The Hedging Channel of Exchange Rate Determination *

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Abstract

We document the exchange rate hedging channel that connects country-level measures of net external financial imbalances with exchange rates. In times of market distress, countries with large positive external imbalances (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 that exchange rate hedging coupled with intermediary constraints can explain these observed relationships between net external imbalances and 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, large institutional investors' disclosure of hedging activities, and central bank swap line usage during the COVID-19 market turmoil.

Keywords: Global Imbalance, Exchange Rate, Forward, Hedging, Covered Interest Rate Parity, Currency Options, COVID19

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

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Introduction

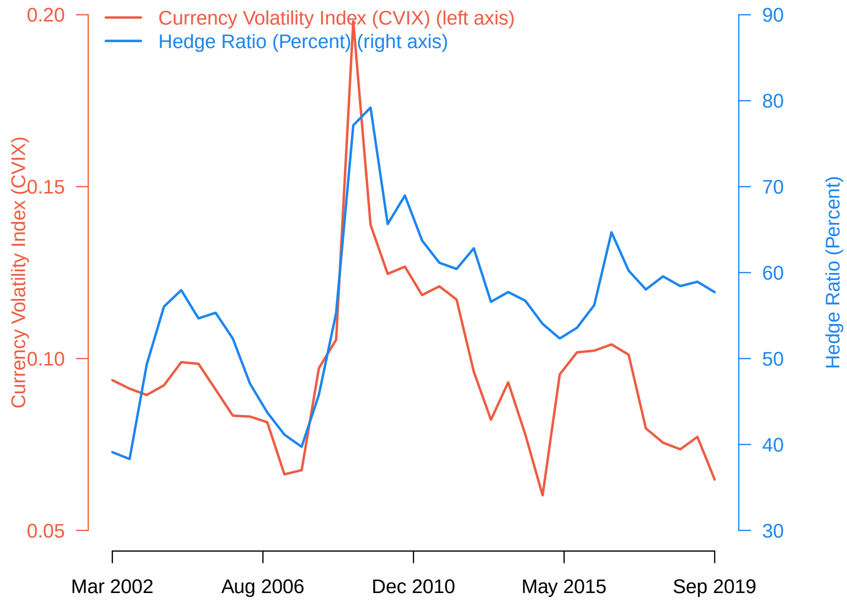
The disconnect between exchange rates and macroeconomic variables remains one of the most persistent puzzles in international economics. In recent years, a growing body of evidence points to financial intermediary constraints and global imbalances as key drivers of exchange rate dynamics [1]. However, there is still relatively little understanding of 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, explain a number of stylized facts in international financial markets.

Our proposed channel centers around exchange rate (FX) hedging activities. Figure 1 shows the hedge ratio of nine large Japanese life insurers on their foreign asset holdings against 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, and is consistent with the finding from Liao (2019) that shows an increasing trend of currency-hedged corporate bond issuance

[1] For instance, Gabaix and Maggiori (2015) models exchange rate determination under limited financial intermediation; Jiang, Krishnamurthy, and Lustig (2019) emphasizes the role of safe asset demand; Lilley, Maggiori, Neiman, and Schreger (2019) documents reconnect between exchange rate movements and international investment positions in recent years.

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) by the foreign currency-denominated asset holdings reported in public disclosures of nine large Japanese insurers.

and Lilley et al. (2019) that highlights the relevance of bond purchase flow for exchange rate comovement.

Second, in countries with large positive external imbalances, as captured by their Net International Investment Positions (NIIP) and particularly their net debt and foreign direct investment (FDI) positions, 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.[2] In contrast, countries with large negative external imbalances generally observe an unconditional forward price of domestic currency that is depressed relative to the U.S. dollar.

[2]A non-zero cross-currency basis (or currency basis) indicates a breakdown of 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.

Third, in periods of increased market volatility, countries with positive external imbalances experience domestic currency appreciation in both spot and forward exchange rate markets whereas countries with negative external imbalances experience currency depreciation. Moreover, forward exchange rates experience a greater magnitude of price movements relative to spot exchange rates after adjusting for interest rate differentials. This difference in exchange rate adjustment between the forward and the spot markets results in the increased cross-sectional dispersion of currency bases in line with the direction and magnitude of external imbalances.

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 [3]) contracts to stabilize the future payoff of her portfolio in domestic currency. If the agent is a net purchaser of foreign assets, then she hedges her exchange rate risk by selling dollars in the forward market. On the other hand, a net borrower hedges exchange rate risk by buying dollars forward. Hence, the quantity of dollar forwards demanded depends on the country's hedge ratio and net foreign asset position.[4]

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.

[3]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.

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

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 spot exchange rate even after adjusting for interest rate differentials. The resulting pricing anomaly is known as a covered interest rate parity deviation and captured by the cross-currency basis spread: the difference between synthetic cash funding rate implied by FX forward and spot prices and actual interest rate. Our model highlights that the unconditional differences between a country's forward and spot exchange rate depend crucially on the magnitude and direction on the country's net external imbalances.

In times of economic distress, investor hedging demand combined with constrained financial intermediation generate predictable changes in forward and spot exchange rates. This occurs 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 as their hedging demand differs in direction.

In addition to affecting the forward exchange rates, investor demand for forwards can spillover 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 periods of market distress when the demand for either entering new hedges or rolling existing maturing hedges are large, hedging demand can drive the dynamics of both spot and forward exchange rate markets in predictable directions linked to countries' net external imbalances — spot exchange rate appreciates (depreciates) for countries with net positive (negative) external imbalance, but by an amount that is less than the changes in the forward exchange rate controlling for interest rate spreads.

In this sense, our model provides a potential explanation for the reconnect between spot exchange rates and macroeconomic variables since the Global Financial Crisis (Lilley et al., 2019). Our model contextualizes two ways in which the hedging channel has become more prominent since the Global Financial Crisis — increased currency hedge ratios of global investors and heightened balance sheet constraints for financial intermediaries. Additionally, we provide suggestive evidence that investment regulations and guidances for institutional investors, as well as optimization around the hedging of currency volatility contributed to a general increase in hedge ratios.

The hedging-driven demand for currencies during times of financial distress can generate persistent differences in the returns to investing in different currencies. A growing literature shows currencies that appreciate in bad times earn a lower risk premia, as they provide a hedge against economic downturns.[5] Our hedging channel posits a mechanism through which the cross-sectional variation in currency excess returns is linked to global imbalances.[6] The unconditional returns on currencies associated with countries with large positive external imbalances, e.g. Japan, is lower on average to compensate for the expected appreciation from hedging flows during times of distress.

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. In addition to the stylized facts discussed earlier, we draw on event studies of three crises — the COVID-19 Pandemic, the Eurozone crisis in 2011, and the Global Financial Crisis — and show that movements in forward and spot exchange rates are all consistent with increases in hedging demand during periods of financial distress.

[5]A growing 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).

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

Additionally, we present evidence in currency option prices that points to the presence of the hedging demand consistent with our observations on forward exchange rates. Countries with positive external imbalances can also hedge against domestic currency appreciation by buying call options on domestic currency. As a result, we find that out-of-the-money call options on currencies with positive (negative) external imbalance generally have a premium (discount) over out-of-the-money puts. In times of financial distress, this spread between currency 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 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 external 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' external imbalances explain heterogeneity in the usage of dollar swap lines by different central banks during the COVID-19 market turmoil. These results highlight the importance of understanding currency hedging motives when conducting central bank interventions. Currency regions with large positive external surpluses (e.g. the Euro area and Japan), need to borrow in dollars to produce domestic currency in the forward market for hedging purposes. As a result, we observe larger draws on the dollar liquidity swap lines in countries with large positive external imbalances, whereas regions with negative external imbalances had zero or little swap line usage.

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 et al. (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 most closely related to the literature studying portfolio balance effects in currency markets (Gabaix and Maggiori, 2015; Greenwood, Hanson, Stein, and Sunderam, 2019; **?**). 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 intermediary in determining spot exchange rates and Greenwood et al. (2019); **?**, that 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 that 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 covered interest rate parity (Du et al., 2018).[7] Others have shown the magnitude of CIP violations co-vary 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), which studies deviations from the law of one price between futures and spot prices in equities and FX with a focus on leverage demand.

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

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.

1 Currency hedging and institutional details

This section provides motivating evidence and institutional details for the use of currency hedges. Figure 1 showed 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.[8] Additionally, the use of derivative instruments for currency hedging are often explicitly excluded from counting toward limits on derivative use. Post-global financial crisis rules for insurers, such as the Solvency II Directive, have also contributed to increased currency hedging.[9] Furthermore, 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, 2019).

Table 1 summarizes the regulatory requirements on pension and insurance sectors and estimated FX hedging ratios for the countries associated with our sample of G-10 currencies. The regulations and currency match requirements are mainly applicable for 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

[8]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).

[9]The Solvency II Directive imposes a capital charge (usually 25%) on currency mismatches of European and U.K. insurers.

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 since exchange rate risk is large relative to fixed income returns but small relative to equity returns and the risk-minimizing currency strategy for a global bond investor is close to a full currency hedge(Campbell, Serfaty-De Medeiros, and Viceira, 2010). Motivated by this evidence, we employ measures of external imbalance that excludes equity portfolio holdings.

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 2 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. [10]

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

[10] 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.

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.

2 Model

In this section, 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 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.

Throughout this section, we emphasize the demand and provision of exchange rate forwards. We focus on forward contracts for analytic tractability, because forward contracts enable us to highlight the effects of the investors altering their foreign asset hedge ratio.

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 country n has a positive external imbalance in U.S. dollars at the end of period 1 ($X^n > 0$), then she receives dollars in period 2 and wants to exchange those dollars into domestic currency. Hence, 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:

$$\text{Demand for forward dollars} = -h^n X^n (1 + r^D) \tag{1}$$

dollars in the forward market. Appendix A.3 provides an extension in which the country-n investor endogenously chooses her optimal hedge ratio h^n in response to her external imbalance and expected exchange rate volatility.

2.2 Supply of Forwards

There exists a currency forward trader (or equivalently FX swap trader) who chooses to devote capital to providing liquidity in forward currency markets and an alternative investment opportunities that provides the profit $G(I)$ for an investment of I. This forward currency trader is specialized 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 that 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 $X^n > 0$, then 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:

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

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 that a profit maximizing forward trader should only provide liquidity in forward markets when it is profitable: $q^n b^n \geq 0$. Therefore, an immidiate result is that b^n must be negative when X^n is positive, and vice versa, to incentivize the trader to supply liquidity. We formalize this intuition and generalize to the n-country case below.

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. [11]

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, then $q^n = 0$ and the basis reduces to zero. Similarly, if there were no costs to providing liquidity in the forward market $\kappa = 0$, 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:

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

[11] Even though the forward trader faces no exchange rate risk in the model, there are known limits to arbitrage in basis trades (**?**).

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 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. (2019).[12]

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. The equilibrium is described by the

[12]The forward trader modeled above differs in that they only arbitrage CIP deviation 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.

following three equations:

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

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

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

We use equations (5)-(7) to analyze the effect of hedging demand on exchange rate markets, and we start by studying the properties of the cross-currency basis.

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 requires the trader provide more liquidity, which requires the forward trader 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 under- valuation 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.[13] However, empirically, X^n is relatively persistent. Thus, we focus our attention 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 showed that Japanese life insurance companies systematically raised and lowered their hedge ratio in accordance with dollar-yen exchange rate volatility. Alternatively, increases in the cost of financial intermediation also increase the costs of providing liquidity for all currencies. For instance, Du et al. (2018) showed cross-currency bases are partially driven by bank balance sheet costs. In times of financial distress, it is likely that both forces work to increase cross-currency basis.

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 $X^n > 0$, then 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 impacts the spot market, because forward traders transact in spot exchange rate markets to produce forwards.

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

Proposition 3. *(Spot exchange rate) An increase in a foreign country's hedge ratio, h, impacts the country's spot exchange rate in proportion to its external imbalance:*

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

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 alleviate funding conditions and sheds light on their limitations. Federal Reserve swap lines provide dollar funding to the broader market by lending dollars to foreign central banks. These foreign central banks, in turn, lend dollars from the swap line to domestic institutions on a collateralized basis. As a result, dollar lending via the swap line is equivalent to providing dollars in the spot market in exchange for foreign currency and simultaneously repurchasing dollars in forward markets. Previous studies have shown that central bank swap lines are effective tools at reducing the currency basis (Goldberg, Kennedy, and Miu, 2010; Bahaj and Reis, 2018).

Our model shows that an increase in hedging activities can generate demand for swap line draws. In periods of market volatility, hedging demand h^n increases, and countries with positive imbalances ($X^n > 0$) purchase home-currency forwards to hedge exchange rate risks from their foreign currency investments. The intermediary produces these forwards but typically needs to charge a higher spread to offset the higher cost in supplying additional forwards. However, the intermediary can potentially utilize the swap line in aiding the production of forwards.Specifically, the intermediary supplying yen forwards for Japanese investors draws on the central bank swap line to borrow dollars today to produce yen for the forward market. The intermediary then sells the yen to the Japanese investor in the forward market to alleviate some of the additional hedging demand. This hedging demand channel for swap line usage is distinct from the usage of swap draws for short-term bank funding needs particularly as highlight in prior work (e.g. Ivashina et al. (2015)). The differentiated use of swap line for funding versus hedging is in part reflected by the maturity of the swap line draws, with funding typically taking shorter maturities.[14]

Our model shows that central bank swap line can accommodate such hedging demand through both a direct and an indirect channel. First, the direct provision of dollar loans against foreign currency collateral reduce a foreign investor's net external imbalance X^n. Second, the announcement of swap lines may instill more confidence in the financial sector. As a result, forward traders may face lower balance sheet costs κ. Moreover, the additional market confidence may reduce expected exchange rate volatility and lower institutional hedging demand h^n. Mapping these channels to the model predictions, a lower X^n, κ and h^n all lead to decreases in the magnitude of cross-currency bases as shown by Proposition 2.

Moreover, the amount of central bank swap line draws should differ according to countries' external imbalances if it were used to satisfy hedging needs. Countries with positive external

[14]**?** shows that short-term FX swaps with overnight maturity are close substitutes to repurchase agreements widely traded in the money market.

imbalance benefits from the dollar swap line through the direct injection of dollar cash that lowers the cost of producing local currency forwards. In contrast, countries with negative external imbalances can benefit from the indirect effect of a lower κ and h^n, but not from the direct effect of a dollar cash injection, thus they should exhibit little draws on the dollar swap line. In fact, any draws on the dollar swap line worsens their negative external imbalances, which could widen their swap basis spread in the positive direction (associated with an undervaluation of lower currency forwards). We show empirical support for these predictions in Section 4.

2.6 Term Structure of Currency Basis

We extend the benchmark model by adding an additional period to study the term structure of forward exchange rates. The term structure of forward exchange rates provide additional heterogeneity that support the hedging channel. We provide the general setup below but leave the model details for interested readers in Appendix A.4. There are now three time periods, $t = 1, 2, 3$. In period 1, the country n investor still has a net external imbalance of X^n, but she now wants to hedge 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_L^n and with probability $1 - \pi$ the hedging demand in period 2 equals h_H^n. 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. Letting $b_1^{n,(2)}$ denote the cross-currency basis in period 1 for the period 3 forward exchange

$$b_1^{n,(2)} = \frac{b_1^n(1 + r_2^n)}{2} + \frac{\pi b_{2,L}^n + (1 - \pi) b_{2,H}^n}{2}, \tag{8}$$

where $b_1^{n,(2)}$ is the cross-currency basis in period 1 on forward exchange rate two periods ahead (in period 3). $b_1^{n,(2)}$ represents the trader's profit in period 3 on each unit of capital she devotes to providing liquidity in the period 3 forward exchange rate market. b_1^n is the one-period currency basis in period 1, and $b_{2,k}^n$ is the one-period basis in period 2 when the hedging demand equals h_k^n for $k = L, H$. $1 + r_2^n$ is the one-period risk-free rate in period 2.

Equation (8) has a very natural interpretation. The first term on the right-hand side, $b_1^n(1 + r_2^n)/2$ represents the contribution of the period 1 currency basis to $b^{n,(2)}$. b_1^n is the swaps trader's profit in period 2, and grows at the rate $1+r_2^n$ from period 2 to period 3. The second term on the right-hand side of equation (8) captures the expected period 2 currency basis.

Equation (8) reveals the slope of the currency basis term structure depends on the expected period 2 basis relative to the period 1 basis. If, in expectation, the currency basis is expected to increase in magnitude from period 1 to period 2, then the two-period basis $b_1^{n,(2)}$ should be larger in magnitude than the period 1 basis b_1^n. Propositions 2 showed currency bases increase 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 are relatively low (and are therefore likely to increase in the future given a sufficiently high π). Conversely, we should expect currency bases to decrease in magnitude with maturity whenever the current magnitude of currency bases are relatively high.

3 Measures of hedging demand

Having provided intuition for the effects of currency hedging on forward and spot exchange rates, we now turn to empirical analysis to test model predictions. We focus 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.[15]

We measure the quantity of external imbalances at the country level using data on Net International Investment Position (NIIP) and its constituent components obtained from the International Monetary Fund's International Financial Statistics data set. We focus our main analysis on two measures in particular: The aggregate NIIP, and the net debt and foreign direct investment (FDI) components of NIIP.[16] Both measures are scaled by nominal GDP. In particular, Section 1 showed external imbalances in debt and FDI positions are more likely to reflect hedging demand, because these investment types are dominated by institutional investors that hedge a greater fraction of their currency exposure either due to regulations or risks. [17]

To measure the price impact of hedging external imbalances, we mainly focus on the cross-currency basis that captures the relative valuation of forward and spot exchange rates after adjusting for interest rate differential. We also analyze the relative pricing of call and put options as additional evidence that corroborates the hedging channel. As we have shown in the model, cross-currency bases serve as important gauges of both hedging demand as well as the limits to arbitrage brought on by intermediary constraints. The direction and magnitude of the basis spreads in levels and in conditional movements reflect valuable information for identifying the source of the demand shock as well as whether the shock is first and foremost impounding the forward or the spot market.

Consistent with existing literature, we use Libor-based cross-currency basis swap levels as our empirical measure.[18] This basis spread is also commonly referred to as the deviations from covered interest rate parity condition, defined as the difference between the forward

[15]The Chinese Yuan and Hong Kong dollar are also among the most frequently transacted, but they are actively managed against USD and affected by capital flow restrictions.

[16]The net debt component of NIIP comprises both portfolio debt as well as other debt investment. The net FDI component of NIIP comprises both debt and equity FDI. FDI indicates larger investments in which the direct investor owns at least 10% of the voting power in the direct investment enterprise.

[17]Campbell et al. (2010) shows that the risk-minimizing currency strategy for a global bond investor is close to a full currency hedge, while the currency risk is attractive for global equity investors

[18]All market data are from Bloomberg.

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 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, since 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). Table 2 provides summary statistics for each of the variables used in our analysis.

Unconditional currency basis and external imbalances

In this section, we present evidence for Proposition 1 in our model that relates currency basis and external imbalance. Fig. 3 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 equates to an undervaluation of the currency in forward markets relative to the spot price.

Fig. 4 shows the average cross-sectional relationship between cross-currency basis spreads and external imbalances before and after the Global Financial Crisis (GFC) in 2008. The inverse relationship between external imbalance and currency basis attests to proposition 1 in our model. The larger the net international investment position, the more that 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. Moreover, the inverse relationship between cross-currency bases and external imbalances appear even stronger when plotted against net debt and FDI, which is likely a stronger indicator of hedging demand.

Comparing the post-GFC sample (Fig. 4.A) with the pre-GFC sample (Fig. 4.B), the inverse relationship between external imbalances and currency bases holds true in both periods but the slope is steeper in the post-GFC period, indicating that the forward and the spot markets are more segmented from one another. 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. The latter channel focused on intermediary constraints has been discussed in prior studies.[19] In addition to steepening of the unconditional relationship, the intercepts have also shifted lower from pre- to post- GFC. This likely reflects a general demand to sell dollar forwards associated with a worsening of the U.S. external imbalance — the U.S.'s NIIP had declined from an average of -18 percent of nominal GDP in the 2000 to 2007 period to an average of -33 percent of nominal GDP since 2008, though the current account deficit has slowed from -4.5 percent to -2.6 percent of nominal GDP.

Table 3 presents panel regressions of cross-currency basis spreads on external imbalances for the post-GFC sample. Consistent with Fig. 4, columns (1) through (4) confirm the strong inverse relationship between external imbalances between external imbalances and cross-currency bases. Columns (5) and (6) provide additional evidence that this inverse relationship is driven by the net debt and CPI components of NIIP rather than the net equity position.

4 Exchange Rate Dynamics and External Imbalances

In this section, we present empirical tests of proposition 2 and 3 from our model. Proposition 2 states that the conditional movements of currency basis spreads in the cross-section

[19] 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.

are predictable from external imbalances. Proposition 3 states that the conditional cross-sectional returns of spot exchange rates are also influenced by the direction and magnitudes of external imbalances. We provide evidence for these propositions first through three case studies during the onset of the Covid-19 pandemic, the GFC, and the Eurozone Crisis. We then conclude with asset pricing factor tests that more formally analyze the relationship between external imbalances and exchange rates.

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. Fig. 5 shows the level of currency bases (Panel A) and cumulative returns in spot exchange rates (Panel B) from February 1, 2020 to March 13, 2020.[20]

The time series show 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 external 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 changes during this period generally mirrored the movements in the currency basis. Yen spot exchange rates appreciated the most, and at the same time, 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 that it had the most undervalued forward price relative to spot price. The one notable exception is the Norwegian Krone, which suffered

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

the 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 Fig 6, we show the changes in currency bases (Panel A) and log spot exchange rates (Panel B) plotted against measures of external imbalances. As we theorized, countries with large positive net foreign 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. In contrast, countries with large external borrowings experienced the opposite dynamics.

4.1.1 Central bank dollar liquidity 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 offers a release valve that temporarily reduces external imbalance X^n. In the case of the the dollar liquidity swap line offered by the Federal Reserve, the Fed entered agreements to sell dollar in the spot market and simultaneously purchase dollars in the forward market with foreign central bank counter-parties that then on lend the dollar liquidity to local institutions. As such, countries with the most demand for buying local currency forwards versus selling dollar forward stand to draw the most from the dollar liquidity facility. In our model, the demand for forwards emanates from the hedging of external imbalances translates into a prediction that the countries with the large net positive external assets also are the ones that draw the most from the dollar swap lines.

Fig. 7 illustrates this logic by showing the positive relationship between the maximum swap draws outstanding during the weeks following the Fed's swap line expansions, and the the associated countries' external imbalances in absolute dollar amounts (rather than as a percentage of GDP as examined above). Countries with low or negative NIIP and CA had little or no use of the dollar swap line, while countries with higher NIIP and CA had larger draws in absolute amount of dollar swap line.

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 Global Financial Crisis and the Eurozone Crisis. Fig. 8 captures changes in currency bases and log exchange rates during the GFC.[21] Consistent with propositions 2 and 3, as well as the evidence from the Covid-19 crisis, currencies with more positive external imbalances generally observed larger decreases in their cross-currency bases. Currencies with more positive external imbalances also experienced domestic currency appreciation. Finally, Fig. 9 shows forward and spot exchange rate dynamics during the Eurzone crisis were also broadly consistent with propositions 2 and 3.[22]

4.3 Cross-sectional Asset Pricing Tests

We turn employ to cross-sectional asset pricing tests to formally test for the comovement in forward and spot exchange rates that are consistent with our hedging channel. The purpose of these tests are to formally assess the following two hypotheses: (1) A country's external 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 6, 8 and 9 exist 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.

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

[22] The Eurozone crisis sample captures the period from July 1, 2011 to August 11, 2011, when the currency bases peaked locally.

First, we construct a risk factor 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 external 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 external imbalances should load more negatively on $\overline{\Delta|b|}_t$. Proposition 3 shows countries with more positive external imbalances appreciate more in response to increases in hedging demand. Hence, changes in the log exchange rate of countries with more positive external balances 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 $\overline{\Delta|b|}_t$.

Fig. 10 plots β^n against the country n external imbalances. Panel A of Fig. 10 plots the betas of currency bases and shows there is a strong negative relation between the betas and the country's external imbalances. Consistent with proposition 2, countries with more positive external imbalances load more negatively on the mean average deviation. As the mean average deviation 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 5 presents the results of each univariate regression of changes in cross-currency bases on changes in the mean absolute deviation. The currencies in Table 5 are ordered left-to-right from most negative average NIIP to most positive NIIP. 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 currency basis over time for many of the currencies in our sample.

Panel B of Fig. 10 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 mean average deviation increases.

Panel B of Table 5 presents the results of each univariate regression of changes in spot exchange rates on changes in the mean absolute deviation. Naturally, the R^2s in panel B of Table 5 tend to be lower relative to 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 are a smaller portion of all the demands for currencies in the spot market. Nevertheless, the average R^2 across the nine currencies is still 0.157.

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 dynamics of forward and spot exchange rate markets.

4.4 Carry trade returns

The conditional spot return and changes in cross-currency basis shown in the previous sections provide an explanation for the highly persistent differences in interest rates and currency returns across countries. A growing literature links differences in interest rates and currency returns across countries to the stochastic properties of currencies (Lustig and Verdelhan, 2007; Lustig, Roussanov, and Verdelhan, 2011). In particular, currencies that are likely to 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. Consistent with this literature, we highlight how time-varying currency hedging behaviors leads to predictable currency returns in both the time series and in the cross-section of countries.

Panel A of Fig. 11 shows the unconditional relationship between average currency excess returns and external imbalances.[23] Countries with large positive external imbalances typically yield lower excess returns, and countries with large negative external imbalances yield higher returns. This result has been highlighted previously by DellaCorte et al. (2016) that attributes to a global imbalance risk factor in explaining this cross-sectional variation in currency excess returns. Our exchange rate hedging channel offers a mechanism to explain why countries with positive external imbalances have currencies that appreciate in bad times and thus obtain unconditionally lower excess returns.

4.5 Term structure of cross-currency basis

The demand for hedging can also explain the term premia of cross-currency basis, as well as the returns from a forward-starting currency basis trade that has recently been described in Du et al. (2019). As we have shown in the conditional movements of 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) showed 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 a term premium and therefore the term structure of cross-currency is typically upward sloping in magnitude.

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

Fig. 12 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. In 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 5 and 6. Hence, the term structure of currency bases inverted during the crisis. This term structure inversion is intuitive as large short-term dislocations are expected to normalize over time.

Next, we test for this systematic variation in the term structure of forward exchange rates more formally. First, Panel A of Fig. 13 confirms the unconditional term structure of cross-currency bases is upwards sloping in magnitude. Countries with negative external 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 external imbalances (e.g. Japan and Switzerland) observe negative term spreads indicating longer maturity forward exchange rates are more overvalued than shorter maturity forwards.

Panel B of Fig. 13 plots the betas of from regressions of changes in the slope of the cross-currency term bases on the mean average deviation of cross-currency bases. These betas show that during periods of financial distress the term structures of cross-currency bases systematically invert: The slopes of the term structures of countries with negative external imbalances become more negative, and the slopes of the term structure of countries with positive external imbalances become more positive. These results show the variation observed in AUD and JPY forward exchange rates in Fig. 12 are indicative of systematic variation in the term structure of forward exchange rates that is consistent with the hedging channel of exchange rate determination.[24]

4.6 Hedged demand and options-pricing

Currency hedging demand also has noticeable impact on the pricing of options on currencies. Out-of-the-money options have been used in prior studies 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 to 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 external imbalance is positive (negative).

Consistent with this intuition, we find that countries with positive (negative) external imbalances have relatively more (less) expensive out-of-the-money call options compared to put options on their currency. This difference in the relative valuation between calls and puts also increases in times of heightened currency volatility. We use risk-reversals, defined as the implied volatility of the out-of-the-money call minus put, as a measure of the relative pricing

[24] 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 B that these relationships also align with countries external imbalances. The conditional return profiles of these sophisticated trading strategies suggest that profits that were previously seen as alphas might in fact have been reflection of betas, as a phenomenon theorized in Cho (2020).

of calls and puts for a given currency.[25]. Risk-reversals are routinely used by traders to assess the relative valuation of calls and puts and has been used in prior studies on currency options such as in Farhi and Gabaix (2016).

Fig. 14 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 Fig. 3. First, options risk reversals increased in magnitude starting in 2008, a fact that has been highlighted in Farhi et al. (2009). In the context of our framework, this widening in the risk-reversal is plausibly linked to the increase in hedging demand since 2008. Second, the figure shows substantial cross-sectional heterogeneity between currencies. Currency regions that has large negative external imbalances, e.g. Australia, typically have the most negative risk-reversal, indicating a premium of put options over call options.[26] Currencies with positive external imbalance or less negative external imbalance, e.g. Japan, have more expensive calls relative to puts, as indicated by positive risk reversals. This positive risk-reversal indicates more expensive hedging cost for currency appreciation rather than depreciation. Lastly, the risk-reversals widen in times of crisis in directions that are aligned with the hedging demand of external imbalances. This dispersion indicates that there is not a single dollar factor that dominate the dynamics of option skew.

Table 7 shows the panel regression of option risk-reversals on various measures of external imbalances. Similar to the previous results, the coefficients for Net Debt and FDI are the most significant. This signals that the hedging of fixed-income like investments are likely stronger than those of equities.

Fig. 15 presents the unconditional and conditional option risk-reversal levels relative to measures of external imbalances. The option risk-reveral results are consistent with the

[25]Our primary measure is the one-year 25-delta risk-reversal, defined as the implied volatility of on the call option 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. A 25-delta option has option price that changes by one-quarter of a unit for every one unit change in the underlying currency price. 25-delta risk reversals is the most frequent indicator of option skewness used in practice. We also show similar results with 3 month maturity options in the appendix

[26]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.

prior pricing dynamics of forwards— call options are expensive for JPY just as forward exchange rate on JPY is overvalued relative to spot exchange rate after adjusting for interest rate differentials. The opposite is true for AUD. This similarity makes intuitive sense as 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 and growing phenomenon around the world. We argued that 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.

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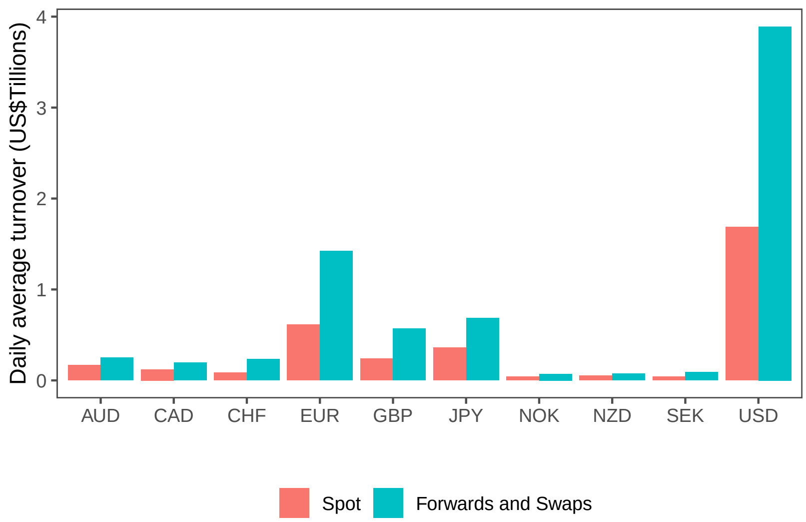
6 Figures and Tables

Figure 2: 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:

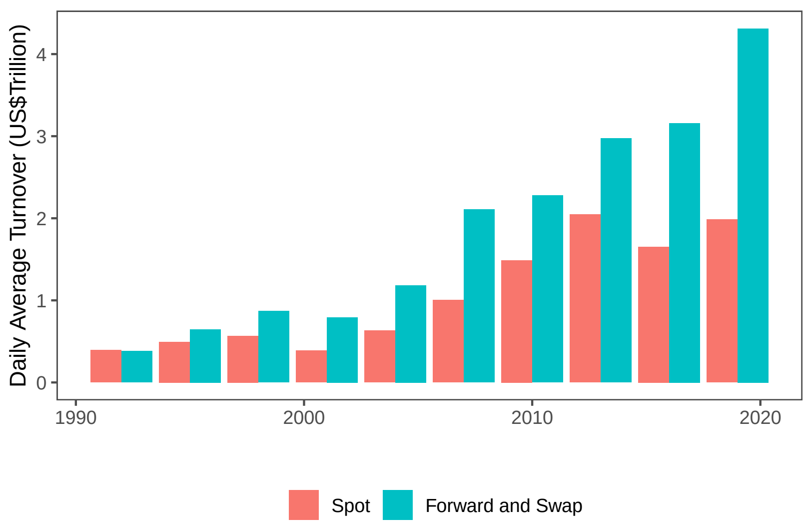


Figure 3: Cross-currency basis

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.

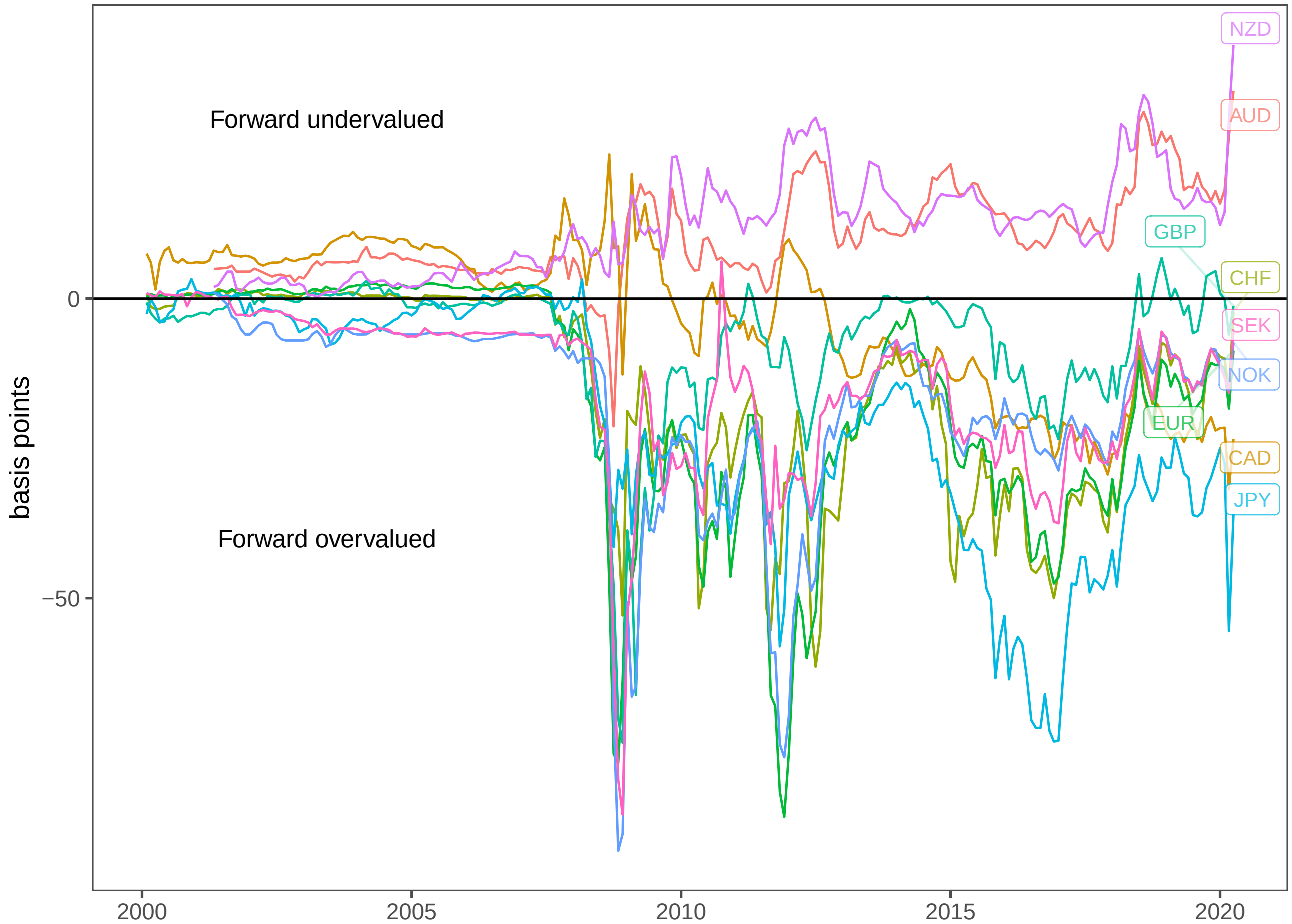
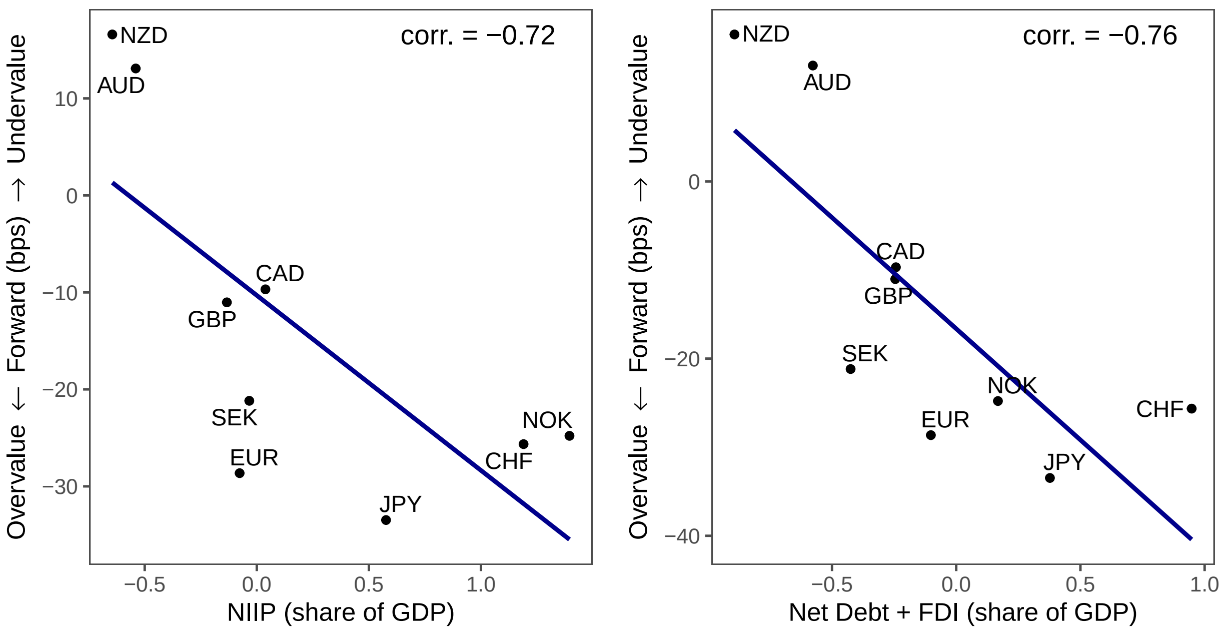


Figure 4: External imbalances and unconditional cross-currency bases

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 2007.

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



Panel B. Panel A. Unconditional cross-currency bases from 2000-2007:

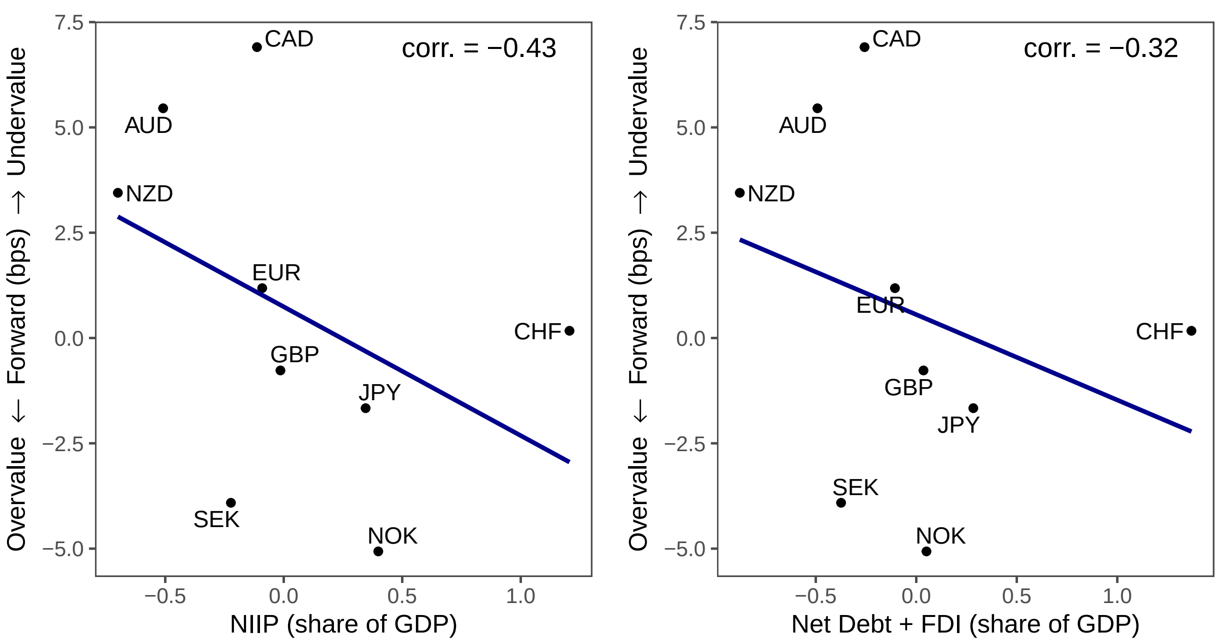
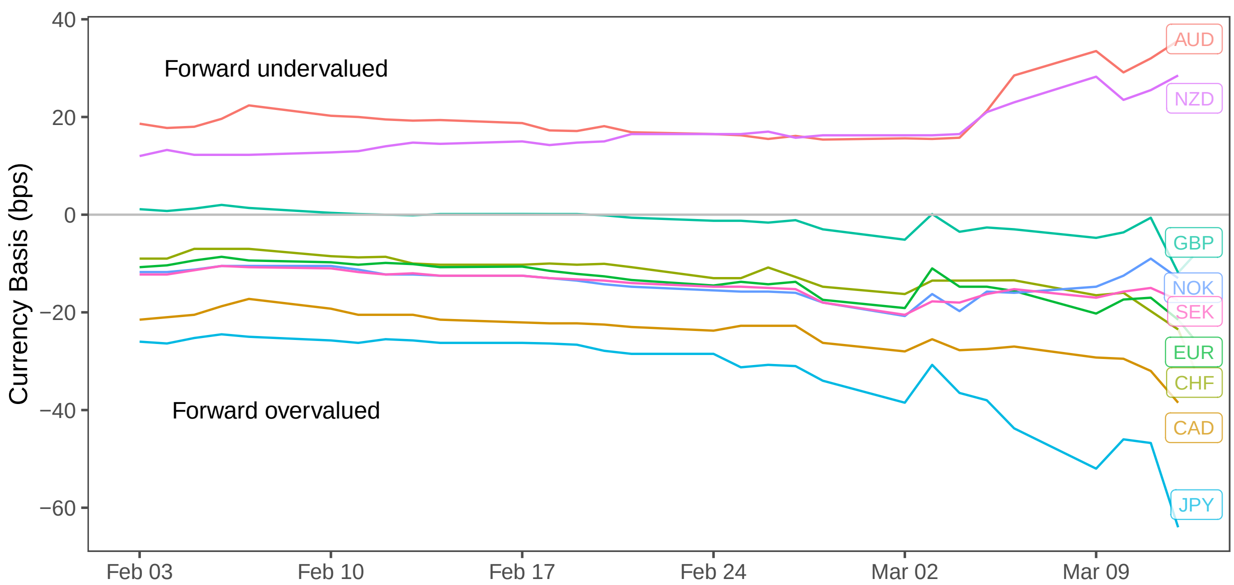


Figure 5: Cross-currency bases and spot exchange rates during COVID-19 crisis

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)

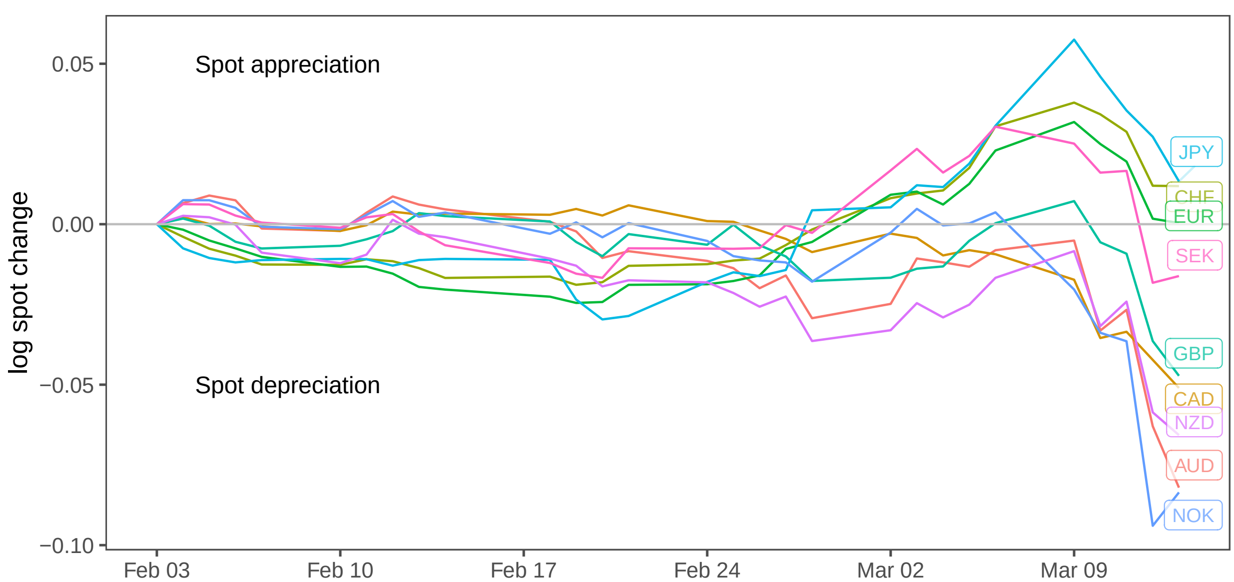
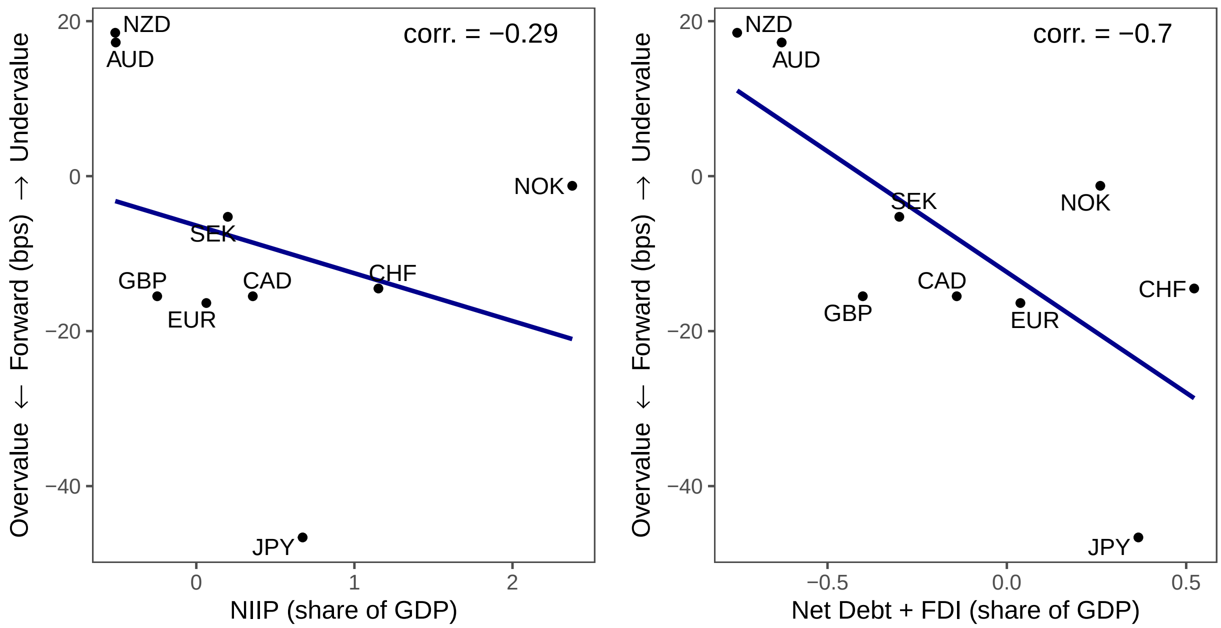


Figure 6: External imbalances and exchange rates during COVID-19 crisis

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

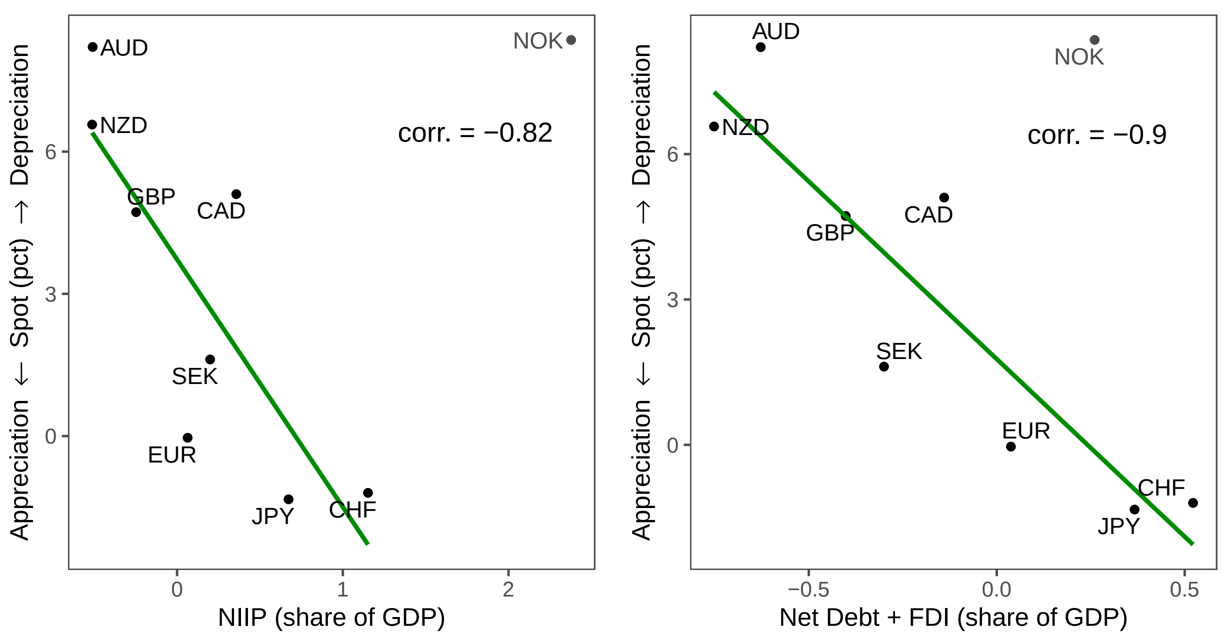


Figure 7: Central bank swap line usage during COVID-19 crisis

This figure plots maximum swap line draws by central banks during the Covid market turmoil against measures of external imbalances taken from the latest quarterly data available in 2019.

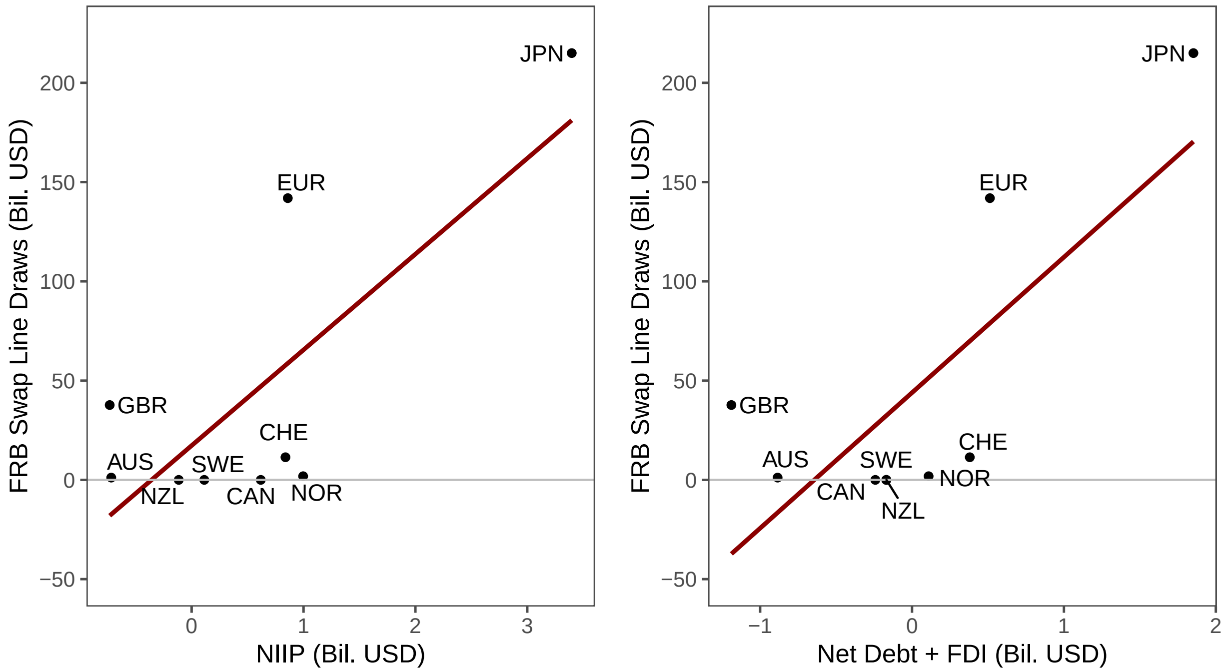
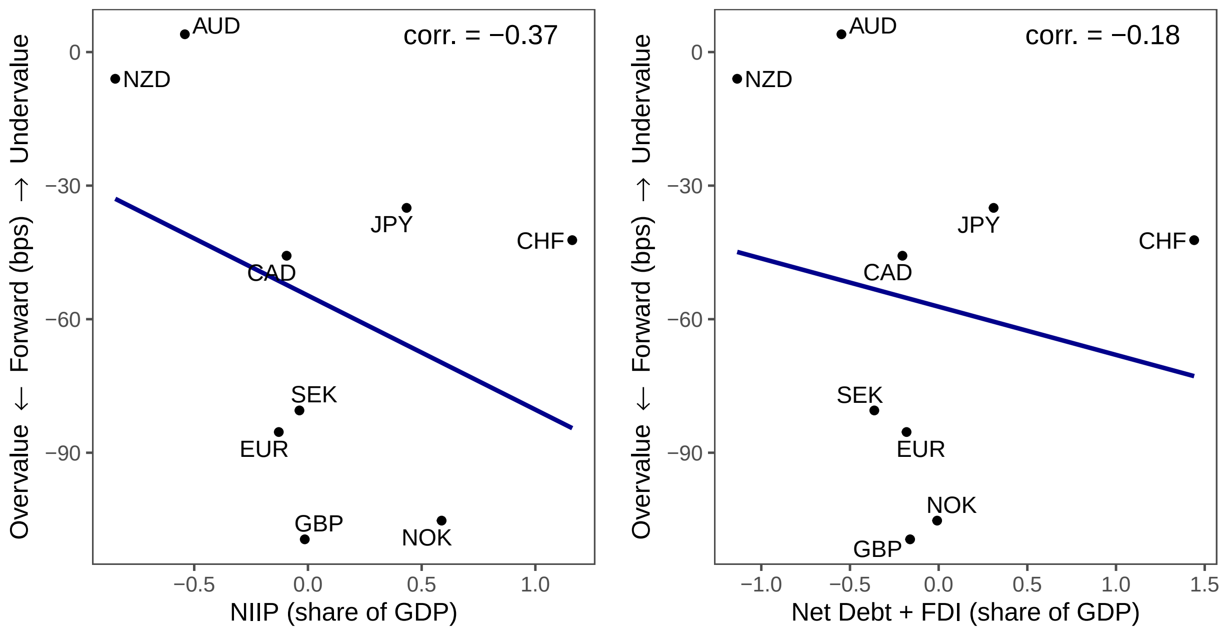


Figure 8: External imbalances and exchange rates during Global Financial Crisis

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

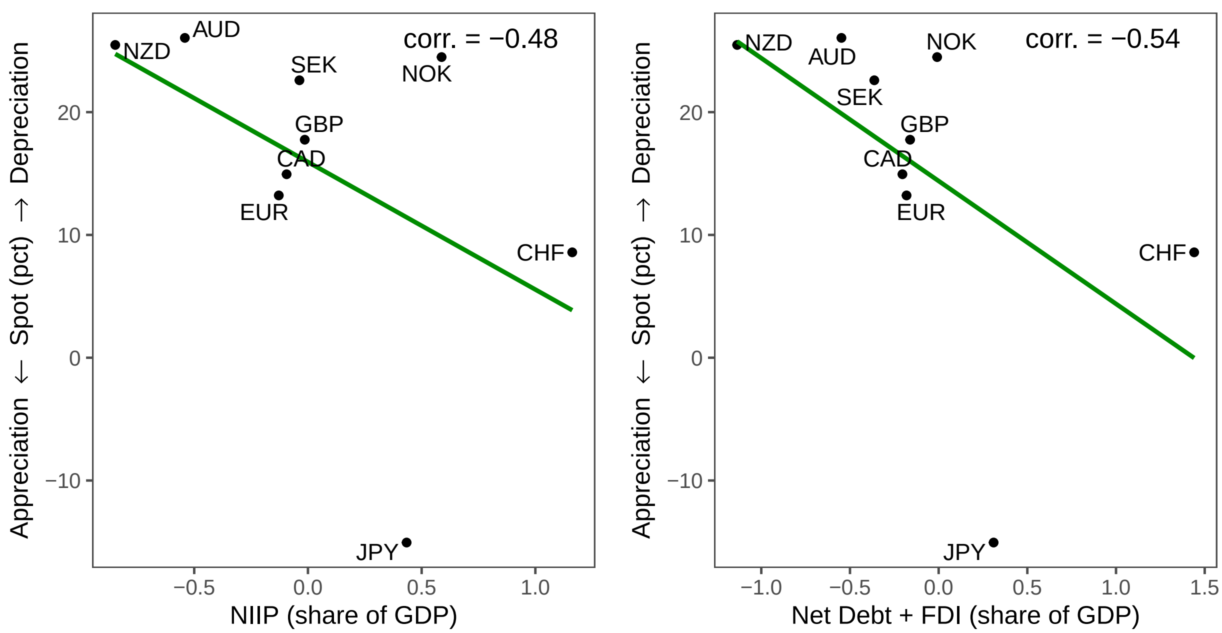
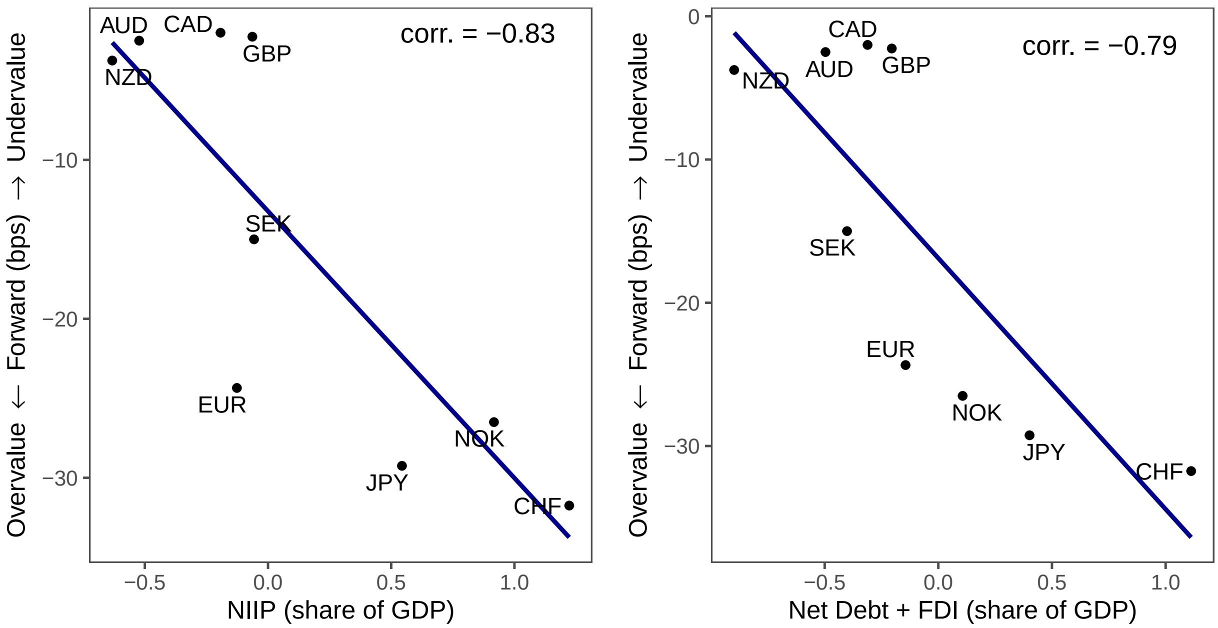


Figure 9: External imbalances and exchange rates during Eurozone crisis

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

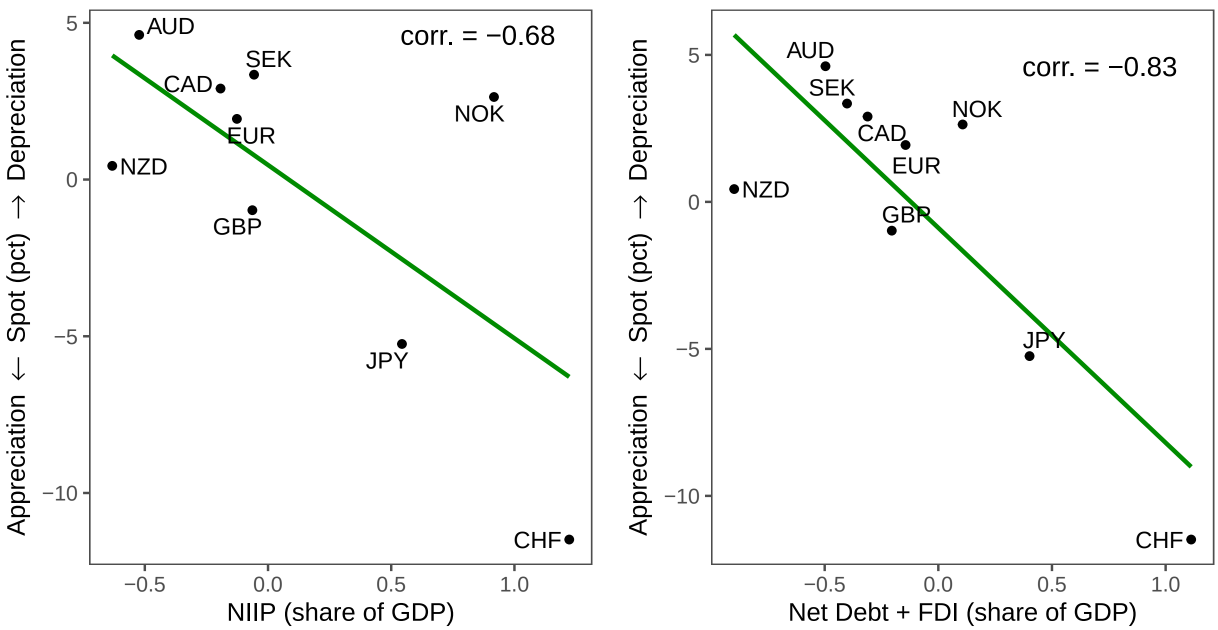
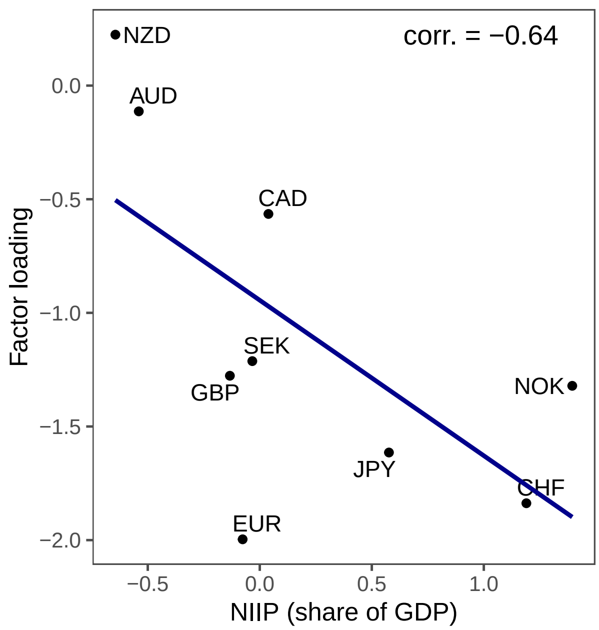
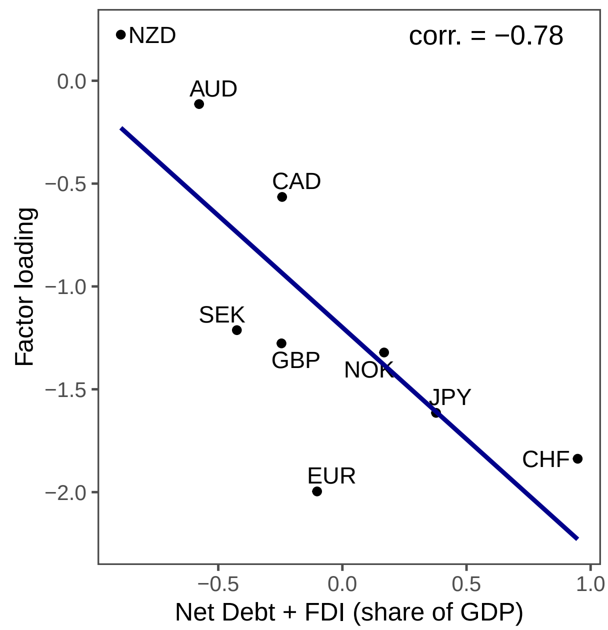


Figure 10: A single factor model of spot and forward exchange rates

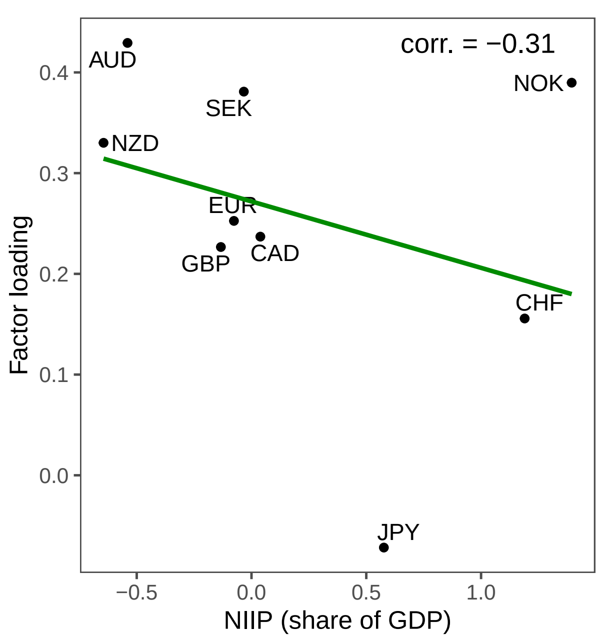
This figure plots coefficients β^n from estimating single-factor models of changes in cross-currency bases, spot exchange rates and the cross-currency term spread against countries' external imbalances. We plot β^n from the regression: $\Delta y_t^n = \alpha^n + \beta^n \overline{\Delta b}_t + \varepsilon_t^n$, 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



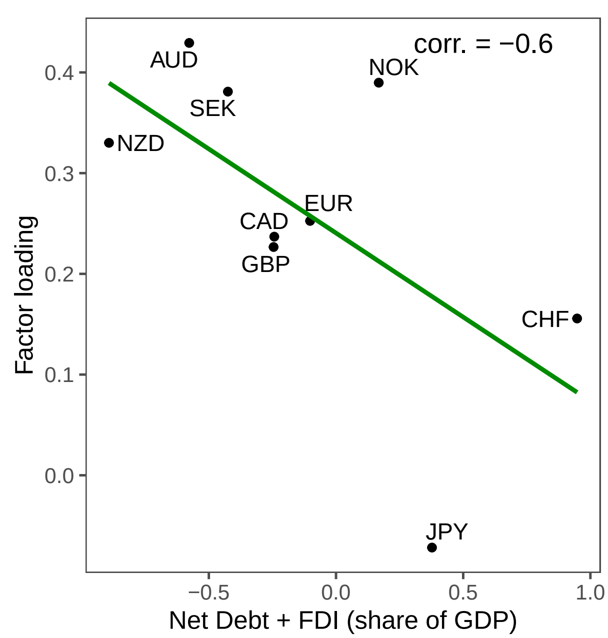
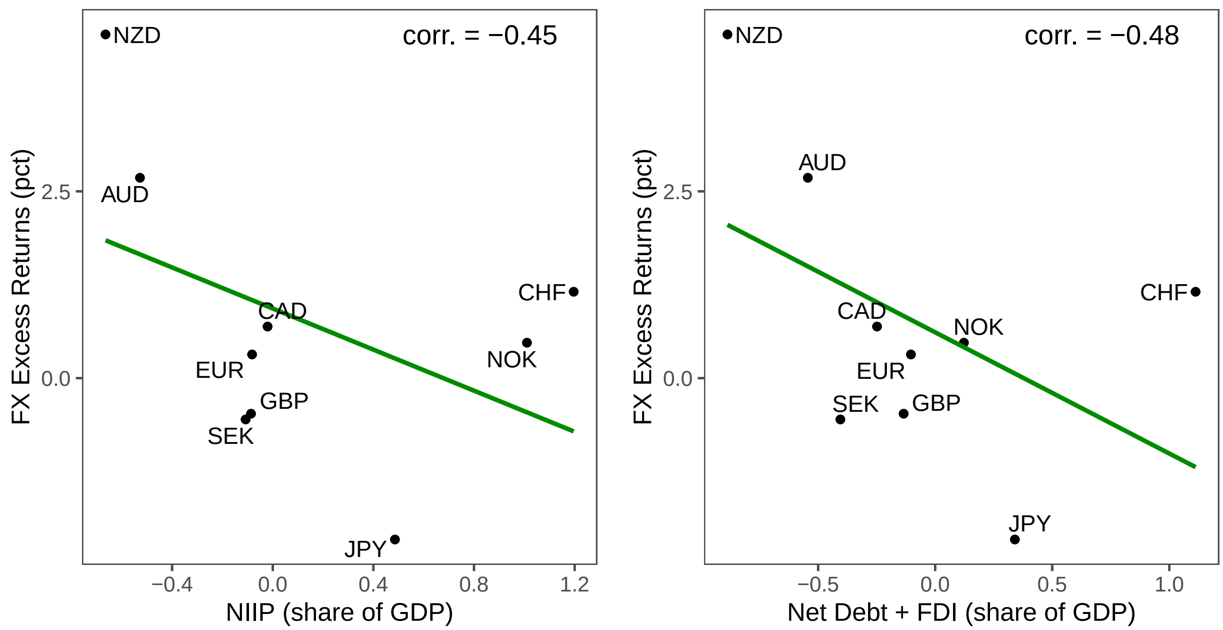


Figure 11: External imbalances and unconditional spot returns

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:

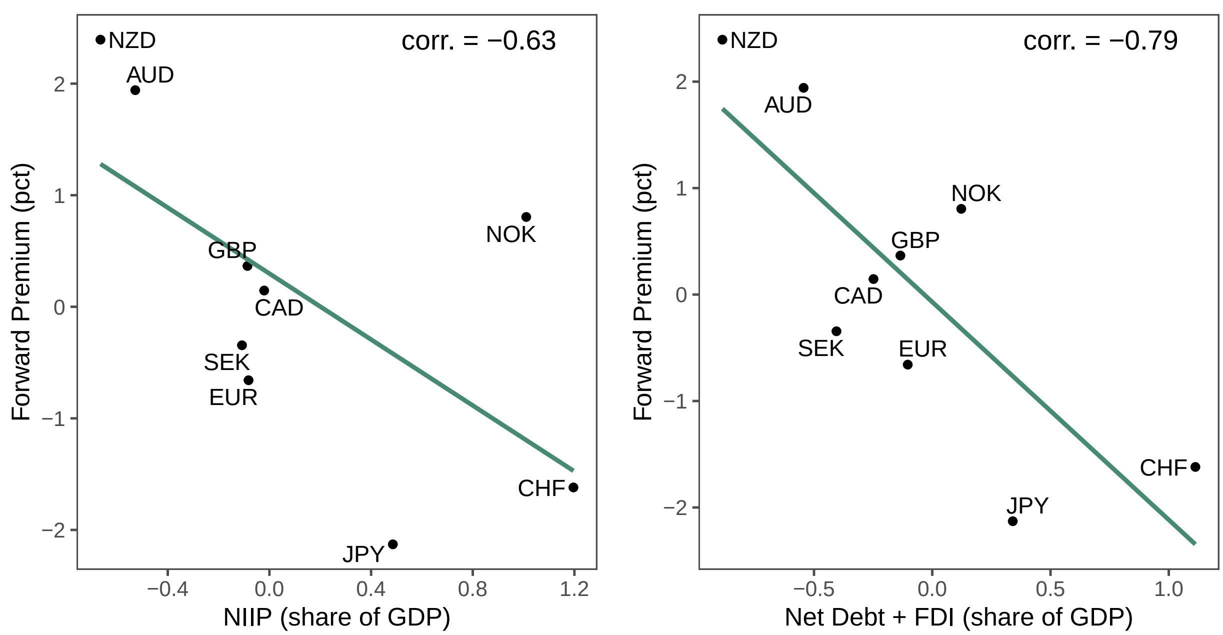


Figure 12: Term structure of cross-currency basis during COVID-19 crisis

This figure presents the term structure of cross-currency basis for the Australian Dollar and the Japanese Yen on two dates around the COVID-19 pandemic.

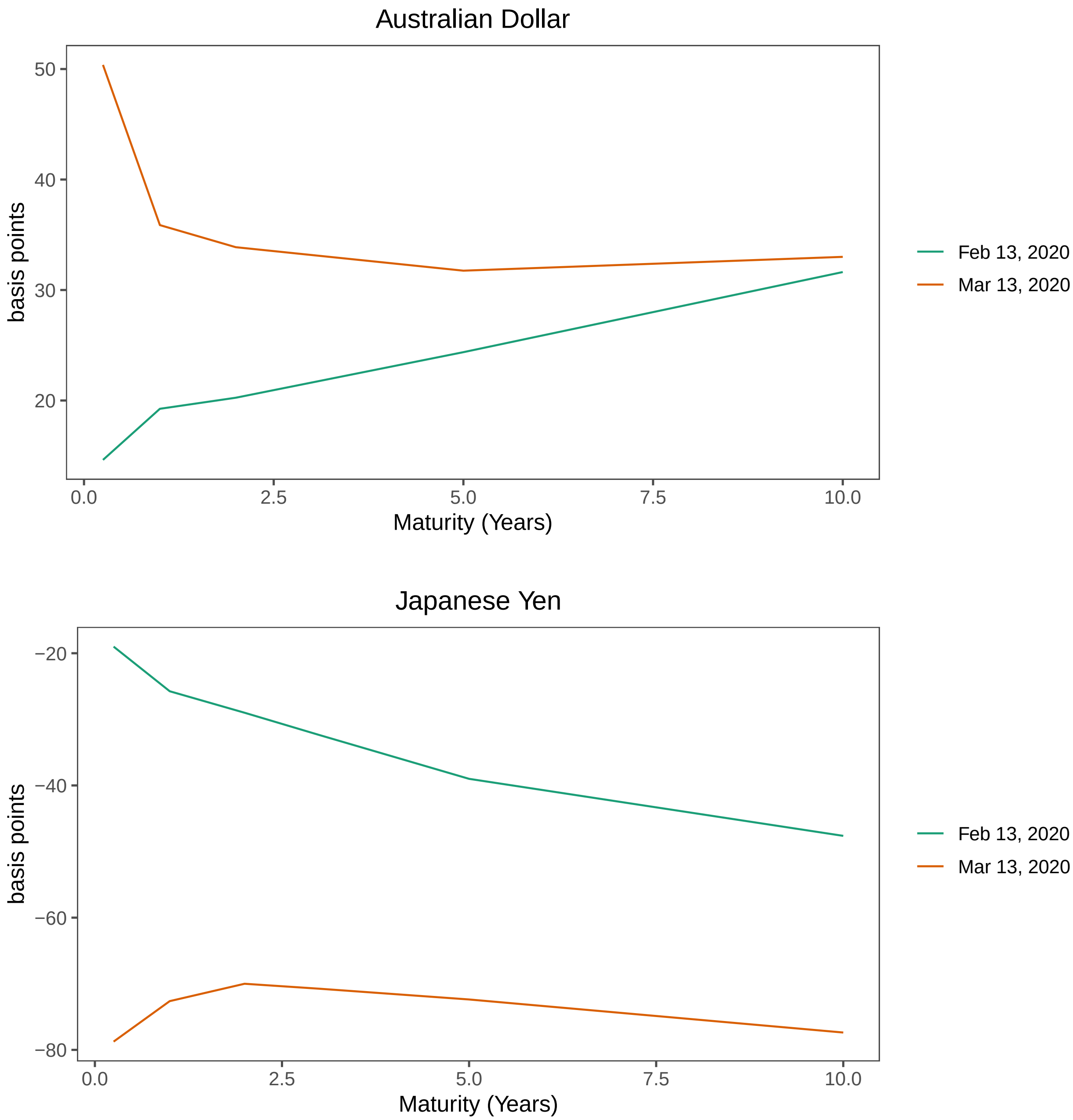
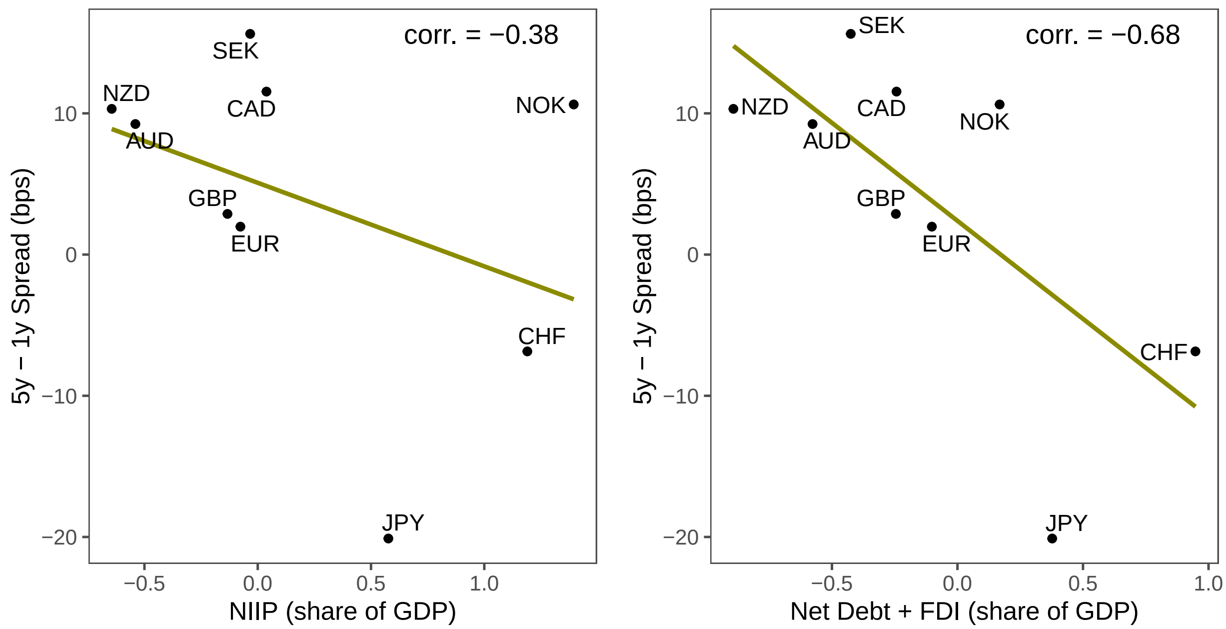


Figure 13: Conditional and unconditional exchange rate forward term structure

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

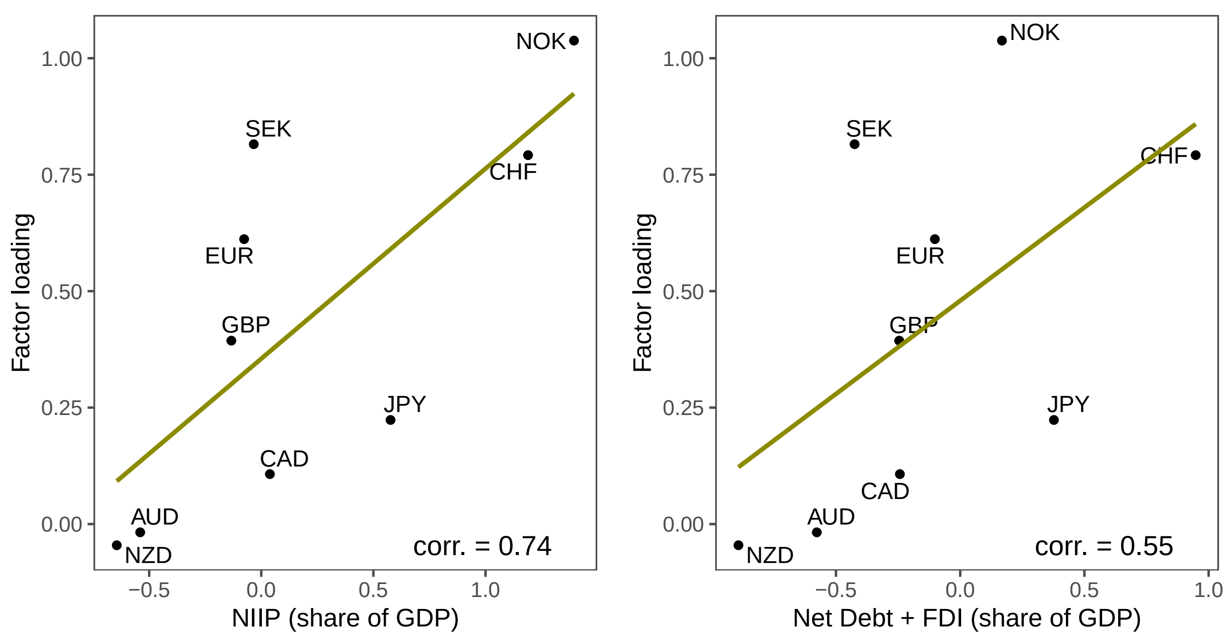


Figure 14: Options risk-reversal

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.

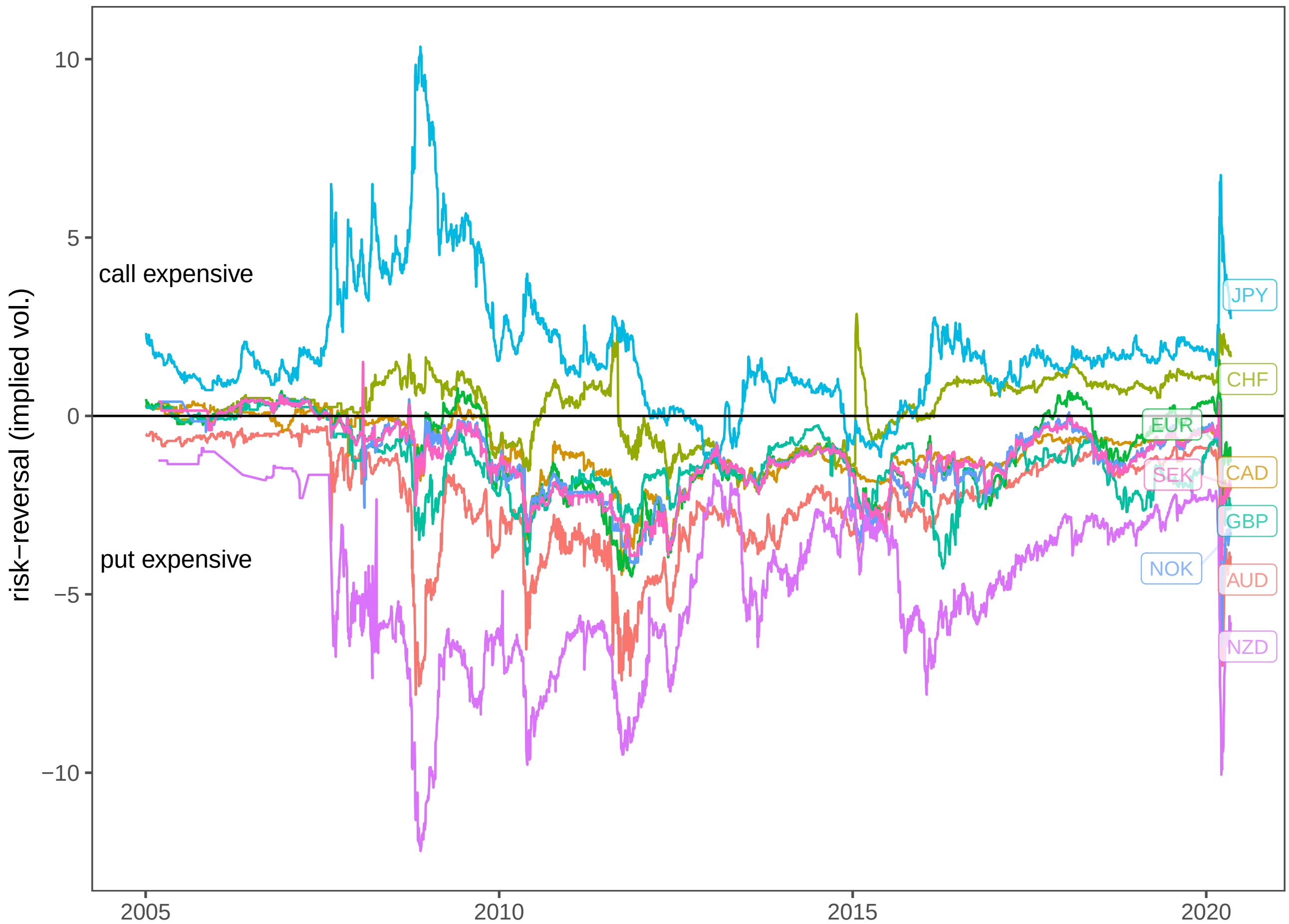
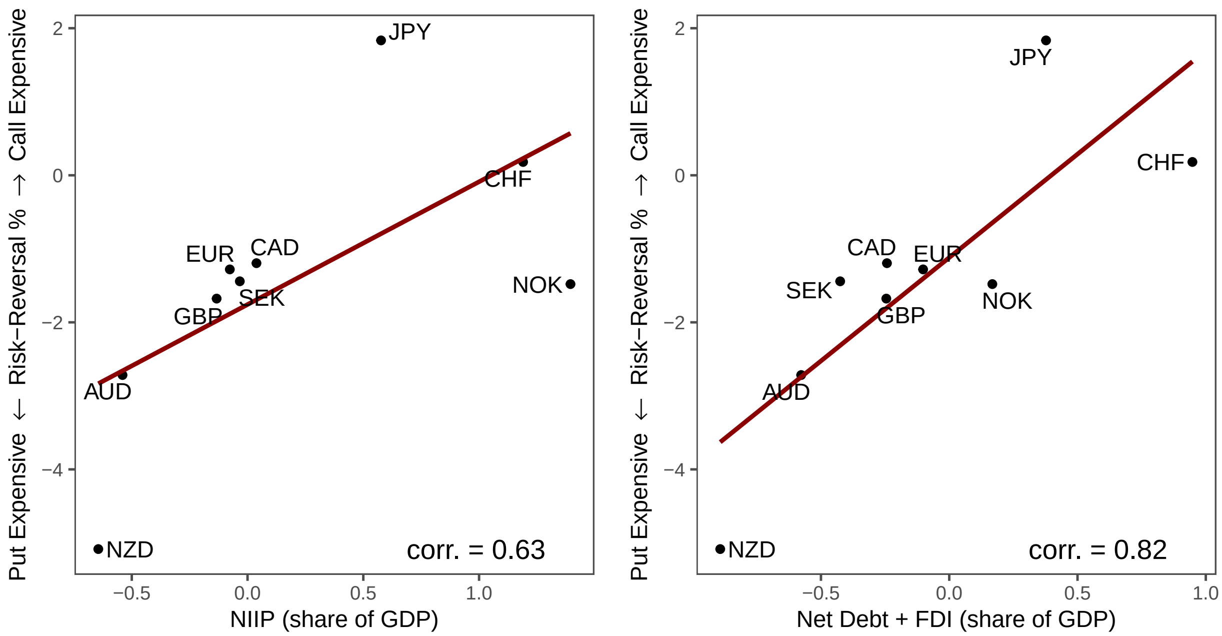


Figure 15: Conditional and unconditional option risk-reversals

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

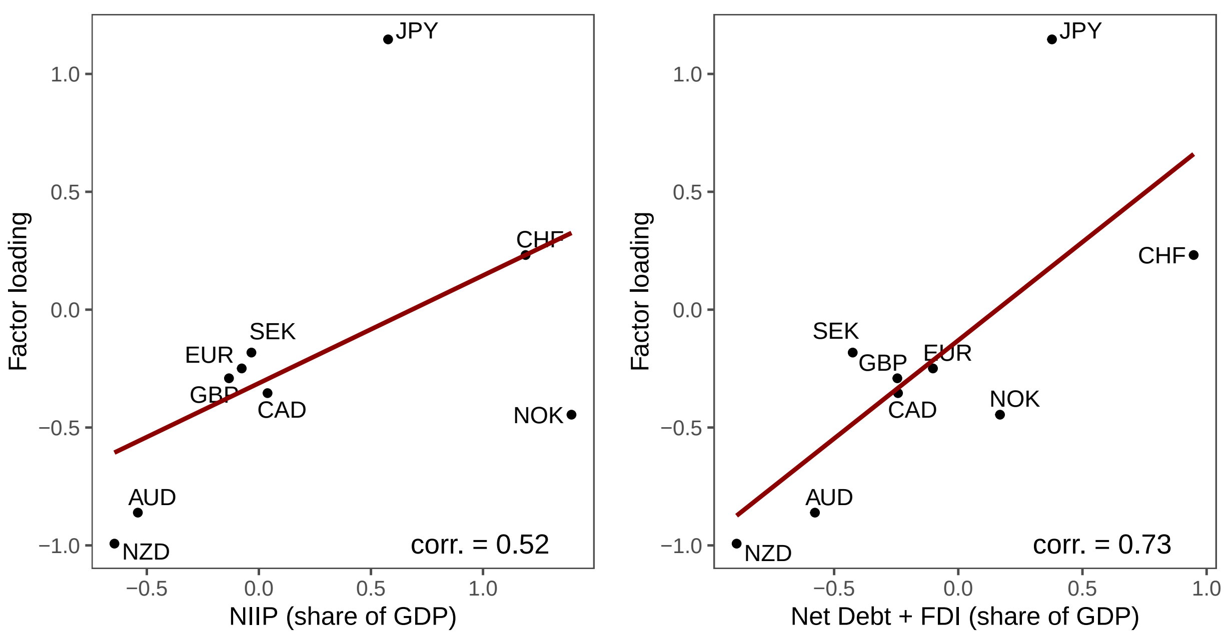


Table 1: Regulatory requirements on currency mismatch and hedging estimates

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 2008 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	18.39	-92.15	42.11
Absolute cross-currency basis (bps)	14.18	14.32	0.01	92.15
Annualized currency excess returns (pct)	0.01	0.11	-0.39	0.35
5-year minus 1-year basis spread (bps)	2.56	11.41	-48.95	60.75
NIIP / GDP	0.14	0.65	-0.85	2.49
Net Debt + FDI / GDP	-0.08	0.56	-1.14	1.66
Equity / GDP	0.08	0.36	-0.74	2.00
Current Account / GDP	0.01	0.02	-0.04	0.05

Table 3: External imbalances and cross-currency bases (2008-2020)

The following table presents panel regressions of monthly average cross-currency bases on measures of external imbalances. 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)	(7)	(8)
NIIP / GDP	−15.750**	−16.363**						
	(6.619)	(6.809)						
Net Debt + FDI / GDP			−23.295***	−23.275**				
			(8.715)	(9.358)				
Net Equity / GDP					0.186	−0.137		
					(7.252)	(8.486)		
CA / GDP							−795.196***	−818.105***
							(200.710)	(218.017)
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	0.272	0.430	0.337	0.479	0.000	0.144	0.282	0.438

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

Table 4: 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 5: Single factor model bases and 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 6: Single factor model of the cross-country 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 7: 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

Appendix
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A Appendix to Section 2

A.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 $b^n < b^m$.

A.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,

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

A.3 Extension: Endogenous Hedge Ratio

In the following appendix, we extend the benchmark model to allow for an endogenous hedge ratio h^n and show the Propositions 1 through 3 hold in a model in which the country n investor's optimal hedge ratio responds endogenously to expected exchange rate volatility. Throughout this appendix, we let S_t^n denote the country n exchange rate in period t.

We assume the country n investor exhibits mean-variance utility over her wealth in domestic currency in period 2:

$$\max_{h^n} h^n X^n (1 + r^D) F^n + (1 - h^n)(1 + r^D) X^n \mathbb{E}\left[S_2^n\right] - \frac{\gamma}{2}\left((1 - h^n)(1 + r^D) X^n\right)^2 V_2^n \tag{12}$$

S_2^n is the period 2 exchange rate and $V_2^n = \text{Var}\left[S_2^n\right]$ is the variance of the period 2 exchange rate.

We take first order conditions of (12) with respect to h^n and simplify to show:

$$h^n = 1 - \frac{\mathbb{E}\left[S_2^n\right] - F^n}{\gamma(1 + r^D) X^n V_2^n}. \tag{13}$$

Equation (13) has a very natural interpretation. The country n investor hedge her currency exposure more if she is more risk averse (higher γ), if she has larger exposure to exchange rate risk (higher X^n), or if the exchange rate is more volatile (higher V_2^n).

The equilibrium is now described equations (5), (7), (6) and equation (13). In this extended model, we can solve for b^n, F^n, S_1^n as well as h^n in terms of the risk-free rates , the excess demand for dollars and the exchange rate volatilities V_2^n.

A.4 Extension: A Three-Period Model

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

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

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

dollars in the forward market maturing in period 3.

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

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

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

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

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

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

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

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

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

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

where:

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

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

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

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

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

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

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

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

B 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[27] return that captures the roll-down and carry of the term-premia capture strategy strategy. Fig. A1 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[28] 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.

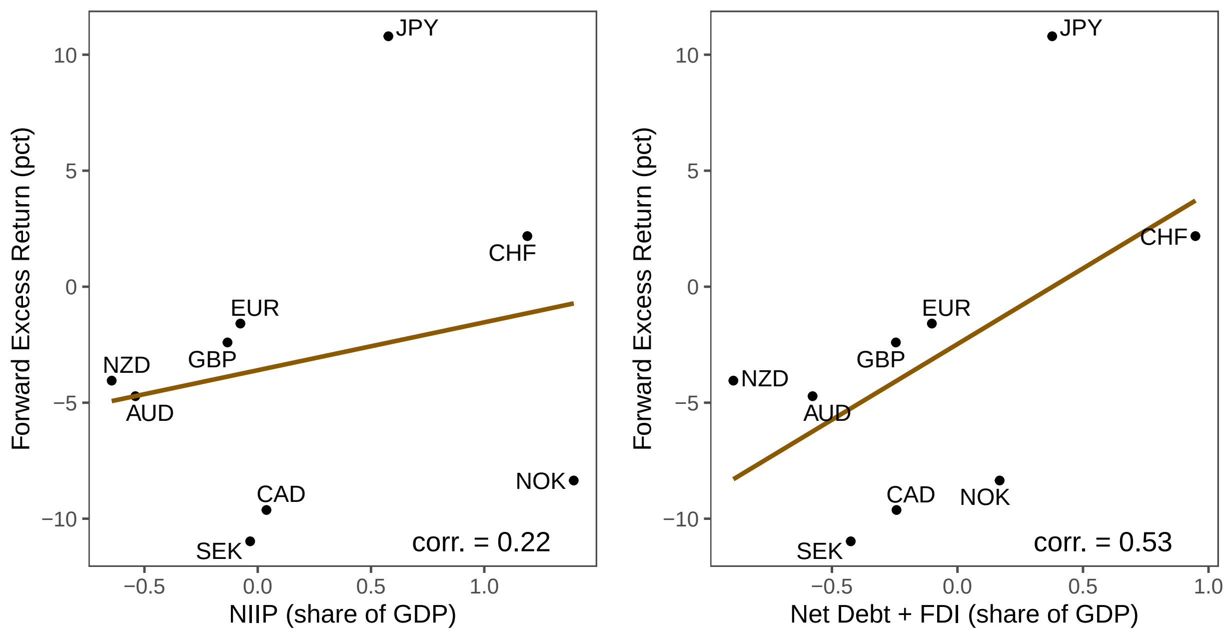
[27]The position involves in the promise of lending dollar against foreign currency cash collateral in one-years time for the period of one year.

[28]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 A1: 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)

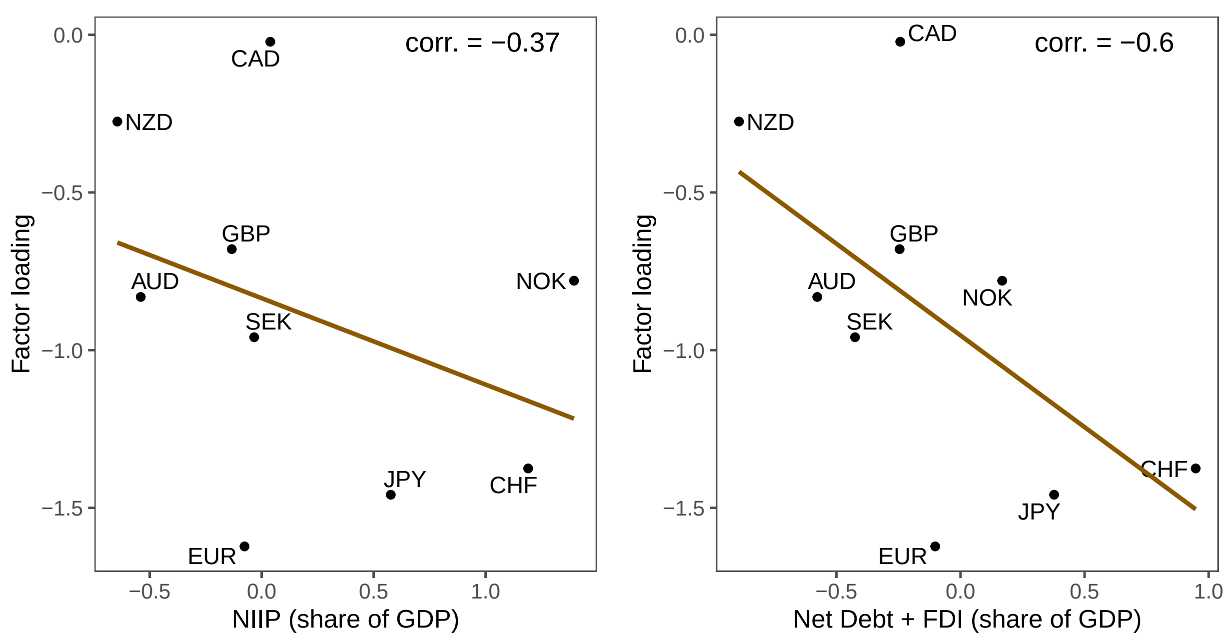


Table A1: Single factor model of basis carry trade

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

C Data Appendix

C.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. 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.