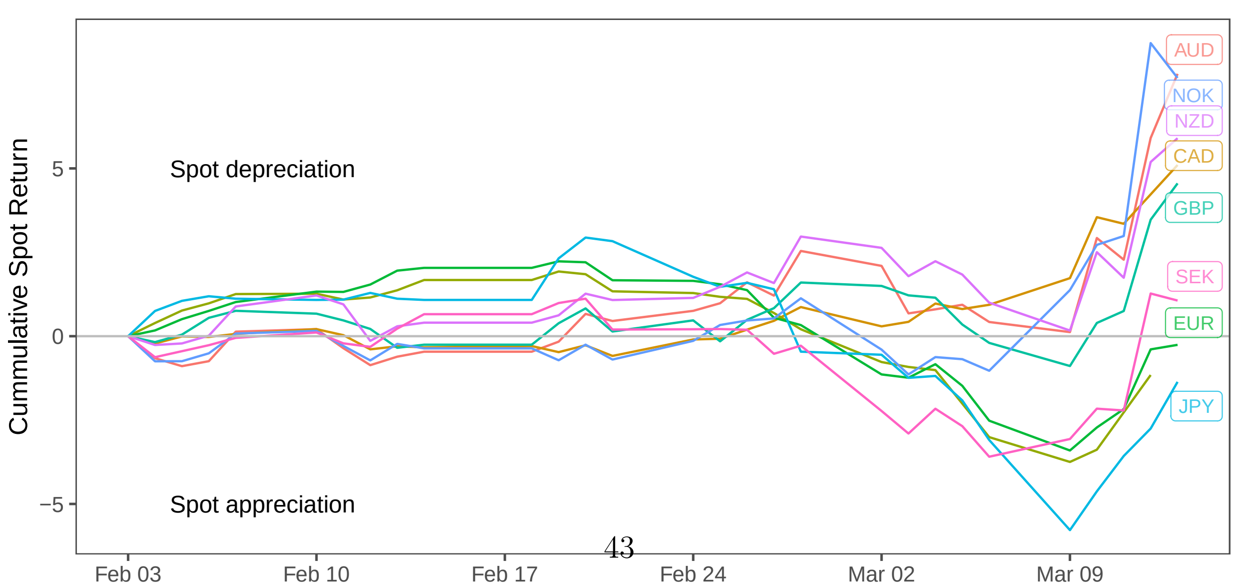


Figure 4: Dollar Imbalances and Currency Excess Returns

In this figure, the left-hand panel plots average 12-month forward premia against countries' average dollar debt imbalances. The slope of the regression line is -4.61 (s.e. = 1.56). The right-hand panel plots average 12-month currency excess returns against countries' dollar debt imbalances. The slope of the regression line is -3.26 (s.e.=2.65).

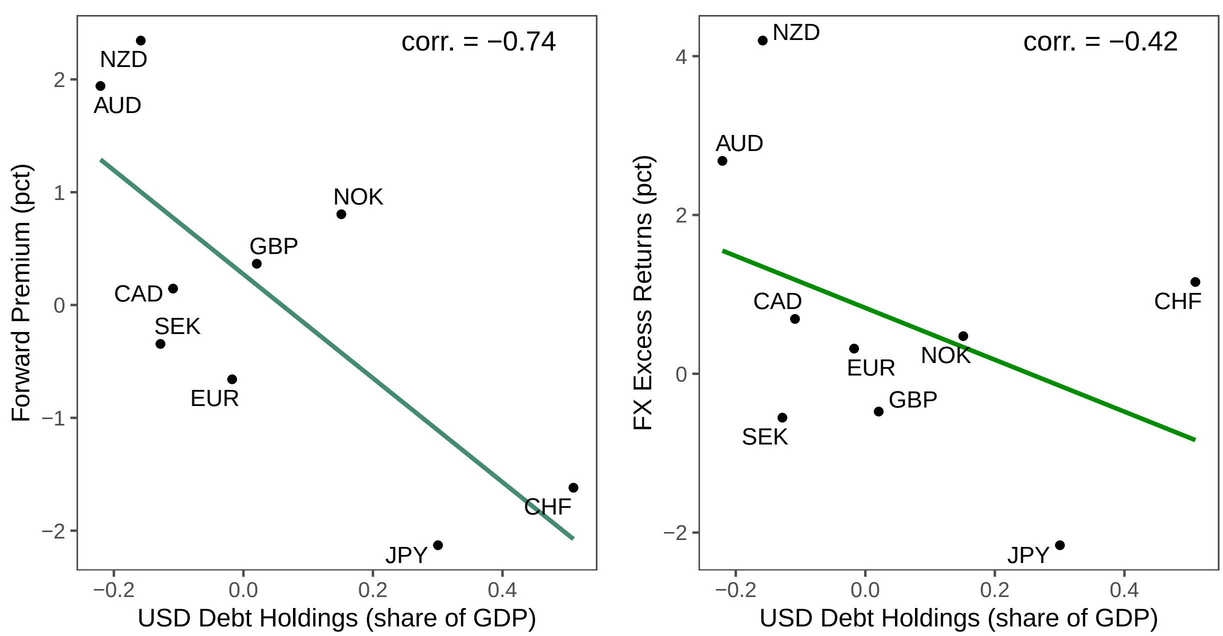


Figure 5: Term Structure of Cross-Currency Basis

This figure shows the term structure of currency basis for the Australian Dollar and the Japanese Yen on two dates during the Covid-19 pandemic.

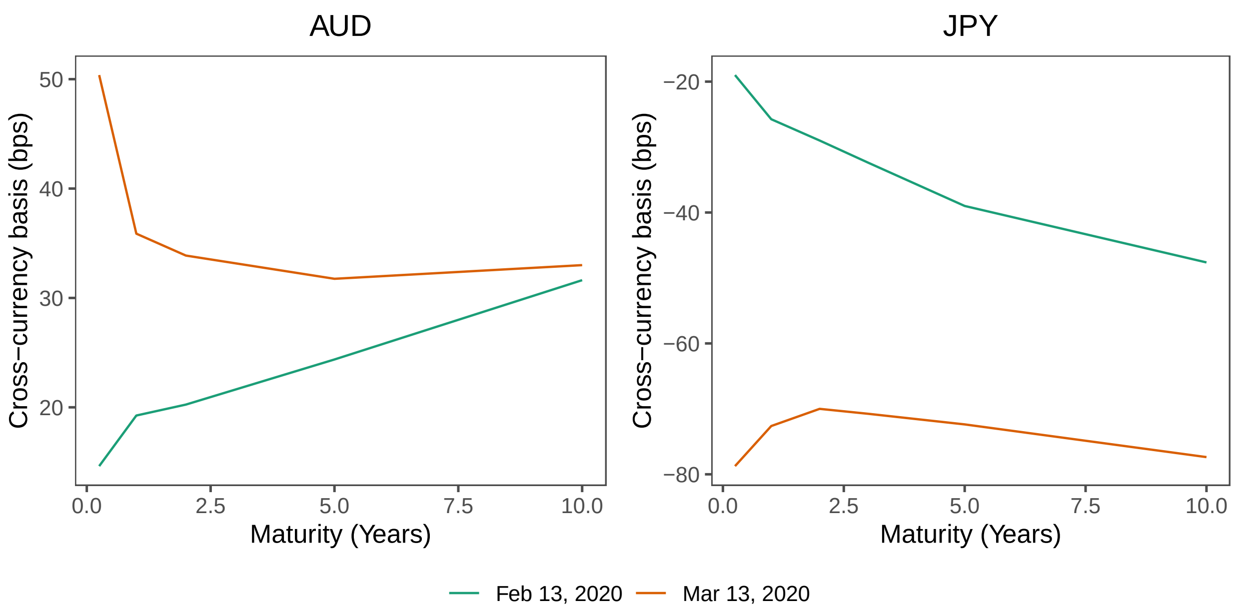


Figure 6: Dollar Imbalances, Exchange Rates and Swap Lines During Covid-19

This figure plots the maximum swap line draw by each central bank between March, 2020 and July, 2020 against the country's dollar imbalance. The slope of the regression line is 0.02 (s.e. = 0.01).

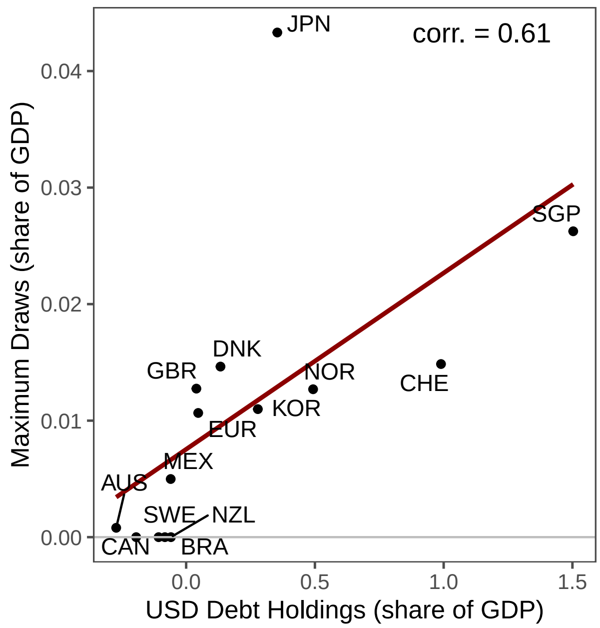


Figure 7: Currency Options Risk-Reversals

This figure presents the relative pricing of calls and puts on currencies as measured by the risk-reversal defined as the 25-delta call minus put implied volatilities for options of 1 year maturity between January 2005 and April 2020.

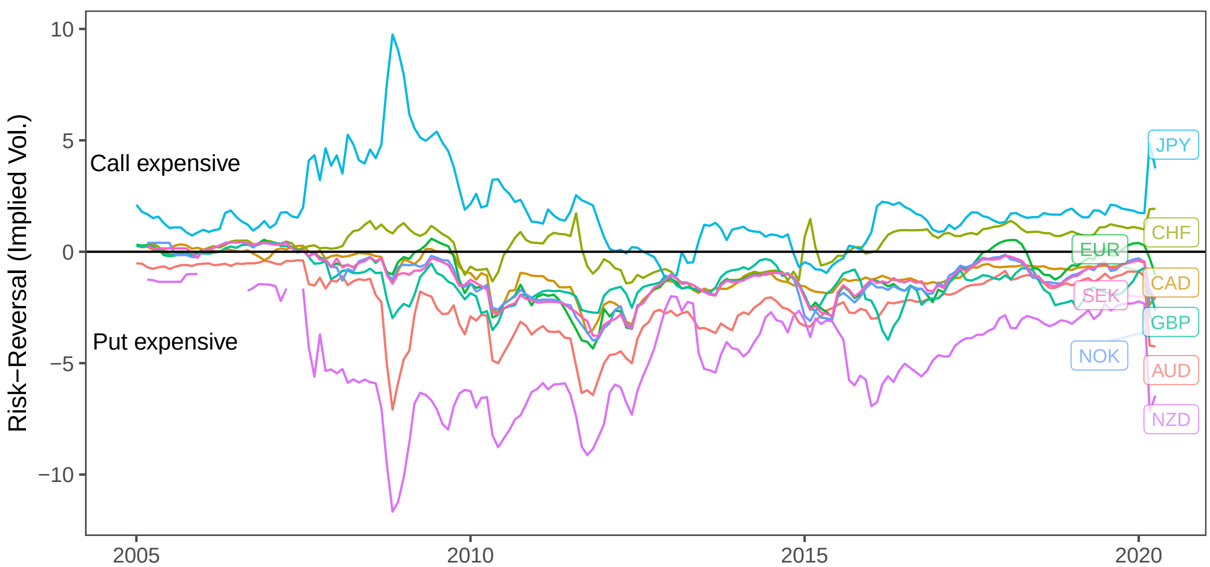


Table 1: Regulatory requirements on currency mismatch and hedging estimates

This table presents regulatory requirements on currency mismatch and hedging estimates across G10 currency countries. Column 1 describes the minimum currency match requirement between assets and liabilities in pensions given by the OECD 2019 Survey of Investment Regulation of Pension Funds. "Prudence rule" indicates no strict rules. However, regulations suggest "prudent investment". Column 2 indicates whether a country's insurance sector falls under Solvency II Directives. Column 3 presents additional hedging estimates from the Australian Bureau of Statistics 2017 Survey on Foreign Currency Exposure and Japanese insurance company investor disclosures.

	Pension: Min. currency match	Insurance: Under Solvency II	Hedging estimates
Australia	Prudence rule		Debt assets: 59% Debt liab.: 80% Equity assets: 22%
Austria	70%	Y	
Belgium		Y	
Canada	Prudence rule		
Switzerland	70%		
Germany	70%	Y	
Denmark	80%	Y	
Spain		Y	
Estonia	50%	Y	
Finland	70%	Y	
France		Y	
United Kingdom		Y	
Greece	70%	Y	
Ireland		Y	
Italy	70%	Y	
Japan			Life Insurers: >50%
Lithuania		Y	
Luxembourg	70%	Y	
Latvia	80%	Y	
Netherlands		Y	
Norway	70%		
New Zealand			
Portugal	70%	Y	
Slovak Republic	70%-95%	Y	
Slovenia		Y	
Sweden	80%-100%		
United States	Prudence rule		

Table 2: Summary Statistics

The sample comprises monthly data for all G-10 currencies (excluding the USD) between January 2000 and April 2020. A currencies' cross-currency bases is the spread between the exchange rate implied currency risk-free rate and the actual risk-free rate. The absolute cross-currency basis is the absolute value of this number. The annualized currency excess return is the difference between the log 12 month forward rate and the log spot exchange rate in 12 months. NIIP, Debt, FDI, Equity and GDP are measured quarterly and provided by the International Financial Statistics (IFS) from the IMF.

	Mean	Std. Dev.	Min	Max
Cross-currency basis (bps)	-8.24	18.37	-92.15	42.11
Absolute cross-currency basis (bps)	14.15	14.31	0.01	92.15
Annualized currency excess returns (pct)	0.69	10.72	-39.01	35.38
5-yr minus 1-yr basis spread (bps)	2.56	11.4	-48.95	60.75
Risk-reversal (bps)	-1.08	2.08	-11.67	9.75
FX Volatility (pct)	10.70	2.84	4.79	22.98
Δ FX Volatility (pct)	-0.01	6.46	-18.15	55.71
USD NIIP / GDP	0.34	0.36	-0.25	1.71
USD Net Debt Holdings / GDP	0.04	0.25	-0.32	0.99
USD Net Equity Holdings / GDP	0.31	0.19	0.04	0.99

Table 3: External Imbalances and Cross-Currency Bases

The following table presents panel regressions of monthly cross-currency bases on measures of external imbalances. The sample period is from 2000 to 2020. Standard errors are clustered by currency.

	Cross-Currency Basis (bps)					
	(1)	(2)	(3)	(4)	(5)	(6)
USD NIIP / GDP	-19.819^{**}	-19.451^{*}				
	(8.155)	(10.574)				
USD Net Debt Holdings / GDP			-29.788^{**}	-28.530^{**}		
			(12.239)	(13.186)		
USD Net Equity Holdings / GDP					-17.811	-13.259
					(13.925)	(24.994)
Fixed Effects		Month		Month		Month
Observations	2,183	2,183	2,183	2,183	2,183	2,183
R^2	0.150	0.389	0.167	0.414	0.035	0.282

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 4: Currency Basis and Spot Exchange Rate Dynamics

The following table presents panel regressions of monthly changes in currency bases and spot exchange rate returns on dollar debt imbalances and measures of exchange rate volatility. *USD Imba.* captures each country's net U.S. dollar debt holdings normalized by GDP. Δ *FX Vol.* captures changes in country specific exchange rate volatility, and Δ *Global FX Vol.* captures changes in global exchange rate volatility defined as the average change in exchange rate volatility over all countries. Standard errors are clustered by currency and date. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

	Currency Basis (bps)		Spot FX (pct)	
	(1)	(2)	(3)	(4)
USD Imba. × (Δ FX Vol.)	-3.19^{**}		-1.27^{*}	
	(1.00)		(0.59)	
USD Imba. × (Δ Global FX Vol.)		-3.29^{**}		-1.24^{*}
		(1.39)		(0.60)
USD Imba.	3.25	3.31	-0.11	-0.10
	(8.27)	(8.25)	(0.35)	(0.36)
Δ FX Vol.	0.00		0.66^{***}	
	(0.53)		(0.18)	
Date F.E.	Y	Y	Y	Y
Currency F.E.	Y	Y	Y	Y
Num. obs.	2,183	2,183	2,183	2,183
R^2 (full model)	0.48	0.49	0.61	0.60
R^2 (proj model)	0.02	0.02	0.07	0.05

Table 5: Currency Return Forecasting Regressions

The following table presents the results of exchange rate return forecasting regressions. For each time horizon, we regress exchange rate returns on *FX Vol.*, *USD Imba.*, and the interaction term *USD Imba.* $\times$ *FX Vol.* at the start of the period. We include a currency fixed effect in all specifications. We compute Newey-West standard errors with lags equal to 1.5 times the return horizon. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

	3 Month	6 Month	9 Month	12 Month
USD Imba. $\times$ FX Vol	1.47^{**}	3.16^{**}	4.48^{**}	5.28^{**}
	(0.67)	(1.28)	(1.94)	(2.56)
FX Vol.	-0.49^{**}	-1.15^{***}	-1.68^{***}	-1.95^{***}
	(0.21)	(0.38)	(0.53)	(0.63)
USD Imba.	2.89^{*}	5.48^{*}	8.03^{*}	10.02^{*}
	(1.75)	(3.17)	(4.34)	(5.41)
Num. obs.	2,156	2,129	2,102	2,075
R^2	0.01	0.03	0.04	0.05

Table 6: Currency Basis Term Structure and Dynamics

The following table presents panel regressions of levels and changes in the 5-year minus 1-year currency basis spread on dollar debt imbalances and measures of exchange rate volatility. Columns (1) and (2) regress the level of the basis spread on dependent variables, while columns (3) and (4) regress changes in the basis spread. See Table 4 for additional variable definitions. Standard errors are clustered by currency and date. *p<0.1; **p<0.05; ***p<0.01

	Levels (bps)		Changes (bps)	
	(1)	(2)	(3)	(4)
USD Imba.	-21.03^{***}	-22.13^{**}	0.43	0.41
	(7.59)	(7.63)	(0.58)	(0.57)
USD Imba. × (Δ FX Vol.)			0.83^{**}	
			(0.35)	
USD Imba. × (Δ Global FX Vol.)				0.68^{*}
				(0.34)
Δ FX Vol.			0.20	
			(0.17)	
Date F.E.	N	Y	Y	Y
Currency F.E.	N	N	Y	Y
Num. obs.	2,180	2,180	2,167	2,167
R^2 (full model)	0.22	0.38	0.34	0.34
R^2 (proj model)	0.22	0.27	0.01	0.01

Table 7: Option Risk-Reversals and Dynamics

The following table presents panel regressions of levels and changes in currency option risk-reversals on dollar debt imbalances and measures of exchange rate volatility. The risk-reversal is the 25-delta call minus put implied volatilities for options of 1-year maturity. Columns (1) and (2) regress the level of the risk-reversal on dependent variables, while columns (3) and (4) regress changes in the risk-reversal. See Table 4 for additional variable definitions. Standard errors are clustered by currency and date. *p<0.1; **p<0.05; ***p<0.01

	Levels (pct)		Changes (pct)	
	(1)	(2)	(3)	(4)
USD Imba.	3.98**	4.10**	0.43**	0.42**
	(1.54)	(1.48)	(0.16)	(0.16)
USD Imba. $\times$ (Δ FX Vol.)			0.42**	
			(0.16)	
USD Imba. $\times$ (Δ Global FX Vol.)				0.39**
				(0.15)
Δ FX Vol.			-0.11^{**}	
			(0.04)	
Date F.E.	N	Y	Y	Y
Currency F.E.	N	N	Y	Y
Num. obs.	1,713	1,713	1,704	1,704
R^2 (full model)	0.24	0.45	0.65	0.65
R^2 (proj model)	0.24	0.31	0.09	0.08

Internet Appendix
-For online publication only-

A Additional Discussion of Exchange Rate Hedging

Compared to earlier surveys that showed little currency hedging by U.S. institutional investors (Levich, Hayt, and Ripston, 1999), these new evidence suggests a possible change in currency markets and distinction between equity and debt investors. The increase in hedging practices potentially contributed to the liquidity and turnover of hedging instruments — the volume of exchange rate hedging instruments (forwards and swaps) has surpassed those of spot transactions in recent years. Figure A2 shows the daily average turnover of the global exchange rate market by currency and instrument based on the Triennial FX Survey published by the Bank of International Settlements. Notably, swap and forward volumes are larger than the spot. In 2019, the forward and swap daily average volume was 136% of spot volume.We combine the transaction volume for forwards and swaps as these two type of transactions are often used interchangeably – a swap is a a package of a spot and a forward transaction.[39]

Why do investors choose to hedge via forwards and swaps instead of trading spot exchange rates? The use of currency forwards as a portfolio adjustment tool is analogous to the use of equity and bond futures by institutional investors to adjust their overall market and duration risks without shifting out of their cash investments. Investors reducing currency exposure via spot transactions would need to also sell their cash asset holdings in the foreign currency. On the other hand, hedging via currency forwards doesn't require liquidating asset holdings. In times of market stress, the use of currency forwards for the reducing currency risk would

[39]Additionally, a large fraction of forward hedging transactions are reported as swaps as investors periodically roll their forward contract by unwinding the near-maturity contract and entering into new longer-maturity contracts, effectively creating a swap. This type of rolling hedge is common as global fixed income benchmarks are often calculated assuming FX hedges with maturities of one month to three months. Empirically, the BIS triennial survey shows a larger swap volume relative to forward volume.

be optimal even if the investor intends on eventually selling their foreign asset holdings, but desires to avoid poor market liquidity for cash assets.

B Appendix to Section 2

B.1 Proof of Proposition 1

The cross-currency basis is given by equation (6). Assumption 1 shows $G(I) > 0$. Hence, the sign of b^n is the same as the sign of $H'(-h^n X^n)$. When $X^n > 0$, $-h^n X^n < 0$ and Assumption 2 shows $H'(-h^n X^n) < 0$. When $X^n < 0$, $-h^n X^n > 0$ and Assumption 2 shows $H'(-h^n X^n) > 0$. Given two countries n and m with $X^n > X^m$, we know $-h^n X^n < -h^n X^m$ and therefore $H'(-h^n X^n) < H'(-h^n X^m)$. Hence $b^n < b^m$.

B.2 Proof of Proposition 2

We prove Proposition 2 by applying the implicit function theorem to equation (6), and by applying Assumptions 1 and 2.

Taking derivatives with respect to $Var[S_2^n]$ shows the magnitude of the country n currency basis increases in magnitude with its own expected exchange rate volatility:

$$\begin{aligned}\frac{\partial b^n}{\partial Var[S_2^n]} =&\kappa^2 G''\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right)\left(H'\left(-h^n X^n\right)\right)^2 \left(\frac{\partial h^n}{\partial Var[S_2^n]}\right) X^n \\ &- \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H''\left(-h^n X^n\right)\left(\frac{\partial h^n}{\partial Var[S_2^n]}\right) X^n.\end{aligned}$$

As a result,

$$\text{sign}\left[\frac{\partial b^n}{\partial Var[S_2^n]}\right] = -\text{sign}\left[X^n\right],$$

because $G''(I) < 0$, $\partial h^n / \partial Var[S_2^n] > 0$, and $\text{sign}[H'(q)] = \text{sign}[q]$, and $H''(q) > 0$.

Taking derivatives of b^n with respect to $Var[S_2^m]$ for $m \neq n$ shows the magnitude of the country n currency basis increases in magnitude with foreign countries' expected exchange rate volatility:

$$\frac{\partial b^n}{\partial Var[S_2^m]} = \kappa^2 G'' \left(W - \kappa \sum_m H\left(-h^m X^m\right) \right) H'\left(-h^n X^n\right) H'\left(-h^m X^m\right) \left(\frac{\partial h^m}{\partial Var[S_2^m]} \right) X^m.$$

As a result, we can also show

$$\text{sign}\left[\frac{\partial b^n}{\partial Var[S_2^m]} \right] = -\text{sign}\left[X^n\right],$$

because $G''(I) < 0$, $\text{sign}\left[H'(-h^m X^m) X^m\right] < 0$, and $\text{sign}\left[H'(-h^n X^n)\right] = -\text{sign}\left[X^n\right]$.

B.3 Proof of Proposition 3

We prove Proposition 3 by applying the implicit function theorem to equation (7), and by applying Assumptions 1 and 2.

Taking derivatives of S^n with respect to $Var[S_2^n]$ yields:

$$\frac{\partial S^n}{\partial Var[S_2^n]} = - \frac{\zeta^n X^n}{(\iota^D - h^n X^n)^2} \frac{\partial h^n}{\partial Var[S_2^n]}.$$

As a result,

$$\text{sign}\left[\frac{\partial S^n}{\partial Var[S_2^n]} \right] = -\text{sign}\left[X^n\right]$$

, because $\partial h^n / \partial Var[S_2^n] > 0$.

B.4 Extension: A Three-Period Model

In the following appendix, we extend the benchmark model to three periods to study the term structure of forward exchange rates. Since there are now multiple periods in which investors and currency traders perform actions, we let t subscripts denote the time period.

We start by describing the actions of the country n investor, which determines the demand for dollars in the forward market maturing in period 2 and 3. The country n investor now has a net external position X^n that matures in period 3. In period 1, the country n investor wants to hedge an exogenous fraction h^n of her external imbalance in each period. Hence, she initially demands:

$$-h^n X^n \left(1 + r_1^D\right) \left(1 + r_2^D\right)$$

dollars in the forward market maturing in period 3.

In period 1, the country n investor can either purchase forward dollars maturing in period 3, or she can purchase forward dollars maturing in period 2 and then roll her forward position to period 3. Let η^n denote the share of the investror's external imbalance hedged by buying dollars in the forward market in period 1 and maturing in period 3. Hence, the country n investor demands $-\eta^n h^n X^n \left(1 + r_1^D\right) \left(1 + r_2^D\right)$ forward dollars at the forward exchange rate of $F_{1,3}^n$ yen per dollar. The Japanese investor hedges the remaining $1 - \eta^n$ share of her desired hedge position by buying $-(1 - \eta^n) h^n X^n \left(1 + r_1^D\right)$ forward dollars maturing in period 2 at the forward exchange rate $F_1^{n,(1)}$.

In period 2, the country n investor faces uncertainty in her hedging demand: With probability π, she decides to hedge a fraction h_L^n of her total position, and with probability $1 - \pi$ she decides to hedge a fraction h_H^n of her total position. Thus, the country n investor demands:

$$-(h_k^n - \eta^n h^n) X^n \left(1 + r_1^D\right) \left(1 + r_2^D\right)$$

dollars forward in period 2 and maturing in period 3. h_k^n denotes the investor's total hedging demand when $k = L, H$. Denote the forward exchange rate for these contracts by $F_2^{n,(1)}$.

The currency trader provides liquidity in the forward exchange rate markets, and prices forward contracts taking into account uncertainty in the investor's hedging demand. The trader continues to face balance sheet costs on her capital devoted to providing liquidity in the swap market. We continue to assume the trader starts each period with wealth W_t, and invests $I_t = W_t - \kappa \sum_n H(q_t^n)$ in the outside option each period. However, we now assume the trader pays the haircut on her total position for providing liquidity to each country n. In other words, q_t^n captures the trader's position for providing liquidity for one-period forwards as well as two-period forwards for the country n investor in period t. The outside option continues to provide a one period return of $G(I_t)$. We continue to assume $G(I_t)$ and $H(I_t)$ behave according to Assumptions 1 and 2.

In period 1, the currency trader decides how much capital to devote towards providing liquidity in one-period forward markets, providing liquidity in the two-period forward market, or investing in the outside option in order to maximize expected discounted profits. Let $b_1^{n,(2)}$ denote the cross-currency basis on the two-period exchange rate forward in period 1:

$$b_1^{n,(2)} = \frac{1}{2}\left(\frac{F_1^{n,(2)}}{S_1^n}\Pi_{t=1}^2(1+r_t^D) - \Pi_{t=1}^2(1+r_t^n)\right).$$

Note, we divide the right-hand side by 2 to express the cross-currency basis in "per period" terms.

Letting the subscripts $\{2,L\}$ and $\{2,H\}$ denote quantities and prices in period 2 when the investor hedging demand equals h_L^n and h_H^n, respectively, we can express the trader's problem as:

$$\max_{q_1^{n,(1)},q_{2,L}^{n,(1)},q_{2,H}^{n,(1)},q_1^{n,(2)}} \sum_n \left\{ \underbrace{\frac{b_1^n q_1^{n,(1)}}{1+r_1^D} + \frac{\pi\left(b_{2,L}^n q_{2,L}^{n,(1)}\right) + (1-\pi)\left(b_{2,H}^n q_{2,H}^{n,(1)}\right)}{(1+r_1^D)(1+r_2^D)}}_{\text{1-period fwds}} + \underbrace{\frac{2b_1^{n,(2)} q_1^{n,(2)}}{(1+r_1^D)(1+r_2^D)}}_{\text{2-period fwds}} \right\} +$$
$$\underbrace{\frac{G(I_1)}{1+r_1^D} + \frac{\pi G(I_{2,L}) + (1-\pi)G(I_{2,H})}{(1+r_1^D)(1+r_2^D)}}_{\text{Profits from other investment}}.$$

where:

$$I_1 = W_1 - \kappa\sum_n H\left(q_1^{n,(1)} + q_1^{n,(2)}\right)$$
$$I_{2,k} = W_2 - \kappa\sum_n H\left(q_{2,k}^{n,(1)} + q_1^{n,(2)}(1+r_1^D)\right) \text{ for } k \in \{L,H\}.$$

The trader's period 1 position $q_1^{n,(2)}$ grows to $q_1^{n,(2)}(1+r_1^D)$ in period 2.

Taking first order conditions of the currency trader's problem with respect to amount of capital devoted to 1-period forwards yields a familiar result: The cross-currency basis in each period and state of the world is proportional to the total trader position in that period and state:

$$b_1^n = \kappa G'\left(I_1\right) H'(q_1^{n,(1)} + q_1^{n,(2)}) \tag{14}$$

$$b_{2,k}^n = \kappa G'\left(I_{2,k}\right) H'(q_{2,k}^{n,(1)} + q_1^{n,(2)}(1 + r_1^D)) \text{ for } k \in \{L, H\}. \tag{15}$$

Taking first order conditions with respect to $q_1^{n,(2)}$ yields :

$$\begin{aligned} 2b_1^{n,(2)} =& \kappa G'\left(I_1\right) H'(q_1^{n,(1)} + q_1^{n,(2)})(1 + r_2^D) + \pi\kappa G'\left(I_{2,L}\right) H'(q_{2,L}^{n,(1)} + q_1^{n,(2)}(1 + r_1^D)) \\ &+ (1 - \pi)\kappa G'\left(I_{2,H}\right) H'(q_{2,H}^{n,(1)} + q_1^{n,(2)}(1 + r_1^D)). \end{aligned}$$

We plug the first order conditions with respect to $q_1^{(1)}$, $q_{2,L}^{(1)}$, and $q_{2,H}^{(1)}$ into the first order condition with respect to $q_1^{(2)}$ to derive equation (10).

C Additional Figures

Figure A1: Cross-currency basis

This figure presents the deviations from covered interest rate parity relations based on cross-currency basis swaps of 1 year maturity for G10 currencies. The sample period expands from January 2008 until April 2020.

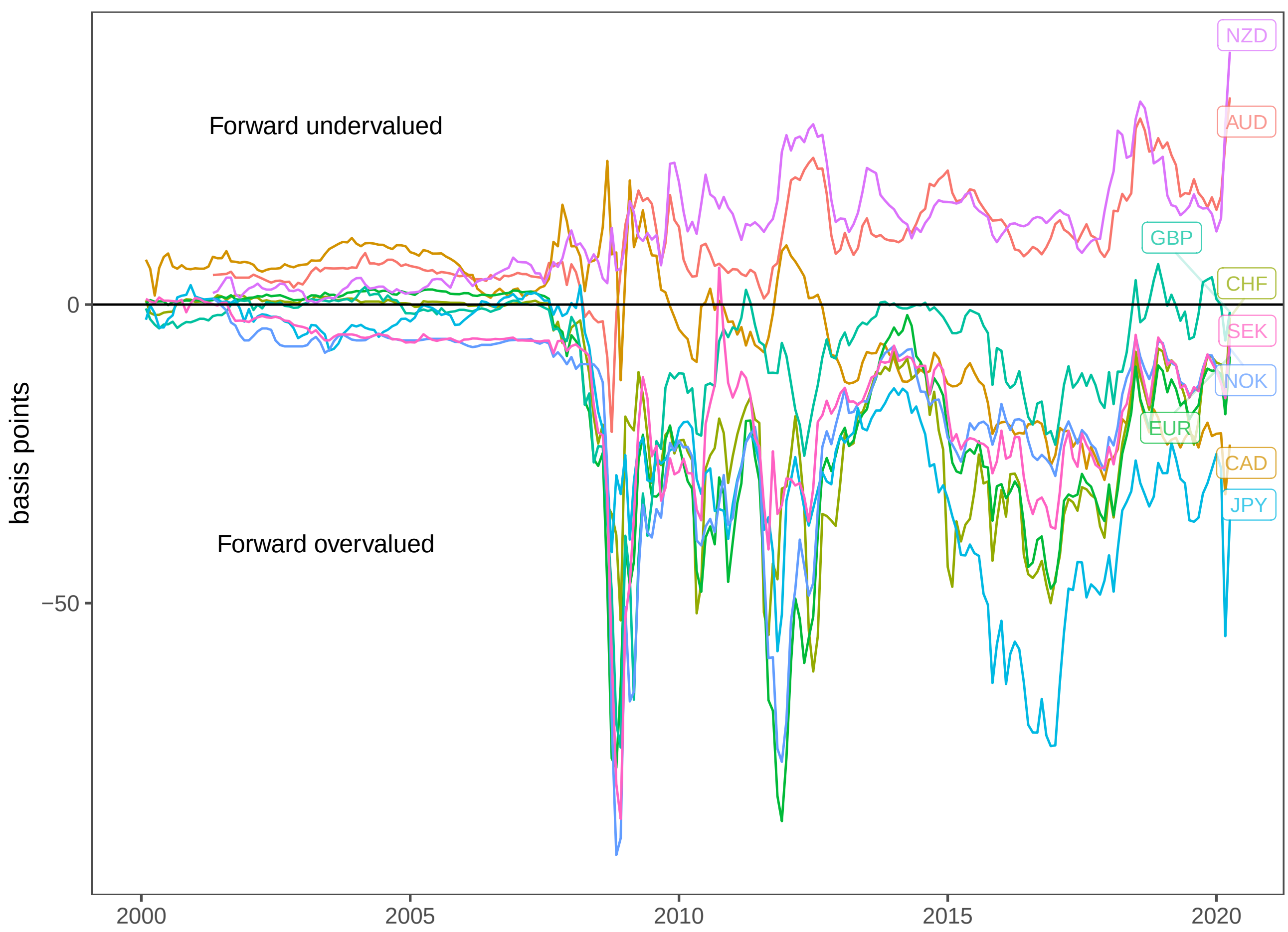
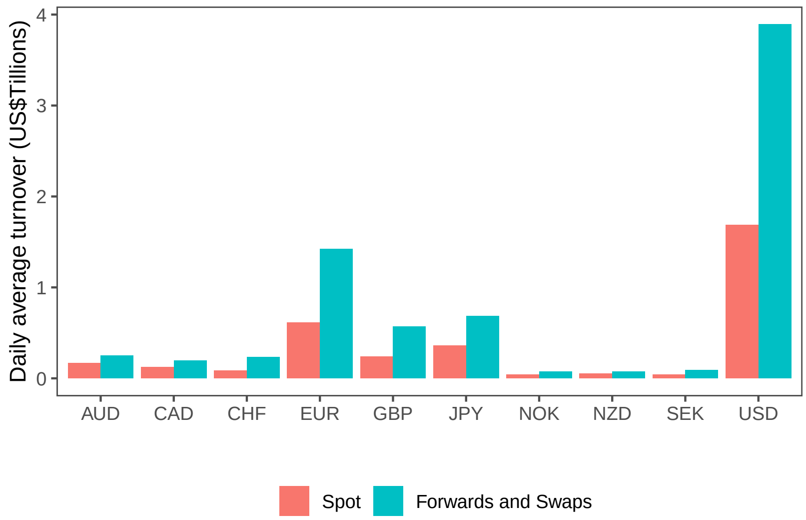


Figure A2: Global foreign exchange market turnover

This figure presents the daily average foreign exchange market turnover as presented in the Triennial Central Bank Survey of Foreign Exchange and Over-the-counter (OTC) Derivatives Markets in 2019 from Bank of International Settlements.

Panel A. Average daily volume by currency and instrument (2019):



Panel B. Evolution of average daily volume by instrument:

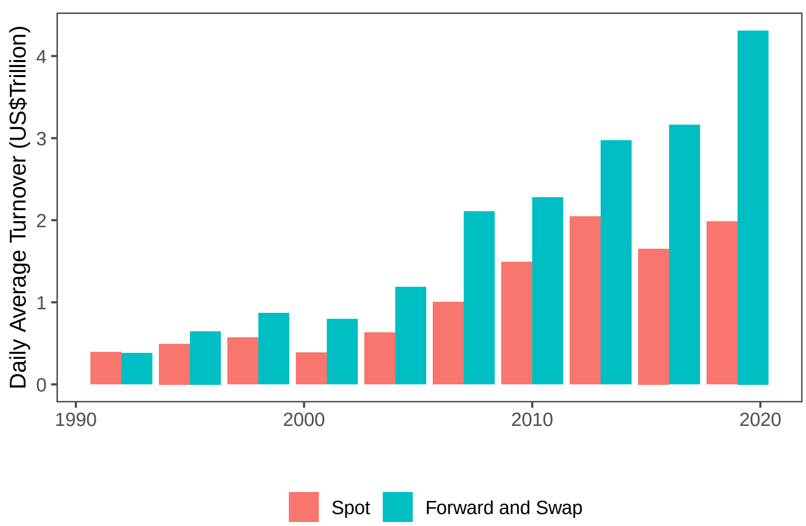
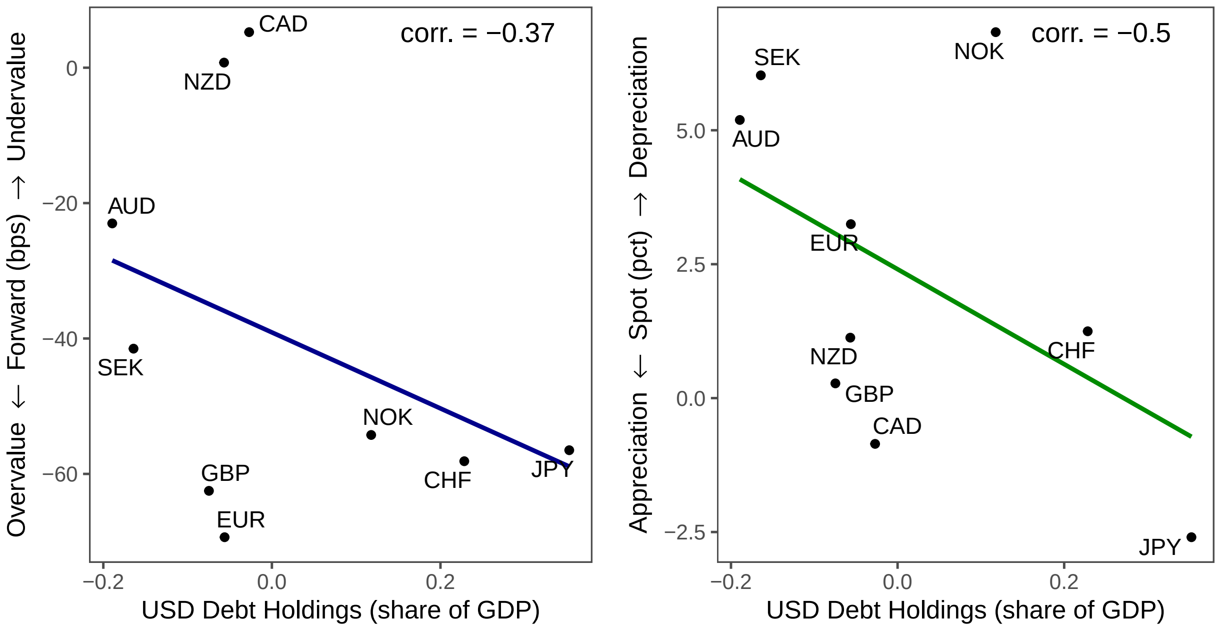


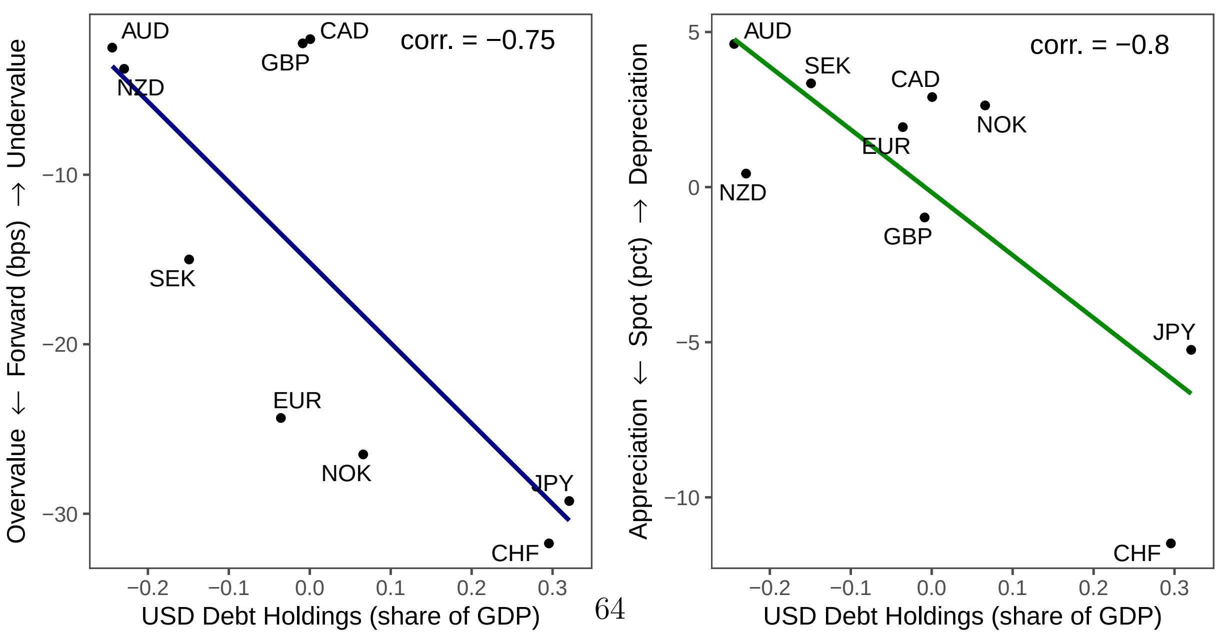
Figure A3: External Imbalances and Exchange Rates During Past Crises

This figure plots changes in currency bases and spot exchange rates during the Global Financial Crisis. We measure changes in currency bases and exchange rates from September 1, 2008 to October 1, 2008, when the magnitude of the bases peaked.

Panel A. Global Financial Crisis



Panel B. Eurozone Crisis



D Data Appendix

D.1 Hedge Ratio of Japanese Life Insurance Companies

Figure 1 shows the hedge ratio of nine traditional Japanese life insurance companies. These companies are: Nippon (AKA Nissay or Nihon Semei), Meiji Yasuda, Dai-Ichi, Sumitumo, Taiju (formerly Mitsui), Daido, Taiyo, Fukoku and Asahi. The quarterly filings for Japanese financial companies (Kessan Tanshin) are publicly available, typically on each company's investor relations platform. Some filings, however, are only published in Japanese, so where necessary we pulled a translated filing from S&P Global Market Intelligence. The data we needed on FX derivatives is typically located in the financial supplement to the quarterly report, which is sometimes issued as a separate document. We only considered assets held on the firm's general account. For each firm, we identified the foreign currency assets (FCA) given by the field "Total assets denominated in a foreign currency". This does not account for assets whose foreign currency cash flows are pegged to the JPY exchange rate. We also identified the notational amount of FX derivatives (net short) held by each company. These FX derivatives are the currency forwards bought and sold, as well as options positions. In practice, the option notionals are small relative to currency forwards, suggesting that the majority of the hedges are implemented through FX forwards. For each firm that distinguishes between hedge and non-hedge accounting, we combined the notational amount of FX derivatives from both hedge and non-hedge accounting. We then divided the sum of the notational amount of all FX derivatives by the sum of all foreign currency assets to get the FX hedge ratio.