The Hedging Channel of Exchange Rate Determination *

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First Draft: April 2020
This Draft: March 2021

We document the currency hedging channel that connects country-level measures of net external financial imbalances to exchange rates. In times of market distress, investors increase their currency hedging activities in proportion to their overall net foreign asset exposure by purchasing forward contracts. Countries with large positive net foreign asset holdings (e.g., Japan) experience domestic currency appreciation, and crucially, forward exchange rates appreciate relatively more than the spot after adjusting for interest rate differentials. Countries with large negative foreign asset positions experience the opposite currency movements. We present a model demonstrating exchange rate hedging coupled with intermediary constraints can explain the observed relationship between gradually adjusting net external imbalances and volatile spot and forward exchange rates. We find empirical support for this currency hedging channel of exchange rate determination in both the conditional and unconditional moments of exchange rates, option prices, and large institutional investors' disclosure of hedging activities. The currency hedging channel also explains the observed cross-sectional heterogeneity in the usage of the Federal Reserve dollar liquidity swap lines during the COVID-19 pandemic — countries that are "dollar rich" in foreign asset holdings borrowed more from the swap line than countries that are "dollar poor."

Keywords: Global Imbalance, Exchange Rate, Hedging, Currency Risk Premia, Covered Interest Rate Parity, Currency Options, Central Bank Swap Line
JEL Classifications:E44, F31, F32, F41, G11, G15, G18, G20

*We thank seminar and conference participants at the Federal Reserve Board, University of Maryland, UNC Junior Finance Roundtable, Federal Reserve Bank of San Francisco, Bank of International Settlements, Nanyan Business School, and BdF-BoE International Macroeconomics Workshop. We thank Wenxin Du, Andrew Lilley, Simon Lloyd, Vania Stavrakeva, Jenny Tang, Kaushik Vasudevan, and Andrea Vedolin for helpful suggestions. We thank John Caramichael for excellent research assistance. The views in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or any other person associated with the Federal Reserve System.

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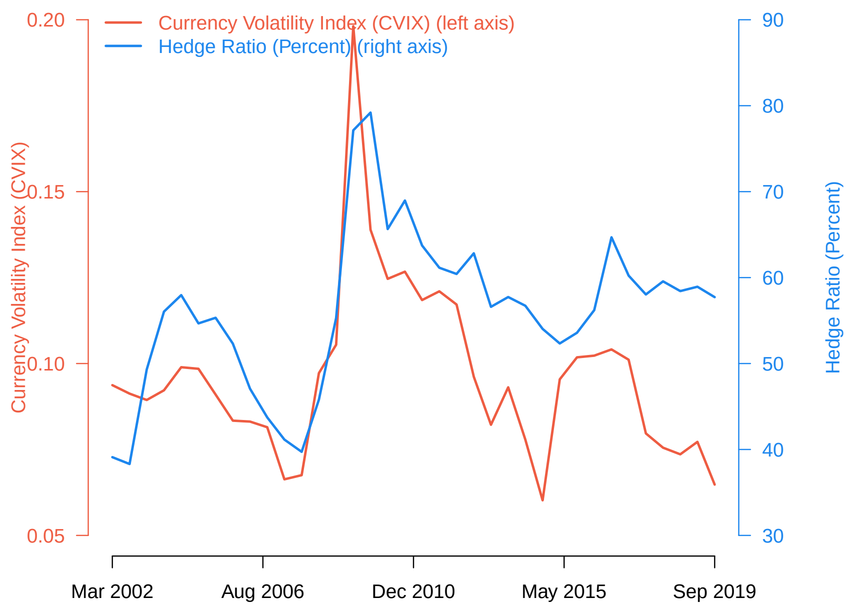
The disconnect between exchange rates and macroeconomic variables remains one of the most persistent puzzles in international economics. In recent years, a growing body of evidence points to financial intermediary constraints and global imbalances as key drivers of exchange rate dynamics.[1] However, conventional macroeconomic models that match international business cycle moments generate counterfactual exchange rate dynamics with insufficient volatility and provide relatively little clarity on the precise mechanisms that link exchange rates, the financial sector, and macroeconomic variables. 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, along with intermediary frictions, explains 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 novel facts that are consistent with a hedging channel of exchange rate determination. First, a large set of institutional investors and borrowers hedge a sizable portion of their currency mismatches. This set of participants has a particularly strong presence in the bond market.

[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; DellaCorte, Riddiough, and Sarno (2016) show global imbalances explain currency returns.

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.

Second, in countries with large positive net U.S. dollar asset holdings, which we term "dollar imbalances,"[2] the forward prices of domestic currency versus the U.S. dollar are unconditionally elevated relative to the spot price after adjusting for the interest rate differentials. This relative valuation between the forward and spot prices results in a currency basis, also known as a deviation from covered interest rate parity (CIP).[3] By contrast, countries with large negative dollar imbalances generally observe an unconditional forward price of domestic currency that is depressed relative to the U.S. dollar.

Third, in periods of increased market volatility, countries with positive dollar imbalances experience domestic currency appreciation in both spot and forward exchange rate markets

[2]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.

[3]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.

whereas countries with negative dollar imbalances experience currency depreciation. The changes in forward exchange rates are larger than those of the spot exchange rate, and the forwards are traded in higher volumes. This difference in exchange rate adjustment between the forward and spot markets results in an increased cross-sectional dispersion of currency bases, accentuating the unconditional relative valuation in line with the direction and magnitude of the dollar asset imbalances.

Lastly, during market distress, countries that have 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 simple model of hedging demand and its impact on exchange rate markets. We consider a foreign country and an associated representative agent who owns a portfolio of U.S. dollar denominated assets. This foreign agent hedges a share of her net foreign asset position with forward (or swap[4]) contracts to stabilize the future payoff of her portfolio in domestic currency. If the agent is a net purchaser of foreign dollar 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 forwards demanded depends on the country's hedge and net foreign dollar asset position.[5]

[4]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.

[5]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.

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.

However, the intermediary has alternative competing investment opportunities, and therefore charges a spread for providing liquidity in forward markets. In our example, the forward price of the yen is elevated relative to the spot exchange rate even after adjusting for interest rate differentials. The resulting pricing anomaly is known as a CIP deviation and is captured by the cross-currency basis spread: the difference between the synthetic cash funding rate implied by forward and spot prices and the actual interest rate. Our model shows the unconditional differences between a country's forward and spot exchange rate depend crucially on the magnitude and direction of the country's net dollar asset imbalances.

In times of economic distress, investor hedging demand combined with constrained financial intermediation generate predictable movements in forward and spot exchange rates. These movements occur due to two factors. First, a rise in a country's hedge ratio increases the magnitude of the investor's demand for forwards in proportion to the country's net foreign asset position. Second, a rise in the constraints to financial intermediation leads to increases in the *absolute level* of bases required to induce intermediaries to provide liquidity. Countries that are net savers should observe a currency basis in the opposite direction of countries that are net borrowers, because their hedging demand differs in direction.

In addition to affecting the forward exchange rates, investor demand for forwards can spill over to the spot exchange rate market. Intermediaries that produce yen in the forward market must buy yen in the spot market. As such, hedging pressure in the forward market imparts price pressure on spot exchange rates in predictable directions linked to countries' net dollar imbalances — spot exchange rates appreciate (depreciate) for countries with positive (negative) dollar imbalances.

Moreover, these systematic exchange rate movements during periods of financial distress generate currency risk that requires compensation. A growing literature on currency risk shows currencies that appreciate in bad times earn lower risk premia, because they provide a hedge against economic downturns.[6] Our hedging channel posits a mechanism through which the cross-sectional variation in currency excess returns is linked to global imbalances.[7] Currencies of countries with negative external imbalances that depreciate in bad times demand higher excess returns, whereas currencies of countries with positive external imbalances appreciate in bad times and obtain lower excess returns in normal times. Thus, our hedging channel provides an explanation for the link between currency excess returns and external imbalances.

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, as well as the behavior of currency options prices. We draw on event studies of three crises — the COVID-19 Pandemic, the Eurozone crisis in 2011, and the Global Financial Crisis — and show movements in forward and spot exchange rates are all consistent with increases in hedging demand during periods of financial distress. Moreover, in times of financial distress, the implied volatility spread between FX call and put options increases in magnitude, consistent with our notion of greater currency hedging demand.

We formalize our case studies through a factor-based asset pricing test, and show there is strong and predictable comovement between forward and spot exchange rates consistent with currency hedging. We construct a risk factor to proxy for changes in countries' hedging

[6] This literature identifies various country-level characteristics that could lead to differences in the stochastic properties of exchange rates. 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). Additionally, downside risks in currencies can rationalize the cross section of currency returns (Lettau, Maggiori, and Weber, 2014).

[7] The relationship between overall external imbalances and currency excess returns has also been studied previously in DellaCorte et al. (2016) and Wiriadinata (2020) that emphasize the retrenchment of investments or changes in asset values rather than the currency hedging channel.

demands and the availability of financial intermediation: changes in the mean absolute magnitude of the cross-currency bases. Consistent with our model, the spot and forward exchange rates of countries with more positive dollar imbalances load more negatively on our risk-factor. Our single-factor model explains a significant amount of variation in spot and forward returns as well as option prices over time.

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 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 long 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. We contribute to this literature by linking the hedged part of investor portfolios to exchange rate dynamics, which helps 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 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; Stavrakeva and Tang, 2020). The portfolio balance view argues for a quantity driven, supply-and-demand approach towards explaining 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 the persistent violations of CIP (Du et al., 2018).[8] 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). More related to our paper is Hazelkorn, Moskowitz, and Vasudevan (2020), who 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 this literature in two ways: First, we explore a channel that connects macroeconomic fundamentals to the large cross-sectional dispersion observed in the conditional and unconditional moments of cross-currency bases, exchange rate returns, and option skews. Second, our proposed channel links forward and spot markets through intermediary activity, thus also connecting the covered interest rate parity anomaly with exchange rate dynamics.

[8]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.[9] 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.[10] In particular, large corporate debt issuers in developed countries have been increasingly engaged in currency-hedged foreign debt issuance in order to obtain cheaper borrowing costs (Liao, 2020).[11] 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 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

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

[10] 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.

[11] 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).

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 Model

We present a model of exchange rate determination that links hedging demand and external imbalances to forward and spot exchange rates. 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^n denote the spot exchange rate in period 1, and we let F^n denote the price of currency forward contract at $t = 1$ that settles at $t = 2$. Both S^n and F^n are quoted in terms of foreign currency per dollar. Hence, increases in S^n and F^n represent U.S. dollar appreciation.

2.1 Demand for Forwards

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.

The country-n investor hedges her exchange rate exposure by trading dollars in the forward market. 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.

For simplicity, we assume the country-n investor hedges an exogenous fraction h^n of the country's external imbalance. Thus, the country-n investor demands

$$-h^n X^n (1 + r^D) \tag{1}$$

dollars in the forward market.

2.2 Supply of Forwards

A currency forward trader (or equivalently FX swap trader) exists who chooses to devote 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.

We start by describing the positions of the trader that produces currency forwards. Let q^n denote the trader's position in dollars taken in period 1 to provide liquidity for the country-n investor in the forward market. To reiterate, 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

$$q^n \underbrace{\left((1+r^D) - \frac{S^n}{F^n}(1+r^n)\right)}_{\text{Cross-currency basis } b^n} \tag{2}$$

dollars from this transaction. 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 FX-implied dollar risk-free rate. The case with $X^n < 0$ is analogous.

Note 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, $\kappa \sum_n H(q^n)$.

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 $H(0) = H'(0) = H''(0) = 0$.*

Crucially, 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. [12]

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

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 liquidity for each currency:

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

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:

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

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) and Gourinchas et al. (2020).[13]

2.4 Equilibrium and Model Predictions

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.

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

$$b^n = \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H'\left(-h^n X^n\right) \tag{5}$$

$$S^n = \frac{\xi^n}{\iota^D - h^n X^n} \tag{6}$$

$$F^n = \frac{\xi^n\left(1 + r^n\right)}{\left(\iota^D - h^n X^n\right)\left(1 + r^D - \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H'\left(-h^n X^n\right)\right)} \tag{7}$$

[13] 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.

We first relate a country's external imbalance to the spread earned by forward traders for providing liquidity to its representative investor – the cross-currency basis. The cross-currency basis is a salient wedge that provides the relative valuation between forward and spot exchange rates and closely reflects hedging demand and intermediary constraints. The dynamics of spot or forward exchange rates are affected by many other variables such as interest rates and excess demand for currencies from unmodelled parts of the economy.

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. In addition, the more extreme the external imbalances, the larger the cross-currency bases are in magnitude.*

Proposition 1 shows 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. Net-lender countries should observe negative currency bases because the forward trader provides liquidity by borrowing at the FX-implied foreign risk-free rate. Net-borrow countries should observe positive currency bases because the trader provides liquidity by borrowing at the actual foreign risk-free rate. Larger external financial imbalances require the trader to provide more liquidity, which requires the forward trader to pay a larger haircut. In return, the trader earns a larger spread on her position.

The signs of the currency basis naturally maps to over- and undervaluation of currency forwards relative to spot exchange rates. A log-linear approximation of the cross-currency basis b^n defined in equation (2) shows the log forward rate is approximately equal to the cross-currency basis plus the log spot exchange rate after adjusting for interest rate differentials:

$$f^n \approx b^n + s^n + r^n - r^D.$$

Countries with positive external imbalances experience negative bases ($b^n < 0$), and the forward price of their domestic currency is elevated relative to the spot price after adjusting for interest rate differentials. 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. 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 currency basis, $|b^n|$, which indicates the degree of forward under/over-valuation, increases in the magnitude of a country's external imbalance X^n, the hedge ratio h^n, and the cost of financial intermediation κ. Moreover, a country with a more positive external imbalance observes a larger decrease (smaller increase) in their cross-currency basis due to increases in h^n and κ:*

$$\frac{\partial^2 b^n}{\partial X^n \partial h^n} < 0, \text{ and } \frac{\partial^2 b^n}{\partial X^n \partial \kappa} < 0.$$

Increases in a country's hedged position (through increases in h^n) and increases in the cost of financial intermediation (κ) have the same qualitative effect on cross-currency bases. Increases in X^n also raises the country's total hedge position.[14] However, empirically, X^n is relatively persistent. Thus, we focus on higher frequency changes in h^n. Increases in hedging demand require the forward trader to provide more liquidity in forwards, which becomes increasingly costly to produce. These additional costs are passed on through larger cross-currency bases. For example, Figure 1 show Japanese life insurance companies systematically raised and lowered their hedge ratio in accordance with dollar-yen exchange rate volatility.

[14]Notably, DellaCorte et al. (2016) explores the role of X^n in driving currency risk premia.

Alternatively, increases in the cost of financial intermediation also increase the costs of providing liquidity for all currencies. For instance, Du et al. (2018) show cross-currency bases are partially driven by bank balance sheet costs. In times of financial distress, both forces are likely to work to increase cross-currency bases.

Crucially, Proposition 2 shows a country's external imbalance identifies the cross-sectional movements in the forward and spot exchange rates during financial distress. If $X^n > 0$, b^n becomes more negative and the country's forward exchange rate becomes even more elevated relative to the spot exchange rate. Alternatively, if $X^n < 0$, then b^n becomes more positive and further depresses the forward rate. Moreover, 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 larger for larger positions. As a result, Proposition 2 shows we should observe a widening of cross-currency basis spreads during times of financial distress.

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) An increase in a foreign country's hedge ratio, h, affects the country's spot exchange rate in proportion to its external imbalance:*

$$\frac{\partial S^n}{\partial h^n} = -\frac{X^n \xi^n}{\left(\iota^n - h^n X^n\right)^2}$$

In times of financial distress, investors increase their hedge ratio in response to increased exchange rate volatility. Forward traders use dollars to purchase additional units of foreign currency to satisfy the additional demand in forward markets from countries with positive external imbalances. As a results, countries with large positive external imbalances experience domestic currency appreciation. By similar logic, countries with large negative foreign asset positions 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.

2.5 Central Bank Swap Lines

Our model also identifies the channels through which central bank swap lines reduce cross-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. [15] 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.

Through 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-dealers. In particular, we note dollar lending via the swap line is equivalent to providing dollars in exchange for foreign currency in the spot market and simultaneously repurchasing dollars in forward markets. Thus, central bank

[15] Note that the intermediaries and the end clients can reside in the same bank holding company, for example, FX dealers and bank asset management arms. We use non-bank to refer to non-intermediaries.

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.[16] On the other hand, intermediaries providing hedging services to countries with negative imbalances would demand foreign currency rather than U.S. dollars.[17] 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 can reduce the magnitude of cross-currency bases b^n by funding intermediaries that provide hedging services to non-intermediary end users. 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.

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

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

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

period and show how hedging demand potentially explains the systematic variation in this term structure of cross-currency bases. We provide the general setup below but leave the model details for interested readers in Appendix B.3. 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.

In period 2, the forward trader faces uncertainty in investors' hedging demands. With probability π, the hedging demand in period 2 equals h^n_L, and with probability $1 - \pi$, the hedging demand in period 2 equals h^n_H. $b^{n,(2)}_1$ denotes the cross-currency basis in period 1 on the forward exchange rate two periods ahead (in period 3), b^n_1 denotes the one-period currency basis in period 1, $b^n_{2,k}$ denotes the one-period basis in period 2 when the hedging demand equals h^n_k for $k = L, H$, and $1 + r^n_2$ 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.

Lemma 2. *The period 1 cross-currency basis for the period 3 forward exchange rate is:*

$$b^{n,(2)}_1 = \frac{b^n_1(1 + r^n_2)}{2} + \frac{\pi b^n_{2,L} + (1 - \pi)b^n_{2,H}}{2}. \tag{8}$$

Equation (8) 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 $b^{n,(2)}_1$ should be larger in magnitude than the period 1 basis b^n_1. 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 Measures of Hedging Demand

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.[18]

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 net debt holdings rather than both debt and equity holdings, because 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

[18]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.[19]

To measure the price impact of hedging dollar imbalances, we start with a focus on the cross-currency basis that captures the relative valuation of forward and spot exchange rates after adjusting for interest rate differentials. Consistent with existing literature, we use Libor-based cross-currency basis swap levels as our empirical measure.[20] This basis spread is also commonly referred to as the deviations from CIP, defined as the difference between the forward premium and interest rate differential:

$$b_t^n \approx (f_{t,t+1}^n - s_t^n) + (r_t^D - r_t^n), \tag{9}$$

where r_t^D and r_t^n are the Libor interest rates in the U.S. and foreign country n, respectively. As defined here and equivalently in equation (2) in levels, foreign currency appreciation in the forward market is represented by results in a negative cross-currency basis b_t^n holding other terms fixed. 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). 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.

[19]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.

[20]All market data are from Bloomberg.

Unconditional Currency Basis and Dollar Imbalances

In this section, we present evidence for Proposition 1 in our model that relates currency basis to dollar imbalances. We begin by familiarizing the reader with our pricing measure that has also been used in previous papers. Figure A2 shows the time series of cross-currency bases for G10 currencies since 2000. For clarity, a negative basis indicates the currency's forward price is overvalued relative to its spot price after adjusting for the interest rate differentials. A positive basis indicates an undervaluation of the currency in forward markets relative to the spot price.

Figure 2 shows the average cross-sectional relationship between cross-currency basis spreads and dollar imbalances before and after the Global Financial Crisis (GFC) in 2008. The inverse relationship between dollar imbalance and currency basis attests to Proposition 1 in our model: the more positive the net dollar imbalance, the more the domestic currency is overvalued in the forward market relative to the spot market. The unconditional averages indicate a persistent hedging demand in which countries with large net foreign asset holdings buy domestic currency forwards as a hedge. Table 3 formally test 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) focus on dollar debt holding imbalances. These regression results corroborate the evidence in Figure 2 and also show the inverse relationship between cross-currency bases and dollar imbalances is stronger for non-equity net investments. The significance in the dollar debt imbalance coefficients but insignificance in the dollar equity imbalance coefficients (Columns 5 and 6) accords with the theoretical prediction of greater currency hedging in debt instruments (Campbell et al., 2010).

Comparing the post-GFC sample (Figure 2.A) with the pre-GFC sample (Figure 2.B), the inverse relationship between dollar imbalances and currency bases holds true in both periods, but the slope is steeper in the post-GFC period, indicating the forward and the spot markets are more segmented from one another.[21] In accordance with proposition 1, the steepening of the relationship since the GFC can reflect an increase in the hedging ratio h or an increase in financial intermediary constraint κ, with the latter channel focused on intermediary constraints discussed in prior studies.[22] In addition to the steepening of the unconditional relationship, the intercepts have also shifted lower from pre- to post- GFC. This intercept down shift likely reflects a general foreign demand to hedge dollar assets associated with a more negative U.S. external imbalance — the U.S.'s NIIP had declined from an average of -18% of nominal GDP between 2000 and 2007 period to an average of -33% of nominal GDP after 2008. The U.S. net dollar imbalance declined from -21 to -29% of GDP over the same periods.

4 Exchange Rate Dynamics and Dollar Imbalances

Next, we present evidence for Propositions 2 and 3, which show countries' dollar imbalances predict systematic movement in countries' cross-currency basis spreads and spot exchange rates. We start by providing evidence for these propositions through case studies during the onset of the COVID-19 pandemic, the GFC, and the eurozone crisis. Afterwards, we conclude with asset pricing factor tests that more formally analyze the relationship between dollar imbalances and exchange rates over the entire sample.

4.1 COVID-19

The market turmoil during the early onset of the COVID-19 pandemic was sharp and unexpected, thus providing an ideal test of our model predictions. Figure 3 shows the level

[21] We also examined other subsamples, for example, pre-GFC defined as the 2000-2005 period and the post-GFC sample defined as post 2010, and found the overall empirical relationships were unaffected by the sample cutoffs.

[22] For example, Basel III regulations raised balance sheet constraints of banks and affiliated broker dealers, see (Du et al., 2018; Adrian, Boyarchenko, and Shachar, 2017; Duffie, 2018) among others.

of currency bases (Panel A) and cumulative returns in spot exchange rates (Panel B) from February 1, 2020, to March 13, 2020.[23]

The time series shows the largest market movements occurred starting in late February. The cross-sectional dispersion in currency bases and log spot returns are generally consistent with the dollar imbalance relationship as predicted by Propositions 2 and 3. Panel A shows that while some currencies (e.g., Japanese yen) had bases that became sharply more negative (indicating relative overvaluation 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.

In Figure 4 Panel A, we show the changes in currency bases and log spot exchange rates plotted against measures of dollar imbalances. As we theorized, countries with large positive net dollar foreign debt investments experienced more negative changes in their cross-currency basis, indicating additional overvaluation in forward relative to spot. At the same time, these countries with large positive net foreign investment positions experienced domestic currency appreciation. By contrast, countries with large external dollar debt borrowings experienced the opposite dynamics.

[23] 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.

4.1.1 FRB Swap Line Usage During COVID-19

As discussed earlier, the offering of central bank swap lines not only reduces constraints for financial intermediaries (reducing κ), but also acts as a lender of last resort for financial intermediaries that supply foreign currency forward. As such, countries with the most demand for buying local currency forwards versus selling dollar forwards stand to draw the most from the dollar liquidity facility. Thus, our framework predicts the countries with the large net positive external dollar imbalances are the ones that draw the most from the dollar swap lines.

Panel B of Figure 4 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, 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. Previous work studying earlier periods of swap line usage highlighted the funding need for dollar liquidity in the banking sector as a factor in the swap line usage (Goldberg et al., 2010). 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, Du, and Liao, 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.[24]

4.2 Global Financial Crisis and Eurozone Crisis

We corroborate our evidence from the COVID-19 crisis by 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).[25] 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.

4.3 Cross-sectional Asset Pricing

In this section, we perform standard cross-sectional asset pricing tests to formally assess the comovement in forward and spot exchange rates with respect to the hedging channel. We test the following two hypotheses: (1) A country's dollar imbalance explains its currency's differential exposure to hedging demands and intermediary constraints, and (2) a country's exposure to hedging demand and intermediary constraints explains variation in its forward and spot exchange rates over time. In other words, we assess whether the dynamics in forward and spot exchange rates observed in the Figures 4 and A3 apply more generally. To perform these tests, we use monthly averages of currency bases and spot exchange rates for each of the currencies in our sample from January 2008 to April 2020.

[24] 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).

[25] Our GFC sample captures the period September 1, 2008 from to October 1, 2008 when the currency bases peaked locally.

First, we construct a risk factor based on the mean absolute deviation (MAD) of cross-currency bases intended to capture changes in hedging demand and intermediary balance sheet costs:

$$\overline{\Delta|b|}_t = \frac{1}{N}\sum_{n=1} |b_t^n| - |b_{t-1}^n|. \tag{10}$$

$\overline{\Delta|b|}_t$ is the average change in the magnitude of currency bases in the sample. Increases in $\overline{\Delta|b|}_t$ signal greater hedging demand or increases in the costs of financial intermediation. Proposition 2 shows countries with more positive dollar imbalances observe larger decreases in their currency bases when either hedging demand or the costs of financial intermediation increase. Hence, the currency basis of countries with more positive dollar imbalances should load more negatively on $\overline{\Delta|b|}_t$. Proposition 3 shows countries with more positive dollar imbalances appreciate more in response to increases in hedging demand. Hence, changes in the log exchange rate of countries with more positive dollar imbalances should load more positively on the $\overline{\Delta|b|}_t$.

We run univariate regressions of the following form:

$$\Delta y_t^n = \alpha^n + \beta^n \overline{\Delta|b|}_t + \varepsilon_t^n, \tag{11}$$

where Δy_t^n captures changes in the variable of interest (i.e., the currency basis or the log spot exchange rate), and β^n captures the loading of Δy_t^n on the risk factor $\overline{\Delta|b|}_t$.

Figure 5 plots β^n against the country-n dollar imbalance. Panel A of Figure 5 plots the betas of currency bases and shows a strong negative relation between the betas and the country's dollar imbalances. Consistent with Proposition 2, countries with more positive dollar imbalances load more negatively on the MAD factor. As the MAD factor increases during times of financial distress, countries with more positive external imbalances observe their cross-currency bases become more negative and their forward exchange rates become more overvalued relative to the spot exchange rate.

Panel A of Table 4 presents the corresponding results of each univariate regression of changes in cross-currency bases on changes in the MAD factor. The currencies in Table 4 are ordered left to right from most negative average net dollar debt investment position to most positive position. These regression results confirm the negative relationship between β^n and country n's external imbalance. Moreover, the R^2 from the univariate regressions tend to be high across the sample, suggesting this single factor model does a good job of explaining changes in the currency basis over time for many of the currencies in our sample.

Panel B of Figure 5 shows a strong negative relationship between currency returns and external imbalances. Consistent with Proposition 3, countries with more positive external imbalances tend to appreciate more when the MAD factor increases.

Panel B of Table 4 presents the results of each univariate regression of changes in spot exchange rates on changes in the MAD factor. Naturally, the R^2s in Panel B of Table 4 tend to be lower than in Panel A, indicating the single factor $\overline{\Delta|b|}_t$ explains a smaller share of the variation in exchange rates relative to the variation in currency bases. The smaller R^2s are consistent with the notion that the demand for currencies in the spot market for hedging purposes is lower than the total demand for currencies in the spot market. Nevertheless, the average R^2 across the nine currencies is still 0.17.

Hence, we conclude our single factor model explains a significant portion of the variation in forward and spot exchange rates over our sample. Taken together, these results provide further evidence the hedging channel of exchange rate determination systematically explains the dynamics of forward and spot exchange rate markets.

4.4 Crash Risk and Carry Trade Returns

The conditional spot return and changes in the cross-currency basis shown in the previous sections provide an explanation for the highly persistent differences in interest rates and currency returns across countries. These differences in interest rates and currency excess returns across countries capture differences in risk premia (Lustig and Verdelhan, 2007;

Lustig, Roussanov, and Verdelhan, 2011). Currencies that appreciate in periods of financial distress have lower unconditional returns, because they provide a hedge against states of the world in which marginal utility is high. Expanding on this literature, we highlight how 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.

Figure 6 shows the unconditional relationship between average currency excess returns and forward premia against countries' net dollar debt holdings.[26] Currencies with large positive net dollar debt investments typically yield lower excess returns, and currencies associated with countries that have large negative net dollar debt yield higher returns. This result has similarly been highlighted by DellaCorte et al. (2016) that 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 a precise mechanism to explain why countries with positive dollar imbalances have currencies that appreciate in bad times, and thus demand unconditionally lower excess returns.

4.5 Term Structure of Cross-Currency Basis

The demand for hedging can also explain the term premia of the cross-currency basis, as well as the returns from a forward-starting currency basis trade that was described in Du et al. (2019). As we showed in the conditional movements of the cross-currency basis, countries with large negative imbalances have forwards that depreciate more than spot rates during a crisis (currency bases become more positive), whereas countries with positive imbalances have forwards that become more overvalued relative to spot rates (currency bases become more negative). In the theory section, equation (8) shows the magnitude of longer maturity forwards (and cross-currency bases) should be larger in magnitude to compensate intermediaries for the possibility of financial crises. In other words, longer maturity forwards embed

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

a term premium, and therefore, the term structure of cross-currency is typically upward sloping in magnitude.

For concreteness, Figure 7 illustrates the evolution of relative forward prices during the COVID-19 pandemic. 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 and 4, 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.

We test for this systematic variation in the term structure of forward exchange rates more formally. First, Panel B of Figure 7 (left) confirms the unconditional term structure of cross-currency bases is upwards sloping in magnitude. Countries with negative dollar imbalances (e.g., Australia) observe positive cross-currency bases term spreads, indicating longer maturity forward exchange rates are more undervalued than shorter maturity forwards. Conversely, countries with positive dollar imbalances (e.g., Japan and Switzerland) observe negative term spreads, indicating longer maturity forward exchange rates are more overvalued than shorter maturity forwards.

The right-hand panel of of Figure 7.B plots the betas from regressions of changes in the slope of the cross-currency term bases on the mean average deviation of cross-currency bases calculated earlier.[27] These betas show that during periods of financial distress, the term structures of cross-currency bases systematically invert: the slopes of the term structures

[27]Table 5 presents presents the corresponding results of each univariate regression of changes in the five-year minus one-year cross-currency basis spread on changes in the MAD factor. The currencies are ordered left to right from the most negative average dollar imbalance to the most positive.

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. These results show the variation observed in AUD and JPY forward exchange rates in Figure 7 Panel A indicate systematic variation in the term structure of forward exchange rates that is consistent with the hedging channel of exchange rate determination.[28]

4.6 Hedged Demand and Options Pricing

Currency hedging demand also has a noticeable impact on the pricing of options on currencies. This 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 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 hedge against the appreciation of home currency (or, equivalently, the devaluation of their foreign currency position) by either buying forwards or purchasing calls on the domestic currency. 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

[28]Du et al. (2019) documents a profitable trading strategy using forwards on cross-currency basis swaps to exploit the term premia. We show in Appendix F that these relationships also align with countries' dollar imbalances. The conditional return profiles of these sophisticated trading strategies suggest that profits that were previously seen as alphas might in fact have been a reflection of betas, as a phenomenon theorized in Cho (2020).

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.[29]. 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).

Panel A of Figure 8 shows the time series of risk reversals for the sample currencies. The graph highlights a few facts that resemble those of the currency basis as shown above in Figure A2. First, options risk reversals increased in magnitude starting in 2008, a fact highlighted in Farhi et al. (2009). In the context of our framework, this widening in the risk-reversal is linked to the increase in hedging demand since 2008. Second, the figure shows substantial cross-sectional heterogeneity between 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.[30] Currencies with positive dollar imbalance or less negative dollar imbalance, for example, 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 6 shows the panel regression of option risk-reversals on various measures of dollar imbalances. Similar to the previous results, the coefficients for net dollar debt are the most significant, which signals the hedging of fixed-income like investments is likely stronger than the hedging of equities.

[29] 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.

[30] 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.

Finally, Panel B of Figure 8 presents the unconditional and conditional option risk-reversal levels relative to measures of dollar imbalances.[31] The option risk-reveral results are consistent with the prior pricing dynamics of forwards— call options are expensive for JPY, just as, forward exchange rate on JPY is overvalued relative to the spot exchange rate after adjusting for interest rate differentials. The opposite is true for AUD. This similarity makes intuitive sense because options and forwards are both hedging instruments that are potentially substitutable. 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, 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).

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.

[31] Table 7 presents presents the corresponding results of each univariate regression of changes in the option risk-reversals on changes in the MAD factor. The currencies are ordered left to right from the most negative average dollar imbalance to the most positive. These regression results confirm the relationship presented in Figure 8 Panel B.

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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. Panel B shows the pre-crisis sample from January 2000 to December 2007.

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

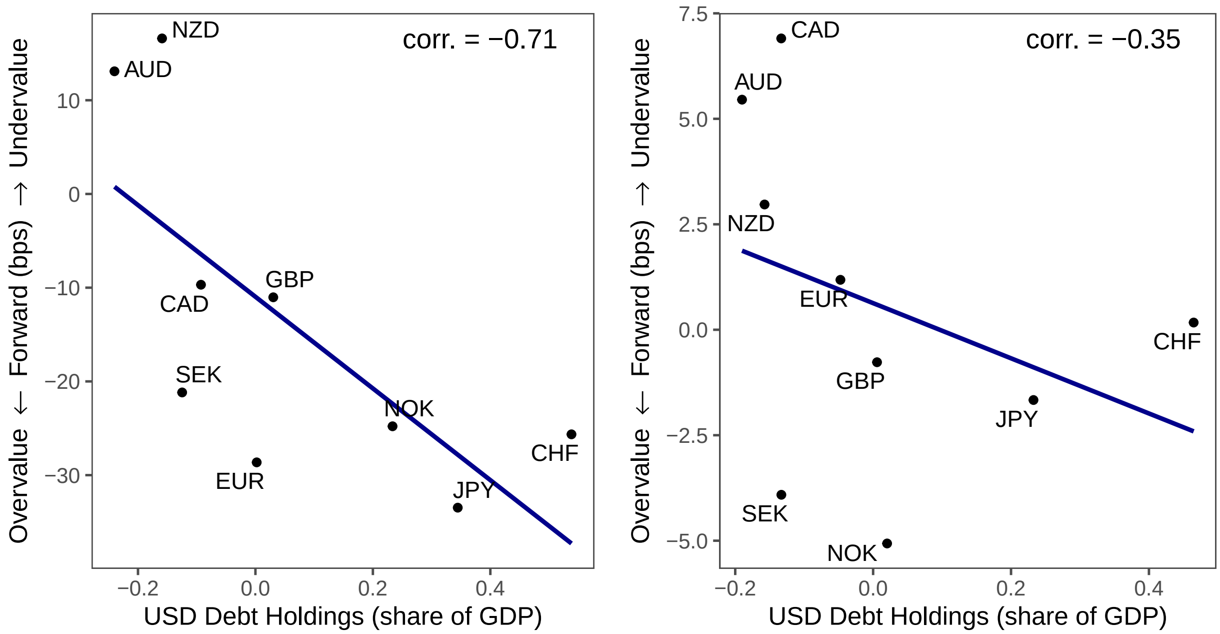
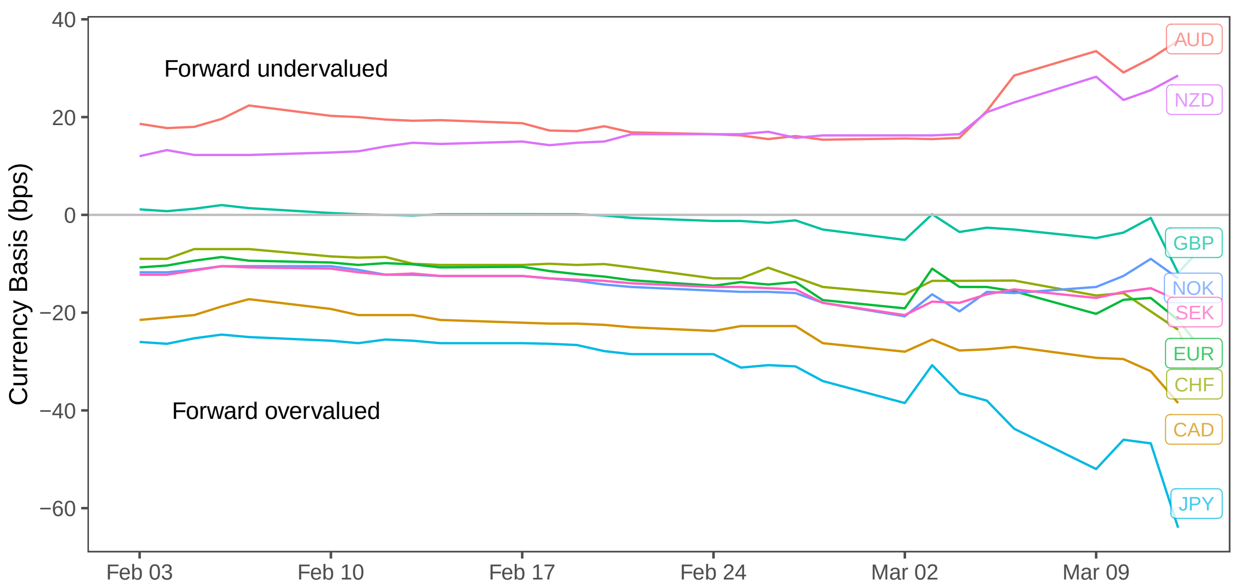


Figure 3: Cross-currency bases and spot exchange rates during Covid-19 crisis

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)

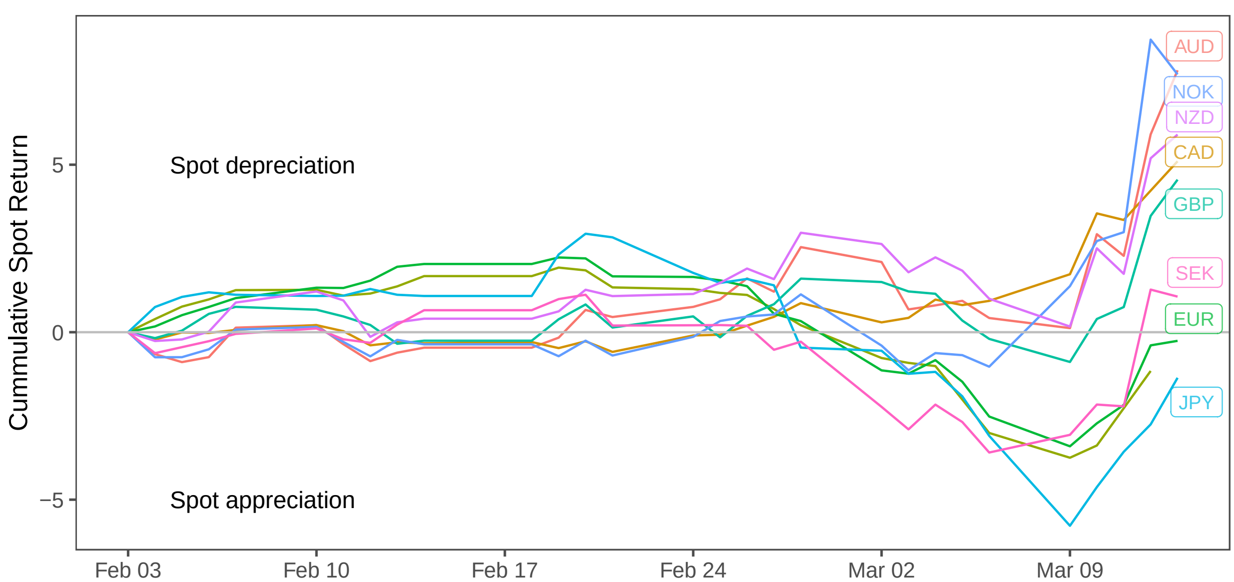
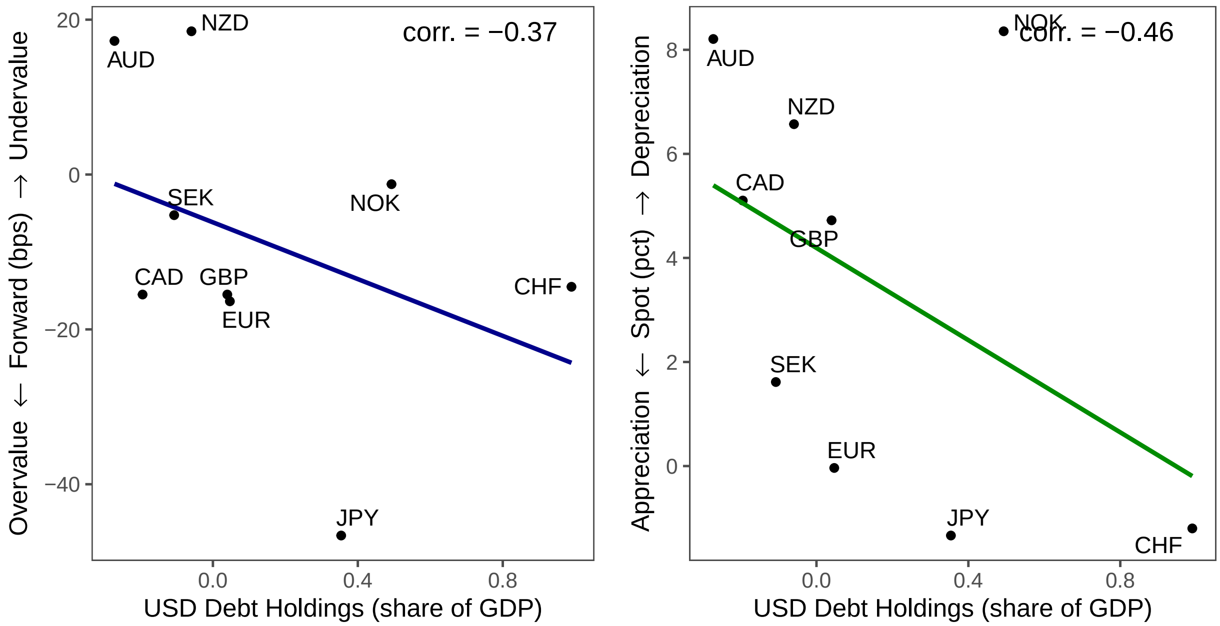


Figure 4: Dollar Imbalances, Exchange Rates and Swap Lines During Covid-19

Panel A plots changes in currency bases and spot exchange rates during the Covid-19 crisis. We measure changes in currency bases and exchange rates from February 1, 2020 to March 13, 2020 – The Friday before the FRB cut the federal funds rate by 100 basis points and extended central bank swap line provision on Sunday March 15, 2020. Panel B plots maximum swap line draws by central banks during the Covid-19 market turmoil against dollar imbalances.

Panel A. Changes in Forward and Spot Exchange Rates



Panel B. FRB Swap Line Draws

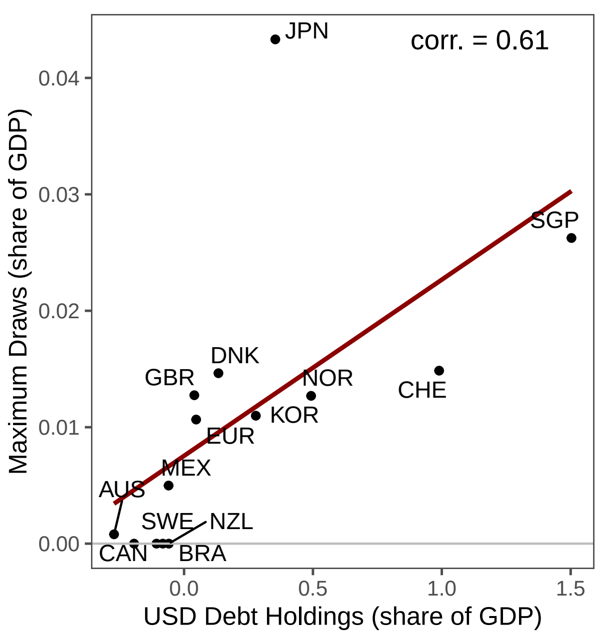
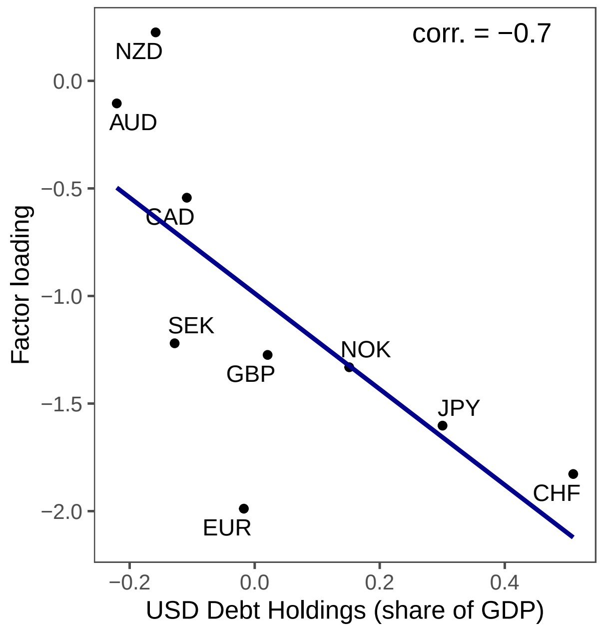


Figure 5: A Single Factor Model of Forward and Spot Exchange Rates

This exhibit presents the coefficients β^n from estimating single-factor models of changes in cross-currency bases (Panel A) and spot exchange rates (Panel B) against countries' dollar imbalances. We plot β^n from the regression: $\Delta y_t^n = \alpha^n + \beta^n \overline{\Delta b}_t + \varepsilon_t^n$, where Δy_t^n represents the outcome variable of interest for country i at date t and $\overline{\Delta b}_t = (1/N) \sum_{n=1}^{N} |b_t^n| - |b_{t-1}^n|$ is the mean absolute deviation (MAD) of countries' cross-currency bases.

Panel A. Cross-currency basis



Panel B. Spot exchange rate log return

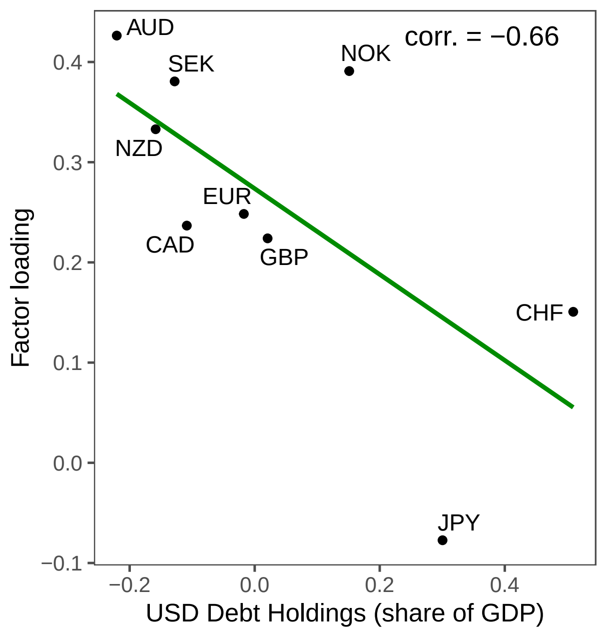
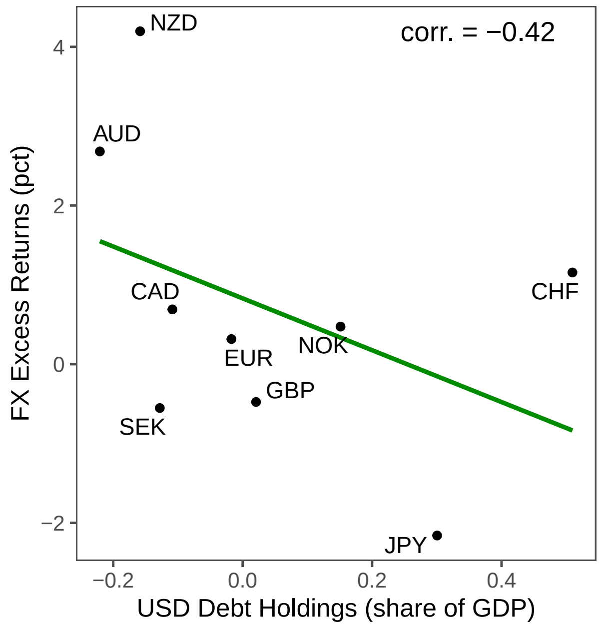


Figure 6: Dollar Imbalances and Currency Excess Returns

Panel A plots average currency excess returns against countries' dollar imbalances. Panel B plots average forward premia against countries' dollar imbalances. The sample comprises monthly observations of 1-year returns of G-10 currencies from January 2000 to April 2020.

Panel A: FX Excess Returns



Panel B: Forward Premia

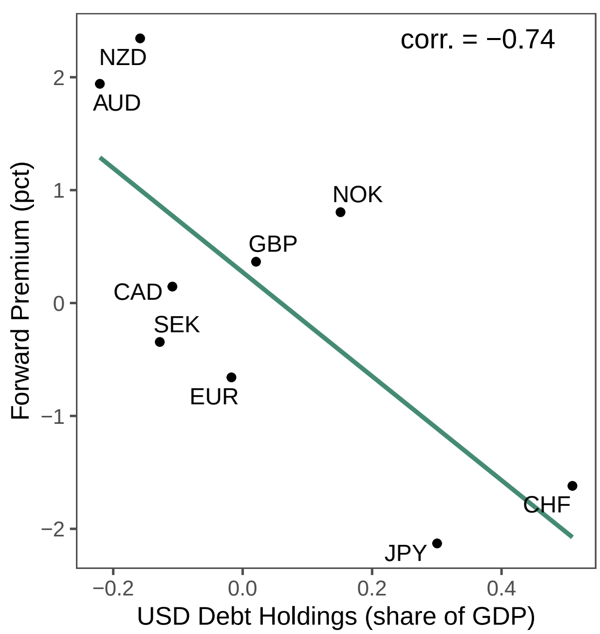
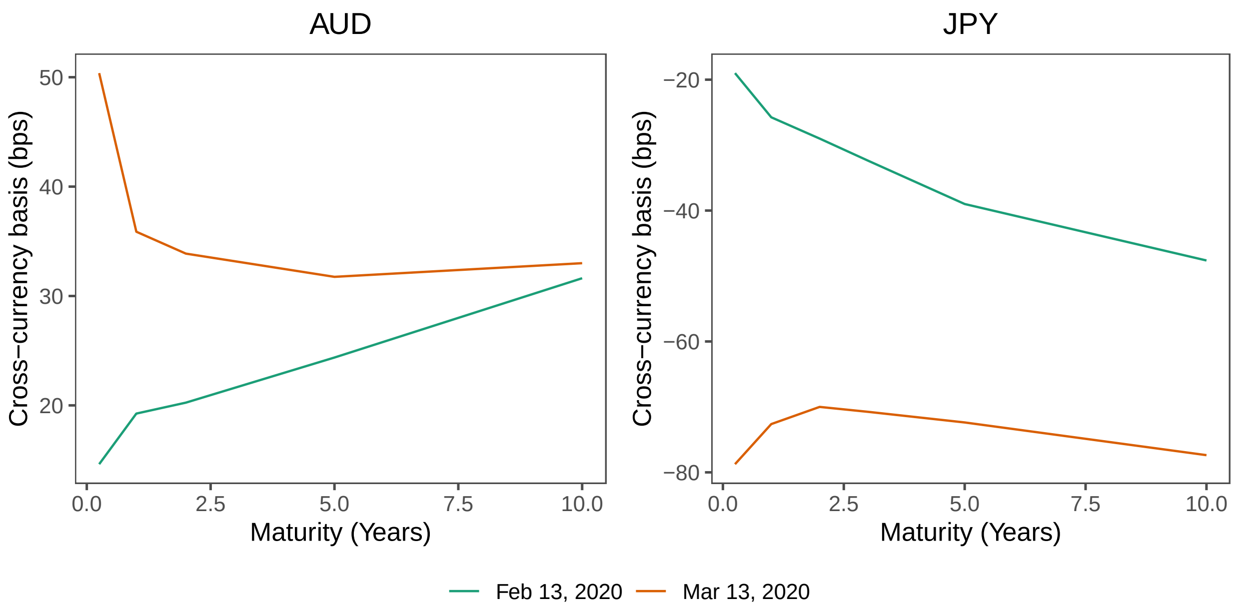


Figure 7: Term Structure of Cross-Currency Basis

Panel A presents the term structure of cross-currency basis for the Australian Dollar and the Japanese Yen on two dates during the Covid-19 pandemic (before and in midst of the market tantrum). The left-hand side of Panel B presents the term structure of cross-currency basis relative to countries' dollar imbalances. We plot the unconditional 5-year minus 1-year cross-currency basis spread. The right-hand side of Panel B plots coefficients β^n from estimating single-factor models of changes in the slope of cross-currency bases term structures against countries' dollar imbalances.

Panel A. Bases Term Structure During Covid-19



Panel B. Conditional and Unconditional Bases Term Structure

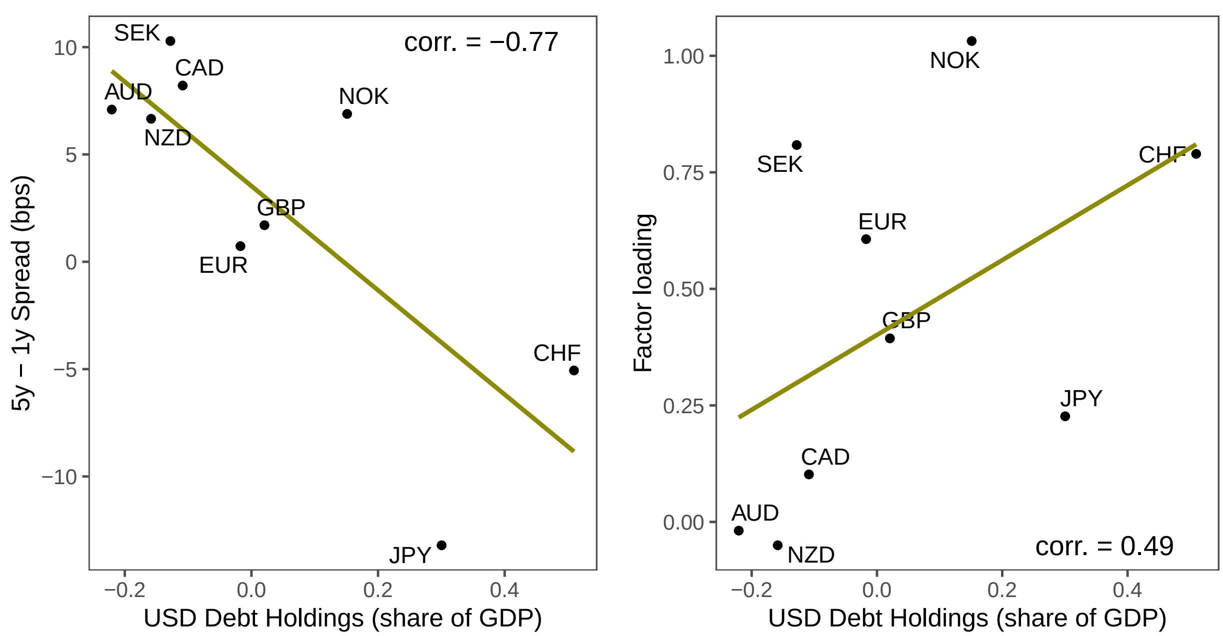
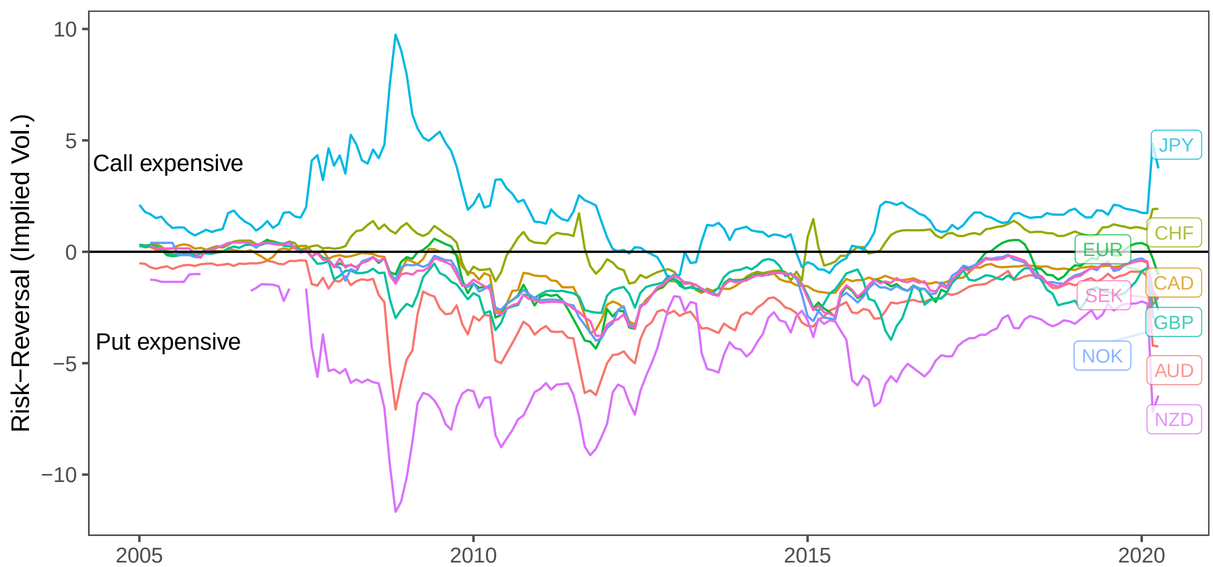


Figure 8: Currency Options Risk-Reversals

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. Panel A presents the time series between January 2005 and April 2020. The left-hand side of Panel B presents the relationship between average risk-reversals and countries' US dollar debt positions. The right-hand side of Panel B shows the coefficients β_i from estimating single-factor models of changes in risk-reversals regressed on the mean absolute magnitudes of risk-reversals.

Panel A. Risk-Reversal Time Series



Panel B. Conditional and Unconditional Risk-Reversals

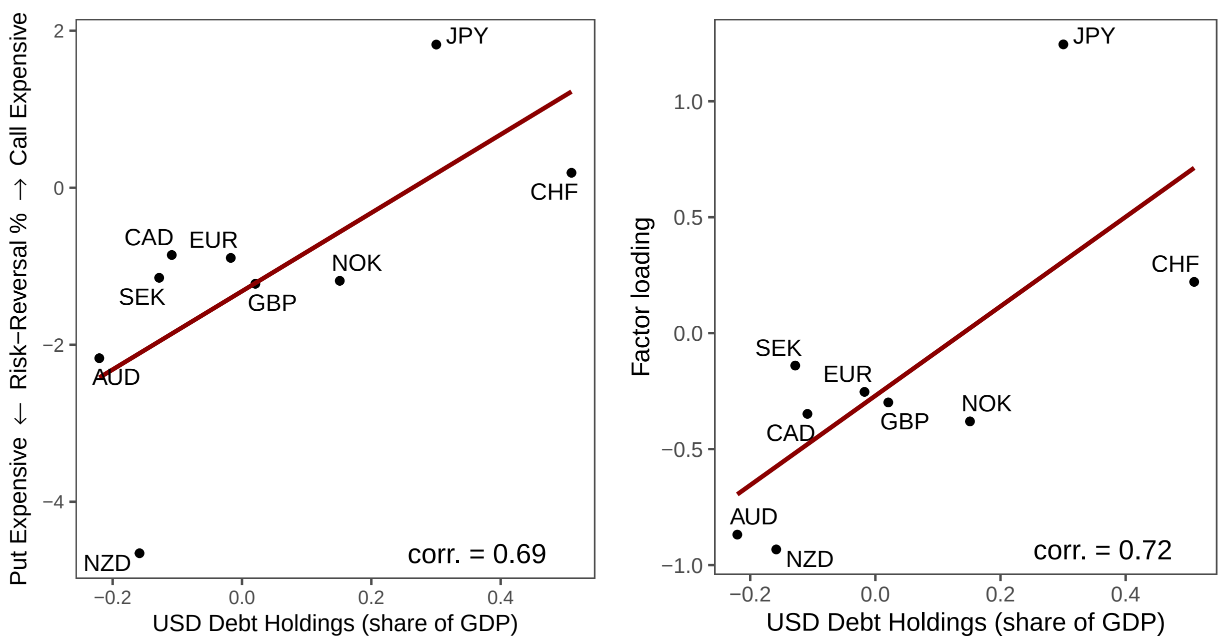


Table 1: Regulatory requirements on currency mismatch and hedging estimates

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
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 (2000-2020)

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 Debt Holdings / GDP			−29.788**	−28.530**		
			(12.239)	(13.186)		
USD 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: Single Factor Model of Currency Bases and Spot Exchange Rates

This table presents regression results from a single factor model of changes in cross-currency bases and spot exchange rates:

$$\Delta y_t^n = \alpha^n + \beta^n \bar{\Delta} b_t + \varepsilon_t^n,$$

where Δy_t^n represents the change in the variable of interest for country n in date t and $\bar{\Delta} b_t = (1/N) \sum_{n=1}^{N} |b_t^n| - |b_{t-1}^n|$ is the average change in the mean absolute magnitude of countries' cross-currency bases. The sample comprises monthly data from January 2008 to April 2020.

	Panel A: Changes in cross-currency basis (bps)								
	NZD	AUD	GBP	EUR	SEK	CAD	JPY	CHF	NOK
β_i	0.224	−0.113	−1.277***	−1.996***	−1.212***	−0.565***	−1.614***	−1.838***	−1.321***
	(0.210)	(0.223)	(0.135)	(0.166)	(0.187)	(0.117)	(0.239)	(0.168)	(0.243)
α_i	−10.138***	−0.977	−1.901***	−0.726	−9.278***	−7.181***	12.706***	3.311***	−10.564***
	(0.746)	(0.793)	(0.478)	(0.589)	(0.662)	(0.416)	(0.848)	(0.596)	(0.864)
Observations	148	148	148	148	148	148	148	148	148
R^2	0.008	0.002	0.381	0.498	0.224	0.138	0.238	0.451	0.168
	Panel B: Changes in log exchange rates (pct)								
	NZD	AUD	GBP	EUR	SEK	CAD	JPY	CHF	NOK
β_i	0.330***	0.429***	0.227***	0.253***	0.381***	0.237***	−0.072	0.156***	0.390***
	(0.059)	(0.060)	(0.049)	(0.048)	(0.051)	(0.042)	(0.054)	(0.053)	(0.054)
α_i	0.143	0.194	0.310*	0.177	0.267	0.210	−0.022	−0.122	0.398**
	(0.211)	(0.212)	(0.175)	(0.169)	(0.181)	(0.151)	(0.190)	(0.188)	(0.191)
Observations	148	148	148	148	148	148	148	148	148
R^2	0.175	0.262	0.127	0.162	0.276	0.176	0.012	0.056	0.265

Table 5: Single Factor Model of the Bases Term Spread

This table presents regression results from a single factor model of changes in cross-currency bases term spread:

$$\Delta s_t^n = \alpha^n + \beta^n \bar{\Delta} b_t + \varepsilon_t^n,$$

where Δs_t^n represents the change in the 5-year minus 1-year cross-country term spread for country n in t and $\bar{\Delta} b_t = (1/N)\sum_{n=1}^{N} |b_t^n| - |b_{t-1}^n|$ is the average change in the mean absolute magnitude of countries' cross-currency bases. The sample comprises monthly data from January 2008 to April 2020.

	Change in cross-currency basis 5y-1y term spread (bps)								
	NZD	AUD	GBP	EUR	SEK	CAD	JPY	CHF	NOK
β_i	-0.045	-0.018	0.394^{***}	0.612^{***}	0.815^{***}	0.107^{*}	0.223^{**}	0.792^{***}	1.038^{***}
	(0.065)	(0.063)	(0.075)	(0.087)	(0.087)	(0.055)	(0.105)	(0.117)	(0.074)
α_i	-0.012	-0.086	-0.048	-0.159	-0.110	0.058	-0.194	-0.190	-0.125
	(0.231)	(0.224)	(0.266)	(0.309)	(0.310)	(0.196)	(0.371)	(0.415)	(0.263)
Observations	148	148	148	148	148	148	148	148	148
R^2	0.003	0.001	0.159	0.253	0.374	0.025	0.030	0.239	0.574

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: External Imbalances and Risk Reversals (2000-2020)

The following table presents panel regressions of monthly currency option risk-reversals on measures of external imbalances. The option risk-reversal is defined as the implied volatilities of the call minus the put of options with one-year maturity and 25-delta. The sample includes G10 currencies from January 2008 to April 2020. Standard errors are clustered by currency.

	Cross-Currency Basis (bps)					
	(1)	(2)	(3)	(4)	(5)	(6)
USD NIIP / GDP	2.379**	2.776***				
	(1.054)	(1.048)				
USD Debt Holdings / GDP			3.975***	4.100***		
			(1.539)	(1.570)		
USD Equity Holdings / GDP					1.395	1.735
					(2.915)	(3.522)
Fixed Effects		Month		Month		Month
Observations	1,713	1,713	1,713	1,713	1,713	1,713
R^2	0.175	0.407	0.242	0.452	0.018	0.228

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

Table 7: Single Factor Model of Option Risk-Reversals

This table presents regression results from a single factor model of changes in options risk-reversals:

$$\Delta rr_t^n = \alpha^n + \beta^n \overline{\Delta rr}_t + \varepsilon_t^n,$$

where Δrr_t^n represents the change in the option risk-reversal on currency n. The option risk-reversal is defined as the implied volatilities of the call minus the put of options with one-year maturity and 25-delta. $\bar{\Delta} rr_t = (1/N)\sum_{n=1}^{N} |rr_t^n| - |rr_{t-1}^n|$ is the average change in the mean absolute magnitude of countries' risk-reversals. The sample comprises monthly data from January 2000 to April 2020.

	Options risk-reversal (pct)								
	NZD	AUD	GBP	EUR	SEK	CAD	JPY	CHF	NOK
Factor Loading	−0.933*	−0.869**	−0.299	−0.253	−0.140	−0.348	1.245***	0.221	−0.381
	(0.558)	(0.364)	(0.248)	(0.283)	(0.245)	(0.215)	(0.419)	(0.219)	(0.257)
Constant	−4.640***	−2.174***	−1.230***	−0.900***	−1.146***	−0.861***	1.805***	0.187***	−1.180***
	(0.169)	(0.104)	(0.071)	(0.081)	(0.073)	(0.061)	(0.119)	(0.065)	(0.076)
Observations	173	198	198	198	182	198	198	182	181
R^2	0.016	0.028	0.007	0.004	0.002	0.013	0.043	0.006	0.012

Note: *p<0.1; **p<0.05; ***p<0.01

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 A1 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.[32]

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

[32]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.

B Appendix to Section 2

B.1 Proof of Proposition 1

The cross-currency basis is given by equation (5). 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 (5), and by applying Assumptions 1 and 2. Taking derivatives with respect to X^n shows:

$$\begin{aligned}\frac{\partial b^n}{\partial X^n} =& h^n \kappa^2 G''\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right)\left(H'\left(-h^n X^n\right)\right)^2 \\ & - h^n \kappa G'\left(W - \kappa \sum_m H\left(-h^m X^m\right)\right) H''\left(-h^n X^n\right) < 0.\end{aligned}$$

Taking derivatives with respect to h^n shows:

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

Thus,

$$sign\left[\frac{\partial b^n}{\partial h^n}\right] = -sign\left[X^n\right].$$

Finally, taking derivatives with respect to κ shows:

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

Thus,

$$sign\left[\frac{\partial b^n}{\partial \kappa}\right] = -sign\left[X^n\right].$$

B.3 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:

$$b_1^n = \kappa G'\left(I_1\right) H'(q_1^{n,(1)} + q_1^{n,(2)}) \tag{12}$$

$$b_{2,k}^n = \kappa G'\left(I_{2,k}\right) H'(q_{2,k}^{n,(1)} + q_1^{n,(2)}(1+r_1^D)) \text{ for } k \in \{L, H\}. \tag{13}$$

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

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

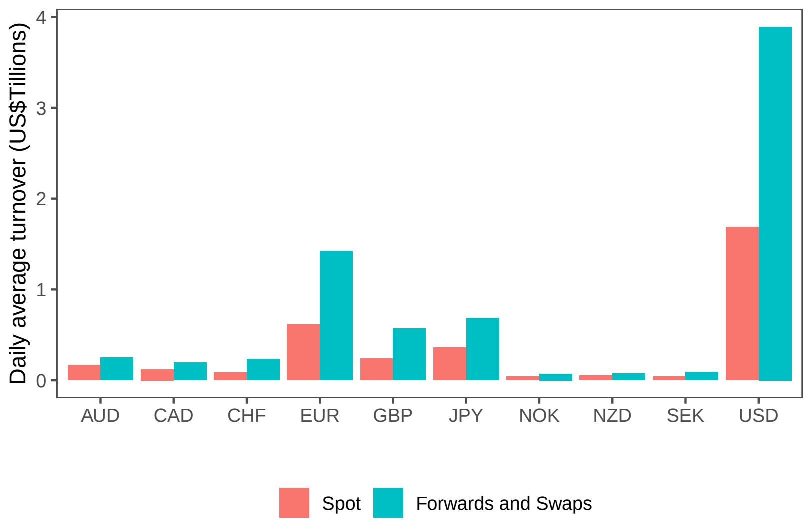
We plug the first order conditions with respect to $q_1^{(1)}$, $q_{2,L}^{(1)}$, and $q_{2,H}^{(1)}$ into the first order condition with respect to $q_1^{(2)}$ to derive equation (8).

C Additional Figures

Figure A1: 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:

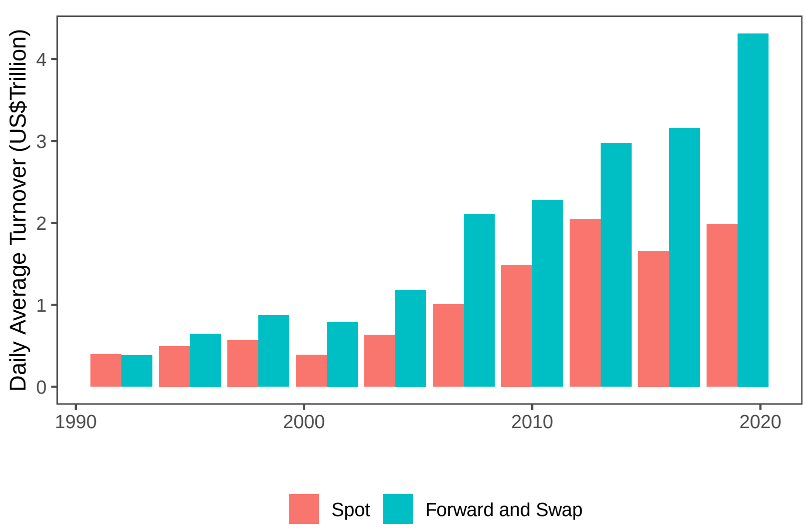


Figure A2: Cross-currency basis

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.

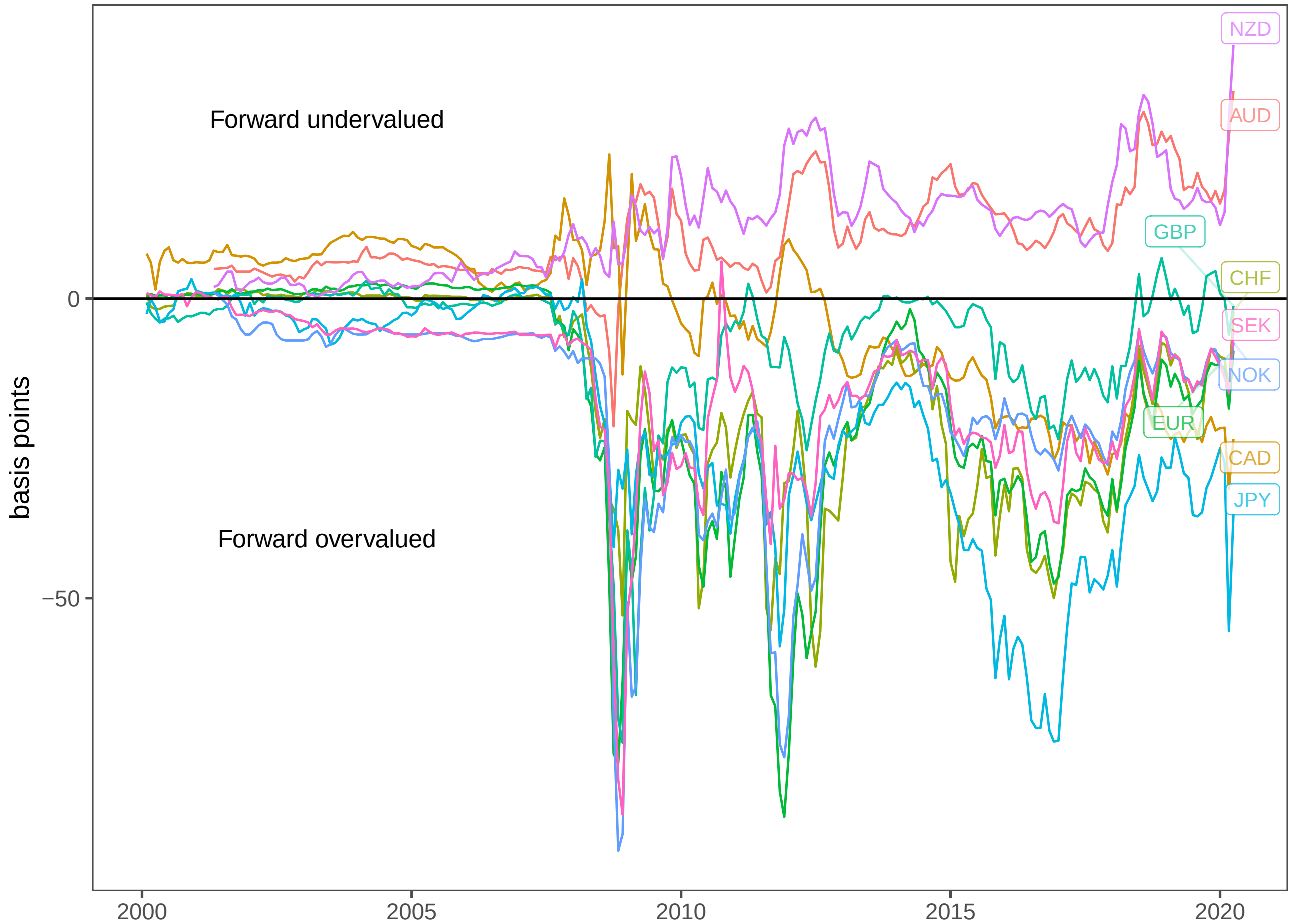
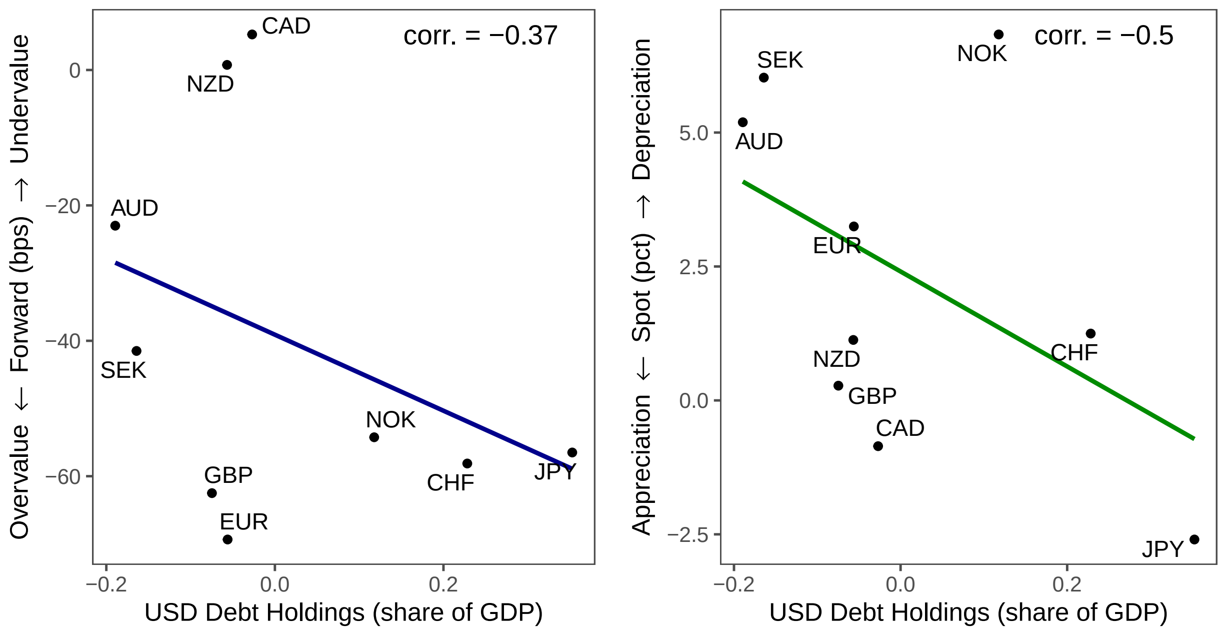


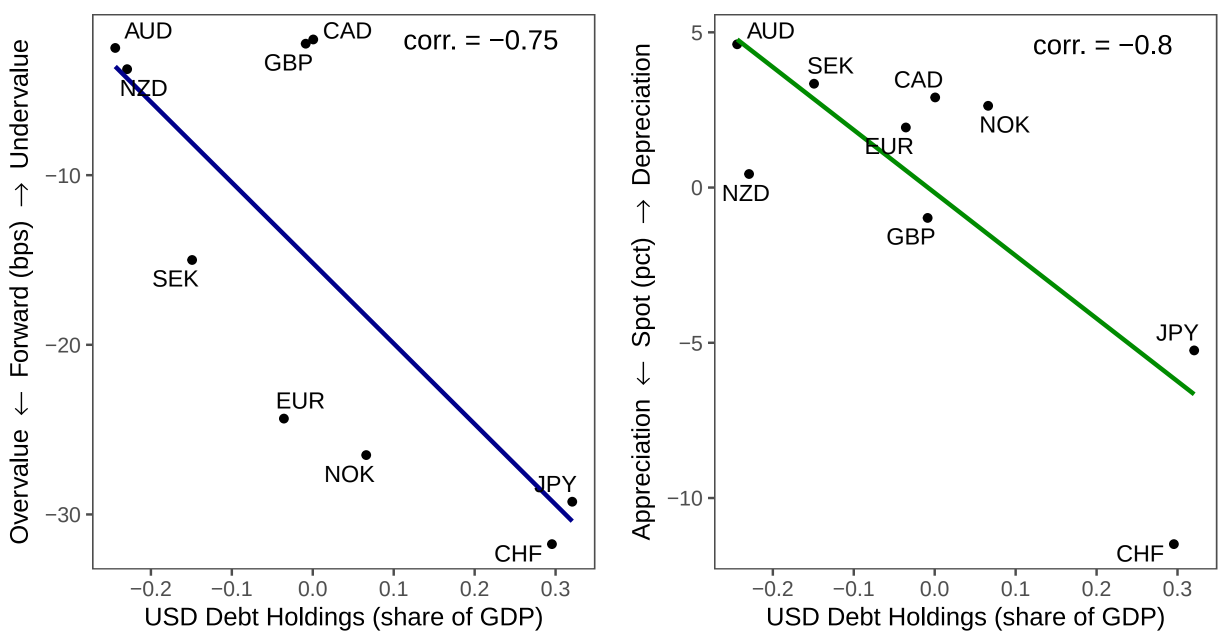
Figure A3: External Imbalances and Exchange Rates During Past Crises

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 Additional Tables

The following appendix contains additional tables showing how different measures of dollar imbalances relate to cross-currency bases and option risk-reversals.

Table A1: External imbalances and cross-currency bases (2000-2020)

The following table presents panel regressions of monthly average 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)	(7)	(8)
NIIP / GDP	−13.520***	−12.822***						
	(4.158)	(4.898)						
Net Debt + FDI / GDP			−12.973*	−13.923**				
			(6.619)	(6.798)				
Net Equity / GDP					−4.043	−0.342		
					(7.379)	(8.138)		
CA / GDP							−452.982***	−512.825***
							(136.827)	(117.830)
Fixed Effects		Month		Month		Month		Month
Observations	2,178	2,178	2,178	2,178	2,178	2,178	2,178	2,178
R^2	0.229	0.466	0.156	0.446	0.006	0.267	0.141	0.444

Note: *p<0.1; **p<0.05; ***p<0.01

Table A2: External imbalances and option risk-reversal

The following table presents panel regressions of monthly average option risk-reversal on measures of external imbalances. The option risk-reversal is defined as the implied volatilities of call minus put of options with one-year maturity and 25-delta. The sample includes G10 currencies from January 2008 to April 2020. Standard errors are clustered by currency.

	option risk-reversal							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NIIP / GDP	1.562*	1.526*						
	(0.842)	(0.892)						
Net Debt + FDI / GDP			2.657***	2.652***				
			(0.971)	(1.006)				
Net Equity / GDP					−0.753	−0.921		
					(0.794)	(0.828)		
CA / GDP							56.130*	59.279*
							(29.269)	(30.723)
Fixed Effects		Month		Month		Month		Month
Observations	1,332	1,332	1,332	1,332	1,332	1,332	1,332	1,332
R^2	0.260	0.365	0.426	0.547	0.022	0.155	0.137	0.274

Note: *p<0.1; **p<0.05; ***p<0.01

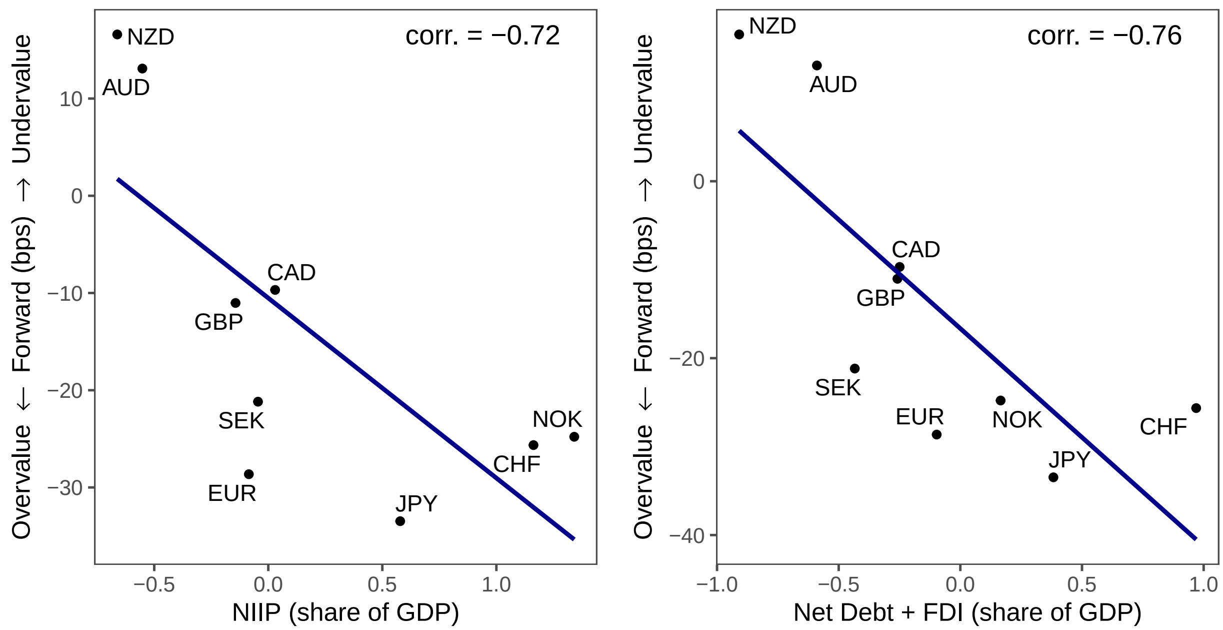
E Figures with Alternate Imbalance Measures

In the following appendix, we explore the relationship between exchange rates, and different measures of external imbalance.We supplement our primary dollar imbalance measure with alternative measures constructed using Net International Investment Position (NIIP) obtained from the International Monetary Fund scaled by the GDP. As discussed in section 1 and further validated in section 4, we focus on foreign non-equity assets due to more prevalent FX hedging practices for fixed income assets and institutions that primarily hold these assets.

Figure A4: External imbalances and unconditional cross-currency bases

This figure presents the average relationship between cross-currency bases and external imbalances pre- and post- 2008. Panel A shows the post-crisis sample from January 2008 to December 2020. Panel B shows the pre-crisis sample from January 2000 to December 2005.

Panel A. Unconditional cross-currency bases from 2008-2020:



Panel B. Panel A. Unconditional cross-currency bases from 2000-2005:

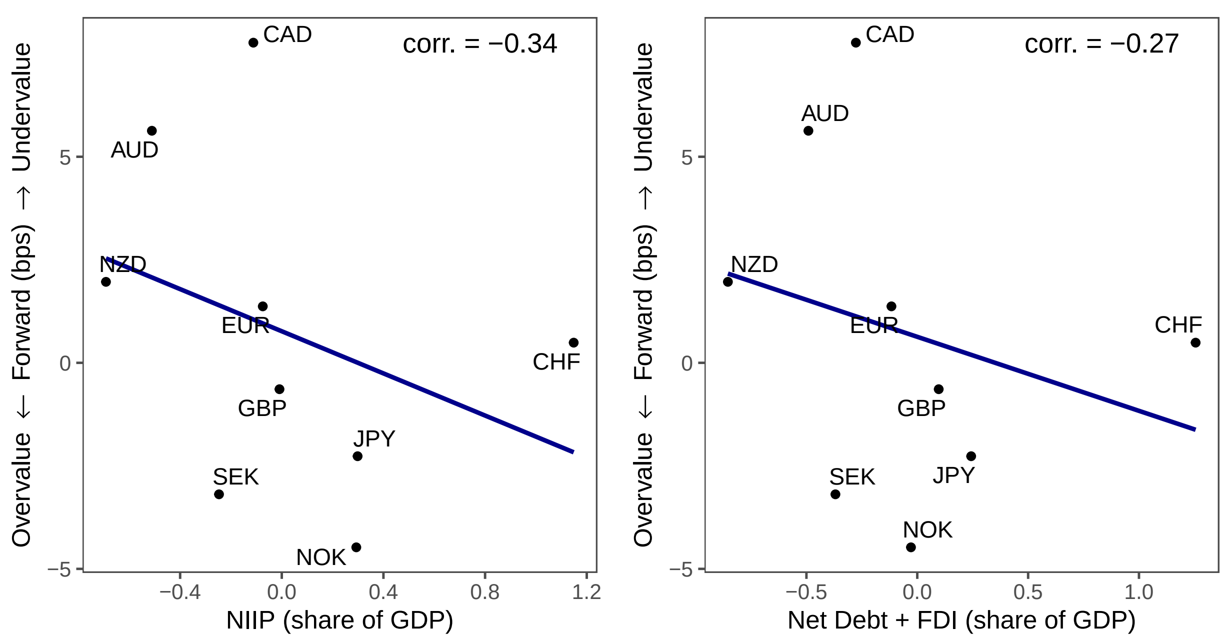
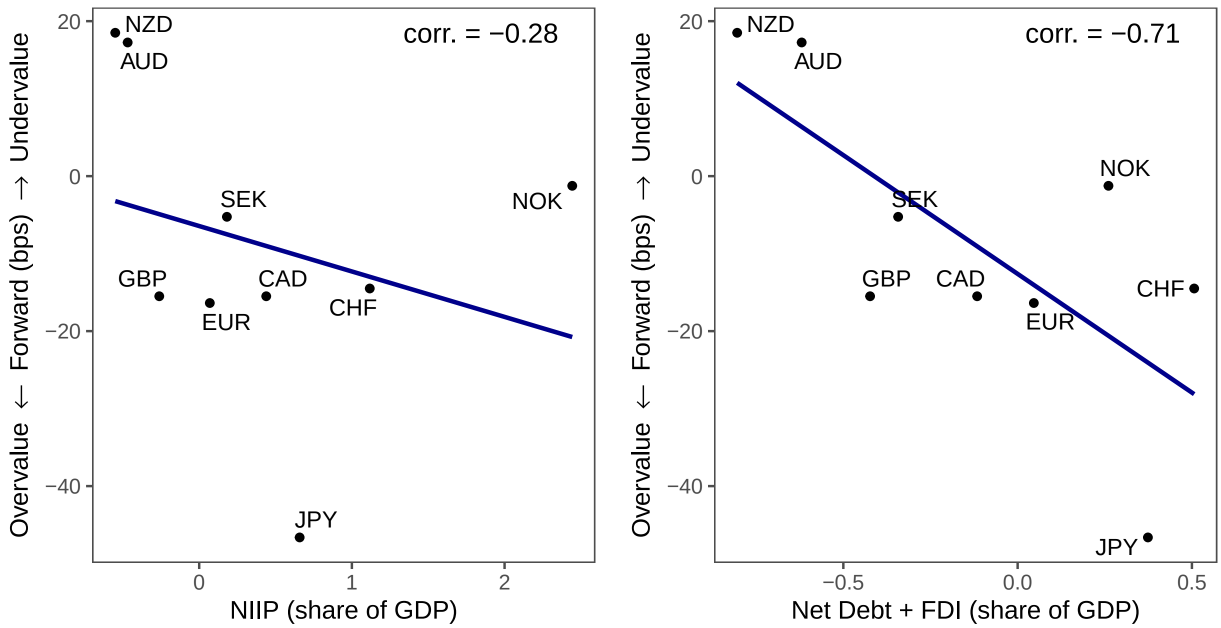


Figure A5: External imbalances and exchange rates during COVID-19 crisis

This figure plots changes in currency bases and spot exchange rates during the COVID-19 crisis. We measure changes in currency bases and exchange rates from February 1, 2020 to 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. The Norwegian Krone is omitted when calculating the correlation and the regression line between log spot exchange rate returns and external imbalances.

Panel A. Changes in Currency Bases



Panel B. Changes in Log Exchange Rates

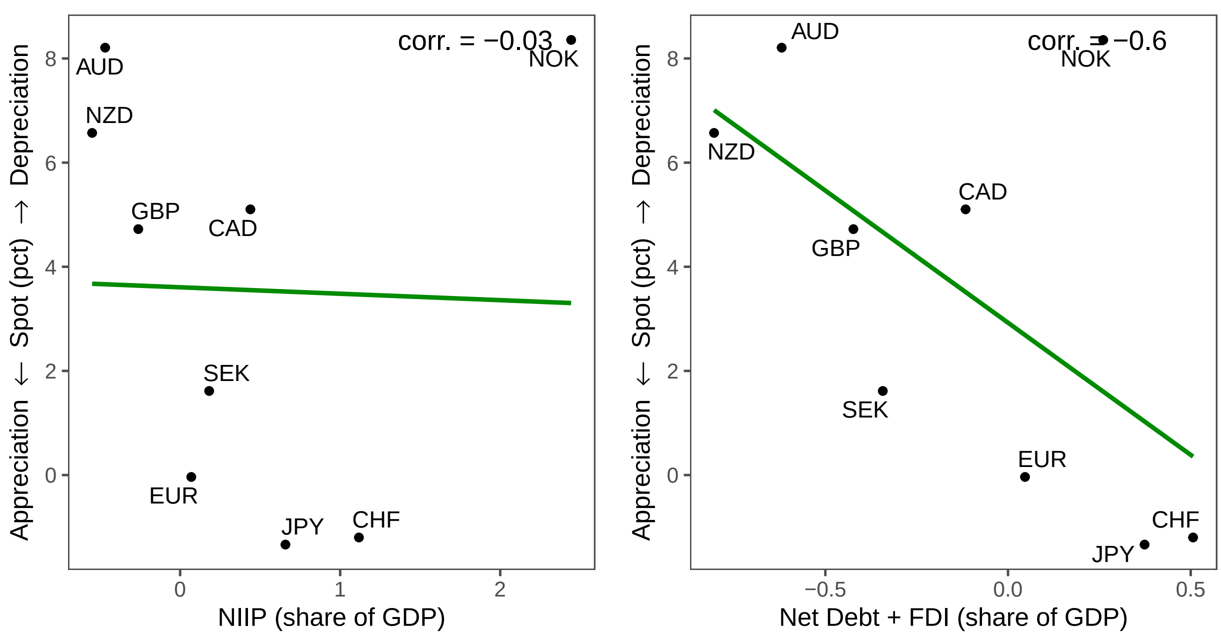
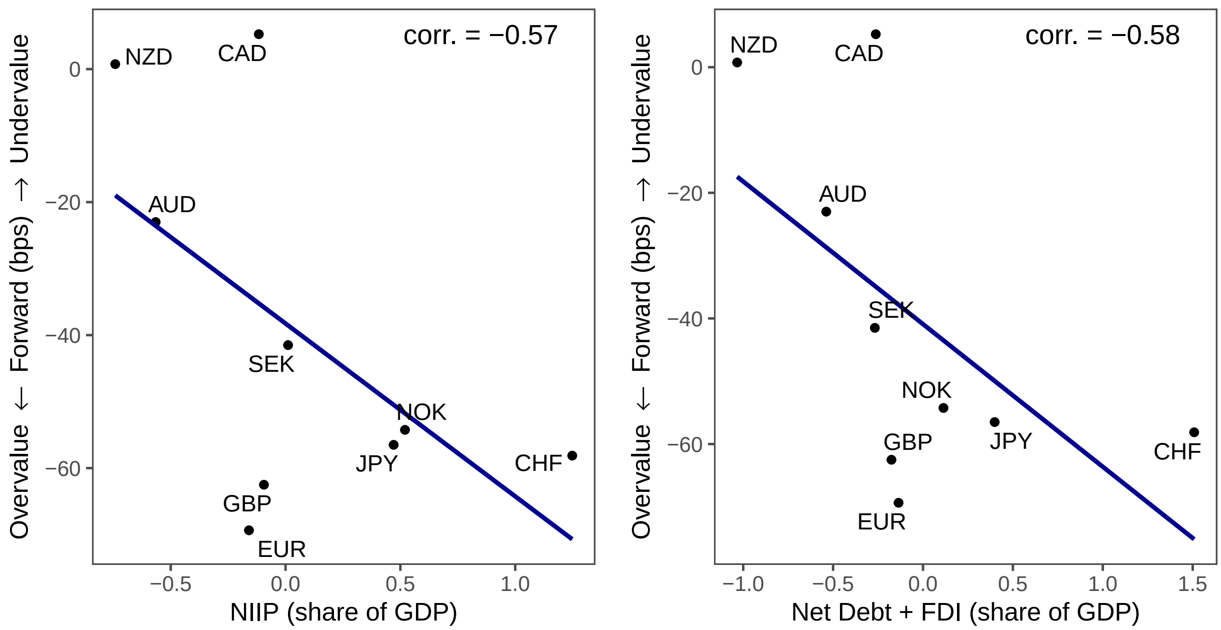


Figure A6: External imbalances and exchange rates during Global Financial Crisis

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. We measure external imbalances in terms of countries' NIIP and current account at the end of 2007.

Panel A. Changes in Currency Bases



Panel B. Changes in Log Exchange Rates

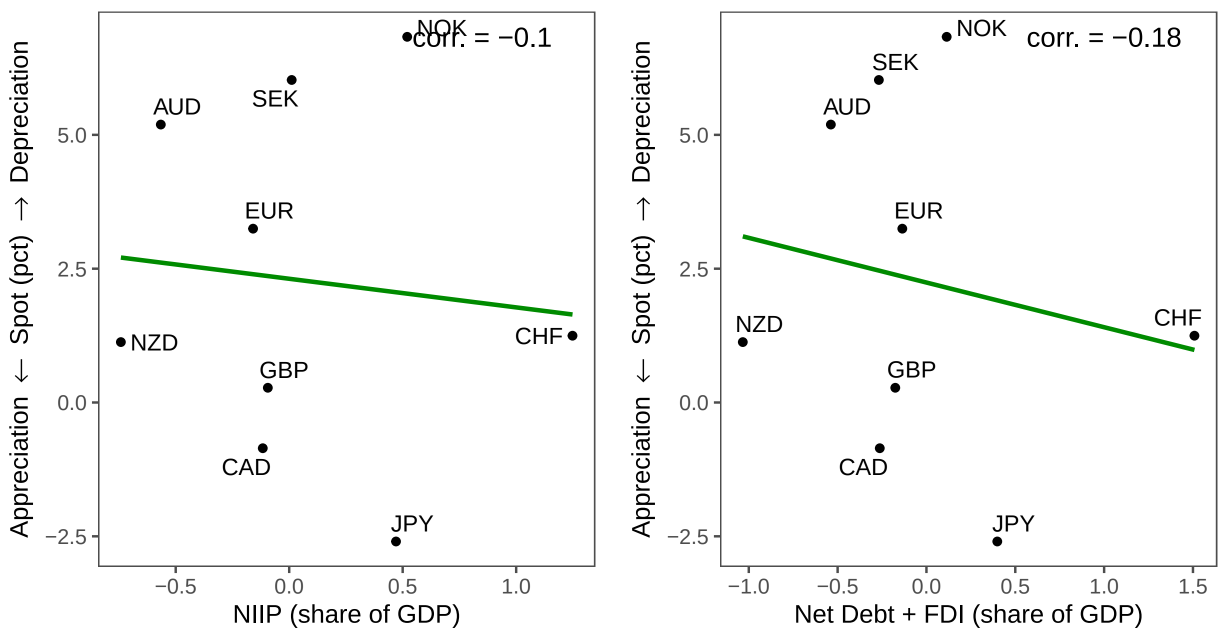
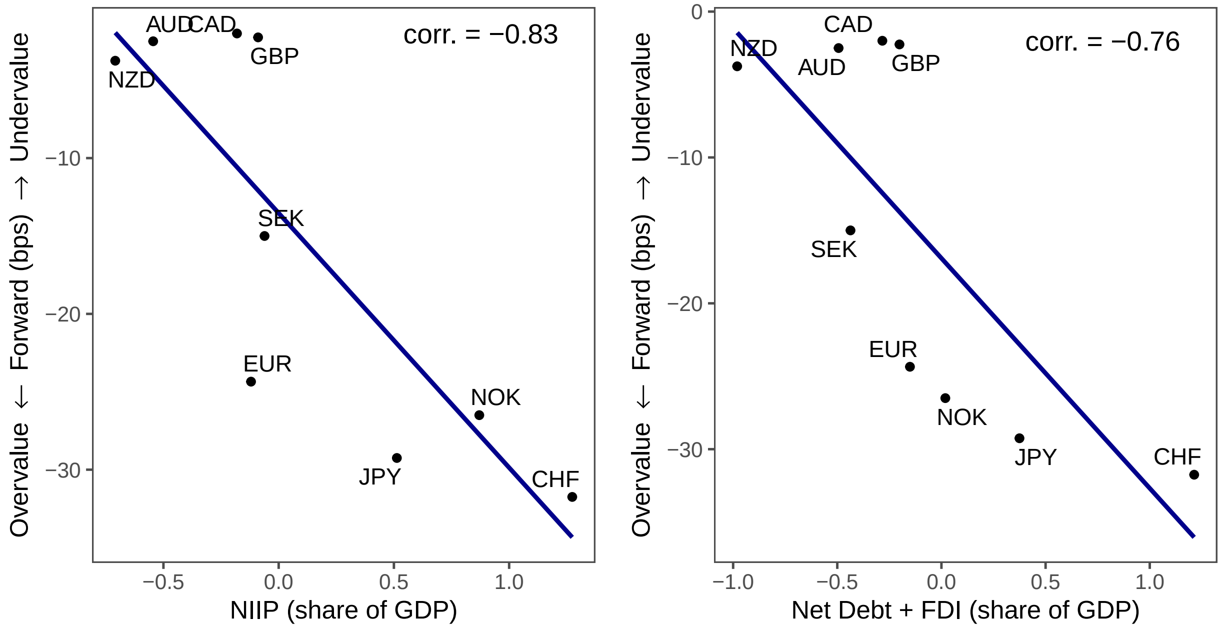


Figure A7: External imbalances and exchange rates during Eurozone crisis

This figure plots changes in currency bases and spot exchange rates during the Eurozone crisis. We measure changes in currency bases and exchange rates from July 1, 2011 to August 11, 2011. We measure external imbalances in terms of countries' NIIP and current account at the end of 2010.

Panel A. Changes in Currency Bases



Panel B. Changes in Log Exchange Rates

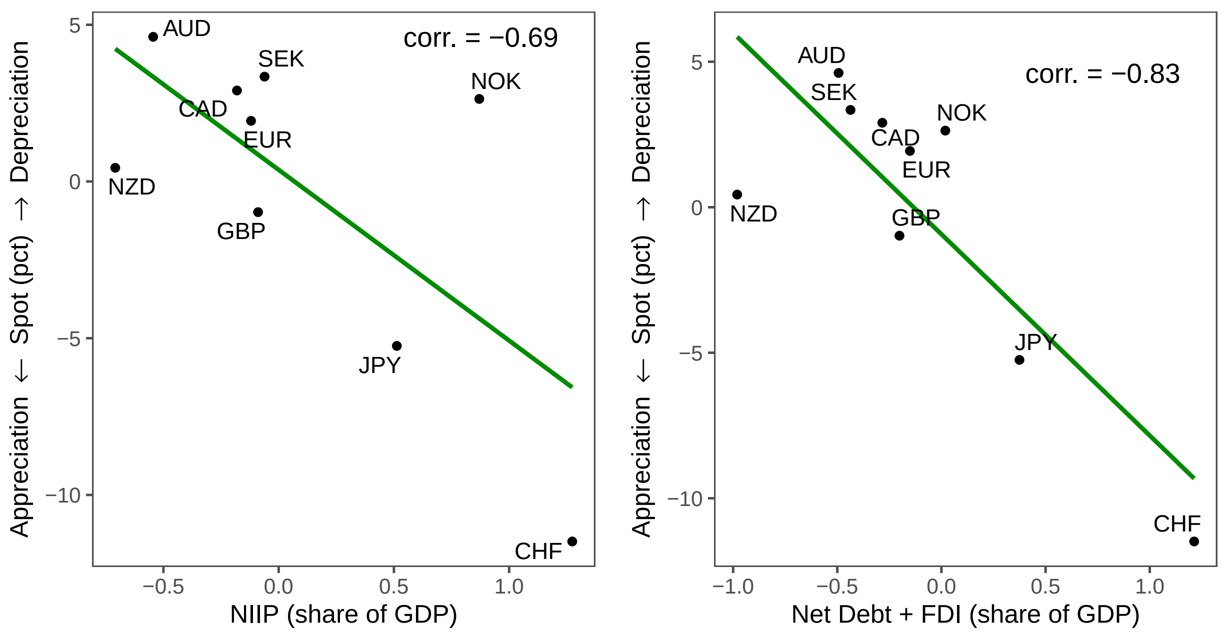
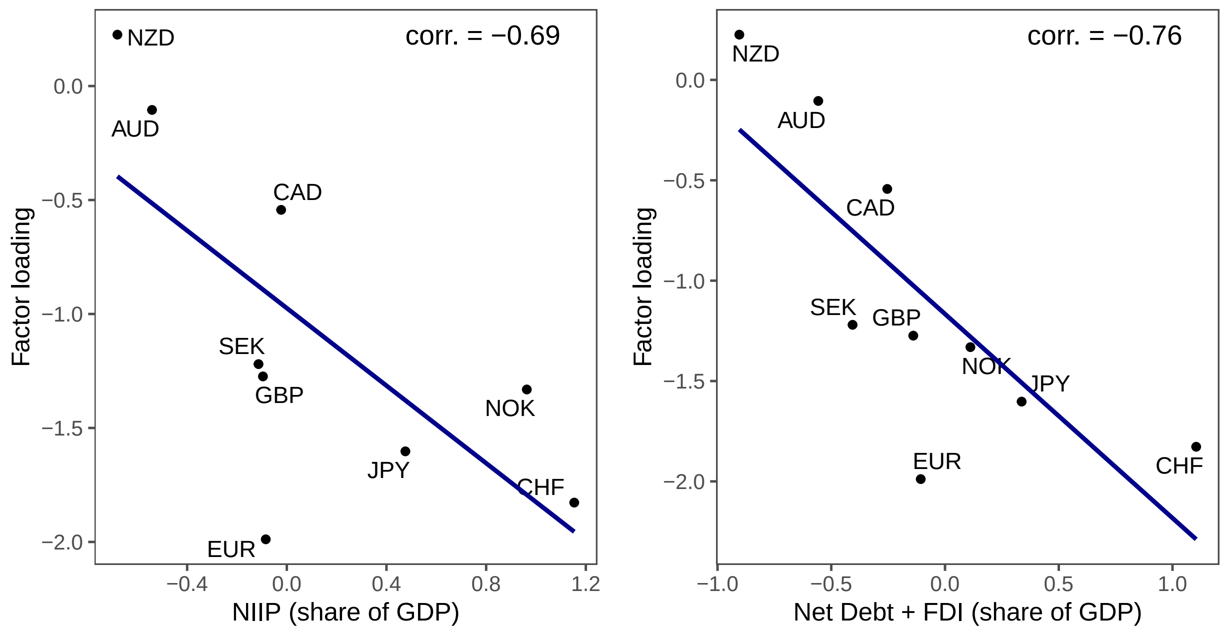


Figure A8: A single factor model of spot and forward exchange rates

This figure plots coefficients β^n from estimating single-factor models of changes in cross-currency bases, spot exchange rates and the cross-currency term spread against countries' external imbalances. We plot β^n from the regression: $\Delta y_t^n = \alpha^n + \beta^n \overline{\Delta b}_t + \varepsilon_t^n$, where Δy_t^n represents the outcome variable of interest for country i at date t and $\overline{\Delta b}_t = (1/N)\sum_{n=1}^{N} |b_t^n| - |b_{t-1}^n|$ is the mean absolute deviation (MAD) of countries' cross-currency bases.

Panel A. Factor loadings of changes in cross-currency bases



Panel B. Factor loadings of changes in spot exchange rates

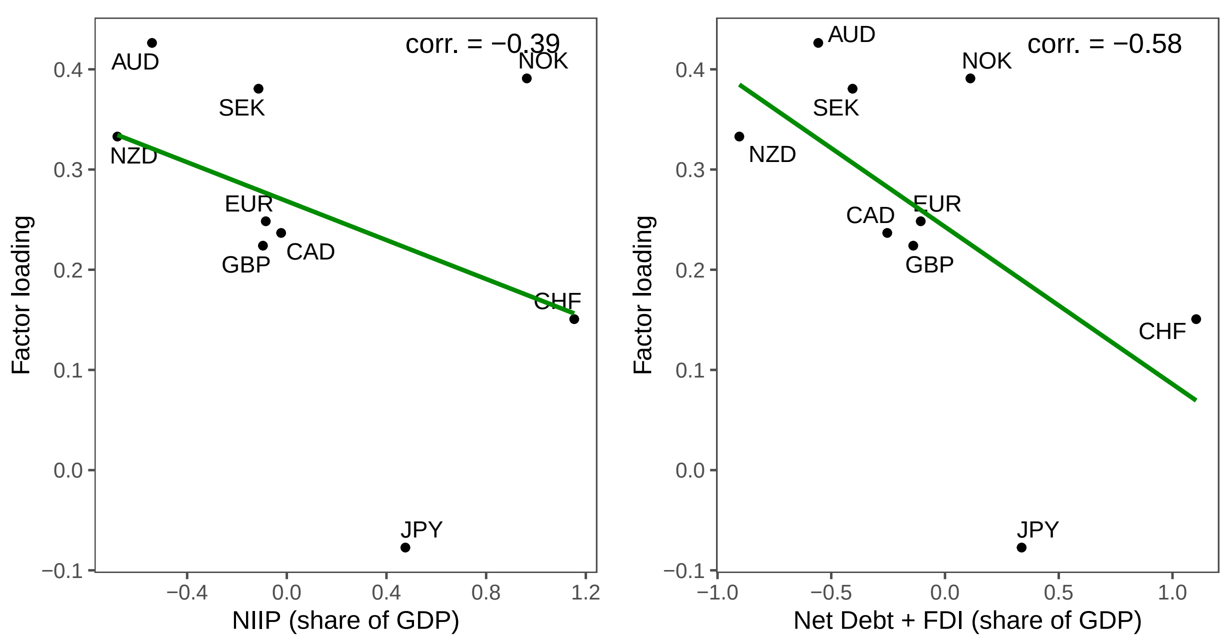
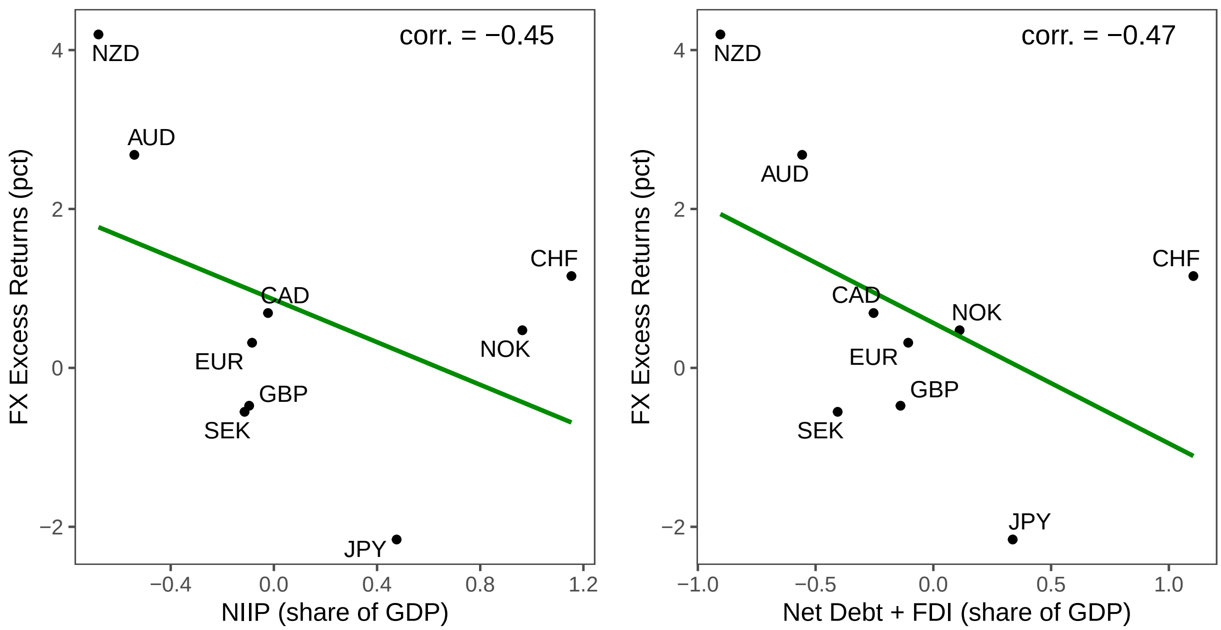


Figure A9: External imbalances and unconditional spot returns

Panel A plots average currency excess returns against measures of external imbalances. Panel B plots average forward premia against external imbalances. The sample comprises monthly observations of 1-year returns of G-10 currencies from January 2000 to April 2020.

Panel A. Average currency excess returns:



Panel B. Average forward premia:

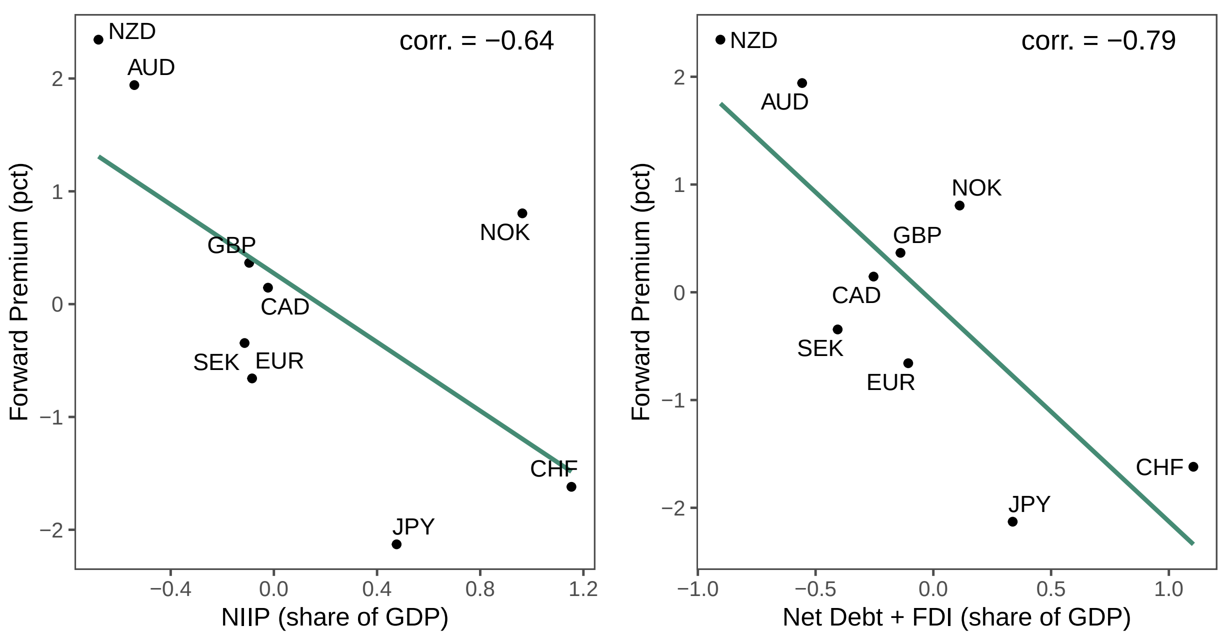
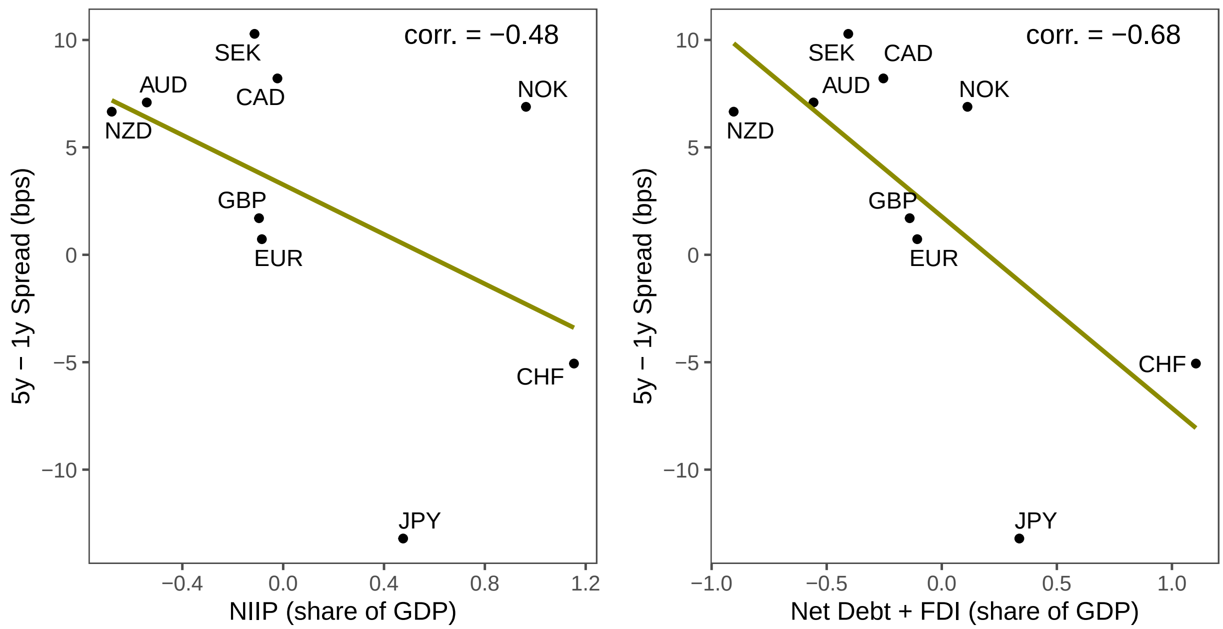


Figure A10: Conditional and unconditional exchange rate forward term structure

Panel A presents the term structure of cross-currency basis relative to countries' external imbalances. We plot the average unconditional 5-year minus 1-year cross-currency basis spread from January 2008 to April 2020. Panel B plots coefficients β^n from estimating single-factor models of changes in the slope of cross-currency bases term structures against countries' external imbalances.

Panel A. Unconditional 5-year minus 1-year bases spread



Panel B. Factor loadings of 5-year minus 1-year bases spread

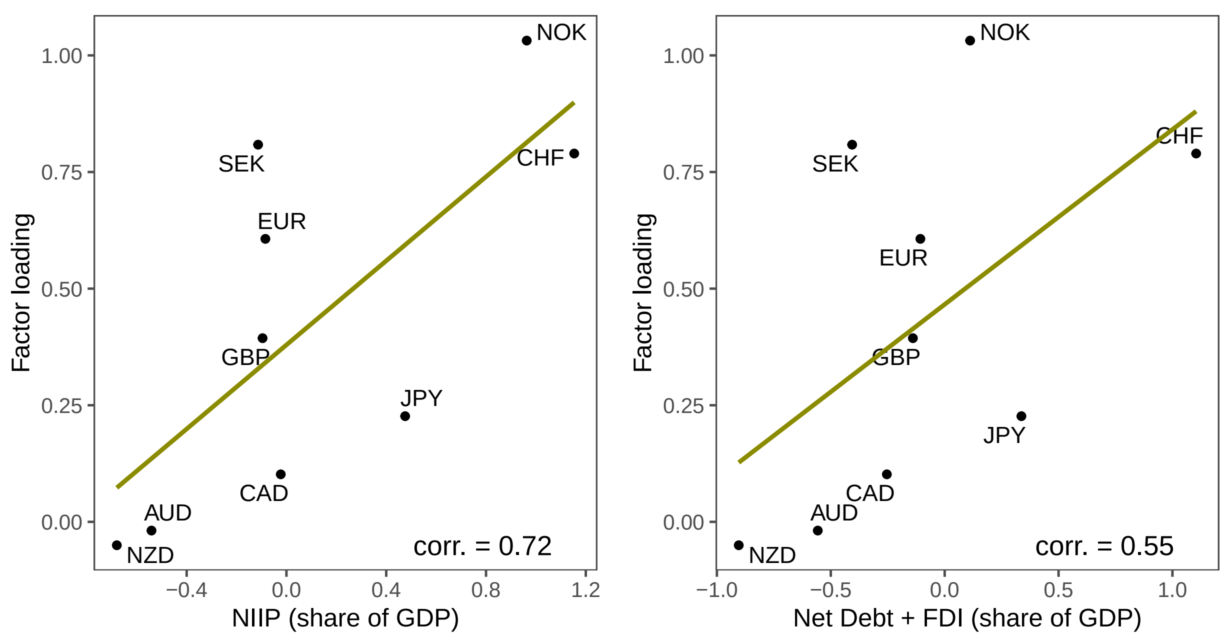
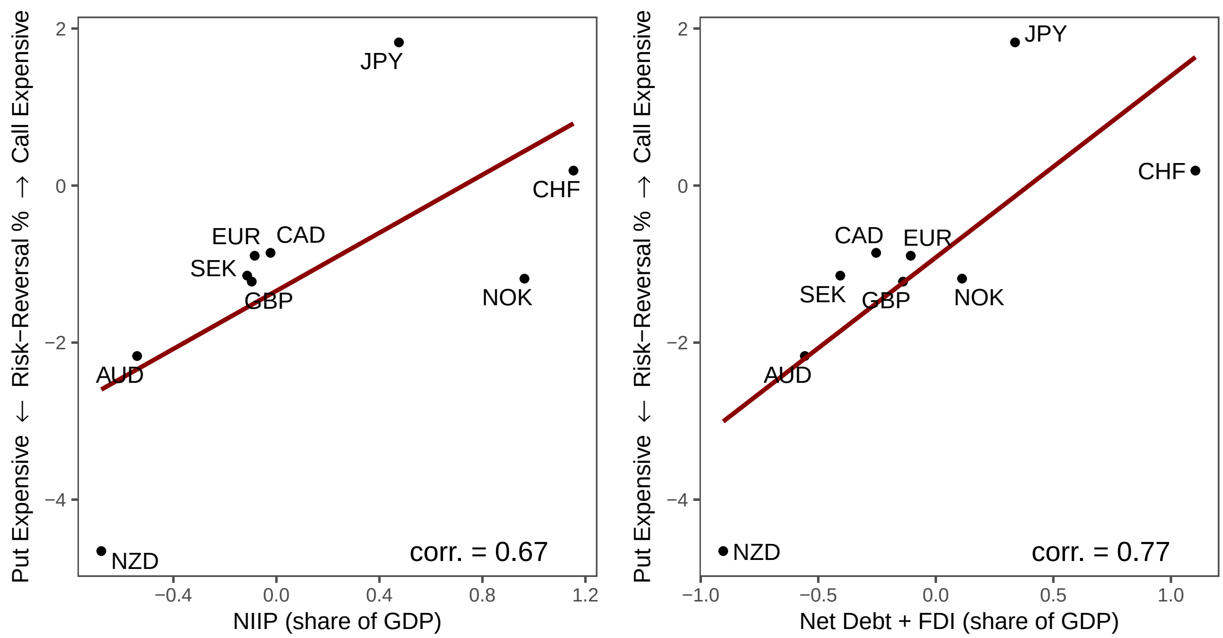


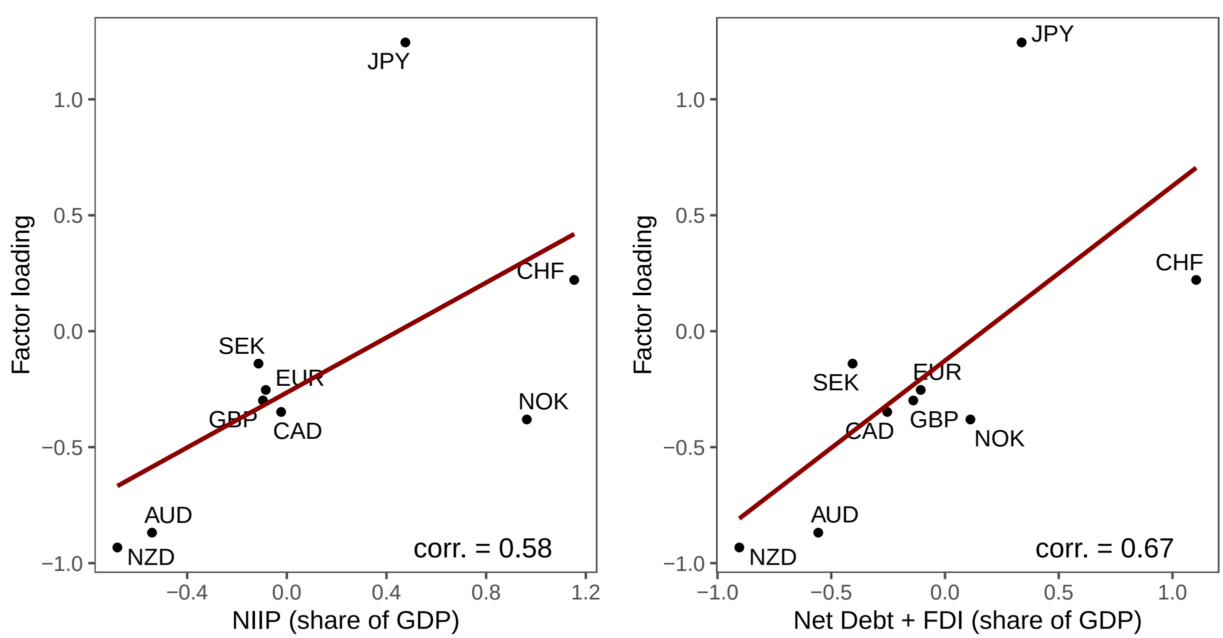
Figure A11: Conditional and unconditional option risk-reversals

This figure presents the relative pricing of calls and puts on currencies relative to countries' external imbalances. Panel A shows the average risk-reversal defined as call minus put implied volatilities for 25-delta, 1-year maturity options. Panel B shows the coefficients β_i from estimating single-factor models of changes in risk-reversal regressed on the mean absolute magnitudes of risk-reversals. The sample comprises monthly data from January 2008 to April 2020.

Panel A. Unconditional risk-reversal



Panel B. Factor loadings of risk-reversal



F Carry trade on cross-currency term structure

Following Du et al. (2019) that documents a trading strategy that exploits the maturity term structure of cross-currency basis, we show that the forward-starting cross-currency basis carry strategy has cross-sectional return variation that is aligned with external imbalances. We calculate the 1-year-forward-1-year cross-currency basis carry strategy[33] return that captures the roll-down and carry of the term-premia capture strategy strategy. Fig. A12 shows that the unconditional and conditional returns are related to external imbalances. Consistent with Du et al. (2019), we find that the position of lending AUD against JPY in forward basis swaps[34] has one of the highest carry returns, reflecting the upward sloping term structure in absolute value discussed in the main text. The negative factor loading of this position shown in panel B is also consistent with the observed basis widening and term structure inversion during crisis periods.

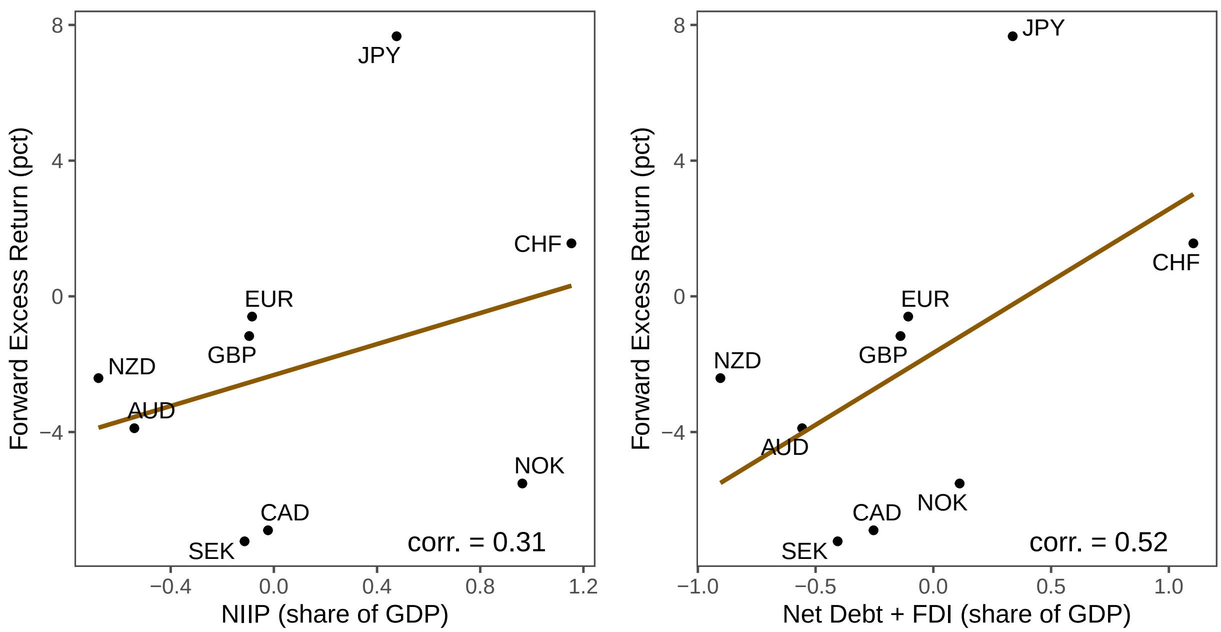
[33]The position involves in the promise of lending dollar against foreign currency cash collateral in one-years time for the period of one year.

[34]Lend AUD versus JPY position is equivalent to entering into a buy AUD/sell JPY spot position and simultaneously sell AUD/buy JPY forward. It is also known as a pay JPY vs receive AUD floating coupon position.

Figure A12: Conditional and unconditional cross-currency basis carry trade

Panel A plots the unconditional return of lend dollar position in 1y-forward-1y cross-currency basis swap from 2008 to 2020 versus measures of external imbalances. Panel B shows the coefficients β_n from single-factor models of the carry trade return: $\Delta rx_t^n = \alpha^n + \beta^n \overline{\Delta b}_t + \varepsilon_t^n$, where Δrx_t^n is the realized 1-year-forward-1-year return for country n at date t and $\overline{\Delta b}_t$ is the the mean absolute deviation of countries' cross-currency bases.

Panel A. Unconditional forward cross-currency basis carry return (bps):



Panel B. Factor loadings of forward cross-currency basis carry returns (bps)

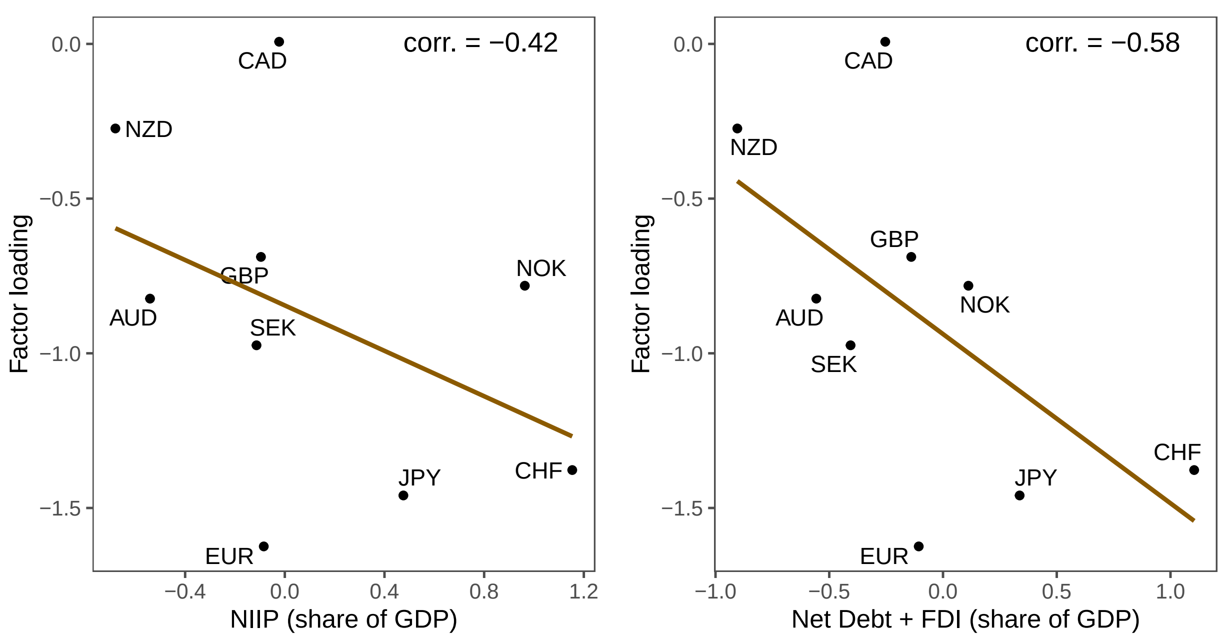


Table A3: Single factor model of basis carry trade

This table presents regression results from single factor models of the cross-currency bases carry trade:

$$\Delta y_t^n = \alpha^n + \beta^n \overline{\Delta b}_t + \varepsilon_t^n,$$

where Δs_t^n is the 1y-forward-1y cross-currency basis carry trade realized PNL for country n in date t and $\bar{\Delta} b_t = (1/N)\sum_{n=1}^{N} |b_t^n| - |b_{t-1}^n|$ is the average change in the absolute magnitude of countries' cross-currency bases. The sample comprises monthly data from January 2010 to April 2019.

	1-year-forward-1-year basis term carry trade realized PNL in basis points								
	NZD	AUD	GBP	EUR	SEK	CAD	JPY	CHF	NOK
β_i	-0.611^{**}	-0.582^{*}	-0.428	-1.571^{**}	-1.186^{***}	-0.576^{***}	-1.950^{***}	-1.729^{***}	-0.834
	(0.295)	(0.295)	(0.408)	(0.628)	(0.389)	(0.195)	(0.574)	(0.537)	(0.504)
α_i	-5.999^{***}	-6.183^{***}	1.209	2.584	-8.664^{***}	-11.156^{***}	16.579^{***}	5.650^{***}	-4.881^{***}
	(0.821)	(0.821)	(1.136)	(1.749)	(1.083)	(0.542)	(1.598)	(1.494)	(1.404)
Observations	124	124	124	124	124	124	124	124	124
R^2	0.034	0.031	0.009	0.049	0.071	0.067	0.086	0.078	0.022

Note: *p<0.1; **p<0.05; ***p<0.01

G Data Appendix

G.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.