# Internal Capital Frictions in Intermediaries and Exchange Rate Dynamics*

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**Abstract**

Intermediary asset pricing theory predicts that financial intermediaries are the marginal investors in segmented markets and thus price many financial assets. Empirically, the literature has used sector-wide leverage as a proxy for their stochastic discount factor. Consistent with the pecking order and the granularity of many markets, we instead propose to use internal capital frictions in large broker-dealers. We test our hypothesis with the covered interest parity (CIP), a no-arbitrage condition that creates a liquidity risk for arbitrageurs, to explain the cross-section of CIP deviations in G-10 currencies. We use changes in the profit and loss statement, crystallized through variation margins, as liquidity shocks at different levels (currency pair, G-10 currency pairs, foreign exchange derivatives trading desk, derivatives) to identify where the capital constraints bind, marking the limit of the firm within the balance sheet of large banks that intermediate the foreign exchange derivative market.

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# Introduction

There is a large literature encompassing economics, corporate finance[1], management[2], and law[3], on the nature of the firm, which stems from the seminal article of Coase (1937) arguing that the trade-off between (external) transaction costs and (internal) production technologies sets the limit of the firm. Specifically, the limit is reached when the firm is indifferent between acquiring a business unit and trading with it in the market[4].

For large banks, these limits are particularly blurred because business units often behave as independent firms within the bank. Indeed, banks have many different operations, often resulting from external acquisitions, reinforced by consolidation in the banking sector after the Great Financial Crisis (GFC) of 2008, rendering them "Too Complex To Fail" (Carmassi and Herring, 2019). This makes large banks hard to manage as a single firm, as their numerous strategic plans to unify can attest[5]. In particular, because the different activities within banks are highly specialized and can be hard to control[6], banks' treasuries interact with internal business units as *a bank within the bank*[7]. Treasuries assess their liquidity risk and implement limits by monitoring their Liquidity Coverage Ratio (LCR), setting Maximum Cumulative Outflows under different scenarios, imposing Value-at-Risk limits, stress-testing, and restricting internal credit lines in case of profit and loss drawdowns.

This internal, market-like behavior between a bank's treasury and its business units could be an important source of slow-moving capital (Duffie, 2010) *within* balance sheets, which in turn affects asset prices. This contrasts with the usual overall balance sheet constraint considered in the intermediary asset pricing literature and is consistent with the pecking order theory in corporate finance, i.e. firms usually prefer to use internal capital to finance their projects instead of raising external funds, often because of moral hazard as in Myers and Majluf (1984) or debt overhang as in Myers (1977).

**This paper directly tests whether deviations from covered interest parity can be explained by the convergence risk that arises from the variation margins on the derivative leg of the arbitrage trade. We hypothesize that internal and external capital frictions make this liquidity risk costly, and we test this mechanism using a regulatory, transaction-level dataset of FX derivatives.**

We test this hypothesis of slow-moving internal capital in the context of one of the most fundamental relationships in international macroeconomics and finance: the covered interest parity (CIP). It states that the risk-free return in two different currencies should be the same, when taking into account the currency hedging cost. This can be viewed both as the law of one price, i.e. a risk-free asset should give the same return, otherwise agents would buy the cheapest asset until the returns converge, and as a no-arbitrage condition, otherwise an agent could borrow risk-free in one currency, invest in the other currency and hedge the currency exposure to receive the difference risk-free at maturity. Both approaches deliver the well-known pricing equation for the foreign exchange forward contract $1 + i_{0,T} = (1 + i^*_{0,T})\frac{F_{0,T}}{S_0}$, or equivalently:

$$F_{0,T} = S_0 \frac{1 + i_{0,T} - b_{0,T}}{1 + i^*_{0,T}}$$

where $i$ is the interest rate in Home, $i^*$ is the interest rate in Foreign, $F$ is the forward rate Foreign/Home, and $S$ is the spot rate Foreign/Home. Any deviation from the CIP is usually introduced as the cross-currency basis $b_{0,T} = (1 + i_{0,T}) - (1 + i^*_{0,T})\frac{F_{0,T}}{S_0}$, a premium or discount on the home interest rate. In practice, the CIP deviations have been significantly negative for most currencies against the US dollar since the GFC (see Figure 1), i.e. the synthetic dollar is more expensive.

The CIP deviations are particularly well-suited to test our hypothesis. As part of counterparty risk mitigation measures, FX swaps and forwards do not require initial margins, but are subject

[1] For a specific discussion of the complex corporate structure of large financial conglomerates, including internal agency problems, see Herring and Carmassi (2012).

[2] For a review of that literature, see, e.g., Maness and Wiggins (2013). For a specific focus on risk management and governance in banks, notably through Value-at-Risk limits, see Stulz (2016).

[3] See Wetzer (2019) on the impact of bank subsidiary ring-fencing on governance and its conflicts under UK law.

[4] Clearly, these limits can sometimes move: in July 2024 and in order to improve quality controls, Boeing decided to buy its supplier Spirit AeroSystems, a former business unit it had sold almost 20 years before.

[5] See, for instance, "The 'one' way for Wall Street banks", Financial Times, 22 June 2024, available here.

[6] See, for instance, "SG trader dismissals shine spotlight on intraday limit controls", Risk.net, 3 May 2024, available here.

[7] For a detailed description of liquidity management within a bank through Funds Transfer Pricing (FTP), see e.g. Tumasyan (2012).

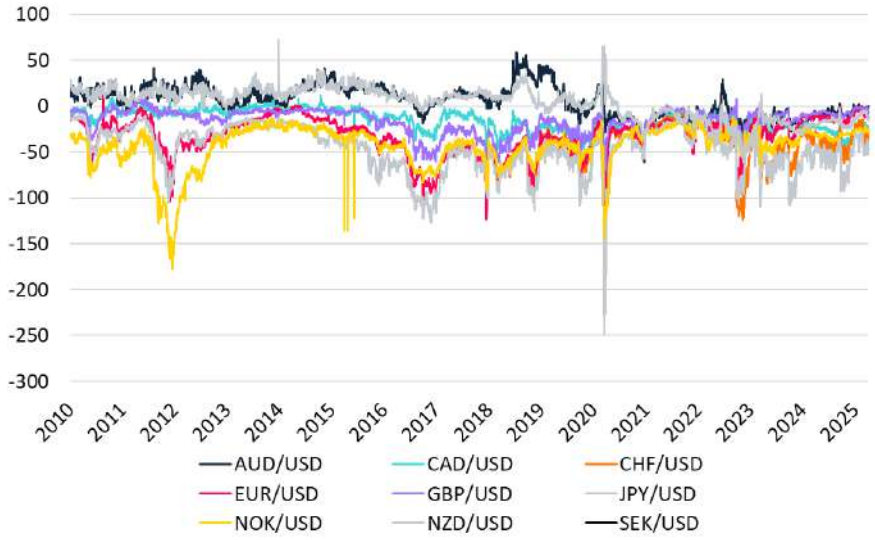



Figure 1: 3-month OIS-implied covered interest rate deviations for the G10 currencies against the USD, in basis points.
Sources: Bloomberg, Authors' calculations as in Siriwardane et al. (2023).

to variation margins to mitigate any counterparty risk[8]. As such, any change to the profit and loss statement (P&L) is directly crystallized as a shock to the available internal liquidity through variation margins. Even if the arbitrage trade *per se* is fully hedged and thus risk-free *at maturity*, the liquidity risk in the interim periods is substantial.

Formally, the variation margin $VM_t$ (or mark-to-market value $V_t$) of the forward contract is:

$$VM_t = V_t = \frac{F_{t,T} - F_{0,T}}{1 + i_{t,T}} \times N \times (-1)^{\mathbb{1}_{Side=S}}$$

with the convention that $VM_t$ is denominated in Home, the notional $N$ is in Foreign, and $F_t$ is quoted as Foreign/Home, i.e. Foreign is the base currency and Home the quote currency (in practice the USD). For the counterparty side, the convention is that the buyer receives the first currency of the pair (i.e. Foreign, the base).

With perfect markets, this would not matter. Variation margins are indeed remunerated at the OIS rate, so the arbitrageur could borrow at the OIS rate to finance the variation margin, without changing either the return or the risk of the trade. But in reality, this liquidity pressure is not neutral for the arbitrageur, because external funding is costly (there is no repo market for derivatives), making internal funds more valuable, and because internal capital might be frictional.

This mechanism is sometimes floated as an explanation for widening bases or drops in liquidity[9], and was the original motivation for the literature on the limits of arbitrage and slow-moving capital. But, to our knowledge, this channel has not been directly tested empirically until now, even though currency moves are notoriously volatile and unpredictable (see Figure 3), at the heart of the literature on the exchange rate disconnect and excess volatility. A back-of-the-envelope calculation for a three-month forward contract with an annual volatility of $\sigma = 15\%$ gives an $\alpha = 95\%$ confidence Value-at-Risk (VaR) for the variation margin (or Margin-at-Risk) of $F^{-1}_{\mathcal{N}(0,1)}(\alpha)\sigma\sqrt{T} \simeq 12\%$ of the notional of the contract. This is a lower bound as the tails of the empirical distribution of FX returns are fatter than a normal distribution. Furthermore, this mechanism has the potential to explain the *cross-section* of CIP deviations across currencies, something that has mostly eluded the existing literature.

[8] See Section 3.1.2 and "Margin requirements for uncleared derivatives", Financial Conduct Authority, 3 February 2017, available here. In the context of an FX swap, as the transaction is fully collateralized by the exchange of notionals in the first leg, and for derivatives in general, the counterparty risk is the risk of not being able to replicate the initial exposure if the other counterparty defaults (replacement-cost risk). The loss given default is thus at most the current value of the contract and the variation margin is exactly this mark-to-market value. The margin thus removes the counterparty risk.

[9] See, for instance, "Dollar rout forces UK currency risk specialist to suspend shares", Financial Times, 22 April 2025, available here on the FX market. On the US Treasuries cash-futures basis, another arbitrage trade that is exposed to a similar convergence risk, see "How the Treasury market got hooked on hedge fund leverage", Financial Times, 25 April 2025, available here, "Basis Trades and Treasury Market Illiquidity", Office for Financial Research, July 2020, available here, or Schrimpf, Shin, and Sushko (2020).

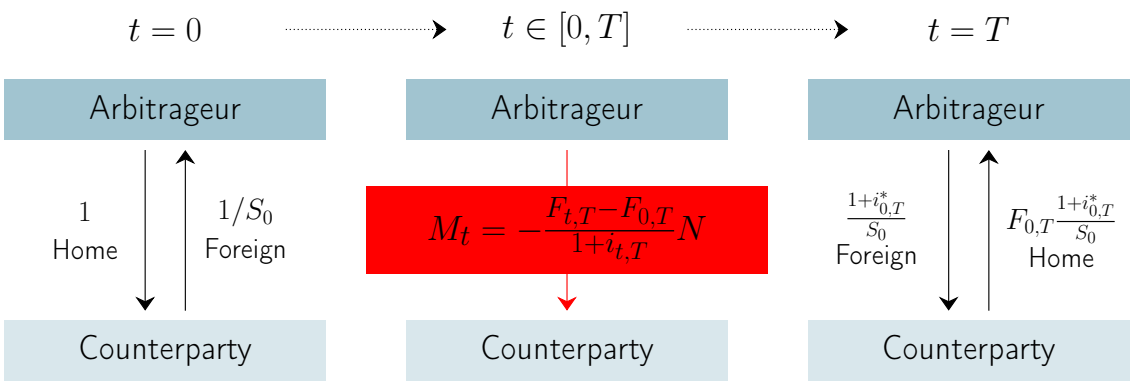



Figure 2: Cash flows of the covered interest parity arbitrage trade over time.
*Notes:* In order to arbitrage away the covered interest parity deviations, the arbitrageur borrows 1 Home at time $t = 0$ and exchanges it for $1/S_0$ Foreign at the spot exchange rate. She then invests at the Foreign interest rate $i^*_{0,T}$ and enters a forward contract to exchange $N = (1 + i^*_{0,T})/S_0$ Foreign into Home at the forward rate $F_{0,T}$. At $t = T$, she thus receives $F_{0,T}(1+i^*_{0,T})/S_0$ Home and repays $1+i_{0,T}$ Home, earning the CIP deviation $-b_{0,T} > 0$. But in the process, for $t \in (0, T)$, the variation margins $M_t$ on the forward leg of the arbitrage trade expose the arbitrageur to convergence risk: changes in the forward rate $F_{t,T}$ lead to changes in the mark-to-market value of the contract, which translates into liquidity shocks through variation margins.

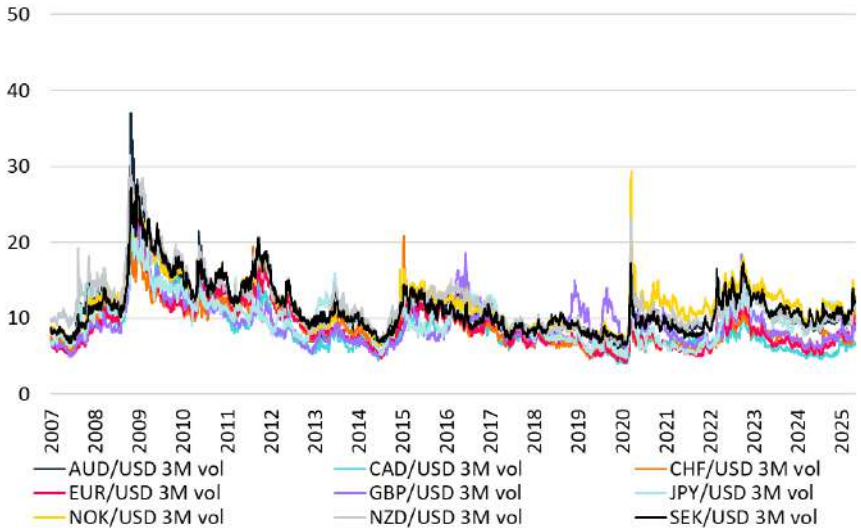
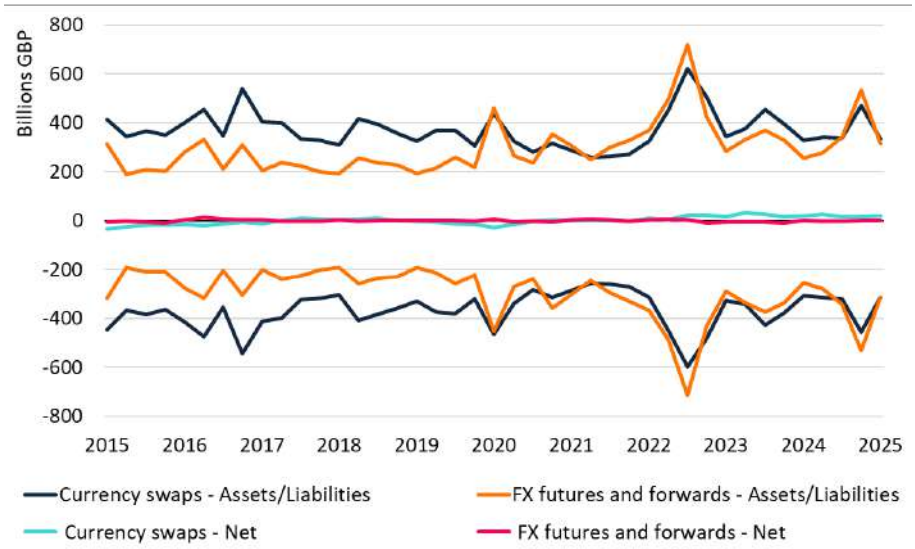



Figure 3: 3-month foreign exchange rate option-implied volatility.
*Notes:* The implied volatility is computed from at-the-money option quotes from brokers and sell-side institutions.
Source: LSEG.

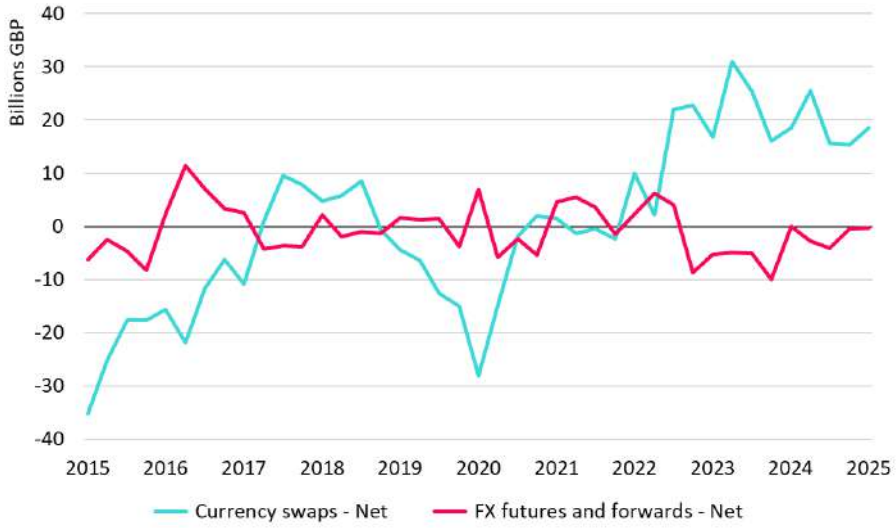
But how large are these variation margins in practice? For the United Kingdom, the Bank of England publishes quarterly aggregates of outstanding contract values of FX derivatives for large banks from which it collects data. In Figure 4, we present the total assets and liabilities that these open positions represent. The gross outstanding values (4a) are considerable, often among the largest items on banks' balance sheets. This is primarily because accounting rules only allow position netting when derivatives are contractually settled on a net basis; FX forward and swap contracts are usually instead "collateralized-to-market". But the net value, assuming perfect netting, still amounts to billions of GBP (4b). This is the same order of magnitude as the annual profits of major UK banks[10].

Furthermore, this aggregates the outstanding positions of different counterparties in a market in zero net supply, suggesting that large individual net positions are averaged out. Alternatively, we

[10] Although an extreme event, when the Swiss National Bank dropped the peg between the euro and the Swiss Franc, several currency brokers reportedly lost hundreds of millions of US dollars in a single day. See, e.g., "Surge of Swiss Franc Triggers Hundreds of Millions in Losses", The Wall Street Journal, 16 January 2015, available here.




(a)




(b)

Figure 4: Quarterly amounts outstanding of UK resident banks' Foreign Exchange Swaps, Foreign Exchange Futures and Forwards - Liabilities and Assets (in billions GBP). Firms reporting have a gross derivatives position on their balance sheet over GBP 10 billion.
Sources: Bank of England (Form DQ), Authors' calculations.

also present evidence on the magnitude of profit and loss changes from foreign exchange derivatives' values at the individual bank level (in billions of USD or GBP), from annual reports and Companies House, the register of companies in the United Kingdom, in Appendix A. Individual positions can indeed be substantial, making the mechanism we investigate first order for banks' treasuries allocating internal liquidity across the different business units and investment opportunities.

The structure of the FX forward market is key to explain why such idiosyncratic shocks to the internal capital of a counterparty could lead to CIP deviations. This over-the-counter market is characterized by a two-tier structure, with a dealer-client segment and a small inter-dealer market that is dominated by a handful of large dealer banks. Because trading relies on existing bilateral relationships, dealers are not substitutable for clients. As such, any shock to the internal capital of one of these dealers can have an impact on the overall market, as other dealers do not immediately enter the market to compensate the retrenchment.

Our analysis is based on daily data to coincide with the profit and loss statement calculations and match this mechanism. Our main data source is the European Market Infrastructure Regulation (EMIR) that mandates counterparties to report all their derivatives transactions and value them daily. Through the Bank of England, we access all transactions for which at least one of the counterparties is based in the United Kingdom. Because London is the capital of foreign exchange

trading, this gives us a significant part of the FX forward market.

As a preview of our results, we first develop a stylized model to serve as a conceptual framework that puts internal liquidity at the heart of the profit maximization problem of the treasury of a bank. The key result is that the stochastic discount factor of the intermediary that prices the forward exchange rate depends on the shadow price of internal liquidity. We then document the network of FX trading to identify these granular intermediaries, and show that they face considerable liquidity pressures from their derivative portfolio. We finally directly estimate in reduced form the systematic relationship between our constructed liquidity shocks and the forward rate offered to counterparties.

The rest of this paper follows our hypothesis that internal capital shocks and frictions within broker-dealers lead to CIP deviations, as these frictions prevent capital from flowing efficiently between business units. We first review the existing literature on the FX market structure, intermediary asset pricing, and internal liquidity in Section 1. We develop a natural framework of forward-looking liquidity risk management in Section 2. We then present our dataset of derivative transactions reported under EMIR in Section 3. Our empirical approach in Section 4 identifies these internal constraints and measures their impact on the CIP deviations. We discuss our results and their implications in Section 5.

# 1 Literature Review

## 1.1 The Market Structure of Foreign Exchange Derivatives

**Our identification strategy relies on the specific market structure of foreign exchange derivatives. The market is over-the-counter (OTC) and intermediated by large dealer banks.**

These features can be explained with search costs; Weill (2020) and Hugonnier, Lester, and Weill (2025) provide a review of this literature based on the idea that dealers can accommodate ad-hoc, large, and infrequent orders without moving the market by internalizing trades. Alternatively, Collin-Dufresne, Hoffmann, and Vogel (2019), for instance, investigate the role of information: the observed two-tier market structure (client-dealer and dealer-dealer) can endogenously emerge from dealers and clients matching on how informed they are, because of the permanent price impact of informed trades (consistent with the FX spot market in Evans and Lyons, 2002). These models give a theoretical grounding for why the withdrawal of liquidity by one of the main dealers might not be compensated by the entry of another one, because trading is based on existing bilateral relationships. This is consistent with the fundamental barriers to all-to-all trading, notably that the counterparties need to have a bilateral master agreement in place to govern their transactions, and that the pricing of such derivatives implies various counterparty-specific adjustments, commonly called XVA[11].

However, these theoretical models struggle to match the complex financial networks observed in this market, with sometimes large intermediation chains[12]. Hence, some empirical studies, including ours, take the financial trading network as given and focus on its implications, notably for price formation. For instance, Hau, Hoffmann, Langfield, and Timmer (2021) document discriminatory pricing behavior by large dealers for EUR/USD forwards, in that a counterparty connected to only one dealer faces worse bid-ask spreads, consistent with monopolistic power in the OTC market (Duffie, Gârleanu, and Pedersen, 2005).

The foreign exchange derivative market is currently undergoing some noteworthy and profound changes. Counterparties are moving away from phone orders towards electronic request-for-quote trading, through systematic internalizers or sometimes multilateral trading facilities[13]. Notwithstanding these changes, we empirically confirm this structure is still prevalent with large, dominant

[11] These adjustments to the perfect-markets, default-free pricing are usually Credit Value Adjustment (CVA) and Deb(i)t Value Adjustment (DVA) if one or the other counterparty defaults (basically zero with daily, two-way, and full variation margins), Regulatory Capital Value Adjustment (KVA) notably because of the leverage ratio costs, and Margin Value Adjustment (MVA) for the cost of having to post *initial* margins (zero for FX forwards). Because the CVA is computed at the counterparty level, trading within existing relationships (netting sets) can lead to better pricing for that counterparty. We focus on the Funding Value Adjustment (FVA) for the capital that needs to be raised (or released) because of the variation margins. Intuitively, derivatives are priced by traders using the internal pricing of funds (e.g. the average cost of funding), even though they are valued at the OIS rate, the correct rate at which the collateral is remunerated. The FVA thus reflects the spread between the OIS rate and the internal funds. See Hull and White (2012), Gregory (2020), and the related literature for the FVA debate in accounting; Andersen, Duffie, and Song (2019) resolves this as reflecting the debt overhang.

[12] For recent work in that direction, see e.g. Hugonnier, Lester, and Weill (2019).

[13] For anecdotal evidence on the recent changes of this market and the challenges of digitization, see for instance "E-trading takes hold for FX swaps – sort of", Risk.net, 4 March 2020, available here. See also Ranaldo (2022).

dealers that intermediate the market. Our work brings up to date the snapshot of the EUR/USD FX forward market presented in Abad, Aldasoro, Aymanns, D'Errico, Fache Rousová, Hoffmann, Langfield, Neychev, and Roukny (2016), covering the European Economic Area (including the United Kingdom at the time). We extend this network analysis to G-10 currency pairs to investigate cross-currency differences and interactions. In contemporary work with EMIR data, Hacioğlu-Hoke, Ostry, Rey, Rousset Planat, Stavrakeva, and Tang (2024) present some stylized facts on the net positions of counterparty types in the FX market. We complement this work by focusing on the network properties of the market and individual positions, using gross positions as well – as is common for financial stability questions – to test our hypothesis of internal liquidity frictions within the dominant dealers.

The market structure for FX forwards thus makes the different granular dealers not substitutable for clients. Therefore, even if variation margins are a zero-sum game, washed out when aggregating over all the counterparties, these idiosyncratic shocks to intermediaries can matter for the overall price of the market.

## 1.2 Intermediary Asset Pricing and the Limits to (CIP) Arbitrage

**A dynamic literature focuses on the consequences of having financial intermediaries as marginal investors on price formation, and notably how prices can move away from fundamental values because of intermediation frictions. Given the market structure for FX forwards, shocks to dealers matter for CIP deviations.**

Theoretical contributions show that the effect of intermediation can be important. Central to this literature is the idea that the stochastic discount factor (SDF) of intermediaries, not households, prices the different assets in the economy, and funding constraints can have an outsize impact on the marginal value of wealth for these intermediaries. He and Krishnamurthy (2012, 2013, 2018) study the effect of market segmentation and the ensuing agency frictions that introduce an **equity capital constraint** on financial intermediaries to explain asset prices' moves during the GFC, *à la* Bernanke and Gertler (1989). Others instead focus on how intermediation agency can lead to **borrowing and collateral constraints** and can thus amplify moves in asset prices, in the tradition of Kiyotaki and Moore (1997), e.g. Brunnermeier and Pedersen (2009). Finally, some models center on intermediaries' **leverage** as in Holmstrom and Tirole (1997), Aiyagari and Gertler (1999), Gertler and Karadi (2011) or Brunnermeier and Sannikov (2014).

Empirically, different studies find evidence that intermediaries indeed price assets in many asset classes. Adrian, Etula, and Muir (2014) (henceforth AEM) show that the aggregate **leverage**[14] of securities broker-dealers is a sufficient pricing factor for equities and Treasuries. Lower leverage forces intermediaries to liquidate and thus a positive payoff that covaries with low leverage should command a lower risk premium. He, Kelly, and Manela (2017) (henceforth HKM) find that the aggregate **equity capital ratio**[15] of primary dealers can explain returns for a large set of asset classes. They find that a payoff when the intermediary capital ratio is low commands a lower risk premium. As discussed in HKM, this seems at first in contradiction with AEM as one SDF is the reciprocal of the other, but both give the same sign for the price of risk; the authors suggest that investigating the internal markets of primary dealers might resolve this puzzle. We focus on how frictional these internal markets are.

Given its market microstructure, the intermediary asset pricing theory is likely to be key for the FX market. Notable theoretical contributions suggest the financial sector is indeed particularly important for exchange rate determination: constraints on and shocks to intermediaries are needed to explain well-known exchange rate disconnects and puzzles, as in Pavlova and Rigobon (2008), Gabaix and Maggiori (2015)[16], and Itskhoki and Mukhin (2021, 2024).

We study an arbitrage condition, which in its pure, theoretical form does not require capital and is thus independent of the pricing kernel. Nevertheless, arbitrage in practice requires capital because of the convergence risk and thus suffers from the constraints aforementioned. For instance, Shleifer and Vishny (1997) model agency frictions arising from outside capital as inefficient, performance-based arbitrage (their introductory example on the limits of arbitrage is actually the variation margins during the life of a derivative contract we investigate quantitatively). Gromb and Vayanos (2010) provide a survey on the theories of limits of arbitrage, for which the financial

[14] Defined as $Leverage_t^{BD} = (TotalFinancialAssets_t^{BD})/(TotalFinancialAssets_t^{BD} - TotalLiabilities_t^{BD})$.

[15] Defined as $EquityRatio_t^{PD} = (MarketEquity_t^{PD})/(MarketEquity_t^{PD} + BookDebt_t^{PD})$.

[16] We contribute to micro-founding the constraint on financiers $\Gamma = \gamma var(e)$. Like them, the risk-bearing capacity of intermediaries depends inversely on the volatility of the future exchange rate. But contrary to their Lemma A.4., because of the variation margins in the interim periods during the life of the forward contracts, net positions coming from the CIP trades (not only UIP ones) also induce risk premia in the stochastic discount factor of intermediaries, so the CIP does not hold. In essence, it makes the CIP arbitrage closer to carry trades than a riskless position.

health of arbitrageurs is crucial because of constraints on leverage and equity capital, nesting some of their models (Gromb and Vayanos, 2002, 2018). In essence, even if a profit is guaranteed by convergence, the arbitrage deviation might worsen before converging to zero. As the deviation worsens, and thus returns increase, arbitrage capital will flow to close the deviation, but might do so only slowly (Duffie, 2010; Duffie and Strulovici, 2012).

**Some specific limits to arbitrage can help explain the CIP deviations, shedding light on the SDF of intermediaries.**

The covered interest parity is such a fundamental relationship in international macroeconomics and finance that a large literature has suggested different limits to arbitrage to explain the sign and persistence of these violations. Before the GFC, the small but statistically significant deviations were mostly explained by capital controls, transaction costs, and credit risk (Duffie and Huang, 1996). Capital flows have been liberalized, transaction costs have come down and mandatory variation margins now mitigate counterparty risk.

Since the GFC and the near end of the unsecured interdealer funding market, the literature has focused on the balance sheet constraints applied to intermediaries to explain CIP deviations, notably the leverage ratio (LR), liquidity coverage ratio (LCR) and net stable funding ratio (NSFR)[17] on regulated intermediaries and arbitrageurs: Du, Tepper, and Verdelhan (2018) explain end-of-quarter jumps by reporting effects, Cenedese, Della Corte, and Wang (2021) study an exogenous change in the reporting frequency. Because banks provide liquidity to other market participants such as hedge funds and investment funds, Boyarchenko, Eisenbach, Gupta, Shachar, and Van Tassel (2018) show that the new risk limits on banks also impacted unregulated arbitrageurs.

Another limit to this arbitrage trade arises from funding frictions, such as segmentation. Sushko, Borio, McCauley, and McGuire (2016) highlight that non-US banks usually have a higher share of assets in dollars than liabilities, making them net buyers of dollars to hedge their exposures and reluctant to arbitrage the CIP deviations away, as predicted in Ivashina, Scharfstein, and Stein (2015). Avdjiev, Du, Koch, and Shin (2019) investigate how the strength of the US dollar affects bank balance sheets. This is consistent with results in other markets, e.g. Eisfeldt, Herskovic, Rajan, and Siriwardane (2022) find that OTC dealers offer trading terms that depend on their heterogeneous risk-bearing capacities. Rime, Schrimpf, and Syrstad (2022) show that CIP deviations are smaller when taking into account unsecured funding rates, instead of OIS rates. However, Global Systemically Important Banks (G-SIBs), on which we focus, retain funding conditions favorable enough to arbitrage the CIP away, especially with secured funding (or internal funds). Anderson, Du, and Schlusche (2021) use the 2016 change in money market funds regulation that caps the maximum exposure to a given counterparty as a negative wholesale funding shock and a limit to this arbitrage. Bahaj and Reis (2021) highlight that central bank swap lines put a ceiling on CIP deviations by providing liquidity in US dollars.

A related explanation put forward by the literature is the role of external funding margins (initial margins or haircuts to enter leveraged positions). Gârleanu and Pedersen (2011) offer an initial margin-based asset pricing model with a higher required return on assets with a higher margin requirement, leading to deviations from the law of one price if assets have different margin requirements. Augustin, Chernov, Schmid, and Song (2024) apply this idea to CIP deviations by identifying the predominant role of risk-based intermediary constraints (proxied by a stochastic discount factor identified in interest rate swaps) over non risk-based ones. Instead, we use dynamic *variation* margins directly as shocks to the SDF of intermediaries and test whether balance sheets are indeed integrated or segmented.

We are close in spirit to Barbiero, Bräuning, Joaquim, and Stein (2024) who study the impact of currency desk value-at-risk limits within dealers on FX returns. They use regulatory data on risk limits and quarterly data on derivatives positions consolidated across subsidiaries at the bank holding company-level to show that the risk limits can impair the smooth intermediation of the FX market. We instead use high-frequency (daily) data on the entire FX derivatives market to match P&L calculations at different levels and identify the actual empirical frictions to internal capital flows, which may or may not correspond to administrative or regulatory limits, and are not necessarily risk limits (Carmassi and Herring, 2019; Fleming and Sarkar, 2014). Indeed, CIP arbitrage is a positive-NPV investment, but which might require liquidity during the life of derivative contract. We focus on this risk.

Cerutti, Obstfeld, and Zhou (2021) compare empirically the contributions of these different explanations for CIP deviations, and find that intermediaries' risk-taking capacity is indeed key.

[17] The LR is a *non-risk-based* leverage ratio that includes both on- and off-balance sheet exposures. The LCR ensures short-term (30-day) resilience to liquidity risk. The NSFR requires banks to maintain a stable funding profile over a year. See the Basel Framework, Basel Committee on Banking Supervision (BCBS), available here. Derivatives can also interact with the Global Systematically Important Banks' capital surcharge, where applicable.

**Nevertheless, the balance sheet and the dollar-funding constraints fail to explain the heterogeneity among different currencies. The CIP deviations should indeed be equalized at the margin, as the same dealers are active across G-10 currency pairs.**

Some recent works offer alternative explanations for the cross-section of CIP deviations. On the demand side, Liao (2020) studies the interaction between CIP deviations and credit spreads, as borrowers want to issue in markets with a lower price of credit risk while hedging their currency exposure. Liao and Zhang (2021) investigate the hedging pressure from net external financial imbalances. On the supply side, Wallen (2022) suggests that market power can explain CIP deviations through mark-ups, in what remains one of the most liquid markets. With US data, Moskowitz, Ross, Ross, and Vasudevan (2024) document market segmentation and counterparty concentration in different currencies, which gives rise to market power and increasing marginal costs. We do not observe dealer specialization in UK data. Nevertheless, these are slow-moving drivers and struggle to explain the high frequency moves in the deviations.

We instead focus on another requirement of Basel III to investigate internal capital frictions: variation margin requirements of highly liquid assets (in practice, cash) to fully collateralize the mark-to-market exposure of derivatives[18]. This is a typical example of a price that is both a reflection of fundamentals (the FX forward changes lead to mark-to-market losses) and a call for action (posting cash), as in Shin (2019), which can give rise to upward-sloping demand and downward-sloping supply, thus potentially becoming a "liquidity black hole". This liquidity requirement creates convergence risk because of the currency risk.

There is indeed a large literature on carry trades and *uncovered* interest parity (UIP) deviations, for which FX risk premia are a key driver (Brunnermeier, Nagel, and Pedersen, 2009; Lustig, Roussanov, and Verdelhan, 2011; Lustig and Verdelhan, 2011; Lustig, Roussanov, and Verdelhan, 2014). The CIP literature has ignored the liquidity risk of the trade, consistently with the idea of an arbitrage condition, but the convergence risk and the variation margins we focus on make that trade risky, and the currency risk should therefore be relevant for CIP deviations as well. This is also the case because the UIP and CIP trades are fundamentally linked by financial intermediaries: if clients engage in a carry trade, dealers have to take the other side and hedge their position. The link between the CIP and UIP deviations can be expressed as:

$$\underbrace{\left(i_{0,1} - i^*_{0,1}\right) - \mathbb{E}_0\left[\Delta s_1\right]}_{\text{UIP deviation}} \equiv \underbrace{f_{0,1} - \mathbb{E}_0[s_1]}_{\text{FX risk premium}} + \underbrace{\left(i_{0,1} - i^*_{0,1}\right) - \left(f_{0,1} - s_0\right)}_{\text{CIP deviation } b}$$

where it becomes clear from $f_{0,1} - s_0 = (i_{0,1} - i^*_{0,1}) - b$ that the decision to enter a currency carry trade depends on the currency risk premium and the CIP basis (either because the investor enters the carry trade with a forward, or because the counterparty hedges the exposure in the derivative market). Conversely, researchers measuring UIP deviations from forward rates take a stance on the CIP basis (often assumed to be zero). But these forward-based measures of currency risk premia then also include the margin-liquidity risk that we associate with the CIP deviations.

**CIP deviations are not simply a curiosity in finance: they have real effects, so understanding their drivers is important.**

For instance, Ippolito, Luis Peydró, Karapetyan, Juelsrud, and Syrstad (2024) document direct effects on bank lending that translate in some (limited) long-term real effects on corporations. For asset allocation and capital flows, Kubitza, Sigaux, and Vandeweyer (2025) find that investors' holdings of USD bonds decrease following a widening of the USD-EUR cross-currency basis. More generally, firms with access to different funding markets compare borrowing costs in their currency and in a synthetic transaction (a foreign denominated bond hedged with an FX swap), and might also decide on the intensive margin how much to hedge their foreign borrowing (in the case of Yankee and Reverse-Yankee bonds, for instance), with direct effects on monetary policy transmission and financial stability. Furthermore, as our study focuses on a relatively liquid market, we hypothesize that markets with a similar structure but less liquid might suffer from larger deviations. Also, the violation of the law of one price in a fundamental and central market like the FX market probably leads to similar violations in other, connected markets.

Our mechanism of liquidity shocks posits that dealers do not provide resources to the FX trading desk with a perfect elasticity. This connects us to the literature on internal liquidity and internal capital frictions.

[18] This requirement also interacts with the LCR and NSFR ratios because of the liquidity needs.

## 1.3 Internal Capital Frictions and Liquidity Risk

**Whereas the literature emphasized sector-wide balance-sheet and external funding constraints, we focus on the role of internal liquidity management in explaining CIP deviations. Variation margins create liquidity risk, which treasuries pass on to trading desks by accounting for the marginal value of cash. This can explain why dealers optimally choose not to close CIP deviations, and the cross-sectional differences across currencies.**

There is growing interest in internal funding frictions as another channel through which intermediaries can be constrained and thus impact asset prices. Indeed, the information asymmetries that lead to transaction costs in the theory of the firm (Coase, 1937) are also prevalent within large and complex firms. For instance, He and Xiong (2013) propose a model of capital immobility and market segmentation based on the agency of fund managers, within a fund family. Andersen, Duffie, and Song (2019) introduce a theoretical justification for Funding Value Adjustments (FVA) as the debt overhang for shareholders from the balance sheet expansion to fund a new investment opportunity, e.g. CIP arbitrage. Nonetheless, this transfer from shareholders to bondholders within the capital structure because of the balance-sheet expansion cannot explain the cross-section of CIP deviations. They obtain a strict, classic pecking order in which new investments are funded first by internal capital, on which we focus, then debt and finally equity.

This is a fundamental result in corporate finance: because of agency frictions, markets require a premium to provide external funding. This usually makes internal liquidity the marginal source of funding for firms. Bolton, Chen, and Wang (2024) survey models of dynamic, forward-looking corporate liquidity management. This **marginal value of cash** explains why financial intermediaries might forgo a (risky) arbitrage opportunity: reducing the volatility of cash flows (such as from variation margins) can increase the value of the firm, as in Décamps, Mariotti, Rochet, and Villeneuve (2011). Liquidity and risk management in a multi-division firm has its own challenges, see Dai, Giroud, Jiang, and Wang (2024) for a two-division model, and firms' treasuries might optimally decide to allocate resources to less risky divisions to protect their liquidity.

This connects well with the original literature on slow-moving capital. Shleifer and Vishny (1997) motivating example for performance based arbitrage is the variation margins on a forward contract that require capital in the interim periods. Mitchell, Pedersen, and Pulvino (2007) hypothesized that internal capital constraints for trading desks with mark-to-market losses in the convertible bond market explain why some multi-strategy hedge funds that were not capital constrained behave like specialized and capital constrained ones.

Empirically, Cetorelli and Goldberg (2012) show that global banks are indeed allocating their internal liquidity carefully between the parent bank and the affiliates. In the credit default swap (CDS) market, Siriwardane (2019) finds that shocks within the CDS portfolio of sellers explain almost as much of the changes in spreads as credit risk changes - even as institution-wide constraints are irrelevant. Pinter, Siriwardane, and Walker (2024) focus on the role of balance sheet segmentation between pension funds and their liability-driven investment funds in explaining the Autumn 2022 fire sales in UK Gilts. Alternatively, Alfaro, Bahaj, Czech, Hazell, and Neamţu (2024) introduce the concept of Liquidity After Solvency Hedging (LASH), as hedges can create liquidity pressures in states where solvency improves. More generally, a large financial industry exists to limit excess liquidity needs, notably in centrally cleared markets through portfolio compression or cross-product margining.

That idiosyncratic shocks such as variation margins (a zero-sum transfer across counterparties) can move the FX forward rate reflects the **granularity** of FX intermediation. Most counterparties trade with a single dealer so its idiosyncratic shocks matter. This is at the heart of the burgeoning literature on granular agents, as in Gabaix and Koijen (2020). For instance, contrary to the usual assumption of homogeneous arbitrageurs, Siriwardane, Sunderam, and Wallen (2023) find evidence that arbitrage is driven by a limited number of market participants: arbitrage activity is not well correlated across asset classes, indicative of funding segmentation but also balance sheet segmentation. Instead of relying on indirect measures of internal liquidity such as past returns, we directly calculate the liquidity shocks within the balance sheets of specific dealers, based on their derivatives portfolio. Thanks to our transaction-level data, we can use this to map the limit of the firm within the balance sheet of the dealers.

Even if margining is good microprudential policy, it can have negative macroprudential consequences, as credit risk is transformed into liquidity risk (Gregory, 2014), especially in the case of synthetic leverage and fire sales. The Financial Stability Board, the Basel Committee on Banking Supervision, the Bank for International Settlements' Committee on Payments and Market Infrastructures and the International Organization of Securities Commissions have been leading policy

work to address the procyclicality of margining[19]. Regulatory focus has moved from bank supervision only to system-wide analyses and contagion, including non-bank financial institutions. Liquidity shocks are indeed worse for counterparties with low cash reserves, and current regulatory work explores liquidity requirements to ensure all market participants can face margin calls on their derivative positions.

This question of liquidity preparedness is indeed central for macroprudential policy institutions. In particular, we investigate the impact of margin shocks from outstanding derivatives on available liquidity. With UK EMIR data, Bardoscia, Bianconi, and Ferrara (2019) investigate the contagion risk between clearing members from margins on derivatives in three asset classes and find that spillovers can be large. Bardoscia, Ferrara, Vause, and Yoganayagam (2021) compare the margin calls for these market participants under stress scenarios to their liquidity buffers and compute the liquidity shortfall when taking into account the payment cycle of Central Counterparty Clearing House (CCP) margins. Czech, Gual-Ricart, Lillis, and Worlidge (2021) investigate the role of non-bank financial institutions in the "dash for cash" in March 2020, including from margin calls. Similarly, with EU EMIR data, Jukonis, Letizia, and Rousova (2022) and Macchiati, Cappiello, Giuzio, Ianiro, and Lillo (2025) measure the liquidity buffers and asset quality of non-banks to respond to margin calls. Zema (2023) recovers the network structure of uncleared derivatives trading from the margins exchanged by market participants across asset classes and documents the redistribution of liquidity in case of a large shock.

We take a different approach: instead of focusing on ex-post fire sales or system-wide stress-testing, we study how past liquidity shocks impact the ex-ante, forward-looking liquidity management of intermediaries reflected in the pricing of FX forwards.

# 2 Conceptual Framework

**We write a simple model to highlight our mechanism in the spirit of Shleifer and Vishny (1997), but with a forward-looking liquidity management problem micro-founded with the insights of Bolton, Chen, and Wang (2011). In essence, the decision to arbitrage away the CIP basis also depends on the funding risk it entails.**

## 2.1 Motivation

A balance-sheet constraint, such as the leverage ratio explored in the literature, struggles to explain the cross-section of currency bases, as an arbitrageur would at least equalize the bases across currencies, up to the constraint. Furthermore, the regulatory reporting frequency for derivatives (daily average reported quarterly in the United States and the United Kingdom, quarter-end snapshot in the European Union) implies that this mechanism is unlikely to explain the time series of bases for contracts that are longer dated and always encompass a regulatory reporting date (e.g. the 3-month maturity we focus on).

Instead, we hypothesize that the cost of external funding (e.g. because of asymmetry of information), the liquidity coverage ratio, the net stable funding ratio, and prudent liquidity risk management give rise to a **liquidity constraint**. This might be because of the need to pay a risk premium and a term premium over the OIS rate. Because internal liquidity thus becomes valuable, the treasury department optimally allocates this scarce resource across investment opportunities that have different (liquidity) risks and returns. This motivates the Funding Value Adjustment (FVA) used by financial intermediaries to account for variation margins through Funds Transfer Pricing, reflecting that they create a funding need at the cost of internal funds, higher than the OIS rate. Although this was a negligible term before the Great Financial Crisis when banks could borrow in the unsecured interdealer funding market (at LIBOR, with a small spread over the OIS rate), it has become significant since.

Because variation margins are reassessed and exchanged daily, they cannot be considered as fungible with other, longer-dated funding sources. This is why the FVA is usually computed by the XVA trading desk within the dealer's treasury **at the derivative-portfolio level** (Albanese, Andersen, and Iabichino, 2014). We make the conservative assumption of perfect rehypothecation

[19]See, e.g., "Streamlining variation margin in centrally cleared markets – examples of effective practices", CPMI-IOSCO, January 2025, here; "Liquidity Preparedness for Margin and Collateral Calls", FSB, December 2024, here; "Streamlining VM processes and IM responsiveness of margin models in noncentrally cleared markets", BCBS-IOSCO, January 2024, here; "Review of margining practices", BCBS-CPMI-IOSCO, September 2022, here. See also "Late call", speech by Nathanaël Benjamin of the Bank of England given at Linklaters hosted by ISDA, July 2024, here; "Mitigating the procyclicality of margins and haircuts in derivatives markets and securities financing transactions", ESRB, January 2020, here.

across derivatives, i.e. variation margins received can be immediately and fully reused, including to post variation margins.

Intuitively, the arbitrageur incurs a cost from not being able to pledge the risk-free CIP arbitrage (or in-the-money derivatives in general) as collateral in a repurchase agreement transaction (repo). Furthermore, perhaps because banks are opaque and highly complex, a treasury in a bank does not offer the trader the *marginal* funding rate reflecting the risk of the investment project, but charges the *average* cost of the bank[20].

## 2.2 Stylized Model

Consider a treasury within a bank allocating scarce liquidity to its foreign exchange trading desk to arbitrage CIP deviations $\boldsymbol{b} = (b^c)_{c=1}^{\mathcal{C}}$, across $\mathcal{C}$ currency pairs, with $\boldsymbol{b} \neq \boldsymbol{0}$.

There are three dates: $t \in \{0, 1, 2\}$, and no discounting. At $t = 0$, the bank decides whether to enter into the CIP deviations arbitrage trade in each currency pair $c \in [\![1, \mathcal{C}]\!]$, and chooses the notional $x_0^c \in \mathbb{R}$ of the trade, $\boldsymbol{x_0} = (x_0^c)_{c=1}^{\mathcal{C}}$. Following the convention of Figure 2 and the empirical regularity that most bases are negative against the US dollar (Home) so that $-b^c > 0$, the trade $x_0^c > 0$ involves selling the Foreign/Home forward (receiving the US dollar). We abstract from the static initial funding[21]; the trade guarantees a payoff $-b^c$ per unit of notional at $t = 2$, which is known at $t = 0$. The **final payoff** from CIP arbitrage is then:

$$\Pi_2^{\text{CIP}} = \sum_{c=1}^{\mathcal{C}} (-b^c) x_0^c \tag{1}$$

Nevertheless, the interim period $t = 1$ is uncertain, because of news or noise traders, for instance. Unexpected changes in the value of the contract in currency pair $c$ give rise to a per-unit-of-notional variation margin on the short forward $M_1^c(\omega)$ in state $\omega \in \Omega$, function of the volatility $\sigma^c$ of the currency pair, e.g. $M_1^c \sim \mathcal{N}(\mu^c, (\sigma^c)^2)$. A negative margin means that the bank has to send cash to its counterparties as collateral. The total, net **variation margin** to finance is thus:

$$M_1(\omega) = \sum_{c=1}^{\mathcal{C}} M_1^c(\omega) x_0^c \tag{2}$$

The treasury has some internal liquidity before FX margins $L_1$ at $t = 1$, e.g. internal funds and margins from the rest of the derivative portfolio. If $M_1(\omega) + L_1 \geq 0$, the treasury can meet all the margin calls using internal liquidity. If $M_1(\omega) + L_1 < 0$, it has to finance the **liquidity shortfall**:

$$S(\omega) = \min\left(M_1(\omega) + L_1, 0\right) \leq 0 \tag{3}$$

To finance this shortfall, the treasury can issue new equity, raise unsecured funding at a premium over the OIS rate, encumber limited safe assets in a repo transaction, or fire-sale assets. Following the literature in corporate finance, we assume that this **external funding is costly**, e.g. because of asymmetric information, dilution, or distress costs, which we model as having a convex cost $\Phi(S)$, e.g. a quadratic cost, where:

$$\Phi : \mathbb{R}_- \to \mathbb{R}_+ \quad \Phi(0) = 0 \quad \Phi'(S) < 0 \quad \Phi''(S) > 0 \tag{4}$$

The bank solves the following **profit maximization** problem at $t = 0$, where the expectation is taken over $\Omega$ (under the physical measure):

$$\max_{(x_0^c)_{c=1}^{\mathcal{C}}} \sum_{c=1}^{\mathcal{C}} (-b^c) x_0^c - \mathbb{E}_0 \left[ \Phi \left( \min \left( \sum_{c=1}^{\mathcal{C}} M_1^c(\omega) x_0^c + L_1, 0 \right) \right) \right] \tag{5}$$

The first term is the known payoff from the CIP bases at maturity. But the second term captures the **expected cost of variation margins** when internal liquidity is insufficient. The treasury optimally trades off the return from the arbitrage trade with the liquidity risk. We assume that the distribution of variation margins and the cost function are such that the problem has an

[20] For anecdotal evidence on the allocation of financing costs in financial intermediaries, see e.g. "Allocating financing costs: centralised vs decentralised treasury", Risk.net, 14 January 2026, available here.

[21] This contrasts with the model in Shleifer and Vishny (1997), where arbitrageurs decide in the initial period how much precautionary liquidity to keep. We instead focus on the state-contingent variation margins in the interim period, to model why a broker-dealer that has an extra US dollar at hand with access to different CIP arbitrage opportunities does not simply arbitrage the largest basis at the margin.

interior solution and that there is uncertainty on whether there will be a liquidity shortfall. Then, the optimality condition is:

$$\forall c \in [\![1, \mathcal{C}]\!], -b^c = \mathbb{E}_0 \left[ M_1^c(\omega) \Phi' \left( S(\omega) \right) \mathbb{1}_{\{M_1(\omega)+L_1 \leq 0\}} \right] \tag{6}$$

$$\iff$$

$$\forall c \in [\![1, \mathcal{C}]\!], -b^c = \Pr \left( M_1(\omega) + L_1 \leq 0 \right) \mathbb{E}_0 \left[ M_1^c(\omega) \Phi' \left( S(\omega) \right) | M_1(\omega) + L_1 \leq 0 \right] \tag{7}$$

**We define the stochastic discount factor of the bank as the state-contingent shadow price of internal liquidity**. It is the (non-negative) marginal value of an extra unit of internal liquidity:

$$\forall \omega \in \Omega, \Lambda(\omega) = -\Phi' \left( S(\omega) \right) \mathbb{1}_{\{M_1(\omega)+L_1 \leq 0\}} \tag{8}$$

The asset pricing equation of the model then becomes, with $M_1^c < 0$ an outflow:

$$\forall c \in [\![1, \mathcal{C}]\!], b^c = \mathbb{E}_0 \left[ \Lambda M_1^c \right] = \mathbb{E}_0 \left[ \Lambda \right] \mathbb{E}_0 \left[ M_1^c \right] + \mathrm{Cov}_0 \left( \Lambda, M_1^c \right) \tag{9}$$

Assume further that margins are jointly Gaussian, $(M_1^1, \ldots, M_1^{\mathcal{C}})' \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma})$, with $\boldsymbol{\Sigma}$ positive definite; $L_1$ deterministic; and that the external funding cost is quadratic $\Phi(S) = \kappa S^2/2$ on $S \in \mathbb{R}_-$, with $\kappa > 0$. Then, the objective is concave. Define the post-margin liquidity $Y = \sum_c x_0^c M_1^c + L_1$, as an affine combination of jointly Gaussian random variables, it is also Gaussian and $Y \sim \mathcal{N}(m, s^2)$, with $m = \boldsymbol{x_0}' \boldsymbol{\mu} + L_1$ and $s^2 = \boldsymbol{x_0}' \boldsymbol{\Sigma} \boldsymbol{x_0}$. Notice that $\Lambda = -\kappa \min(Y, 0) \equiv g(Y)$ only depends on $Y$, with $g'(y) = -\kappa \mathbb{1}\{y < 0\}$ a.e. Using that $(M_1^c, Y)$ is jointly Gaussian, the linear projection is exact:

$$M_1^c = \mu^c + \beta^c (Y - m) + \varepsilon^c, \qquad \beta^c = \frac{\mathrm{Cov}(M_1^c, Y)}{s^2}, \qquad \mathbb{E}_0[g(Y)\varepsilon^c] = \mathbb{E}_0[g(Y)]\,\mathbb{E}_0[\varepsilon^c] = 0$$

because $\varepsilon^c$ is uncorrelated with $Y$ by construction and jointly Gaussian, hence independent.

Substituting into (9), with the normal density on $\mathbb{R}$, $f : y \to \frac{1}{\sqrt{2\pi s^2}} e^{-\frac{(y-m)^2}{2s^2}}$, and $f' : y \to -\frac{y-m}{s^2} f(y)$:

$$\mathbb{E}_0[g(Y)] = \int_{-\infty}^{+\infty} -\kappa \min(y, 0) f(y) dy = -\kappa \int_{-\infty}^{0} y f(y) dy = -\kappa \left[ mN\left(-\tfrac{m}{s}\right) - s\phi\left(-\tfrac{m}{s}\right) \right] \geq 0$$

$$\begin{aligned}
\mathrm{Cov}_0 \left( g(Y), M_1^c \right) &= \mathrm{Cov}_0 \left( g(Y), \mu^c + \beta^c (Y - m) + \varepsilon^c \right) \\
&= \beta^c \, \mathbb{E}_0 \left[ g(Y)(Y - m) \right] \\
&= \beta^c \int_{-\infty}^{+\infty} g(y)(-s^2) f'(y) dy \\
&= \beta^c \, s^2 \int_{-\infty}^{+\infty} g'(y) f(y) dy \\
&= -\beta^c \, s^2 \, \kappa \, N\left(-\tfrac{m}{s}\right) \\
\mathrm{Cov}_0 \left( g(Y), M_1^c \right) &= -\mathrm{Cov}(M_1^c, Y) \, \kappa \, N\left(-\tfrac{m}{s}\right)
\end{aligned}$$

with $(Y - m)/s \sim \mathcal{N}(0, 1)$, $\phi$ the standard normal density, $N$ the standard normal cumulative distribution function, and where we used Stein's Gaussian identity (integrating by parts).

Combining the different expressions, we get:

$$\forall c \in [\![1, \mathcal{C}]\!], b^c = -\kappa \Big\{ \mu^c \Big[ m \, N\big(-\tfrac{m}{s}\big) - s \, \phi\big(-\tfrac{m}{s}\big) \Big] + N\left(-\tfrac{m}{s}\right) (\boldsymbol{\Sigma} \boldsymbol{x_0})_c \Big\} \tag{10}$$

where the first term is compensation for the expected drift under the physical probability and the second term is compensation for the liquidity risk created by currency volatility (price of risk $\times$ quantity of risk). If the marginal investors bearing FX risk are risk-neutral, then $\boldsymbol{\mu} = \mathbf{0}$ (there is no FX risk premium[22]) but the risk of costly liquidity is priced by the bank:

$$\boldsymbol{b} = -\kappa N\left(-\tfrac{m}{s}\right) \boldsymbol{\Sigma} \boldsymbol{x_0} \tag{11}$$

[22]Note that $\mathbb{E}_0[M_1^c] = -(\mathbb{E}_0[F_{1,2}] - F_{0,2})$ up to discounting, with Foreign trading at a forward premium $F_{t,T} =$

## 2.3 Predictions

The natural, key prediction of our model is that internal liquidity and liquidity risk affect the bank's pricing and positioning. Indeed, following the intermediary asset pricing literature, if financial intermediaries are the marginal investors in the FX market in general equilibrium, then they price the foreign exchange forward rate.

In particular, the treasury allocates liquidity across arbitrage opportunities by equating, at the margin, the CIP bases to the expected liquidity cost implied by the variation margins, leading to cross-sectional and time-series variation in CIP bases that is directly linked to margin dynamics.

This leads to the following comparative statics, holding positions $\boldsymbol{x_0}$ fixed to describe how the basis the bank requires at its current inventory responds to shocks (with "wider" meaning a larger $|b^c|$):

- Holding the liquidity risk $N(-m/s)$ fixed, **a currency's basis is proportional to its covariance with the total margin flow** $(\boldsymbol{\Sigma x_0})_c$, the liquidity beta, which accounts not only for the currency's own margin volatility $\sigma_c^2$ but also for its correlation with the other margins.
- **A higher volatility widens all the bases.** Consider a scaling of the variance-covariance matrix $\lambda^2\boldsymbol{\Sigma}$, $\lambda > 0$, a proportional rise in all margin volatilities but keeping correlations unchanged. Then $\boldsymbol{b}(\lambda) = -\kappa N\left(-\frac{m}{\lambda s}\right)\lambda^2\boldsymbol{\Sigma x_0}$ and $\partial\boldsymbol{b}/\partial\lambda = -\kappa\lambda\left[\frac{m}{\lambda s}\phi\left(-\frac{m}{\lambda s}\right) + 2N\left(-\frac{m}{\lambda s}\right)\right]\boldsymbol{\Sigma x_0}$, where the first term is the effect on the probability of a liquidity shortfall, and the second term is the effect on the liquidity beta (the liquidity requirement for the margin). The function $u$ on $\mathbb{R}$ $z \to z\phi(-z) + 2N(-z)$ has derivative $u' : z \to -(1+z^2)\phi(-z) < 0$ so u is decreasing, and $\lim_{z\to\infty} u(z) = 0$ thus $u > 0$, and indeed $\boldsymbol{b}$ widens with $\lambda$.
- **A negative shock to the available liquidity** $L_1$ **widens bases**, proportionally across currencies, as $-\partial b^c/\partial L_1 = -\frac{\kappa}{s}\phi(-\frac{m}{s})(\boldsymbol{\Sigma x_0})_c$.

This last consideration brings the natural extension of internal liquidity (non-)fungibility and frictions. Let $u \in [\![1, U]\!]$ index a partition of the balance-sheet of the bank, with $u = 1$ the FX forwards in currency pair $c$. Each unit $u$ has a liquidity line $\bar{L}_u$ and a margin flow $V_u$, with $V_1 = x_0^c M_1^c$, and $\boldsymbol{V} = (V^c)_{c=1}^{\mathcal{C}}$ jointly Gaussian with mean zero. Now, to account for internal liquidity frictions, only a fraction $\gamma_u \in [0, 1]$ of unit $u$'s liquidity is available to the desk within the margin horizon, for instance because of monitoring controls from the treasury that require an approval with a lag: $\forall u \in [\![1, U]\!], \gamma_u = 1$ corresponds to a perfect internal capital market, and $\forall u \geq 2, \gamma_u = 0$ to a fully segmented desk (we assume that $\gamma_1 = 1$). The internal liquidity available to the desk trading $c$ is $Y = \sum_{u=1}^{U}\gamma_u\left(\bar{L}_u + V_u\right)$, Gaussian with $m = \sum_{u=1}^{U}\gamma_u\bar{L}_u$ and $s^2 = \boldsymbol{\gamma' V' V \gamma}$. The previous derivations go through with:

$$\forall c \in [\![1, \mathcal{C}]\!], b^c = -\kappa\, N\left(-\tfrac{m}{s}\right)\left[x_0^c\sigma_c^2 + \sum_{u\geq 2}\gamma_u \mathrm{Cov}(M_1^c, V_u)\right] \tag{12}$$

The partition can be within the currency desk, for instance, in which case each currency is priced in isolation and cross-currency covariances are irrelevant under full segmentation; or the partition can be across other business units, so that the relevant liquidity beta is the covariance with the bank's total margin flow under perfect integration.

## 2.4 A First Test

We start by testing in Table 1 some key drivers of FX contract values – the changes in the spot rate, interest rates and currencies' implied volatilities – on CIP deviations, in a daily-frequency regression in the spirit of Avdjiev et al. (2019). They focus instead on the role of the broad dollar on the balance sheet of large banks to explain CIP deviations, but this cannot account for the heterogeneity in CIP deviations across different currency pairs, as banks should equalize the

$S_t\frac{1+i_{t,T}-b_{t,T}}{1+i^*_{t,T}} > S_t$ when $i > i^*$ and $b < 0$ as is the case empirically for most G-10 currencies against the USD. When UIP fails, it typically means that the low-yielding Foreign appreciates by less than the forward premium predicts, so the forward rate drifts down towards the spot rate $\mathbb{E}_0[F_{1,2}] - F_{0,2} < 0$ and $\mu^c > 0$: an expected inflow from the drift that should narrow the basis, with a stronger effect for the lowest-yielding currencies (*e.g.* JPY or CHF). This is empirically contradicted as the lowest yields are associated with the most negative bases: the drift term cannot account for the cross-section of bases, and the liquidity-risk term dominates in our framework. Furthermore, anecdotal evidence suggests that practitioners price under the risk-neutral measure, not the physical one, so do not price the drift.

deviations from the arbitrage opportunities at the margin (as the same banks are dominant in the different currency/USD pairs). In contrast, our channel of convergence risk through variation margins has the potential to explain the cross-section of CIP deviations. We find these drivers to be statistically significant explanatory variables, in particular, a rise in implied volatility worsens the deviation from the covered interest parity. One exception is the spot rate, which could be explained by the aggregation across counterparties whereas the model requires conditioning on the existing inventory, which we do later. The $R^2$ remains very small, perhaps expected at a daily frequency.

| $\Delta b_{c,t}$ | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| $\Delta Spot_{c,t}$ | 0.1283 | | | | 0.0231 |
| | (0.1195) | | | | (0.0901) |
| $\Delta i_{c,t}$ | | -0.0347** | | | -0.0417*** |
| | | (0.0124) | | | (0.0132) |
| $\Delta i_{USD,t}$ | | | 0.1102*** | | 0.0905*** |
| | | | (0.0265) | | (0.0156) |
| $\Delta IVol_{c,t}$ | | | | -0.1245*** | -0.0886*** |
| | | | | (0.0358) | (0.0285) |
| R-squared | 0.0003 | 0.0019 | 0.0085 | 0.0067 | 0.0133 |
| Observations | 33,743 | 26,512 | 33,743 | 33,743 | 26,512 |

Table 1: Key drivers of changes in the value of foreign exchange derivatives and CIP deviations. *Notes:* We regress the daily changes in the 3-month CIP deviation $\Delta b_{c,t}$ for currency $c$ against the US dollar (computed as in Siriwardane et al. (2023)) on the daily log changes in the bilateral spot rate $\Delta Spot_{c,t}$, the 3-month OIS rates in currency $c$ and in USD $\Delta i_{c,t}$ and $\Delta i_{USD,t}$, and the 3-month implied volatility of currency pair $c$/USD $\Delta IVol_{c,t}$, with currency pair fixed effects. Robust standard errors in parentheses, two-way clustered by currency and date. *** p<0.01, ** p<0.05, * p<0.1.
Sources: Bloomberg, LSEG, Authors' calculations.

# 3 (UK) European Market Infrastructure Regulation Data

**We use a unique regulatory dataset that covers the forward rate and daily valuations of every FX forward traded by at least one UK entity to compute dealer-level variation margin shocks and study the dispersion of transacted FX forward rates.**

We look at the data through three angles. First, we look at the stock of outstanding foreign exchange forward contracts to document the trading network and the dominance of a small subset of counterparties. Then, we look specifically at the CIP deviation at the contract-level on new transactions. Finally, we compute the net value of outstanding contracts on all the outstanding derivative transactions for the previously identified counterparties intermediating the market.

## 3.1 EMIR Regulatory Framework

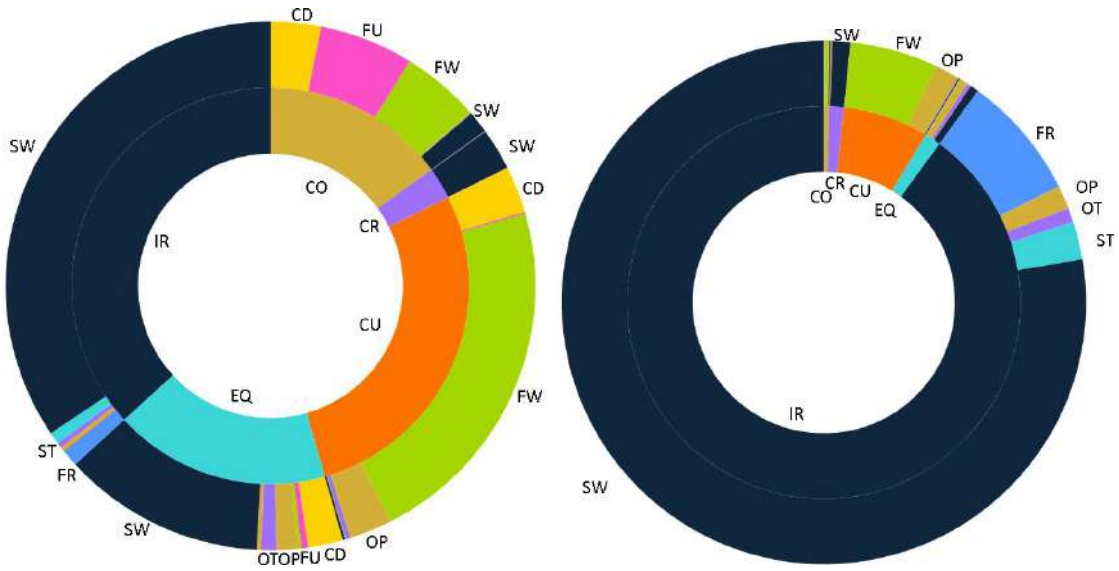
### 3.1.1 Presentation of the Regulation

Our main data source is the European Market Infrastructure Regulation (EMIR), which is the implementation of the global push for transparency in markets for derivatives after the Great Financial Crisis in the European Union and the United Kingdom, as agreed by the Group of Twenty within the Financial Stability Board. It comprises the European Regulation 648/2012, amended by successive Directives and Regulations, the UK onshoring legislation post-Brexit, and the different technical standards set by the Bank of England and the Financial Conduct Authority in coordination with international fora. It applies to counterparties based in the United Kingdom on all derivative contract types, on all underlying asset classes, whether the derivative is exchange-traded or traded over-the-counter. It also covers all the trades cleared by a UK CCP, and contracts

with a denomination or payment in GBP, or where the underlying security is a UK entity[23].

### 3.1.2 The Three Pillars: Reporting, Clearing, and Risk Mitigation Obligations

Counterparties subject to EMIR have to **report** their new trades or any modification to their outstanding contracts (the "activity reports" represent the flow), and submit a daily, mark-to-market valuation of their outstanding contracts[24] (the "state reports" represent the stock), to registered trade repositories. Regulators, such as the Bank of England, access these reports through the trade repositories. We focus on the state reports that we illustrate in Figure 5: for a given day, on average 24 million open positions are reported, with 129 fields to report for each counterparty subject to EMIR.




(a) Distribution of open positions (24 million) (b) Distribution of notional values (USD782 trillion)

Figure 5: Distribution of reported **outstanding** derivative transactions, in terms of number of reports (5a) and of notional (5b). **Asset classes** (inner circle) – CO: Commodity and emission allowances; CR: Credit; CU: Currency; EQ: Equity; IR: Interest Rate. **Contract types** (outer circle) – CD: Financial contracts for difference; FR: Forward rate agreements; FU: Futures; FW: Forwards; OP: Option; SB: Spreadbet; SW: Swap; ST: Swaption; OT: Other.
*Notes:* This Figure is based on raw EMIR data, in particular it is not deduplicated nor winsorized. Sources: EMIR position data (stock) reported to the Bank of England (26 June 2024).

Our main contract type and asset class pair is the foreign exchange forward, which encompasses foreign exchange swaps[25]. For a given day and after deduplication if both counterparties report, the Bank of England receives reports for 4.0 million outstanding FX forwards that represent a total notional value of USD 39 trillion, on average between 1 January 2023 and 30 June 2024.

Whereas the literature on FX forwards often had to rely on quotes (aggregated across different dealers, but not necessarily prices from executed transactions), or order-flows from one dealer for a short period of time, often for one currency pair, or more recently data from the Continuous Linked Settlement (CLS) group focused on its settlement members' trades[26], our data covers all the transactions in the United Kingdom. Among the many fields reported, we focus on the date, price (forward rate), notional, counterparties, and value of the contract (that translates into the variation margin).

[23] For the last two cases, we do not know what is the actual reporting rate when none of the counterparties is based in the UK and the trade is not cleared by a UK CCP.

[24] Small non-financial counterparties (NFC-) are exempt from this. In practice, this does not materially change the coverage of the data as they usually trade with financial counterparties (FC), which are subject to the daily valuation requirement.

[25] Although this is inconsistent with reporting regulations from the Financial Conduct Authority and the European Securities and Markets Authority, it follows market practice for consistency across regulatory regimes, and seems to be preferred in case one of the legs needed to be modified later, see e.g. here. Currency swaps, which have a maturity greater than a year and lead to exchanges of coupons indexed on an interest rate, are reported as interest rate swaps under EMIR.

[26] CLS removes the settlement ("Herstatt") risk stemming from the exchange of gross liabilities in physical FX forwards and swaps by ensuring payment versus payment settlement.

EMIR mandates **risk mitigation** measures on derivative contracts and requires **central clearing** for standardized contracts. FX derivatives in general are not standardized and thus remain uncleared; they instead fall under the requirement of **bilateral margining**. FX forwards and swaps are subject to variation margins, calculated daily and exchanged within the same business day of the calculation date on a net basis, over the transactions covered by the bilateral netting agreement. Variation margins are usually transferred outright and can be reused (Gregory, 2014). Intragroup transactions are exempt from margining.

We offer a detailed discussion of the regulatory requirements in Appendix B, including the limited exemption that exists for small non-financial corporations that can instead be charged credit and funding value adjustments. As 94% of the outstanding notionals for FX forwards are between financial counterparties, we make the conservative assumption that all the FX derivatives lead to a variation margin equal to the reported value of the outstanding contract.

### 3.1.3 Comparison with the Bank for International Settlements Data

As we work with a confidential, regulatory dataset, we benchmark it to the data published by the Bank for International Settlements (BIS) in its flagship Triennial Survey and in the OTC derivatives statistics. These aggregates are based on trades reported by participating dealer banks. We present in Table 2 the differences between these sources.

| | **(UK-)EMIR** | **BIS Triennial Survey** | **BIS OTC derivatives** |
|---|---|---|---|
| Coverage | All derivatives | FX spot and derivatives,<br>Interest rate derivatives | OTC derivatives |
| Scope | All UK-based entities<br>(at least one counterparty) | "Reporting dealers"<br>$>$ 50 jurisdictions | Dealer banks<br>12 jurisdictions |
| Stock or Flow | Stock and Flow | Flow | Stock |
| Level | Transaction | Jurisdiction-sector | Jurisdiction-sector |
| Consolidation | None | None | Worldwide<br>excluding intragroup |
| Frequency | Daily | Every 3 years | Every 6 months |
| Access | Confidential<br>Some public aggregates | Public aggregates<br>(jurisdiction-sector) | Public aggregates<br>(sector) |

Table 2: Comparison between EMIR and BIS data.

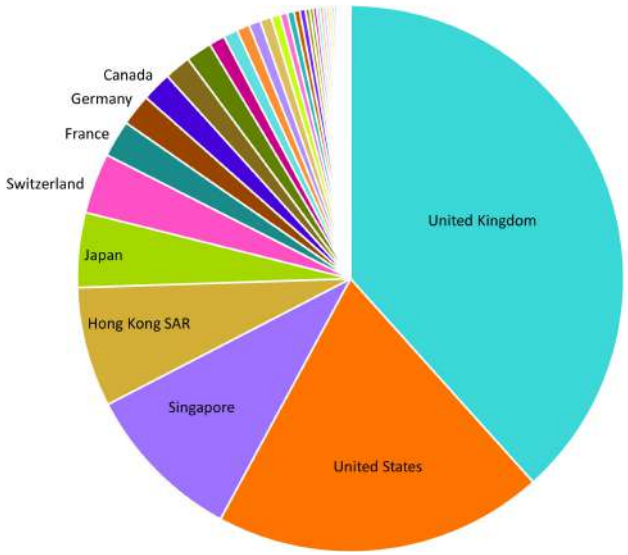



Figure 6: Daily turnover by country.
Source: Outright forwards, FX swaps and currency swaps, BIS, 2022.

First, the Triennial Survey indicates that the United Kingdom plays a central role in the FX derivatives market. Figure 6 presents the average daily turnover in April 2022, the United Kingdom has the largest share in the world, with around 40% of the global turnover (Bank for International

Settlements, 2022)[27].

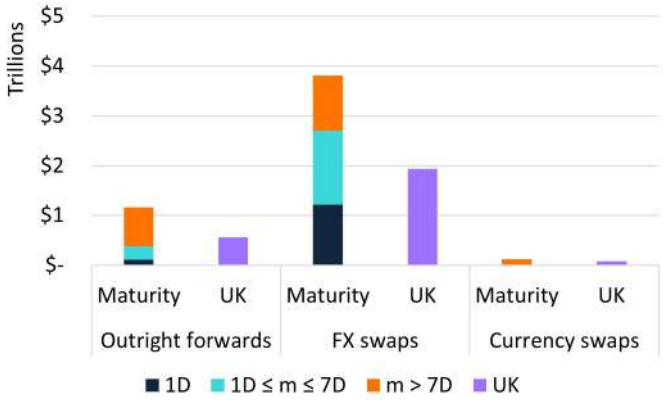



Figure 7: Daily turnover by maturity and for the UK.
Source: Outright forwards, FX swaps and currency swaps, BIS, 2022.

In Figure 7, we present the average daily total notional traded for foreign exchange derivatives, by maturity and for the United Kingdom, as reported by the BIS. Many derivatives are very short term, with a maturity of a few days. The BIS includes short-term FX derivatives with a maturity of one or two days, which can actually be spot transactions (because most FX spot transactions settle in T+2) or overnight swaps often used to match the settlement cycle of securities[28], and might not match the definition of FX derivative transactions under European law. Under MiFID II and EMIR, an FX derivative is only considered a derivative if its maturity is greater than three days (in practice, counterparties report shorter-dated derivatives). This limits any direct comparison of the total notionals.

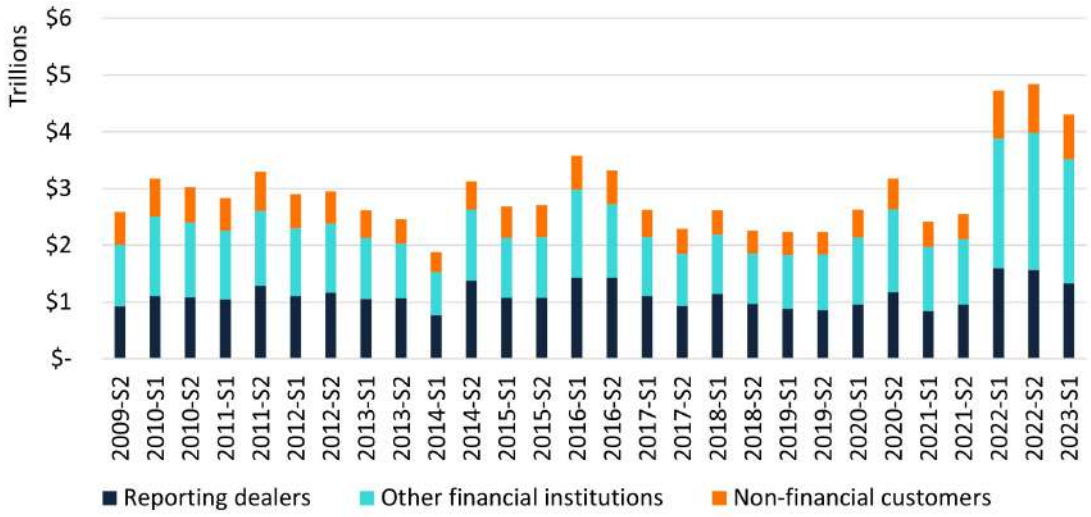



Figure 8: Gross market value of outstanding foreign exchange derivatives contracts.
Source: FX forwards, FX swaps and currency swaps, BIS, S1-2023.

A key motivation for our hypothesis is presented in Figure 8: the gross market value of outstanding foreign exchange derivative contracts is both significantly large and fluctuating, including for dealers. Nonetheless, the BIS reports the data on a gross basis, meaning that two opposite contracts on the same underlying are not netted, but the absolute values are added.

[27]This under-estimates the true share. We thank the statistics team of the BIS for clarifying the "net-gross" basis on which the data is reported: the share is computed on volumes de-duplicated between reporting dealers at the domestic level, to avoid double counting, but not cross-border. This mechanically compresses country shares as in 2022 inter-dealer trading represented 46% of global turnover, of which 68% was cross-border, confirming that we see a significant part of the international FX derivative market.

[28]For anecdotal evidence on this and recent changes, see e.g. "FX dealers face end-of-day trading stress from T+1 shift", Risk.net, 26 April 2024, available here.

Instead, the EMIR database offers a valuation at the contract level, enabling us to correctly net contracts, which reflects the actual profit and loss statement changes and the associated liquidity needed to answer margin calls.

## 3.2 Market Structure of Outstanding FX Forwards in G-10 Currencies

We use the position (or stock) data of all outstanding FX forward contracts on a daily basis to study the market structure network.

The very granular level of reporting and the comprehensiveness of EMIR data have generated strong interest, notwithstanding the inherent technical challenges of such a large dataset. Where previous work oftentimes focused on only one trade repository, and almost always only based on one report, we use all the trade repositories and match the duplicated reports to improve their reliability when both counterparties are subject to the reporting obligation.

### 3.2.1 Data Cleaning

We start by presenting our data cleaning strategy.

First, we create a unique key based on the "unique" (at the counterparty-pair level) trade identifier and the Legal Entity Identifiers of the counterparties alphabetically sorted. We drop transactions with a key appearing more than twice, and de-duplicate the dataset based on this key to reconcile the two reports, where appropriate (17% of the transactions), prioritizing the most recent timestamp.

Then, we remove transactions with a termination date, or with a maturity date before the report date, or identified as outliers by the Bank of England pre-processing checks. We remove position level reports, supplements to trade level reporting in fungible products, that account for 0.1% of currency forward and swap reports. We discard reports where the Classification of Financial Instruments (or CFI, the ISO norm 10962:2015 widely used by market participants) code reported is inconsistent with the reported asset class and contract type, or where inconsistent fields are reported. We also drop reports where the FX basis is inconsistent with the notional currencies reported, and where the notional value in USD is less than 1,000 or more than 10 billion. We drop the contracts with a maturity over a year (technically interest rate, not foreign exchange, derivatives as coupons are exchanged). In total, this cleaning procedure drops on average 4.7% of the transactions.

Contrary to regulatory reporting standards for FX forwards, counterparties do not report their side based on the alphabetically sorted currency ISO code (the buyer receives the first currency). Instead, the side is based on whether the reporting counterparty receives the base currency. We validate this market practice by checking the consistency of the valuation of the contract.

### 3.2.2 Descriptive Statistics

We first document the market structure for FX forwards in G-10 currencies. We present the trading network for EUR/USD FX forwards in Figure 9. We present some descriptive statistics of the network in Figure 10.

**Degrees** are the number of distinct counterparties for a given counterparty, which we present in descending order: we find a power law, indicative of granular intermediaries. **Assortativity** measures the average number of degrees of the connected counterparties for a given number of degrees: we observe that highly connected counterparties tend to be connected with otherwise isolated counterparties, consistent with dealers not being substitutable for clients. **Centrality** captures the importance within the network, we use both degree centrality and eigenvector centrality and we find that these measures are highly correlated. We compare the centrality measure to the total gross position: the two measures are tightly associated. The distributions of **notionals and contract values** summarize trade sizes and the mark-to-market values of the outstanding trades. For the valuations, many contracts are very short term (often even technically spot transactions), which mechanically concentrates the distribution of values around zero. Nonetheless, many contracts have a large value, requiring commensurate liquidity needs. We also show that across time, the **number of counterparties and outstanding transactions** is stable, consistent with this being a stock. **Concentration** measures the dominance of the largest institutions based on the Herfindahl-Hirschman Index (HHI).

Appendix C contains a similar presentation for the other G-10 currency pairs against the US dollar.

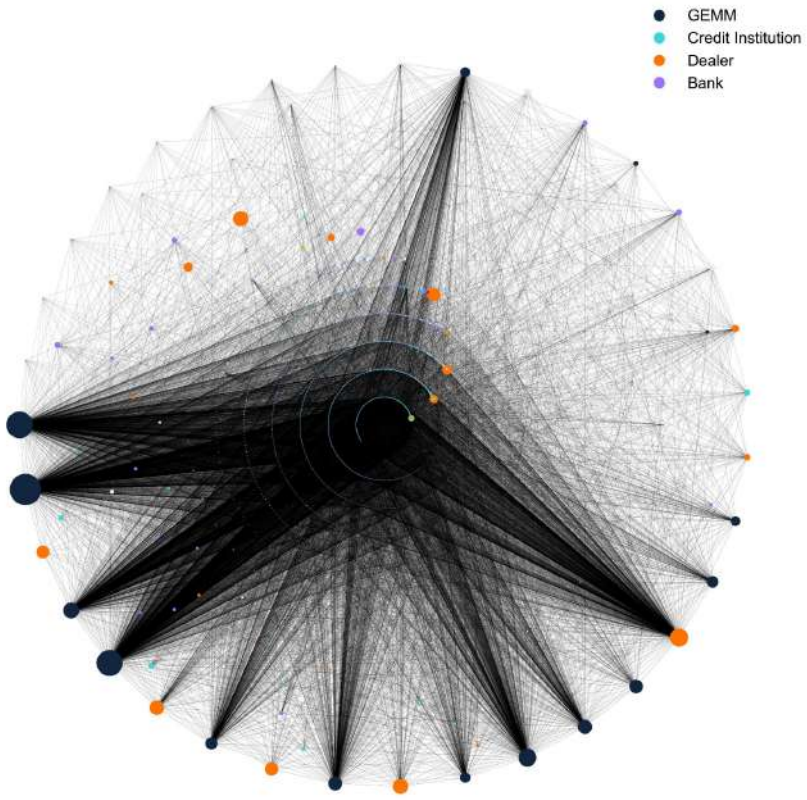
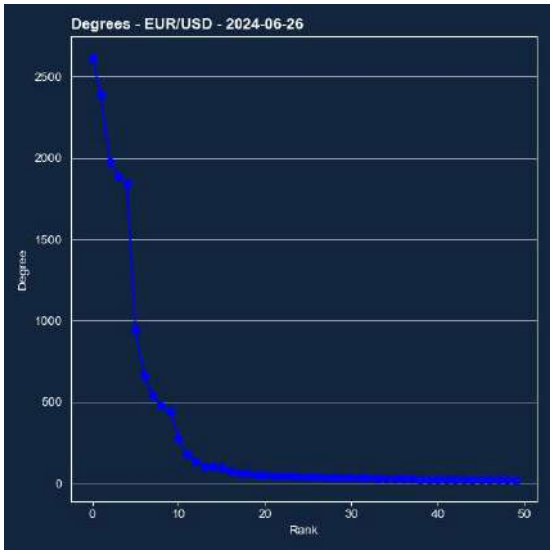
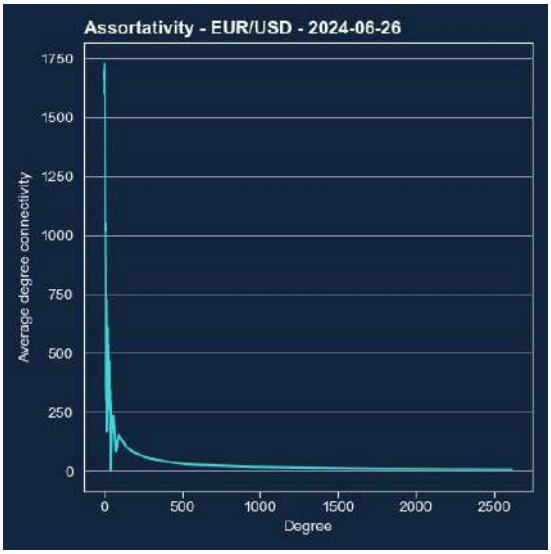


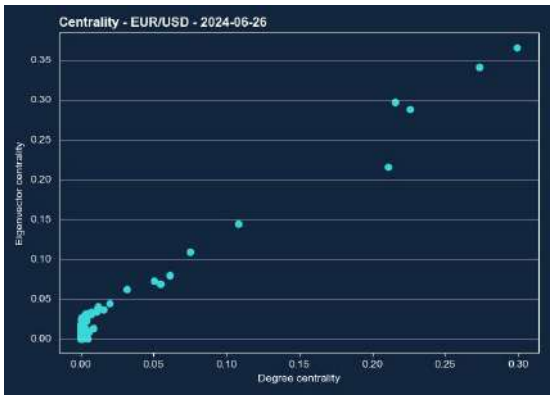

Figure 9: Network of outstanding derivative transactions in EUR/USD FX forwards.
*Notes:* This Figure is based on the cleaned and processed EMIR data. The counterparties are positioned as the k-cores of the graph, so that the inner counterparties have a smaller degree in the graph and the outer counterparties are the most connected. The size of the counterparties is proportional to their gross overall positions, the edges are proportional to the gross bilateral positions. GEMMs are Gilt-Edged Market Makers, primary dealers in UK public debt.
Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



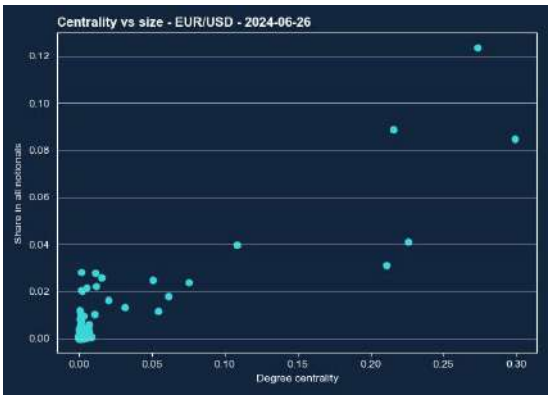

(a) Degrees



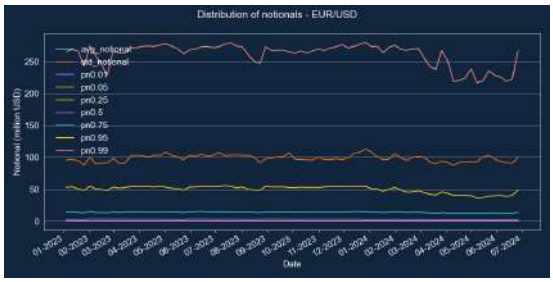

(b) Assortativity



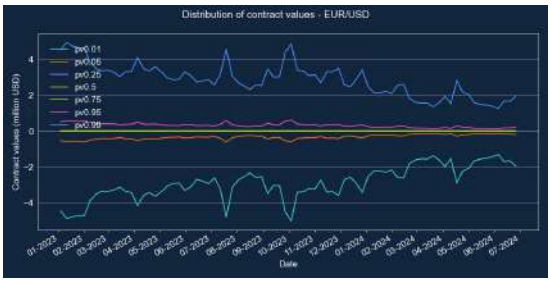

(c) Centrality



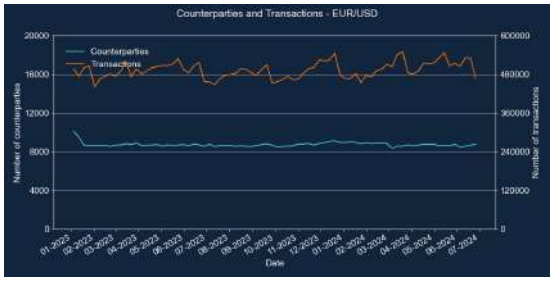

(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 10: Properties of the network of outstanding derivative transactions in EUR-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

**We naturally create our set of main dealers as the union of the top 10 counterparties in terms of degrees in each G-10 currency pair transactions** (this corresponds to the inflection point in the degree rank curves that follow a power law). We use degrees rather than gross notional values to identify top counterparties as this approach is more robust to misreporting (but highly correlated in practice). We get 11 UK-based counterparties[29], a set that we henceforth denote $\mathbb{D}$. The same dealers are therefore the main counterparties in the most traded currency pairs (there appears to be no specialization at that level). This suggests that a single balance-sheet constraint for each dealer (or for the entire dealer sector), as often posited in the literature, is unlikely to fully explain the cross-section of CIP deviations, as all the dealers are active in all the currency pairs and should equalize the different bases in equilibrium.

## 3.3 Contract-Level CIP Deviations on New FX Forward Transactions

Whereas most of the literature relies on an aggregate quote from market data providers, we make full use of the cross-sectional dispersion in FX forward rates. For this, we focus on new transactions and compute a contract-level CIP deviation.

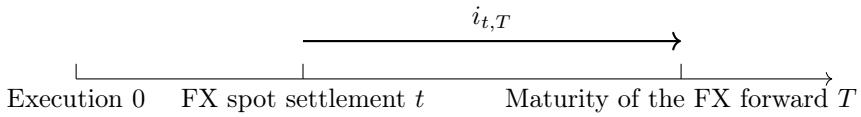
### 3.3.1 Data Cleaning

From the stock data, we create a dataset of new contracts indexed by their execution date. We study the period between 1 January 2023 and 30 June 2024. We find 27 million new FX forward transactions, totaling USD 604 trillion of notionals. The trades between dealers in $\mathbb{D}$ (the top 11 counterparties) represent only 3% of the trades (7% of notionals), but their dealer-client transactions ($\mathbb{D} - \overline{\mathbb{D}}$) represent 70% of the trades (88% of notionals). 20% of the trades are classified as intragroup (36% of notionals). Contracts with a negative tenor from the spot settlement date (overnight or tomorrow/next transactions) represent 12% of the transactions (27% of notionals); those with a maturity equal to the spot settlement date (spot transactions) represent 27% of the transactions (29% of notionals).

We enrich the EMIR data with different datasets. First, the spot rate is not reported, as swaps are reported as forwards in practice, so that only the forward rate is available to us. We use the London closing mid price of the execution date for the spot rate from LSEG, consistent with a swap having a zero value at origination. Around 4% of the reported forward rates are obviously inconsistent (mostly inverted, i.e. $1/F$ instead of $F$). We correct these by checking the alternative fields and the distance with the OIS-implied forward rates.

To compute the CIP deviation at the contract level, we use the zero coupon OIS curves from LSEG, quoted following the money market convention (per annum basis, we use the convention actual/360, or actual/365 where appropriate[30]). We have OIS data for the following G-10 currencies, to which we restrict our analysis: AUD, CAD, CHF, EUR, GBP, JPY, NOK, NZD, SEK, and USD. We interpolate the zero curves with cubic splines, we use QuantLib's calendars to adjust the tenors with respect to the respective OIS settlement dates. We correct the tenor of the FX forward for the settlement date of the spot FX rate[31], following market conventions and Jewitt (2015). More precisely, with the interpolated rates $(i_{0,N})_{N\in[1,365]}$ for the Home OIS curves, we compute the forward OIS rate (if $t < T$) as:

$$i_{t,T} = \left[ \left( \frac{1 + \frac{i_{0,T}}{100} \frac{T}{DayC}}{1 + \frac{i_{0,t}}{100} \frac{t}{DayC}} \right) - 1 \right] \times \frac{DayC}{T - t} \times 100$$




and equivalently for Foreign, where $t$ is the number of days between the execution date and the FX spot settlement date, $T$ is the number of days between the execution date and the maturity date, and $DayC$ is the day count convention of the OIS rate.

We compute our preferred measure of the CIP deviations at the contract level as:

[29] We ignore the 2 non-UK based counterparties, for which we do not have the entire derivative portfolio. These 2 counterparties are never in the top 6 counterparties for any G-10 currency pair in our dataset.

[30] We use Open Gamma's Interest Rate Instruments and Market Conventions Guide, available here.

[31] We use Refinitiv FX Trade Reporting currency holidays, available here.

$$b_T = \left[\left(1 + \frac{i_{t,T}}{100}\frac{T-t}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{T-t}{DayC^*}\right)\frac{F_{0,T}}{S_0}\right] \times \frac{360}{T-t} \times 100$$

which is the annualized (simple) return from arbitraging the CIP deviation between $t$ and $T$.

Following the literature, e.g. Sushko et al. (2016), we have also looked at the alternative definition (equivalent up to the first order approximation, see Appendix E):

$$b_T = \left[\left(1 + \frac{i_{t,T}}{100}\frac{360}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0}\right)^{\frac{360}{T-t}}\right] \times 10000$$

which is the (exponential) return from arbitraging the CIP deviation on the annualized gap between the forward rate $F_{0,T}$ and the spot rate $S_0$, extending the definition for currency swaps.

For contracts maturing before the spot settlement date (overnight and tomorrow/next contracts), the spot leg is actually the one furthest away in time and we adjust the formulae *mutatis mutandis*.

Consistent with our hypothesis, we keep transactions between intermediaries in $\mathbb{D}$ and counterparties in $\overline{\mathbb{D}}$, not intragroup, and with a tenor greater than 7 days for our main analysis (to focus on the convergence risk and ignore intraday changes in the spot rate that would be mistakenly attributed to the forward rate). We winsorize the distribution of CIP deviations at the 1st and 99th percentiles (5th-95th in robustness checks), by currency pair. Our resulting dataset has 6 million transactions totaling USD 98 trillion of notional.

## 3.4 Variation Margins of Dealers

For the different dealers in $\mathbb{D}$, we compute the net value of their outstanding derivative contracts. This corresponds, in our stylized model, to $M^c_1(\omega)$, the net variation margin flow, and potentially a tightening of the liquidity available $\widetilde{L_1}(\omega)$. Thanks to our dataset, we do it on the entire derivative book of each dealer, not only on FX derivatives: we include all asset classes and contract types.

### 3.4.1 Data Cleaning

We do this by restricting our analysis to the valuations submitted by each dealer (i.e. we only consider reports coming from the dealers in $\mathbb{D}$, ignoring the reports of the other counterparties, to match as closely as possible the profit and loss calculation of the market participant of interest).

Because any transaction maturing or closed drops out of our sample, we also carry over the last value indefinitely, to match the permanent impact of a profit or loss on a transaction on the P&L, and then look in our analysis at the changes over different horizons.

We convert all the values in USD: around 75% of the valuation submitted are in USD, and when the field for variation margins is filled (as the reported VM is aggregated at the netting-set level that we cannot recover, we use the contract value instead that is well reported), it is in USD for 85% of the reports. This is the natural unit of account for FX forwards (Jewitt, 2015), where the USD is the base or quote currency for 90% of the transactions, and also follows the ISDA Standard Credit Support Annex that treats cross-currency products as in USD for margin purposes. However, it could introduce some currency moves for other asset classes and contract types where VMs are denominated in other currencies (we ignore this). We use the contemporaneous FX spot rate for the conversions.

We remove any reported value greater than half the reported notional (highly indicative of a misreported currency, which represents at most 2% of all reports in terms of notionals for some of the intermediaries). We keep the latest valuation for each contract if more than one was submitted for a given contract at a given date. We remove intragroup transactions that are exempt from mandatory margining. We winsorize the contract values and notionals at the 1st–99th percentiles to remove reporting outliers (for robustness, we also winsorized at the 5th–95th percentiles). We do it by currency pair for currency derivatives, by swap index for interest rate swaps, and by asset class and contract type for the other derivatives.

Our resulting dataset of derivatives valuations is indexed by the reporting date, where we exclude weekends and UK bank holidays. We compute aggregates at the dealer-date-currency pair level by summing the values, thus assuming perfect netting[32].

[32]The ability to net the actual associated cash-flows depends on the netting agreements. Although the ISDA Master Agreement version is often reported under EMIR, we do not know which transactions can be netted with which counterparties and under what conditions. We therefore make the conservative assumption to test our hypothesis that counterparties can perfectly net their exposures, thus limiting their cash needs. Even if this approach

### 3.4.2 Descriptive Statistics

We show in Figure 11 the cumulative (including the maturing contracts for which we carry over the last value) values in EUR/USD FX forward for the dealers in $\mathbb{D}$. The net value across our set of counterparties is significant: between USD 1 and 10 billion, averaging some larger individual positions for confidentiality. It is also time-varying, translating into large changes in liquidity posted or received. To construct our shocks, we look at the changes of this cumulative value over different horizons.

We present the cumulative values for the other G-10 currency pairs against the US dollar in Appendix D.

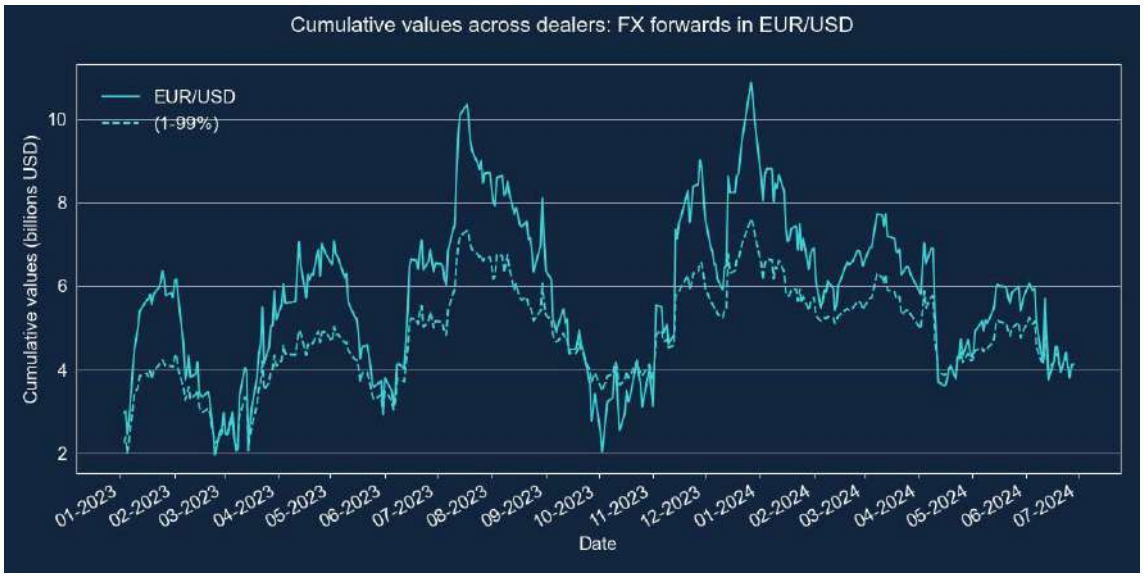



Figure 11: Cumulative net values of EUR/USD FX forwards for the main dealers in $\mathbb{D}$. The dashed line is the winsorized value.
Sources: EMIR position data (stock) reported to the Bank of England. The time series are covering 1 January 2023 to 30 June 2024.

# 4 Empirical Analysis

**We hypothesize the existence of internal capital frictions within the intermediaries we identified, so that internal liquidity might flow to FX trading desks to close wider CIP deviations, but might do so only slowly.**

## 4.1 Within-Balance-Sheet Segmentation

The idea is that balance sheets might be segmented at some level, so that only direct shocks to the FX trading desk really matter, for instance. If not, shocks further away from the FX trading desks could explain wider quoted prices on FX forward rates, as internal liquidity is repriced consistently across the dealer. We thus start by partitioning the balance sheet of the intermediaries into different levels, as presented in Figure 12.

Recall that the first-order condition (12) of our model characterizes the basis given the inventory: $b^c = -\kappa\, N\big(-\frac{m}{s}\big)\left[x_0^c\sigma_c^2 + \sum_{u\geq 2}\gamma_u \mathrm{Cov}(M_1^c, V_u)\right]$, where $\gamma_u$ is the pass-through of other units' liquidity. Consider first full segmentation, *i.e.* $\forall u > 1, \gamma_u = 0$ and therefore $b^c = -\kappa\, N\big(-\frac{m}{s}\big)\, x_0^c\sigma_c^2$.

Given the net positions $\big((x_d^c)_{c=1}^{\mathcal{C}}\big)_{d\in\mathbb{D}}$ normalized by the dealer's average notional, we define the following proxy for risk based on the currency's implied volatility $IVol_c$:

does not necessarily reflect the actual bilateral contracts for netting between counterparties, it does reflect ultimately the *minimum* liquidity required to cover the outstanding positions of a counterparty, as variation margins can be reused. In practice, the timing between when a counterparty receives and posts margins can create additional liquidity needs. For instance, for centrally cleared contracts, a CCP can request intra-day variation margins from debtors and only post the variation margins to creditors the following morning. The use of automated workflows in post-trade solutions for uncleared derivative trading, such as margin and settlement managers, can limit this - hence our conservative approach.

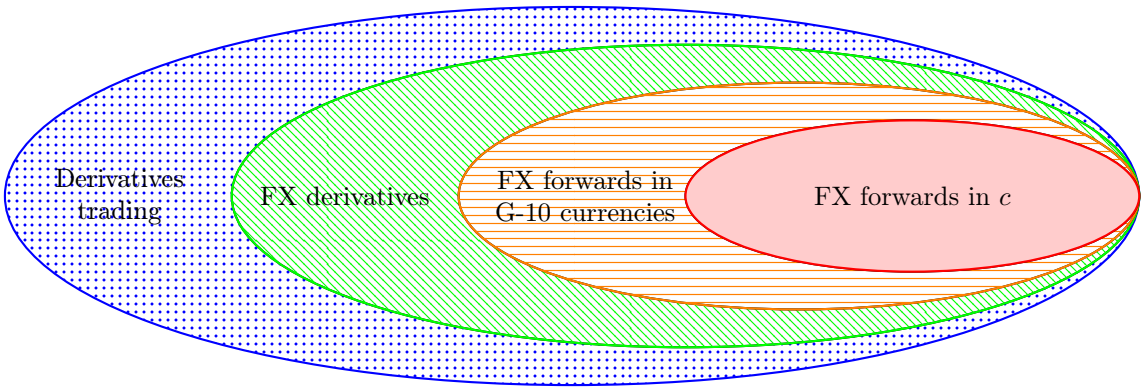



Figure 12: Partition of the balance sheet of a major broker dealer into different levels.
*Notes:* We construct the net variation margins for each dealer $d$ and each currency pair $c$ on the partition of the balance sheet for every reported date $t$. We use the following levels: all the outstanding FX forwards in $c$, all the other FX forwards in G-10 currencies, the rest of the FX derivatives (split into FX forwards in non-G-10 currencies and other contracts), and all the other derivatives (split into cross currency swaps in $c$, other G-10 cross currency swaps, other interest rate swaps, credit derivatives, equity derivatives, commodity derivatives).

$$Q_{d,c,t-1} = x^c_{d,t-1} \times IVol^2_{c,t-1}$$

Consider the liquidity shocks realized up to $t-1$, $\Delta pnl_{d,c,t-1}$, that affect the available liquidity $m_{d,c,t-1}$ around a steady state liquidity level $\ell_{d,c}$, so that $m_{d,c,t-1} = \ell_{d,c} + \Delta pnl_{d,c,t-1}$. Taking a first-order Taylor expansion around the steady state, holding $s$ at its steady-state value, $N(-m/s) \approx \bar{N} - a\Delta pnl$ with $\bar{N} = N(-\ell/s)$ and $a = \phi(-\ell/s)/s > 0$, and we get the following:

$$b^c_{d,t} \approx \theta\, Q_{d,c,t-1} + \lambda_1 \Delta pnl_{d,c,t-1} Q_{d,c,t-1}$$

with $\theta = -\kappa\bar{N} < 0$ and $\lambda_1 = \kappa\, a > 0$, assuming that $\kappa$ (in units of inventory) is common across dealers.

We can then estimate the following regression, on transaction $\tau$ between dealer $d$ and client $k$ in currency pair $c$ at time $t$:

$$b_\tau = \alpha_{c,t} + \alpha_{d,t} + \alpha_{d,k} + \theta\, Q_{d,c,t-1} + \lambda_1 \left(\Delta pnl_{d,c,t-1} \times Q_{d,c,t-1}\right) + \delta' X_\tau + \varepsilon_\tau \tag{13}$$

where:

- $\alpha_{c,t}$ are currency $\times$ date fixed effects to account for the currency's CIP-basis level, implied volatility, or interest rates, which are common for every dealer,
- $\alpha_{d,t}$ are dealer $\times$ date fixed effects to account for the dealer's credit spread, funding shocks, aggregate balance-sheet constraints (*e.g.* the leverage ratio), or risk appetite,
- $\alpha_{d,k}$ are dealer-client fixed effects to account for persistent market power, bilateral netting sets, and collateral agreements,
- $X$ controls for some transaction-specific characteristics, such as the size of the contract and the tenor bucket, but also for the side of the trade relative to the dealer's inventory to absorb inventory management motives,
- standard errors are estimated with wo-way clustering by dealer and date, as the shocks are assigned at the dealer level, with serial correlation for cumulative shocks.

From this restricted regression, we can now test:

- the regression adding $\Delta pnl_u \times Q$, with $u$ : {G-10 currencies ex $c$} $H_0$ : $\{\gamma_u = 0\}$ vs $H_1$ : $\{\gamma_u > 0\}$,
- the regression adding $\Delta pnl_u \times Q$, the pair-level variation margin, whose main effect should be less important than interacted with $Q$.

Given the stylized fact that there is limited dealer substitutability because of the OTC bilateral trading relationships, these price changes largely reflect market-wide changes.

We develop our analysis at different levels of granularity. We first test sector-wide shocks, aggregated across our set of intermediaries, on the overall CIP deviations used in the literature. We then run panel regressions at the dealer–currency level, and finally perform analyses at the transaction-level to test our hypothesis on the cross-section of CIP deviations.

Guided by the liquidity risk management strategies of banks detailed in their annual reports, we investigate the effect at different horizons: short-term (a few days), and with longer lags (month-to-date, quarter-to-date, year-to-date).

In all our specifications, we make the conservative assumption that variation margins across different contracts can be perfectly netted, thus limiting the required liquidity. In practice, settlement cycles could exacerbate these liquidity needs over a very short horizon.

## 4.2 A first test: overall CIP deviations

We start by testing our hypothesis at an aggregate-level to explain the usual data series of CIP deviations at a date and currency pair level, often computed from Bloomberg quotes, as in Siriwardane et al. (2023). We aggregate our P&L shocks in two alternative ways.

### 4.2.1 Assuming a representative dealer sector

First, we aggregate P&L shocks as if the dealers in $\mathbb{D}$ could be summarized as one, representative dealer sector (the assumption underlying the use of a sectoral measure, such as leverage). We test:

$$b_{c,t} = \sum_{j \in \mathbb{J}(c)} \beta_j \times \sum_{d \in \mathbb{D}} \Delta P\&L_{d,j,t-1} + \gamma \mathbf{X}_{c,t} + \epsilon_{c,t}$$

where:

- $b_{c,t}$ is the CIP deviation at time $t$ in currency pair $c$,
- $\mathbb{J}(c)$ is the partition of the dealers' balance sheets into the FX forwards in currency $c$, the rest of the FX forwards in G10 currencies, the rest of the FX derivatives trading desk, and all the other derivatives (as in Figure 12),
- $\mathbb{D}$ is the set of dealers, the intermediaries in FX forwards identified from the network,
- $P\&L_{d,j,t}$ is the profit and loss statement of dealer $d$ at level $j$ at time $t$, in millions of US dollars. Because we carry over maturing contracts, we look at the changes over different horizons: year-to-date, quarter-to-date, month-to-date, 5-day change, 1-day change.
- $\mathbf{X}_{c,t}$ is a vector of controls, we use currency pair fixed effects.

**Warning**

Final results under approval from the Bank of England.

We do not find a clear systematic association, except for interest rate swaps that are not cross-currency swaps, consistent with the fact that idiosyncratic shocks wash out across the set we consider.

### 4.2.2 Accounting for the granularity of intermediaries

Then, consistent with our hypothesis of granular intermediaries, we instead consider a weighted average of normalized P&L shocks. We normalize the individual P&L shocks by the average outstanding notionals (the size of the relevant derivative portfolio), and weight them by the average share of the intermediary in the total notional outstanding of the currency. Formally:

$$\Delta pnl_{d,j,t-1} = \frac{\Delta P\&L_{d,j,t-1}}{\sum_{s=t-T}^{t-1} \frac{1}{T} Notional_{d,j,s}} \times 10^4$$

where we normalize P&L shocks by $Notional_{d,j,s}$, which is the total notional amount *outstanding* for dealer $d$ in partition $j$ at time $s$, averaged over the $T$ preceding days to smooth out any misreporting or unusually large, short-lived position (we take $T = 60$ trading days in our baseline specification, to smooth over the quarter). For interpretability, we rescale the shock in basis points of inventory (average outstanding notional). We then test:

$$b_{c,t} = \sum_{j \in \mathbb{J}(c)} \beta_j \times \sum_{d \in \mathbb{D}} \omega_d(c) \Delta pnl_{d,j,t-1} + \gamma \mathbf{X}_{c,t} + \epsilon_{c,t}$$

where $\omega_d(c)$ is the weight of dealer $d$ in currency pair $c$. We use the average share of total (gross) notional in $c$ over the sample.

**Warning**

Final results under approval from the Bank of England.

## 4.3 Aggregated at (date, intermediary, FX basis, tenor bucket)

We now move to our dataset of contract-level CIP deviation. As an intermediary step, we aggregate CIP deviations at a date $t$, intermediary $d$, currency pair $c$, and tenor bucket $\theta$ level. We weight the deviations by the notional of the contract. Formally:

$$b_{d,c,\theta,t} = \frac{\sum_{\tau \in \mathcal{T}(d,c,\theta,t)} Notional_\tau \times b_\tau}{\sum_{\tau \in \mathcal{T}(d,c,\theta,t)} Notional_\tau}$$

where $b_\tau$ is the CIP-deviation for contract $\tau$, and $\mathcal{T}(d,c,\theta,t)$ is the set of transactions of intermediary $d$ in currency $c$ at date $t$ with a tenor in $\theta$. We define the following tenor buckets: short term if less than a week, medium term if up to 45 days, intermediate term if up to 100 days, long term otherwise. We then test:

$$b_{d,c,\theta,t} = \sum_{j \in \mathbb{J}(c)} \beta_j \Delta pnl_{d,j,t-1} + \gamma \mathbf{X}_{d,c,\theta,t} + \varepsilon_{d,c,\theta,t}$$

**Warning**

Final results under approval from the Bank of England.

## 4.4 Transaction-level analysis

Making full use of the variation within our dataset, we run a contract-level regression. We test:

$$b_\tau = \sum_{j \in \mathbb{J}(c(\tau))} \beta_j \Delta pnl_{d(\tau),j,t(\tau)-1} + \gamma \mathbf{X}_{\tau,d(\tau),c(\tau),t(\tau)} + \varepsilon_\tau$$

for transaction $\tau$, in currency pair $c(\tau)$, at time $t(\tau)$, executed by intermediary $d(\tau)$. We control for date $\times$ currency pair fixed effects to absorb the daily average level of the basis (e.g. including the currency implied volatility), to investigate the differential effect from the liquidity shocks. Thanks to our transaction-level dataset, we also control for bilateral fixed effects, which cover bespoke netting arrangements, for instance, and other potential confounders such as XVAs or market power. We control for some transaction-specific characteristics such as the size of the contract and the tenor bucket. We cluster standard errors by date and currency.

We also control for the side of the intermediary in the transaction, interacted with its outstanding portfolio, as the intermediary should offer better prices on transactions that reduce its exposure to liquidity shocks and reduce its inventory.

We can saturate the empirical model thanks to the granularity of our dataset. We control for time $\times$ currency pair fixed effects to absorb the daily average level of the basis (e.g. including the currency implied volatility), to investigate the differential effect from the liquidity shocks. Thanks to our transaction-level dataset, we also control for bilateral fixed effects, which cover bespoke netting arrangements, for instance, and other potential confounders such as XVAs or market power. We control for some transaction-specific characteristics such as the size of the contract and the tenor bucket. We cluster standard errors by date and currency.

| |
|---|
| $\Delta$ Value FX forwards in $c \times$ *widens* |
| $\Delta$ Value FX forwards in G-10 $\times$ *widens* |
| $\Delta$ Value FX forwards in ex-G-10 $\times$ *widens* |
| $\Delta$ Value other currency derivatives $\times$ *widens* |
| $\Delta$ Value IRS G-10 $\times$ *widens* |
| $\Delta$ Value other IRS $\times$ *widens* |

OLS estimation. Dependent variable: contract level CIP deviation in basis points.
Winsorized 1-99th percentiles.
The variable *widens* is defined as whether the transaction increases the existing directional position of the dealer or helps it net the outstanding positions.
Observations: 2,649,954 (restricted to the maturity bucket 45 to 100 days).
Standard errors: two-way clustered by time and dealer.
Fixed effects: currency pair $\times$ time (2,217) and dealer-client (29,102).
Significance codes: ***: 0.01, **: 0.05, *: 0.1

**Warning**

Final results under approval from the Bank of England.

# 5 Discussion

## 5.1 Potential endogeneity and omitted variables

Motivated by the conceptual framework we developed in Section 2, our empirical specification tests the impact of liquidity shocks to large dealers on the CIP basis they charge to their counterparties. We constructed these liquidity shocks as the profit and loss changes on outstanding derivatives, crystallized as liquidity shocks by variation margins. We acknowledge that our key mechanism sits deep within major financial institutions, and thus makes it challenging to rule out endogeneity or omitted variable biases.

The concern of **reverse causality** is that changes in CIP deviations might themselves affect the mark-to-market values of outstanding derivatives. To mitigate this problem, we lag our liquidity shocks to impose a clear temporal ordering, as the shocks are predetermined to match the last end-of-day P&L statement of the derivative portfolio. Nonetheless, it is still possible that arbitrageurs anticipate future moves in the basis, e.g. because of technical factors, and adjust their positions and pricing beforehand. We note that the moves in the CIP bases are relatively small compared to moves in the spot, forward and interest rates, and thus unlikely to be the main driver of the mark-to-market changes we use.

Any **omitted variable** (global risk factors, funding conditions, shocks to the FX market...) affecting both the CIP bases and our P&L shocks would introduce bias in our estimates. To alleviate this concern, we make use of the rich variation in our granular dataset and include high-dimensional fixed effects: dealer, currency, and time, and in some specifications dealer-client. These fixed effects absorb movements that are common across dealers or currencies.

More conceptually, CIP deviations are the result of limits to arbitrage. A widening of the no-arbitrage violations reflects more constrained arbitrage capital. This is why any relevant omitted variable is likely to operate *within* the balance sheet of the dealers we focus on. Our measures of mark-to-market values capture an important component of these constraints, which we naturally interpret through the lens of a liquidity constraint, but other channels might be relevant, such as capital constraints, risk aversion, or changes in the funding conditions.

EMIR data, although promising to better understand derivatives markets, has many challenges and likely introduces **measurement error** in our proxies for liquidity shocks. Our cleaning procedure aims at removing obvious outliers but is in itself indicative of misreporting. Classic measurement errors would bias our estimates towards zero. We have also made the conservative assumption of perfect netting in the derivative portfolio, across bilateral agreements with perfect rehypothecation. In reality, segmentation and segregation could amplify our mechanism.

Notwithstanding these concerns, our empirical results suggest that internal liquidity is likely to be a relevant mechanism to explain CIP deviations, in line with our theoretical model.

## 5.2 Policy implications

**Our results have implications for margin requirements, liquidity regulation, and the use of CIP deviations as proxies for stress in international dollar funding markets.**

The Great Financial Crisis starkly highlighted the risks stemming from derivatives within the financial system. In order to limit credit risk, regulators enacted risk mitigation measures to protect market participants from the potential default of their counterparties, such as initial and variation margin requirements.

Regulators were mindful of the potential consequences of segregating cash (or other HQLA with a haircut) through initial margins on the liquidity available to market participants, and their procyclicality as initial margins are recalibrated on observed volatility. But, in contrast, the assumption of the Basel Committee on Banking Supervision was that variation margins were unequivocally improving financial stability, as they only consist of a transfer of liquidity from one counterparty to another one, thus neutral for the overall liquidity in the financial system.

But this fails to recognize the **granularity** of key intermediaries and the **marginal value of cash** arising from liquidity risk and costly external funding, which can differ across market participants. Empirically, we document that the over-the-counter market for FX forwards is intermediated by a handful of very large dealers that are exposed to significant liquidity shocks from the changes in the mark-to-market value of their derivative portfolio. We show that these idiosyncratic liquidity shocks can indeed translate into aggregate changes, which we interpret through the framework of forward-looking liquidity management, in line with the corporate finance literature, constraining arbitrage capital. This implies that variation margins are not neutral once within-balance-sheet constraints and internal capital markets are taken into account. Regulators could

incorporate these insights in microprudential supervision, e.g. when assessing liquidity buffers, and in macroprudential policies, e.g. when conducting system-wide stress tests.

The mechanism of internal liquidity frictions we investigate also has implications for central bank interventions. Covered interest parity deviations are often used as measures of financial stress and market liquidity evaporating, for instance when deciding central bank swap lines. Our analysis suggests that CIP deviations not only capture the overall demand for US dollar funding, but also the internal liquidity of a limited set of key dealers. Taking into account the internal organization of these intermediaries and their granularity might allow for more targeted interventions to ensure smooth market functioning.

Our results also inform the analysis of financial stability and monetary policy transmission. Because of its granularity, the health of a single key financial institution can have direct consequences on the real economy, for instance on the costs or quantities to hedge currency risk from international trade for firms or from portfolio flows for investors. These liquidity requirements also imply that counterparties with less liquidity might optimally decide to hedge a smaller share of their risks through derivatives, as they account for their marginal value of cash, potentially leaving the real sector more exposed to risks.

# Conclusion

Arbitraging covered interest parity deviations is a risky arbitrage: arbitrageurs have to hold on to the derivative leg of the trade, which exposes them to convergence risk through variation margins. These risk mitigation requirements reduce credit risk but imply liquidity needs. Given that internal liquidity has value, banks' treasuries might prevent foreign exchange trading desks from closing the deviations in order to limit their liquidity risk - even more so when internal liquidity is scarcer and more valuable, or when the volatility of variation margins is higher. This makes CIP deviations a natural laboratory to test internal liquidity frictions and whether the marginal value of cash proxies the stochastic discount factor of intermediaries.

Empirically, we first document that the over-the-counter trading network for foreign exchange forwards is highly intermediated, with some key granular dealers on which we focus. Second, we show that the trades of these intermediaries with their clients represent a major share of all transactions, but that there is dispersion in the offered forward rates, away from the CIP-predicted one. Third, we highlight that the total net value of foreign exchange derivatives, which directly translates into liquidity requirements through variation margins, is considerable for these intermediaries, of a similar magnitude to their annual operating income, and fluctuates over time.

We then directly test whether these liquidity shocks, reflecting profit and loss changes, explain the deviations from covered interest parity, and the changes thereof. We use this test to map where the liquidity constraint binds within the different levels of the partitioned balance sheet of dealers, indicative of within-balance-sheet segmentation. Future work could use the change in margin reporting requirements under EMIR Refit to exploit potential segmentation across bilateral netting sets and better isolate exogenous variation margin shocks.

Our findings suggest that internal capital frictions within the balance sheets of granular financial intermediaries, rather than the aggregate dealer sector leverage alone, are a key state variable for the forward exchange rate determination.

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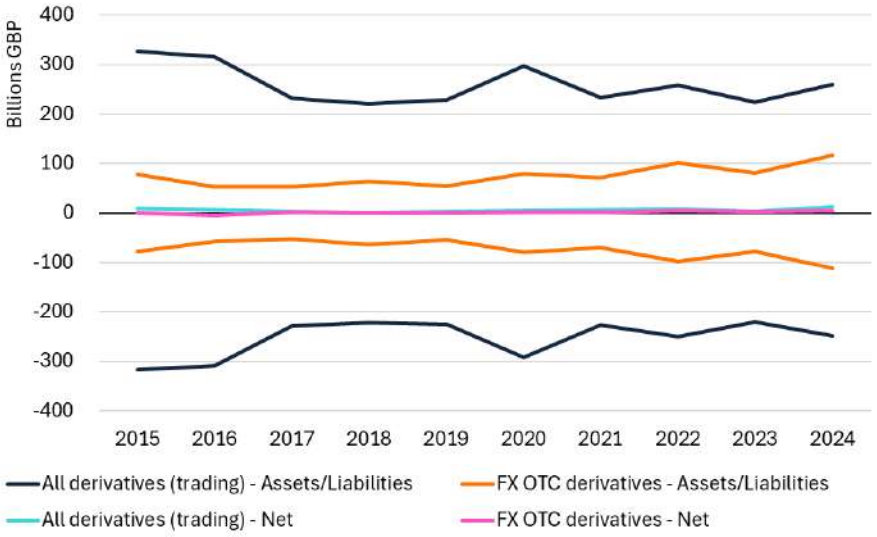
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# A Individual Banks: Derivatives Accounted at Fair Value

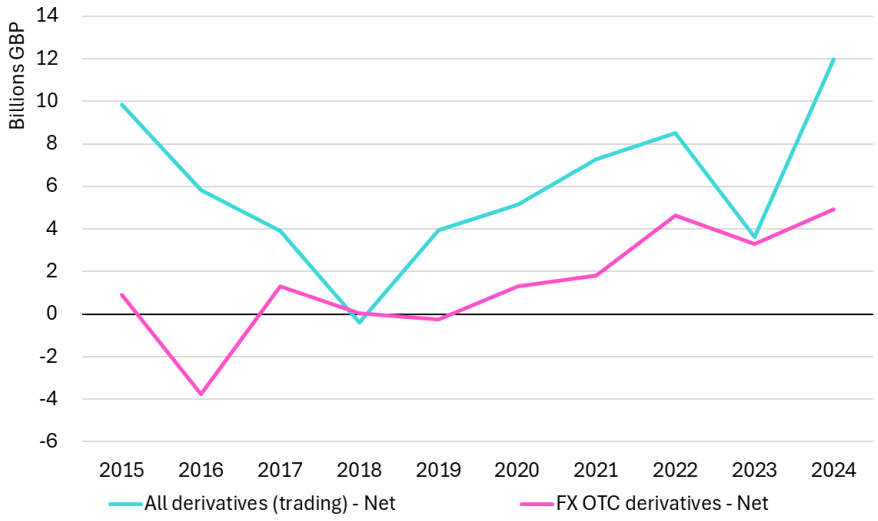
We present some balance-sheet data on derivatives from public annual accounts, for selected Gilt-Edged Market Makers (GEMMs, primary dealers in UK public debt). In GAAP and IFRS accounting standards, outstanding derivatives held for trading enter the balance sheet from their trade date at their fair value through profit or loss. Derivatives are presented as financial assets (respectively liabilities) if their fair value is positive (respectively negative). Under IFRS rules, the gross positions are only netted in accounting terms if they contractually settle simultaneously or on a net basis: this would for instance be the case for some cleared transactions "settled-to-market"[33], but not for the (mostly) uncleared transactions we focus on, which are "collateralized-to-market" through variation margins. We thus take the conservative approach of using net profit and loss shocks in our analysis. We ignore derivatives classified as hedges (e.g. if the functional currency is not the local currency), which only constitute a fraction of the derivative portfolio: the hedged item can be accounted for on an amortized cost basis, but we are unable to attribute the hedges to their hedged item.

[33] In that case, the variation margin paid to the central clearing counterparty is treated as a settlement payment of the derivative position, not a collateral transfer. As it does not change the economic exposure, the BIS confirmed that this accounting treatment should not reduce the associated capital requirements for clearing members, see here. This practice supports our approach to use reported contract values in EMIR, instead of reported initial and variation margins.

## A.1 Barclays Bank PLC



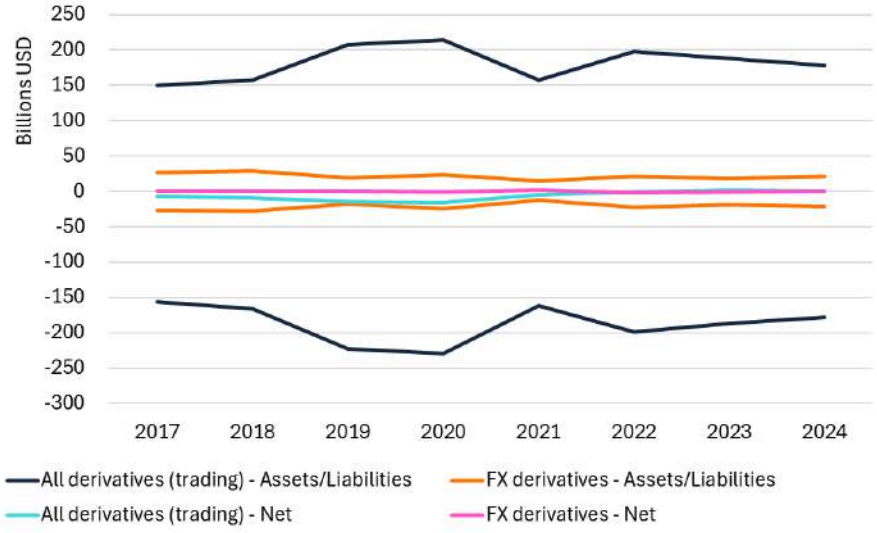

(a)



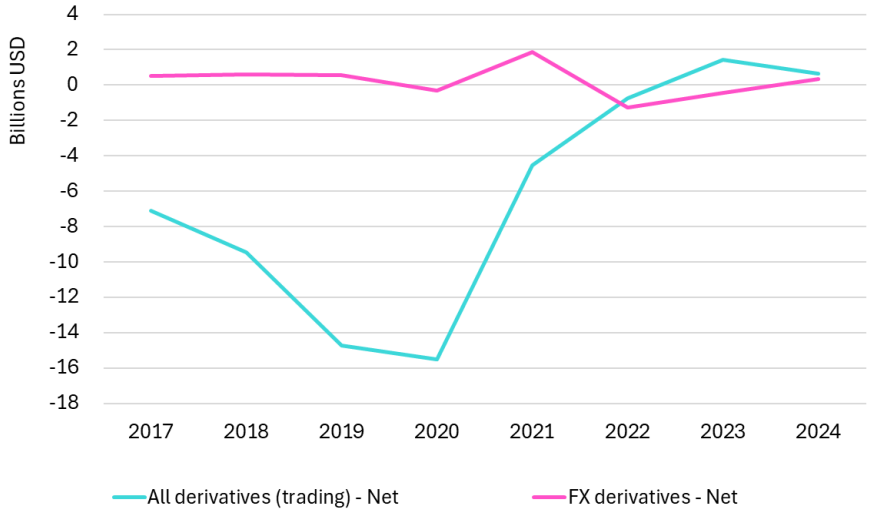

(b)

Figure 13: Fair values of derivatives held for trading for Barclays Bank PLC: Foreign exchange OTC derivatives and all derivatives (including FX OTC ones) held for trading - Assets and Liabilities (in billions GBP), and Net values (Assets − Liabilities).
Sources: Companies House, Barclays Bank PLC (Annual Reports: Notes to the financial statements, Assets and liabilities held at fair value, Derivatives), Authors' calculations.

## A.2 Citigroup Global Markets Limited



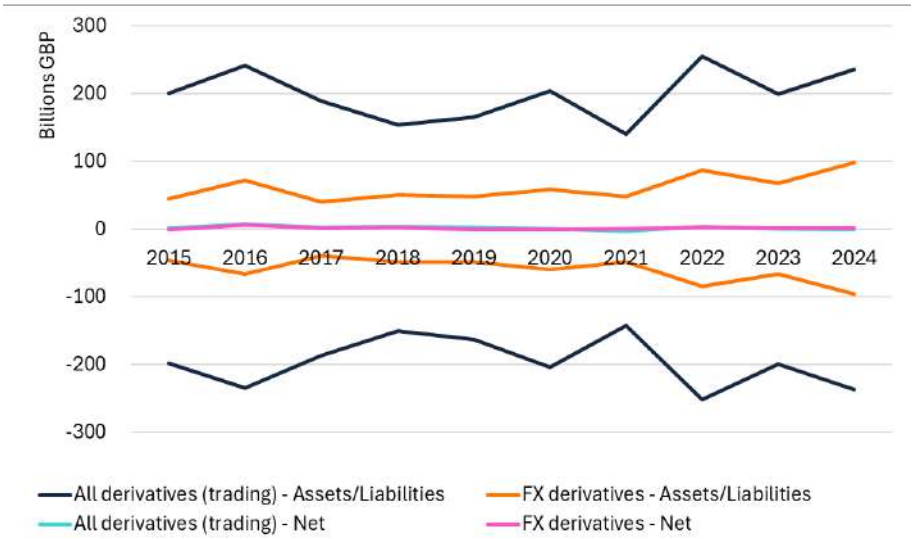

(a)




(b)

Figure 14: Fair values of derivatives held for trading for Citigroup Global Markets Limited: Foreign exchange derivatives and all derivatives (including FX ones) held for trading - Assets and Liabilities (in billions USD), and Net values (Assets − Liabilities). The breakdown by asset class is not available before 2017.
Sources: Companies House, Citigroup Global Markets Limited (Annual Reports: Notes to the financial statements, Derivatives), Authors' calculations.

## A.3 HSBC Bank PLC




(a)




(b)

Figure 15: Fair values of derivatives held for trading for HSBC Bank PLC: Foreign exchange derivatives and all derivatives (including FX ones) held for trading - Assets and Liabilities (in billions GBP), and Net values (Assets − Liabilities). We ignore the offset from settled to market house cleared contracts in the gross positions.
Sources: Companies House, HSBC Bank PLC (Annual Reports: Notes to the financial statements, Assets and liabilities held at fair value, Derivative financial instruments), Authors' calculations.

# B EMIR Variation Margin Requirements on FX Derivatives

Variation margins on derivatives were an established risk management practice between market participants before the GFC, but with some large exemptions, e.g. infamously for AAA-rated monoline insurers like AIG. In contrast, initial margins were a relatively new requirement following the crisis, recognizing that gross – not only net – positions can matter. Initial margins are exchanged on a gross basis at the inception of a derivative transaction and are usually segregated.

EMIR originally followed the guidelines of the Basel Committee[34], making variation margins mandatory on FX forwards and FX swaps, without mandatory initial margins on these contracts (initial margins on currency swaps still apply to the interest rate part of the contract). As the successive EMIR margin requirements entered into force in March 2017, it appeared that some smaller non-financial counterparties were unprepared, both for the administrative requirements (such as having risk management procedures and bilateral collateral agreements in place) and the operational set-up (such as having the liquidity to face margin calls). Furthermore, different EU Member States had different definitions of FX spot and FX short-term derivative contracts. The mandatory variation margin requirement was therefore suspended until January 2018[35], when the revision of the Markets in Financial Instruments Directive (MiFID II) entered into force and clarified the definitions of FX derivatives as financial instruments, thus covered by EMIR with mandatory variation margins.

To avoid disruptions, the European Supervisory Agencies recommended to exempt physically settled FX forwards where at least one of the counterparties is not a financial institution from the mandatory variation margin requirement, so that it only applies to financial firms and systemically important non-financial entities. This follows the assumption that small non-financial institutions do not pose a systemic risk and use these contracts to hedge operations. This recommendation was enacted into EU and UK law[36].

Trading over-the-counter allows counterparties to decide bilaterally the conditions under which they trade, including their collateral agreement (Credit Support Annexes). The ISDA Standard Credit Support Annex specifies by default that variation margins should be in cash with zero thresholds and zero minimum transfer amounts. If the counterparties fall under different regulatory regimes, they usually follow the ISDA 2016 Variation Margin Protocol published by the International Swaps and Derivatives Association that sets best practices, and the regime that applies to the bilateral relationship is the stricter one that applies to either counterparty. The process of exchanging margins can then be automated, as recommended by the BCBS: major counterparties often coordinate their margin calls on third-party platforms[37].

Large banks have a strong incentive to exchange daily variation margins in cash with their counterparties. Only then can they limit the replacement cost of their derivative positions with the variation margins in the calculation of the leverage ratio, under the Capital Requirements Regulation (CRR II)[38]. Furthermore, assuming the bank hedges its trade with financial counterparties that require variation margins, not receiving variation margins on the original client's trade creates liquidity and counterparty risk. Note that counterparties that are not banks, in-

[34] Universal two-way margining: "All covered entities that engage in non-centrally cleared derivatives must exchange, on a bilateral basis, the full amount of variation margin [i.e. a zero threshold and a zero minimum transfer amount] on a regular basis (eg daily).", MGN 20.4, Basel Framework, Basel Committee on Banking Supervision (BCBS), available here. EMIR allows for a threshold lower than EUR 500 000 and tolerates a slight delay in the exchange of variation margins only if there are commensurate initial margins in place. There are some other marginal, exceptional cases under EMIR: no mandatory margining for covered bond issues and one-way margining (collection only) for transactions with counterparties in non-netting jurisdictions.

[35] See Article 37 of Commission Delegated Regulation (EU) 2016/2251 of 4 October 2016 with regard to regulatory technical standards for risk-mitigation techniques for OTC derivative contracts not cleared by a central counterparty, available here.

[36] "By way of derogation [...], counterparties *may provide* in their risk management procedures that variation margins are not required to be posted or collected for physically settled foreign exchange forward contracts and physically settled foreign exchange swap contracts where one of the counterparties is not [a credit institution or an investment firm]" (our emphasis, it has to be actively included in bilateral agreements), Article 1 of Commission Delegated Regulation (EU) 2021/236 of 21 December 2020 amending technical standards laid down in Delegated Regulation (EU) 2016/2251 as regards to the timing of when certain risk management procedures will start to apply for the purpose of the exchange of collateral, available here. The Basel Committee on Banking Supervision incorporated this view in its "Margin requirements for non-centrally cleared derivatives", available here.

[37] See, e.g., Acadia's Margin Manager (LSEG group) here, or OSTTRA (TriOptima) triResolve Margin here.

[38] See Article 429, Regulation (EU) 2019/876 of the European Parliament and of the Council of 20 May 2019 amending Regulation (EU) No 575/2013 as regards the leverage ratio, the net stable funding ratio, requirements for own funds and eligible liabilities, counterparty credit risk, market risk, exposures to central counterparties, exposures to collective investment undertakings, large exposures, reporting and disclosure requirements, and Regulation (EU) No 648/2012, here. For the net stable funding ratio (Article 428), the variation margins can be deducted from the derivatives' fair values if the collateral is Level 1 HQLA (cash and non-cash, excluding covered bonds).

cluding supranational entities and non-financial companies, thus have a real incentive to exchange variation margins, even if not mandated: because margins lower both liquidity and credit risks, not posting margins leads to a worse price through XVA adjustments, in effect an upfront cost to compensate intermediaries for the risks they face (Gregory, 2014).

To highlight how market practice can be more stringent than legal requirements, we present in Table 3 the results of the ISDA Margin Survey Year-end 2024 that covers the world's major 32 financial institutions[39]. Discretionary margins are received and posted under bilateral collateral agreements with counterparties not under regulatory margin requirements, as this is prudent and common counterparty risk management. Participants collected USD 1.0 trillion of variation margins for non-cleared derivatives (a wider set than FX forwards only), of which USD 744.5 billion were regulatory and USD 283.3 billion were discretionary. They posted USD 706.7 billion of variation margins, of which USD 514.4 billion were regulatory and USD 192.3 billion were discretionary. As variation margins can be netted over the bilateral netting set, this also suggests significantly large individual and bilateral positions.

| Type | Category | Received | | Posted | |
|---|---|---|---|---|---|
| | | Amount ($bn) | Composition (%) | Amount ($bn) | Composition (%) |
| Variation Margins | Regulatory | 745 | Cash 72<br>Govies 18<br>Other 10 | 514 | Cash 88<br>Govies 11<br>Other 2 |
| | Discretionary | 283 | Cash 59<br>Govies 17<br>Other 25 | 192 | Cash 74<br>Govies 24<br>Other 2 |
| Initial Margins | Regulatory | 354 | Cash 3<br>Govies 63<br>Other 34 | 313 | Cash 3<br>Govies 66<br>Other 31 |
| | Discretionary | 77 | Cash 47<br>Govies 16<br>Other 37 | 15 | Cash 47<br>Govies 15<br>Other 38 |

Table 3: Initial and variation margins received and posted by the 32 largest institutions in non-cleared derivatives surveyed – Amounts (in USD billions) and Composition (in %). Govies: Government securities, Other: Other securities. Because of rounding, numbers and percentages might not add up. The higher proportion of government securities used for initial margins partly reflects the stronger creditor protection in the event of custodian bankruptcy (rather than fungible cash). Discretionary initial margins are also known as independent amounts.
Source: ISDA Margin Survey Year-end 2024.

Using a Bank of England's classification of financial institutions, we find that a large majority of FX forwards in our dataset are between two financial institutions (85% of transactions in terms of number of transactions, 94% when weighted by notionals), and therefore indeed covered by mandatory margining. This constitutes a lower bound as the classification is not exhaustive for counterparties established in third-countries. This is further supported by the share of transactions reported as directly linked to commercial activity or treasury financing being around 1%.

Intragroup transactions are exempt from margining, subject to certain conditions, notably that both counterparties are included in the same consolidation on a full basis, under a common risk management framework, and that there is a recognized equivalence if one of the counterparties is not based in the United Kingdom[40].

Single-stock equity options and equity index options are not currently subject to margin requirements because of the lack of implementation in other jurisdictions, to avoid regulatory arbitrage. Options in general only lead to a one-way margining (from the seller to the buyer), given the asymmetric payoff of the contract.

[39] Available here.

[40] See Article 3 (Intragroup transactions) of Regulation (EU) No 648/2012 of the European Parliament and of the Council of 4 July 2012 on OTC derivatives, central counterparties and trade repositories, available here, and "Margin requirements for uncleared derivatives", FCA, available here. Currently, there are temporary exemptions to intragroup margining even when there is no equivalence recognition.

# C Market Structure of Outstanding FX Forwards in G-10 Currencies

## C.1 AUD/USD

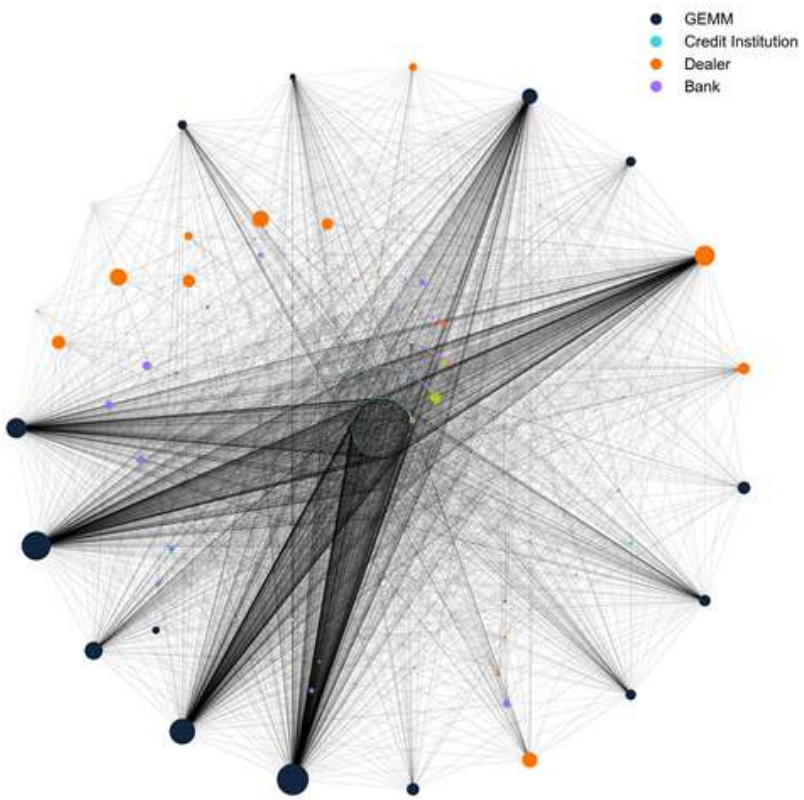
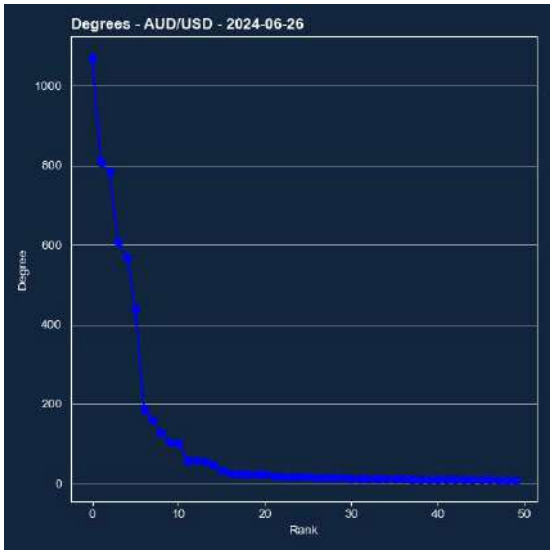
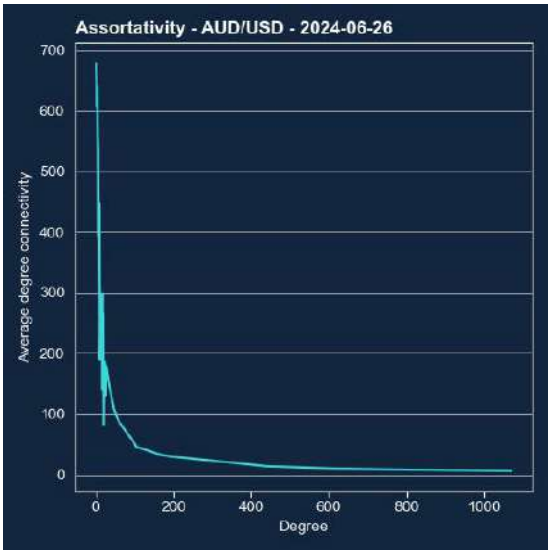


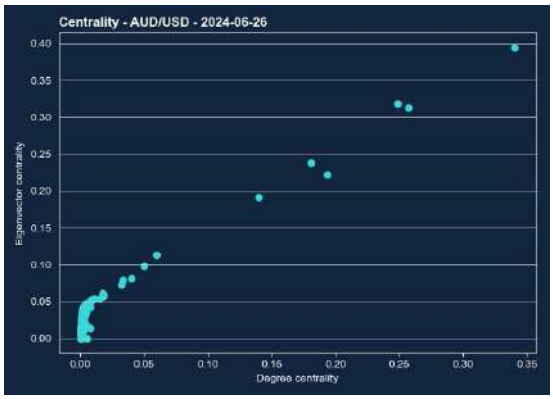

Figure 16: Network of outstanding derivative transactions in AUD/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



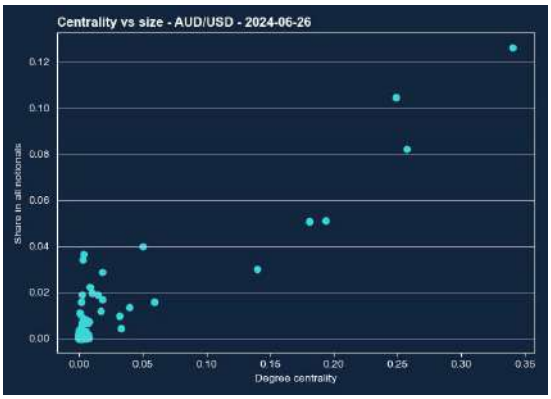

(a) Degrees



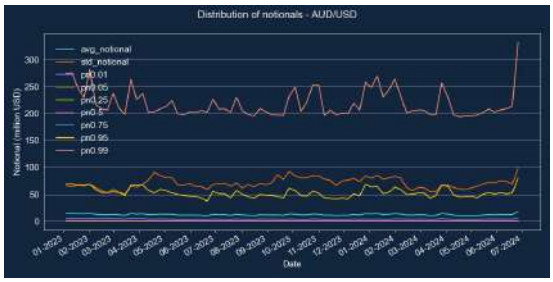

(b) Assortativity




(c) Centrality




(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 17: Properties of the network of outstanding derivative transactions in AUD-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.2 CAD/USD

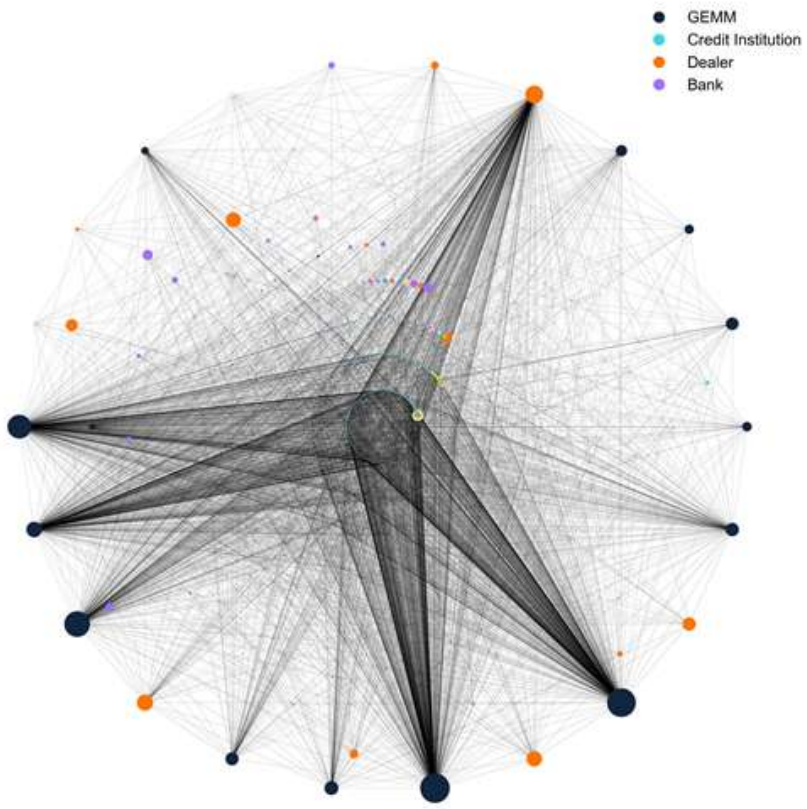
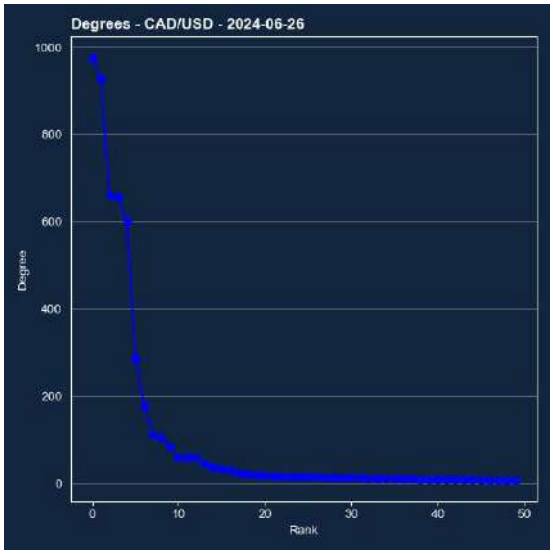
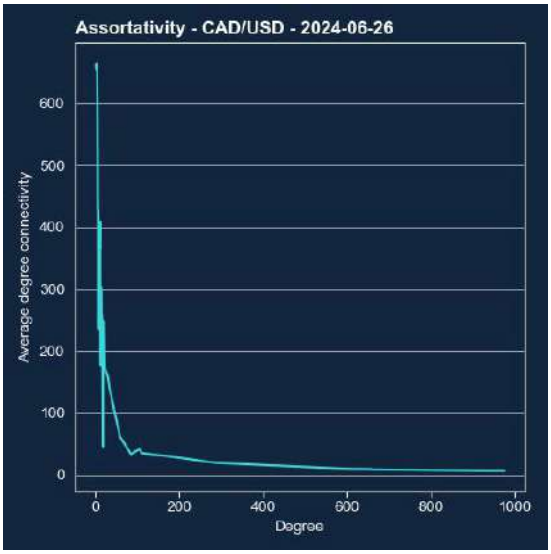


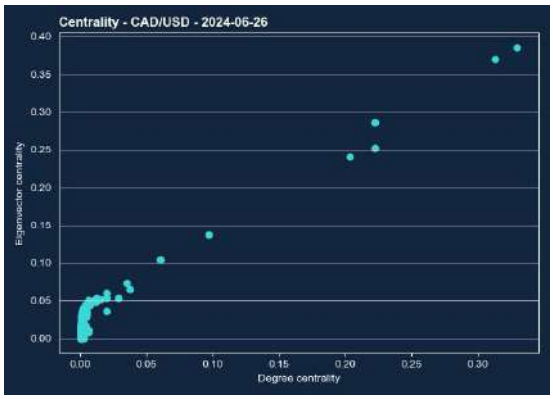

Figure 18: Network of outstanding derivative transactions in CAD/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



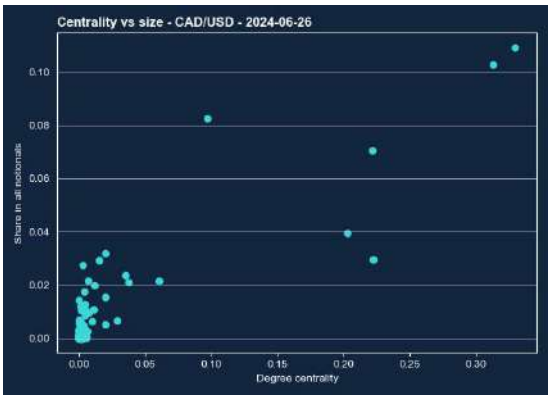

(a) Degrees



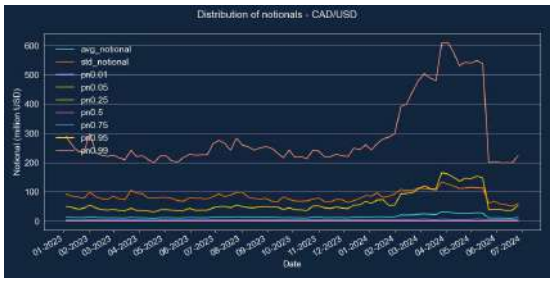

(b) Assortativity



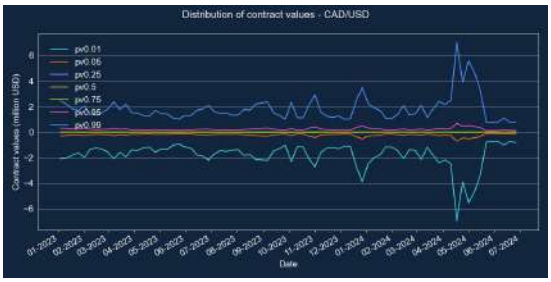

(c) Centrality



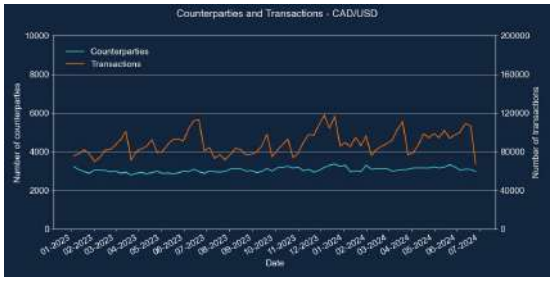

(d) Size



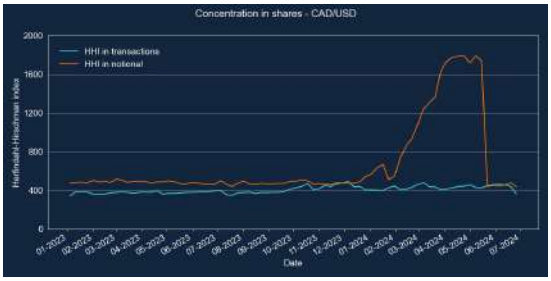

(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 19: Properties of the network of outstanding derivative transactions in CAD-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.3 CHF/USD

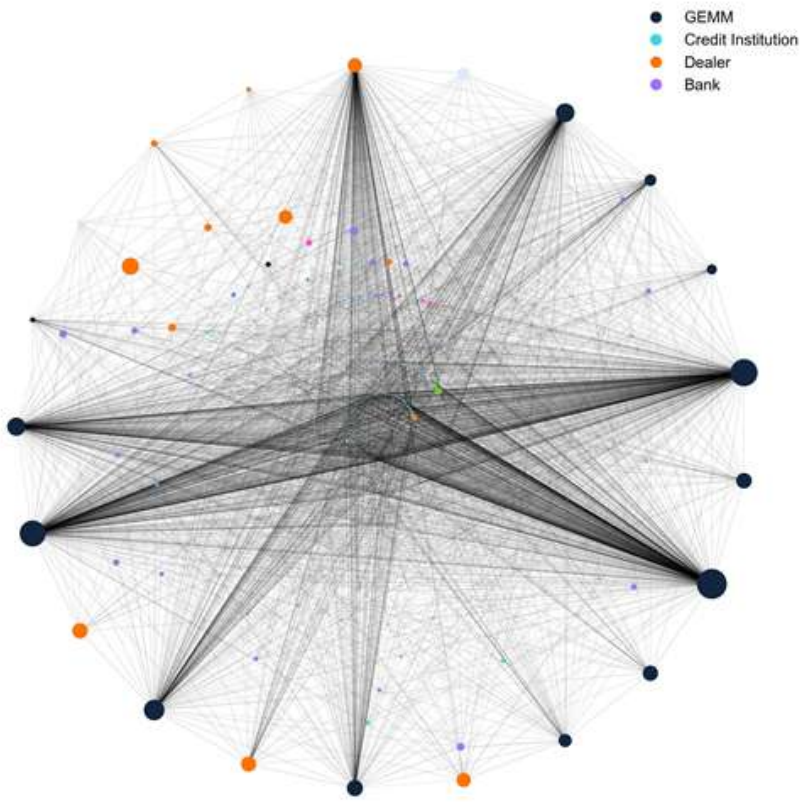
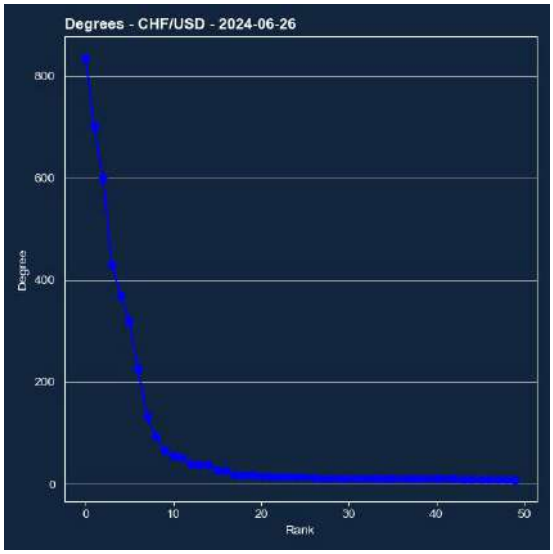
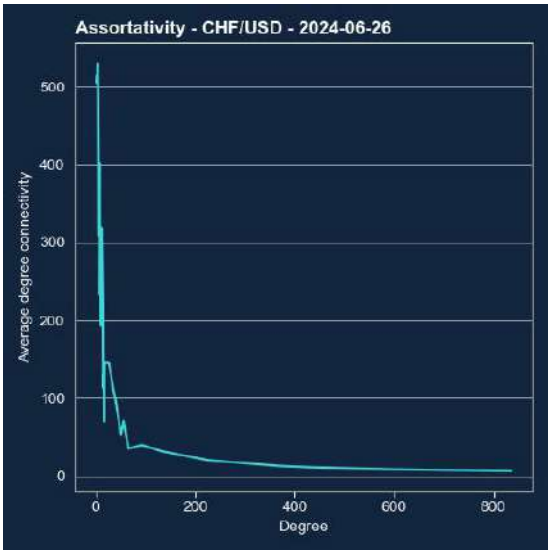


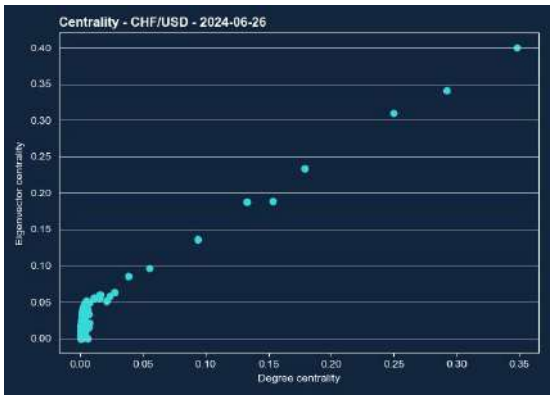

Figure 20: Network of outstanding derivative transactions in CHF/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



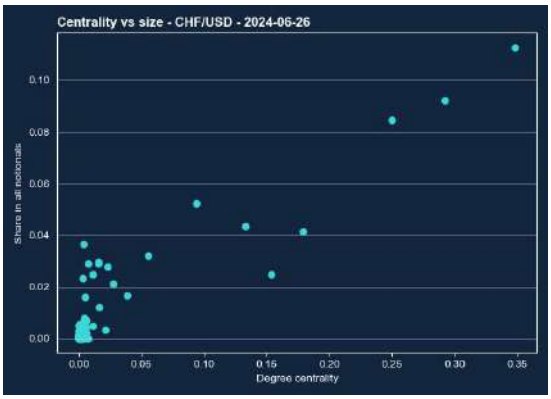

(a) Degrees



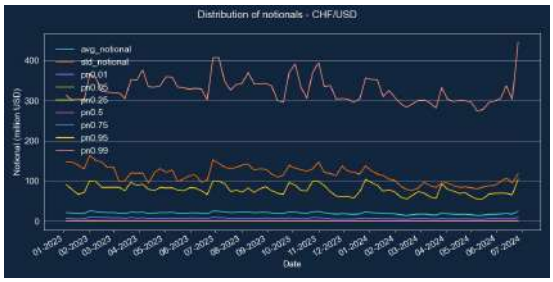

(b) Assortativity




(c) Centrality



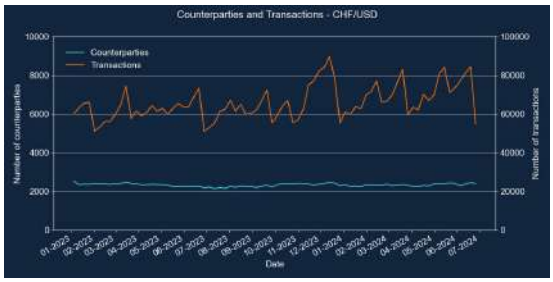

(d) Size



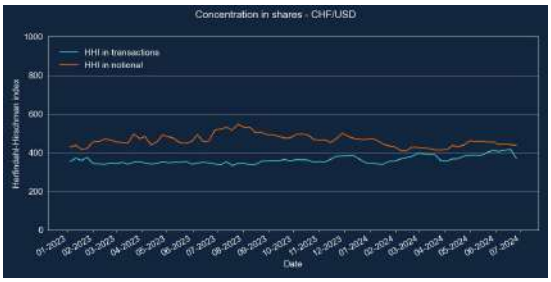

(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 21: Properties of the network of outstanding derivative transactions in CHF-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.4 GBP/USD

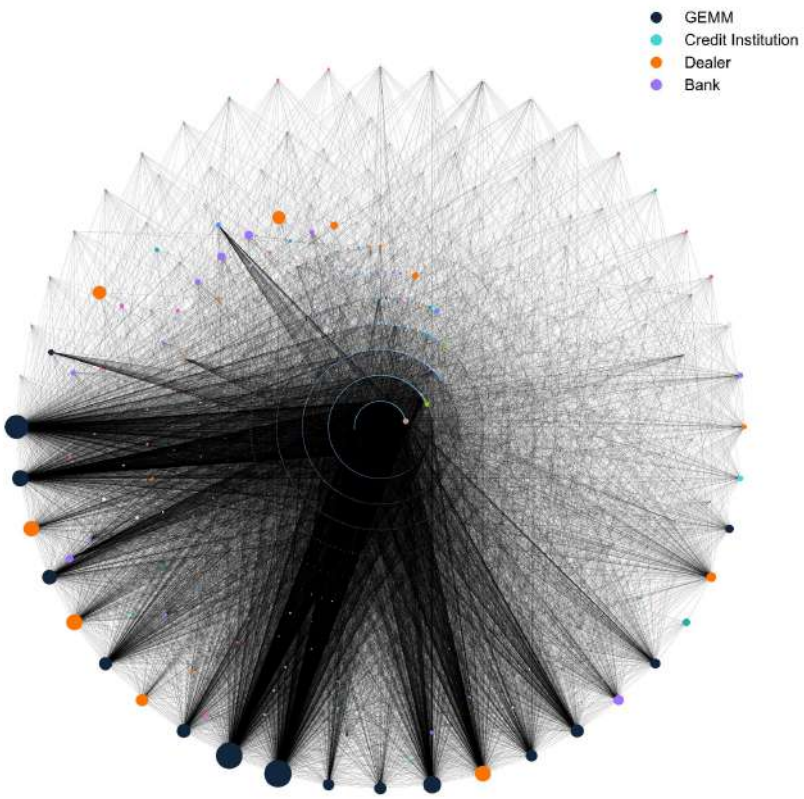
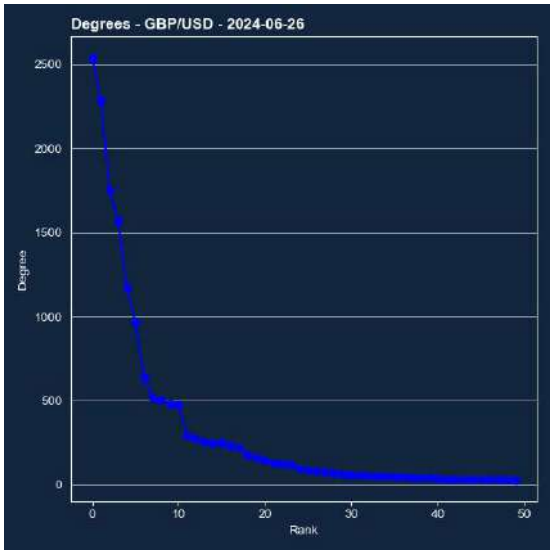
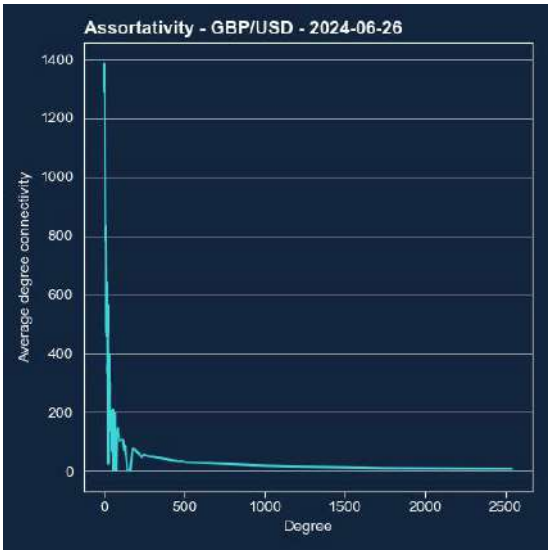


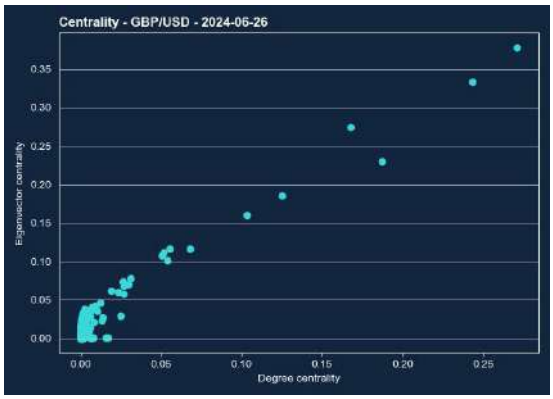

Figure 22: Network of outstanding derivative transactions in GBP/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



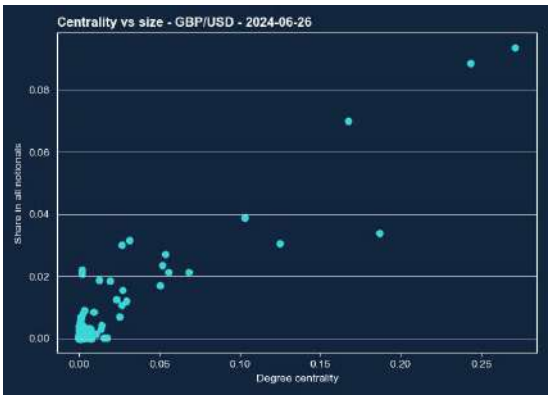

(a) Degrees



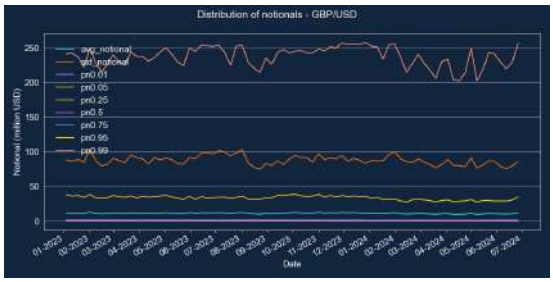

(b) Assortativity



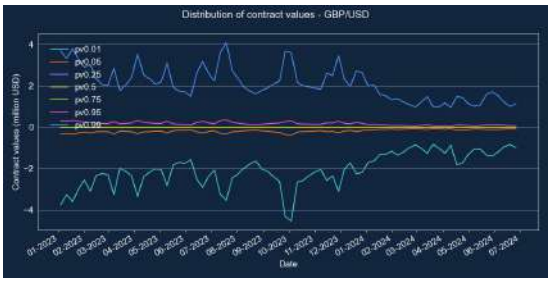

(c) Centrality




(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 23: Properties of the network of outstanding derivative transactions in GBP-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.5 JPY/USD

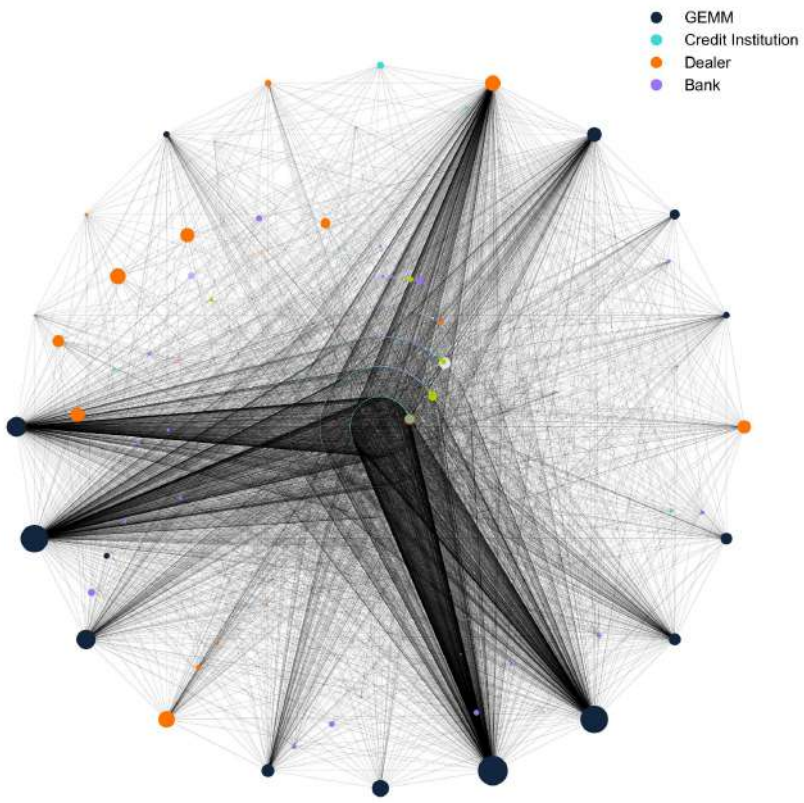
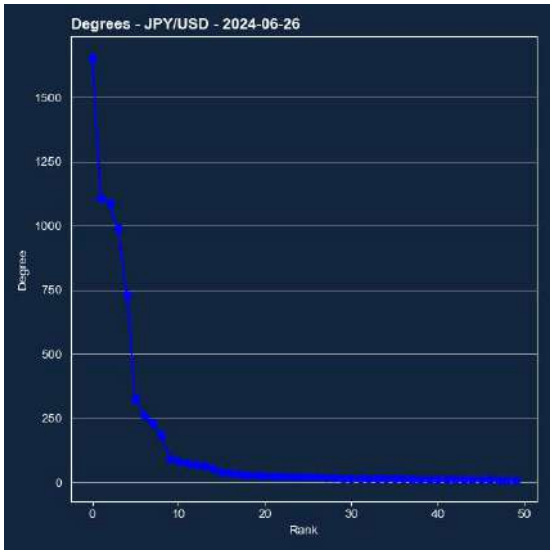
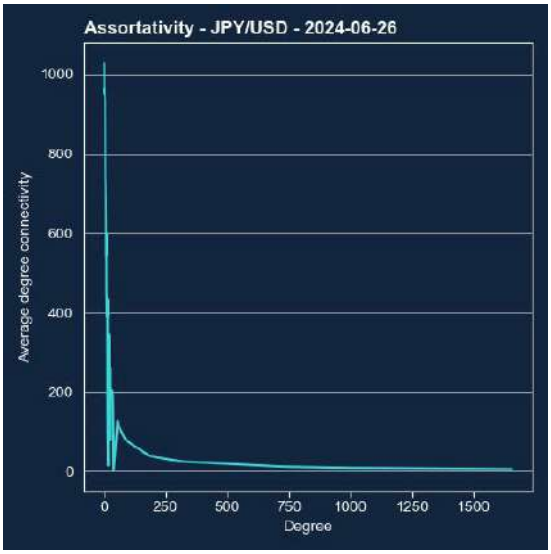


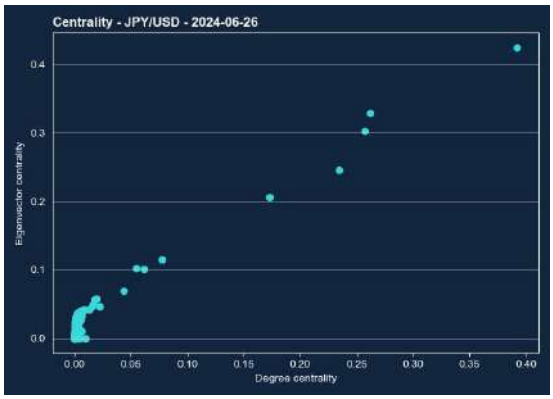

Figure 24: Network of outstanding derivative transactions in JPY/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



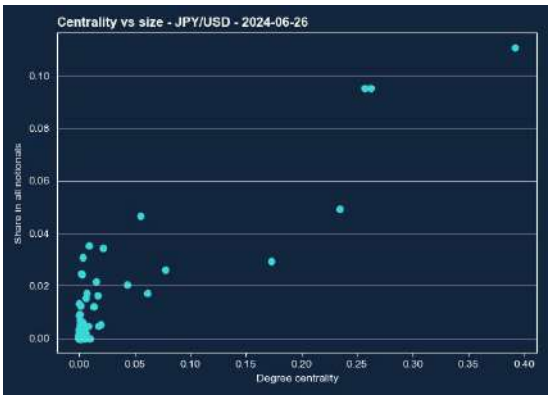

(a) Degrees



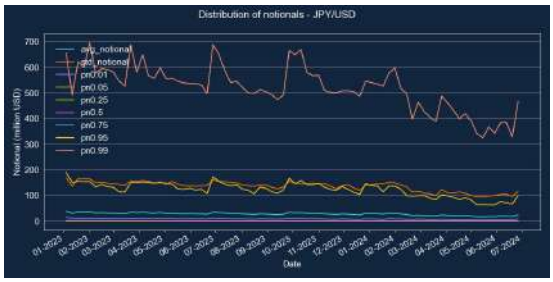

(b) Assortativity




(c) Centrality




(d) Size



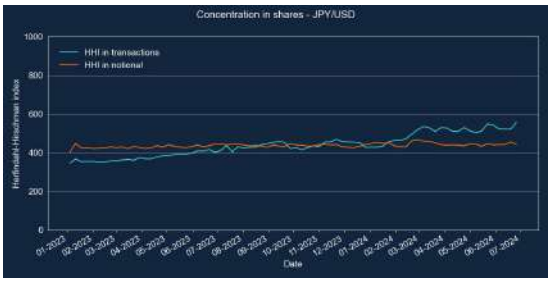

(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 25: Properties of the network of outstanding derivative transactions in JPY-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.6 NOK/USD

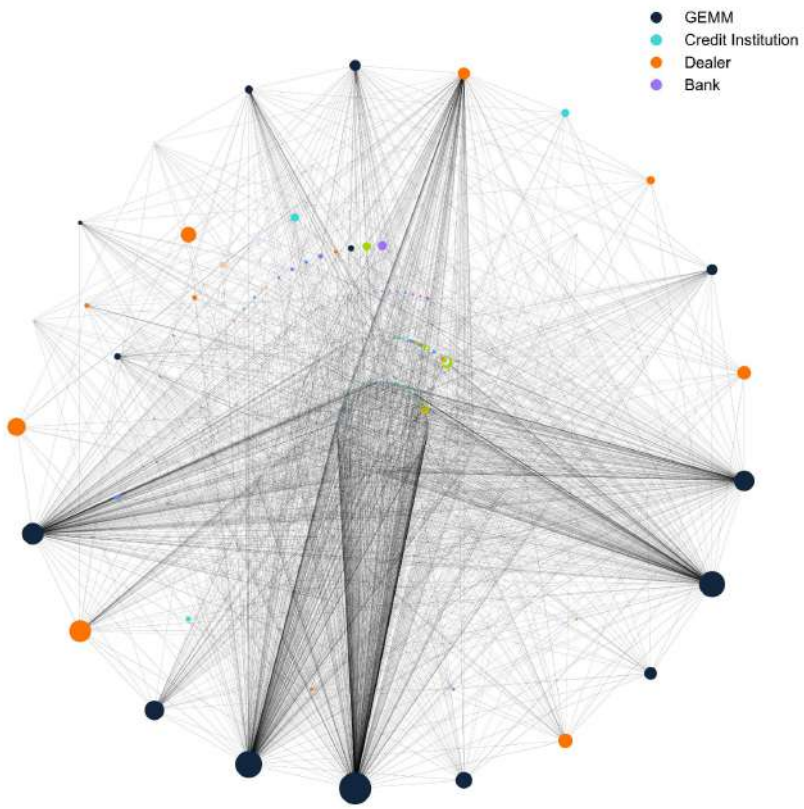
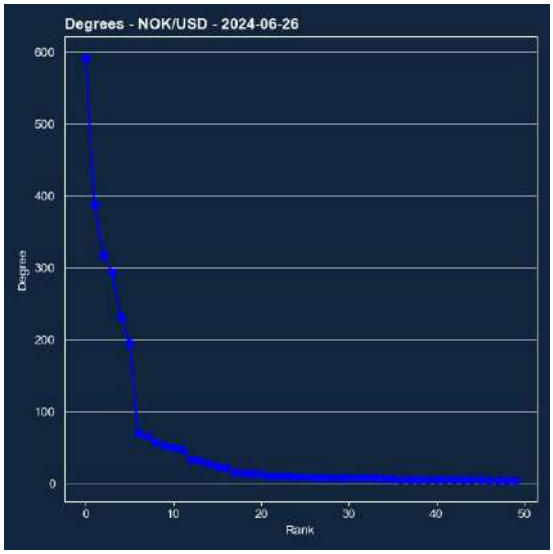
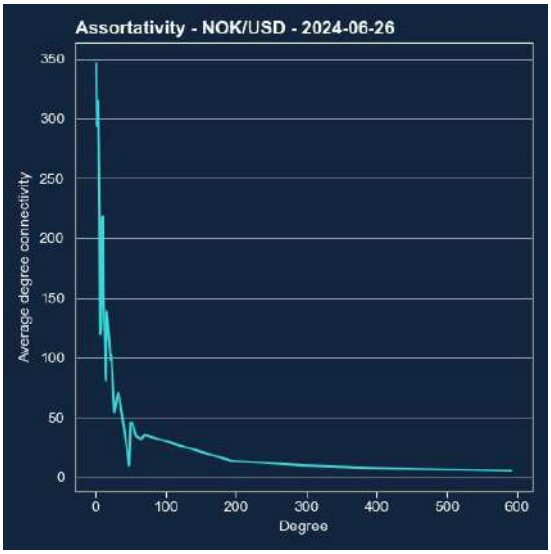


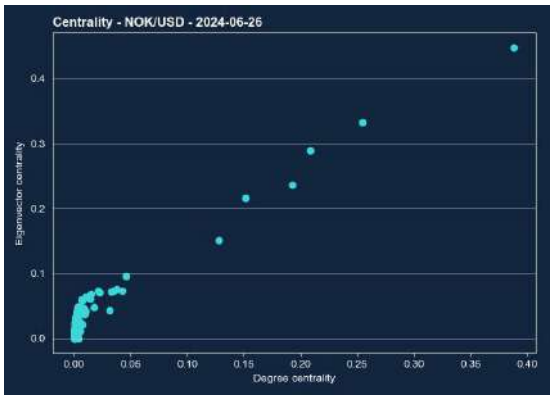

Figure 26: Network of outstanding derivative transactions in NOK/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



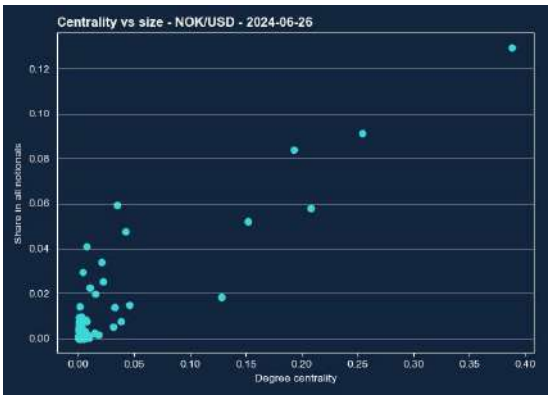

(a) Degrees



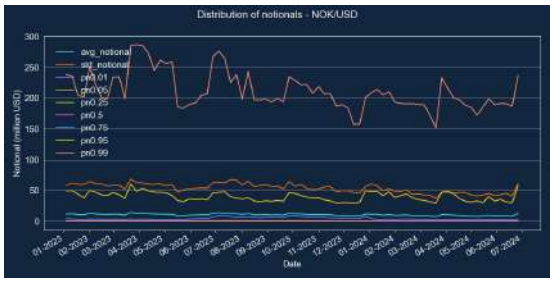

(b) Assortativity



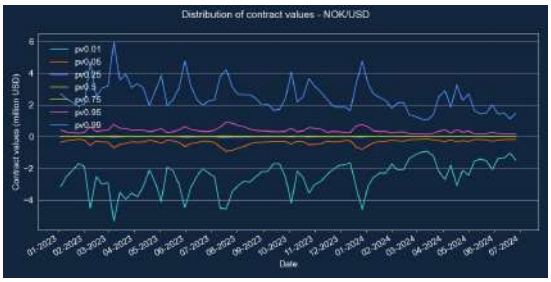

(c) Centrality




(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 27: Properties of the network of outstanding derivative transactions in NOK-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.7 NZD/USD

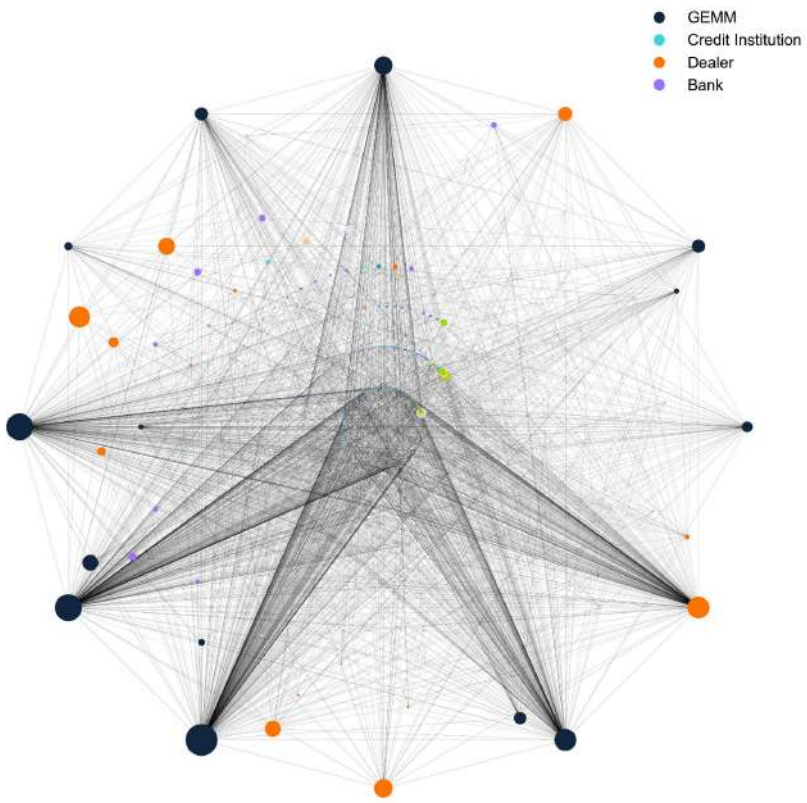
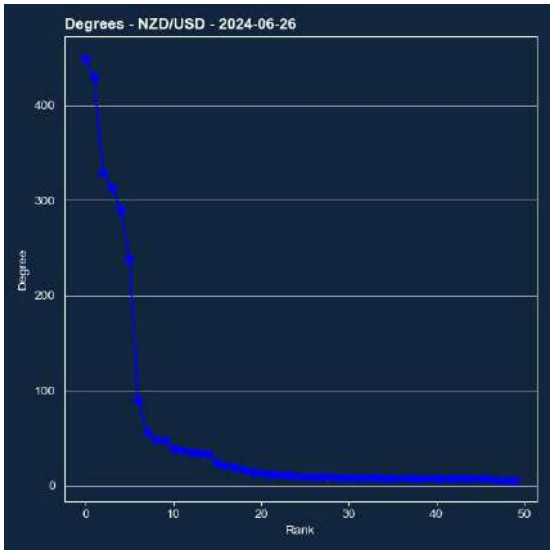
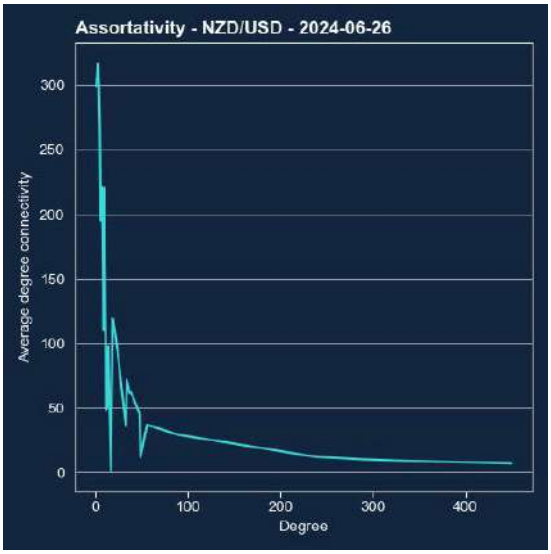


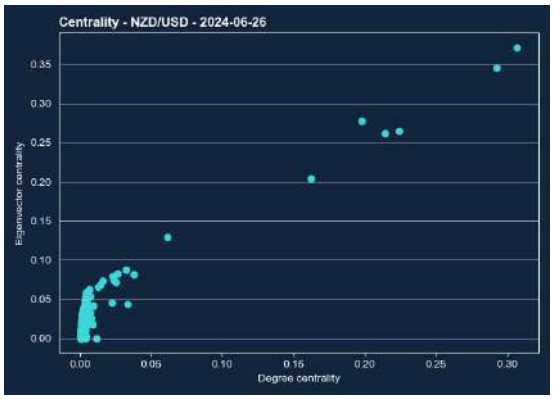

Figure 28: Network of outstanding derivative transactions in NZD/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



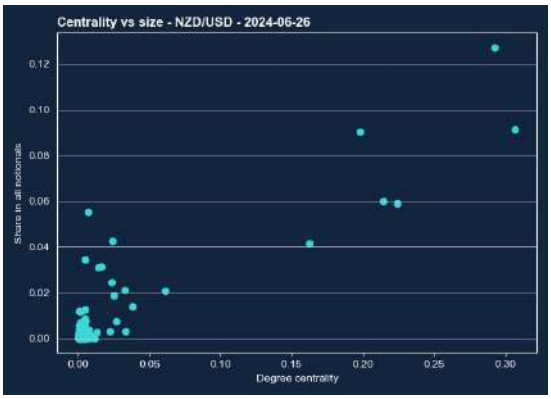

(a) Degrees



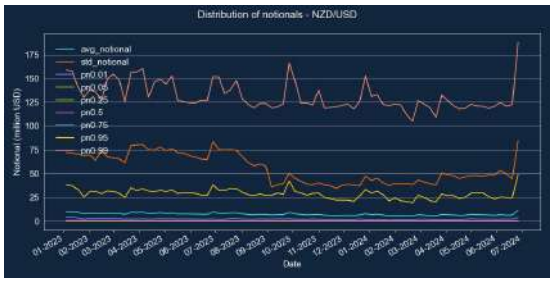

(b) Assortativity



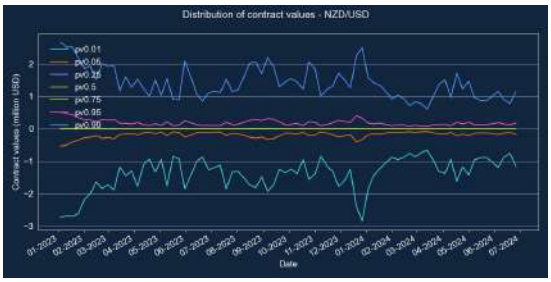

(c) Centrality




(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 29: Properties of the network of outstanding derivative transactions in NZD-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

## C.8 SEK/USD

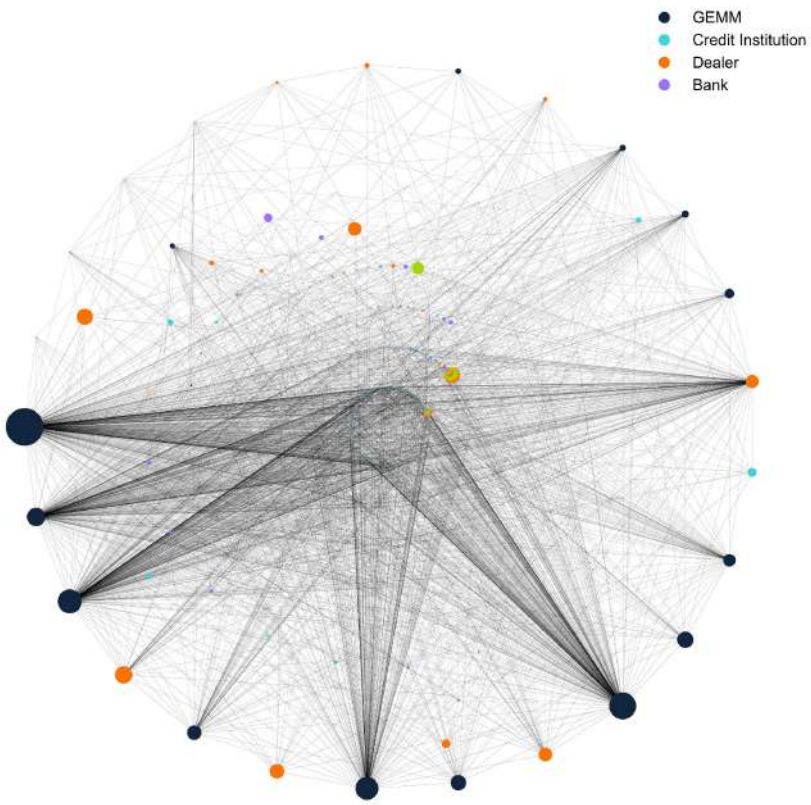
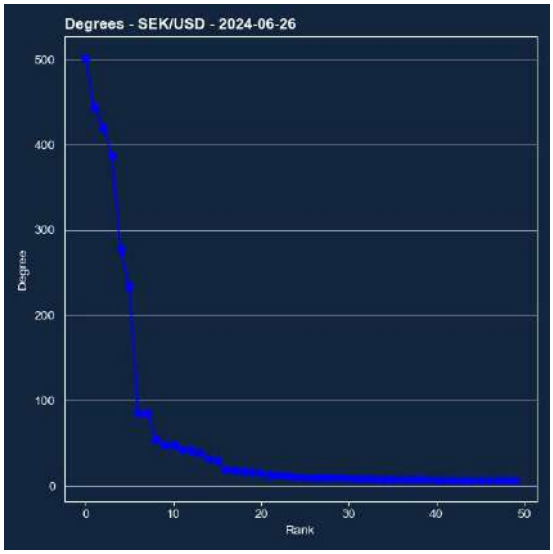
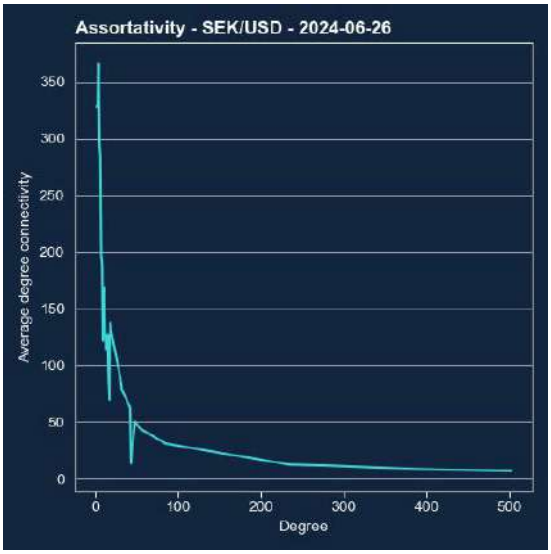


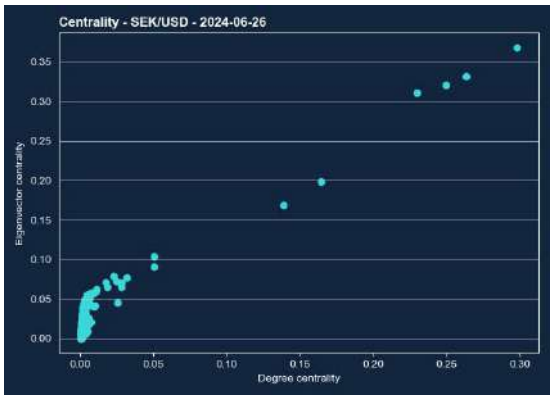

Figure 30: Network of outstanding derivative transactions in SEK/USD FX forwards. Source: EMIR position data (stock) reported to the Bank of England (26 June 2024).



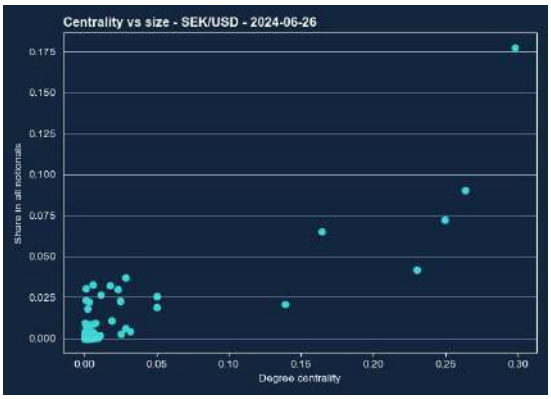

(a) Degrees



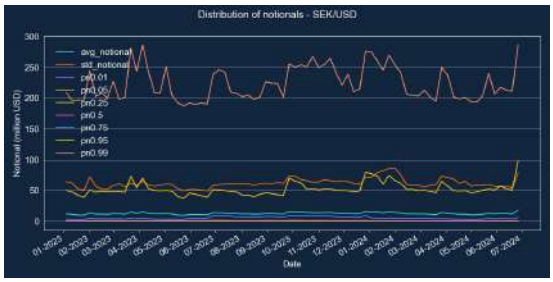

(b) Assortativity



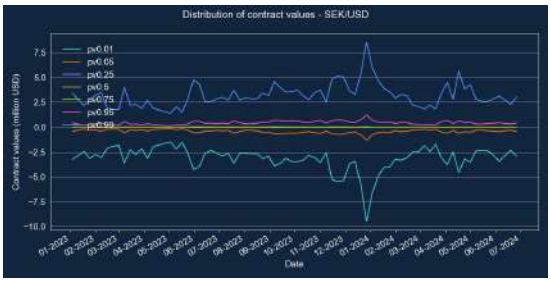

(c) Centrality




(d) Size




(e) Distribution of notionals




(f) Distribution of contract values




(g) Number of transactions and counterparties




(h) Concentration

Figure 31: Properties of the network of outstanding derivative transactions in SEK-USD FX forwards.
Sources: EMIR position data (stock) reported to the Bank of England. For snapshots, the data refers to 26 June 2024. The time series are covering 1 January 2023 to 30 June 2024.

# D Cumulative Values in G-10 Currencies for the Granular Dealers




(a) AUD/USD




(b) CAD/USD



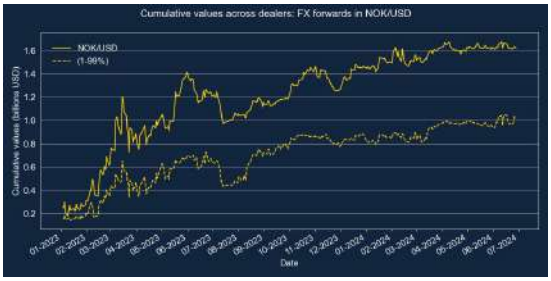

(c) CHF/USD




(d) GBP/USD




(e) JPY/USD




(f) NOK/USD




(g) NZD/USD




(h) SEK/USD

Figure 32: Cumulative net values of FX forwards for the main dealers in $\mathbb{D}$.
Sources: EMIR position data (stock) reported to the Bank of England. The time series are covering 1 January 2023 to 30 June 2024.

# E CIP deviation $b_T$ equivalent definitions

Consider the definition of the CIP deviation from Sushko et al. (2016) as:

$$b_T = \left(1 + \frac{i_{t,T}}{100}\frac{360}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0}\right)^{\frac{360}{T-t}}$$

We want to show that it is equivalent to our alternative measure, up to the first order Taylor approximation.

For $\frac{F_{0,T}}{S_0}$ close to 1, $log\left(\frac{F_{0,T}}{S_0}\right) \approx \frac{F_{0,T}}{S_0} - 1$ is close to 0, so: $\left(\frac{F_{0,T}}{S_0}\right)^{\frac{360}{T-t}} = exp\left(\frac{360}{T-t} log\left(\frac{F_{0,T}}{S_0}\right)\right) \approx 1 + \frac{360}{T-t} log\left(\frac{F_{0,T}}{S_0}\right)$.

Hence, up to a first order approximation:

$$\begin{aligned}
b_T &= \left(1 + \frac{i_{t,T}}{100}\frac{360}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0}\right)^{\frac{360}{T-t}} \\
&\approx \left(1 + \frac{i_{t,T}}{100}\frac{360}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\left(1 + \frac{360}{T-t} log\left(\frac{F_{0,T}}{S_0}\right)\right) \\
&\approx \left[\left(\frac{i_{t,T}}{100}\frac{T-t}{DayC} - \frac{i^*_{t,T}}{100}\frac{T-t}{DayC^*}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0} - 1\right)\right] \times \frac{360}{T-t} \\
&\approx \left[\left(1 + \frac{i_{t,T}}{100}\frac{T-t}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{T-t}{DayC^*}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\frac{F_{0,T}}{S_0} + \left(1 + \frac{i^*_{t,T}}{100}\frac{360}{DayC^*}\right)\right] \times \frac{360}{T-t} \\
&\approx \left[\left(1 + \frac{i_{t,T}}{100}\frac{T-t}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{T-t}{DayC^*}\right)\frac{F_{0,T}}{S_0} + \frac{i^*_{t,T}}{100}\left(\frac{T-t}{DayC^*} - \frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0} - 1\right)\right] \times \frac{360}{T-t} \\
b_T &= \left[\left(1 + \frac{i_{t,T}}{100}\frac{T-t}{DayC}\right) - \left(1 + \frac{i^*_{t,T}}{100}\frac{T-t}{DayC^*}\right)\frac{F_{0,T}}{S_0}\right] \times \frac{360}{T-t}
\end{aligned}$$

for $\frac{i^*_{t,T}}{100}\left(\frac{T-t}{DayC^*} - \frac{360}{DayC^*}\right)\left(\frac{F_{0,T}}{S_0} - 1\right)$ sufficiently small.