



BIS Working Papers

No 1383

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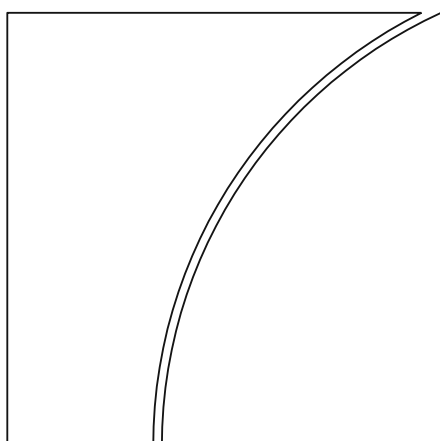
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Monetary and Economic Department

October 2026

JEL classification: E44, E58, F3, F38, G15

Keywords: exchange rates, non-deliverable forwards, capital controls, price discovery



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ISSN 1020-0959 (print)

ISSN 1682-7678 (online)

Offshore Forwards and Exchange Rate Transmission in Emerging Markets*

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This version: 7th October 2026

Abstract

We study how offshore non-deliverable forward (NDF) markets transmit exchange-rate pressures to domestic currency markets. Using unique transaction-level data on the universe of centrally cleared NDFs for ten emerging-market currencies over 2013–2025, we show that offshore NDF order flow moves both offshore forward and domestic spot exchange rates and widens the offshore–onshore forward spread. To our knowledge, this is the first transaction-level evidence on price formation in these markets. A \$1 billion long-USD order flow depreciates the domestic spot rate by about 10 basis points and the offshore NDF rate by about 18 basis points. The spot impact is larger when dealer balance sheets are tight. Policy episodes in the Chinese renminbi, Malaysian ringgit, and Indian rupee show how changes in offshore speculative activity and arbitrage between offshore and onshore markets affect the spread and domestic exchange rates. We rationalize these findings with a model in which offshore demand pressure generates NDF order flow, dealers hedge inventory through domestic spot markets, and capital controls limit intermediation between offshore and onshore forward markets.

JEL classification: E44; E58; F31; F38; G15

Keywords: Exchange Rates; Non-Deliverable Forwards; Capital Controls; Price Discovery

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1 Introduction

Offshore non-deliverable forward (NDF) markets are an important venue for price discovery in emerging-market (EM) currencies. Where capital controls restrict offshore investors’ access to domestic forward and spot markets, NDFs allow investors to take EM-currency positions without delivering the underlying currency. These contracts settle in U.S. dollars and are traded in offshore hubs such as London and Singapore, making the offshore NDF market a major venue for trading in currencies subject to capital controls (Lipscomb, 2005; Patel and Xia, 2019; Caballero et al., 2022).

Offshore NDF markets provide broader benefits in the form of price discovery, liquidity, and market access for investors facing capital controls (McCauley et al., 2014). The policy relevance of these markets came into focus in April 2026, when the Reserve Bank of India temporarily restricted Indian banks from offering rupee NDF contracts to clients after a build-up of positions and arbitrage activity between offshore and onshore markets. The stated concern in India was that while offshore-onshore linkages support price discovery in normal times, excessive position building can instead amplify exchange-rate volatility (Reuters, 2026). This policy response raises a central question. How important is offshore demand pressure for domestic exchange rates, and how do capital controls and intermediation constraints affect its transmission?²

We answer these questions using transaction-level data on the universe of NDF trades cleared through LCH ForexClear for ten EM currency pairs over 2013–2025. For every trade, we observe the timestamp, price, notional amount, and dealer-versus-client classification on each leg. We use these data to construct signed order-flow imbalance measures at intraday frequency and estimate how offshore order flow affects NDF, onshore forward, and domestic spot rates, and how these effects vary with intermediary conditions and regulatory access.

To organize the empirical analysis, we develop a simple equilibrium model of offshore NDF, onshore forward, and domestic spot markets under capital controls. The model builds on Liao and Zhang (2025), in which dealers hedge forward exposure in spot subject to balance-sheet costs, and De Leo et al. (2024), in which capital controls segment offshore and onshore currency markets. Offshore investors take long-USD, short-EM positions in NDFs when they expect greater EM depreciation than domestic investors. We refer to the resulting net demand as *offshore demand pressure*. Capital controls separate the two investor bases and restrict the arbitrage that would otherwise reduce differences between offshore and domestic valuations.

²Throughout the paper, the domestic or onshore exchange rate refers to the *deliverable* spot rate determined in the onshore market. Three prices thus need to be distinguished: the onshore (deliverable) spot rate, the onshore (deliverable) forward rate, and the offshore NDF rate, which is cash-settled in U.S. dollars. We use “domestic spot,” “onshore spot,” and “domestic exchange rate” interchangeably for the first of these. Throughout the empirical analysis, all exchange rates are quoted as EM currency units per U.S. dollar, so an increase denotes a depreciation of the EM currency; the model uses the same convention.

An offshore dealer absorbs offshore order flow that is not intermediated across the capital-control barrier and hedges the resulting inventory in domestic spot. An arbitrageur trades the offshore–onshore forward spread subject to balance-sheet costs. An onshore dealer takes the other side of the arbitrageur’s domestic forward position and also hedges in spot. Offshore order flow therefore transmits to domestic spot through dealer hedging, while intermediary balance-sheet costs determine the offshore–onshore forward spread.

The model generates two main predictions. First, greater offshore demand pressure moves the NDF rate, domestic spot rate, and offshore–onshore spread in the direction of the net offshore position. The offshore NDF responds more than the onshore forward because the NDF rate also compensates the offshore dealer for the cost of absorbing residual inventory. Second, tighter intermediation constraints widen the offshore–onshore spread generated by a given amount of order flow. In equilibrium, tighter constraints also reduce the amount of offshore flow executed and weaken its transmission to the domestic spot market. The two forces are thus separately identifiable: shifts in demand pressure move prices and the spread together, while shifts in intermediation costs move the spread relative to prices.

We begin with four policy episodes that illustrate these mechanisms. Following the August 2015 reform of the People’s Bank of China central-parity regime, the renminbi depreciated sharply, the offshore–onshore spread widened substantially, and cumulative offshore order imbalance moved toward long-USD and short-renminbi positions. Malaysia’s November 2016 restrictions reduced domestic-bank participation in offshore ringgit NDF activity and were followed by a sharp compression of the offshore–onshore spread and a reversal in cumulative long-USD and short-ringgit order imbalance. In 2020, the Reserve Bank of India permitted Indian banks to participate in offshore rupee NDF markets, increasing the set of intermediaries able to operate across offshore and onshore markets. The offshore–onshore spread narrowed substantially following the reform. The April 2026 restrictions moved regulatory access in the opposite direction by limiting Indian-bank participation in the offshore NDF market and were followed by a widening of the spread.

We then estimate the price impact of offshore order flow across the full panel of ten currencies. These markets are sizable. LCH clears roughly 5,500 NDF trades per day across the ten currencies, with a combined daily notional of approximately \$30 billion, and the most active pairs, KRW, INR, and TWD, each record \$5–7 billion per day. A \$1 billion increase in long-USD and short-EM order flow depreciates the domestic spot rate by approximately 10 basis points. The offshore NDF response is approximately 18 basis points, nearly twice as large though less precisely estimated, consistent with an increase in the offshore premium in addition to the response of the domestic spot market. Price impact also varies with intermediary conditions. When intermediary constraints are tighter, we expect a greater price impact of order flow, as dealers need to adjust prices by more to clear trades. The estimated spot response falls from 17.8 basis points when the

gross FX positions of New York reporting dealers are one standard deviation below their mean to 7.1 basis points when they are one standard deviation above their mean.

At high frequency, an innovation in NDF order flow moves both the offshore NDF and domestic spot rates within minutes, with a larger response in the NDF market. Information shares based on [Hasbrouck \(1995\)](#) and [Gonzalo and Granger \(1995\)](#) show that price discovery is shared across venues. The onshore market leads in the most actively traded pairs, while the NDF accounts for a larger share of price discovery in less actively traded pairs.

Finally, we incorporate the onshore forward rate and measure the offshore–onshore spread directly. A daily structural vector autoregression shows that an innovation in NDF order flow widens the offshore–onshore spread and generates a persistent response in the domestic spot rate.

Each piece of evidence maps to a specific mechanism in the model. The panel price-impact estimates correspond to the model’s conditional price-impact expressions: the spot response per unit of flow measures the depth of the domestic spot market, while the larger NDF response reflects the additional inventory premium charged by the offshore dealer. The intraday adjustment pattern, in which the NDF moves first and the spot rate follows within minutes, is the footprint of the dealer-hedging channel through which offshore positions reach the domestic market. The widening of the offshore–onshore spread after an order-flow innovation in the daily analysis corresponds to intermediaries pricing residual inventory, and its gradual decay is consistent with arbitrage capital absorbing the imbalance over time. Finally, the policy episodes move the model’s two forces separately: the 2015 renminbi reform and the 2016 Malaysian restrictions shifted offshore demand pressure, while the 2020 and 2026 Indian reforms shifted the cost of intermediation, with spread responses of the predicted sign in each case.

Our contribution is threefold. First, we provide transaction-level evidence on signed order flow in offshore NDF markets across ten controlled currencies. To our knowledge, this is the first analysis of price formation in these markets based on signed transaction-level data. Existing evidence relies on quoted rates, which contain neither quantities nor trade direction ([Park, 2001](#); [Ding et al., 2014](#)), or uses trade-repository data descriptively ([Pezzini, 2018](#)). We develop a model in which differences between offshore and domestic expectations generate offshore demand pressure, dealer hedging transmits that flow to domestic spot, and intermediary balance-sheet costs determine the offshore–onshore spread; the model separates the forces that drive offshore demand, conditional price impact, and market segmentation. And we combine intraday and daily evidence with four policy episodes to show that both transmission and segmentation vary with intermediary conditions and with the regulatory access of domestic banks to offshore markets. These results connect the literatures on FX order flow and price discovery, intermediary asset pricing, and segmented currency markets under capital controls.

Taken together, our results show that order flow in offshore markets transmits to domestic spot rates, while capital controls and intermediation constraints affect the extent of this transmission and the size of the offshore–onshore spread. An important policy margin is the ability of domestic banks to participate in offshore NDF markets. Expanding this access increases arbitrage between offshore and onshore markets and reduces the offshore–onshore spread, while restrictions on access reduce cross-market intermediation.

The remainder of the paper is structured as follows. Section 2 reviews the related literature. Section 3 describes the institutional setting and data. Section 4 presents the theoretical model and its empirical predictions. Section 5 reports the empirical results. Section 6 concludes.

2 Related Literature

Our paper contributes to three related strands of the literature. The first studies offshore NDF markets and capital controls in emerging economies. The second studies exchange-rate determination through financial intermediaries and order flow. The third studies segmentation between offshore and onshore currency markets.

A large literature studies the development of offshore NDF markets and their interaction with domestic currency markets. [Lipscomb \(2005\)](#) provides an early overview of NDF markets and the role of capital controls in sustaining offshore trading. [McCauley et al. \(2014\)](#) document the growth of offshore activity and the post-crisis clearing reforms that moved a large share of NDF trading onto central counterparties. [Patel and Xia \(2019\)](#) show that offshore NDF trading has grown substantially relative to onshore markets and that offshore rates Granger-cause onshore exchange rates for most EM currencies. [Schmittmann and Teng \(2020\)](#) study offshore currency markets in Asia, while [Caballero et al. \(2022\)](#) document the broader shift of EM currency trading toward offshore venues. Related work studies capital controls and their effects on financial markets ([Forbes and Warnock, 2012](#); [Fernández et al., 2016](#); [Klein and Shambaugh, 2015](#); [Pasricha, 2017](#)). [Bahaj and Reis \(2026a\)](#) study China’s parallel onshore and offshore currencies and show how restrictions on convertibility, together with monetary and liquidity policies, allow policymakers to manage the link between offshore and onshore exchange rates. Country-specific studies of the Indian rupee NDF market include [Patnaik and Sengupta \(2021\)](#) and [Patnaik et al. \(2016\)](#). [Hutchison et al. \(2012\)](#) estimate no-arbitrage bands implied by CIP deviations in the offshore rupee NDF market and show that these bands shift with changes in Indian capital controls. Closest to our data, [Pezzini \(2018\)](#) provides descriptive evidence on the NDF market using trade-level data from the Hong Kong Trade Repository, while quote-based studies document price discovery between NDF and onshore markets, including [Park \(2001\)](#) for the Korean won and [Ding et al. \(2014\)](#) for the renminbi. Together with the Granger-causality evidence of [Patel and Xia \(2019\)](#), this

work establishes offshore NDF markets as an important venue for price discovery in EM currencies. We add transaction-level evidence on signed offshore NDF order flow, which allows us to study how offshore trading is transmitted to domestic exchange rates. We also examine changes in domestic-bank participation in offshore NDF markets and their effects on the offshore–onshore spread and domestic spot rate.

A second related literature studies the role of financial intermediaries in exchange-rate determination. [Gabaix and Maggiori \(2015\)](#) and [Maggiori \(2017\)](#) show how constrained intermediaries absorb cross-border imbalances and affect equilibrium exchange rates, while [Itskhoki and Mukhin \(2021\)](#) emphasize the role of financial-market segmentation. Closest to our mechanism, [Liao and Zhang \(2025\)](#) show that forward hedging demand affects spot exchange rates through dealer hedging, with intermediary constraints determining the resulting basis. Related empirical work links intermediary balance sheets to asset prices and currency bases ([He et al., 2017](#); [Cenedese et al., 2021](#)), while [Bräuer and Hau \(2022\)](#) show that hedging demand explains an important share of forward-premium variation. [Camanho et al. \(2022\)](#) and [Bahaj and Reis \(2026b\)](#) study intermediary frictions in capital flows and currency internationalization. In closely related contemporaneous work, [Naudon and Barria \(2026\)](#) show that local banks in the Chilean onshore market absorb non-resident NDF demand and that the price impact of these flows on the spot rate and cross-currency basis varies with intermediary balance-sheet capacity. We study a different market structure. Our data cover transaction-level order flow in the offshore cleared NDF market across ten currencies, which allows us to examine transmission to domestic spot together with offshore–onshore segmentation and changes in regulatory access. Our model applies the dealer-hedging channel to segmented NDF markets, where offshore positions are transmitted to domestic spot through dealer hedging and intermediation across offshore and onshore markets.

Finally, our analysis relates to the FX microstructure and offshore–onshore segmentation literatures. A large FX microstructure literature shows that order flow contains information about exchange-rate movements ([Evans and Lyons, 2002](#); [Ranaldo and Somogyi, 2021](#)). We extend this analysis to offshore NDF markets using signed transaction-level order flow and examine its transmission to domestic spot prices. [Cerutti and Zhou \(2023\)](#) document substantial offshore–onshore forward spreads across EM currencies and show that capital controls, sovereign risk, and global financial conditions are important determinants. [Török \(2026\)](#) documents time-varying CIP deviations in frontier-currency NDF markets that widen sharply when devaluations are anticipated, including in the Egyptian Pound. [De Leo et al. \(2024\)](#) develop a model in which speculative forward demand generates CIP deviations when capital controls limit arbitrage, while [Liu et al. \(2022\)](#) show that capital controls alter the relation between currency risk and expected returns. We complement this work by linking offshore order flow directly to the domestic spot rate and the offshore–onshore spread, and by examining how these responses vary

with intermediary conditions and changes in regulatory access.

3 Institutional Details and Data

In our empirical analysis, we use transaction-level data on centrally cleared NDFs from LCH ForexClear, combined with high-frequency price data from LSEG Tick History and daily forward rates from Bloomberg. We first describe the institutional setting and mechanics of the offshore NDF market. We then introduce the transaction and price data and construct the two main variables used in the empirical analysis, order-flow imbalance and the offshore–onshore forward spread. Finally, we describe the global risk and dealer balance-sheet variables used in the state-dependent analysis.

3.1 Non-Deliverable Forward Contracts

Many EM economies maintain capital-account restrictions that limit non-resident access to onshore FX markets. Domestic forward and spot markets may be subject to documentation requirements, position limits, and know-your-customer restrictions that make direct participation costly or infeasible for offshore investors. A *non-deliverable forward* (NDF) allows investors to take a forward position in a currency without delivering the underlying currency. The contract instead settles in U.S. dollars. Although NDFs are not exclusively an EM instrument, they are used predominantly for EM and frontier currencies where capital controls restrict offshore access to domestic forward and spot markets. Trading takes place predominantly in London and Singapore, and an increasing share of NDF activity is centrally cleared.³ Offshore NDF markets play a broader role in the FX ecosystem for these currencies. They widen market access by allowing investors to obtain currency exposure that capital controls would otherwise preclude, provide a liquid venue for hedging and position-taking, and contribute to price discovery and market efficiency by aggregating information from investors who cannot transact onshore.

Two counterparties agree at trade date t on a notional amount N , a forward rate F , and a fixing date T . At fixing, no physical delivery of the EM currency takes place. Instead, the contract settles in U.S. dollars based on the difference between the prevailing reference rate S_T and the agreed forward rate F . For a notional of N U.S. dollars, a long-USD and short-EM position pays

$$\text{Settlement}_T^{\$} = N \frac{S_T - F}{S_T}, \quad (1)$$

where S is quoted in EM units per USD, such as INR/USD. The opposite party, which is

³Offshore investors are not the only participants in these markets. Some EM central banks also intervene through NDFs or NDF-like cash-settled instruments rather than in the spot market, in part because cash-settled intervention does not directly commit foreign exchange reserves.

long EM and short USD, receives the negative of this amount. Cash settlement therefore gives offshore investors currency exposure without requiring them to hold or deliver the EM currency.

NDF exposure takes two main contract forms. *Outright NDFs* are stand-alone forward contracts on a single currency pair, struck at a forward rate and settled in U.S. dollars at fixing. *NDF swaps* combine an NDF with an offsetting spot transaction or a second NDF leg and are used to roll positions or manage funding across maturities. Either type of contract may remain bilateral or be transferred to a central counterparty such as LCH ForexClear after execution. The CCP becomes the buyer to every seller and the seller to every buyer and guarantees performance if one party defaults. Our LCH ForexClear sample contains the universe of NDF trades cleared through LCH and consists predominantly of outright NDFs at short and medium maturities, as shown in Table 1. Bilateral trades that are not centrally cleared are not observed in our data.

At maturity, NDFs settle against a published reference fixing rate S_T , which determines the U.S. dollar cash flow of the contract. Contract terms and fixing benchmarks follow the market-standard documentation published by EMTA, the trade association for emerging-market trading. EMTA specifies the recommended fixing rate for each currency.⁴ These fixing rates are typically published by an official body or benchmark administrator in the onshore market and serve as the settlement reference for the corresponding NDF contracts.

NDF example. Figure 1 illustrates the contractual flows in an INR/USD NDF with a forward rate of $F = 83$ INR per USD and a notional of $N = \$1$ million. At the trade date, the two counterparties agree on the forward rate and notional but exchange no cash, as shown in panel (a). At fixing, the reference rate S_T is observed and the contract settles in U.S. dollars, as shown in panel (b). The long-INR counterparty gains if the rupee appreciates, $S_T < F$, and loses if the rupee depreciates, $S_T > F$. The short-INR counterparty has the opposite payoff. No Indian rupees change hands at any point.

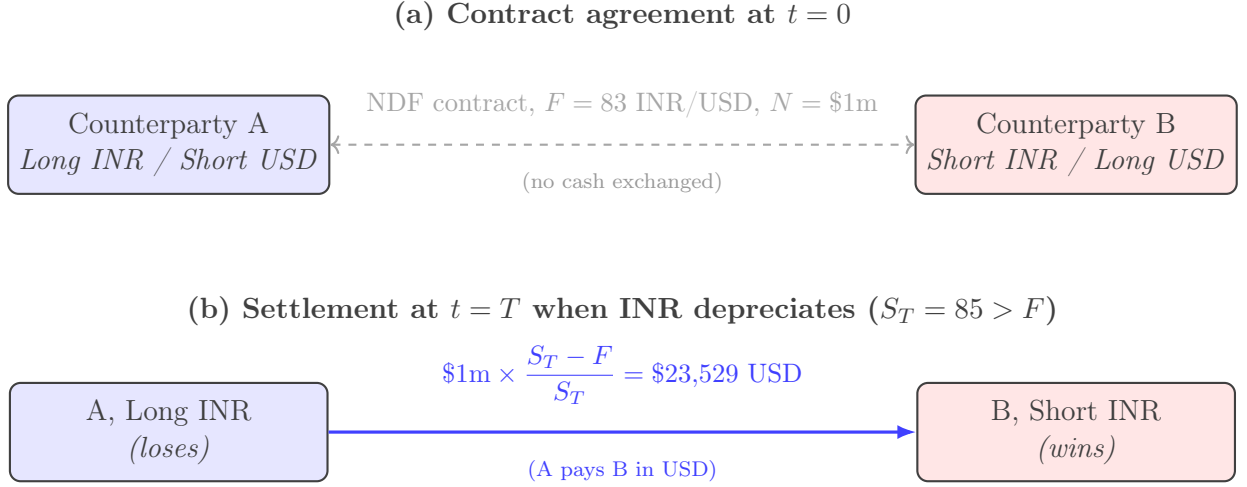
3.2 LCH Offshore NDF Data

LCH ForexClear transactions. Our main transaction data come from LCH ForexClear, the dominant central counterparty for centrally cleared NDFs. LCH accounted for approximately 98.1% of NDF volume cleared across CCPs in 2024.⁵ We observe the

⁴EMTA publishes standardized NDF documentation and recommended fixing benchmarks for each currency. See <https://www.emta.org>. On the institutional background of NDF markets and fixing conventions, see Lipscomb (2005) and Patel and Xia (2019).

⁵The estimate is based on CCPView data reported in ION/Clarus, “2024 CCP Volumes and Share in CRD and FXD,” which compares NDF volume cleared through LCH ForexClear, Comder, and CME OTC. See <https://iongroup.com/blog/markets/2024-ccp-volumes-and-share-in-crd-and-fxd/>. The 98.1% figure refers to NDF volume cleared through CCPs and not to the total NDF market, which

Figure 1: NDF contract and settlement flows



Notes. The figure illustrates the contractual flows in an INR/USD NDF with forward rate $F = 83$ INR per USD and notional $N = \$1$ million. Panel (a) shows the contract agreement at $t = 0$, when the two counterparties agree on the forward rate and notional but exchange no cash. Panel (b) shows settlement at $t = T$ when the INR fixing rate S_T is above the forward rate and the INR has depreciated. The long-INR counterparty A pays the U.S. dollar settlement amount to the short-INR counterparty B. When $S_T < F$, the INR has appreciated and the direction of the payment reverses. All settlement is in U.S. dollars and no Indian rupees change hands.

universe of NDF trades cleared through LCH for the ten currencies in our sample at the transaction level, with timestamps precise to the second. The timestamps record the registration of each trade in the ForexClear clearing system, which we use as a proxy for the execution time. Clearing of NDFs is a post-trade activity, and LCH is required to novate or reject submitted trades within 10 seconds under European regulatory requirements.⁶ For each trade, we observe the currency pair, notional amount in U.S. dollars, trade direction, NDF price, prevailing spot price, fixing and maturity dates, and an anonymized member identifier on each leg. The full list of variables is reported in Table A.1 of Appendix A.1. The LCH sample runs from January 2013 to December 2025.⁷

Our forward and spot panel covers ten EM currency pairs against the U.S. dollar, the currencies with sufficient centrally cleared NDF activity at LCH for the high-frequency analysis. These are the Brazilian real (BRL), Chilean peso (CLP), Chinese renminbi (CNY), Colombian peso (COP), Indian rupee (INR), Indonesian rupiah (IDR), Korean won (KRW), Malaysian ringgit (MYR), Philippine peso (PHP), and New Taiwan dollar

also includes uncleared bilateral trading.

⁶See the Reserve Bank of Australia's assessment of LCH (2018), Appendix B, <https://www.rba.gov.au/payments-and-infrastructure/financial-market-infrastructure/clearing-and-settlement-facilities/assessments/lch/2018/appendix-b.html>.

⁷Trade counts and volumes are reported on a net basis, so that each economic trade is counted once. ForexClear reports statistics on a gross basis covering both legs of each cleared trade, which accounts for the difference between our figures and ForexClear's published volumes.

(TWD). We omit currencies such as the Thai baht and Vietnamese dong, where cleared activity is too sparse for the five-minute analysis. Appendix A.2 reports descriptive evidence on offshore–onshore forward spreads and CIP deviations for the ten currencies.

The member identifiers allow us to classify counterparties into three groups, as shown in Figure A.1. *Forex clearing members* are large global banks with direct CCP membership that clear their own and client trades. *Dealers* are affiliates of clearing members that trade NDFs and clear through their parent’s CCP membership. *Clients* are banks that do not hold direct clearing membership and clear through a clearing member acting as client-clearing broker. All counterparties in the dataset are banks. We use this classification to separate client-cleared and house order flow in the robustness tests of Appendix C.1.

Because all counterparties are banks, the cleared order flow is predominantly interbank. Signed order flow therefore measures the net offshore demand pressure reaching dealers, including the redistribution of positions originated by end investors, rather than the identified positions of particular trader types.

Table 1 summarizes the LCH transaction data. The top five clearing members account for between 39% of cleared volume for INR and 61% for MYR, while the top ten account for between 63% and 84%. Trading is concentrated at short and medium maturities. Contracts with maturities of 8–90 days account for around 70% of cleared volume across currencies, while maturities beyond one year account for less than 2.5%. Trading activity also differs substantially across currencies. KRW, INR, and TWD each record around 1,000–1,500 trades per day and daily volumes of around \$5–7 billion, while MYR records fewer than 50 trades per day and daily volume of around \$0.2 billion. Mean trade sizes range from around \$3.7 million for KRW to \$17 million for BRL and CNY.

Table 1: Transaction statistics by currency

	USD/BRL	USD/CLP	USD/CNY	USD/COP	USD/IDR	USD/INR	USD/KRW	USD/MYR	USD/PHP	USD/TWD
<i>Panel A: Trade Characteristics</i>										
Trades per trading day	267.6	177.9	98.0	162.2	477.3	1,473.2	1,482.9	42.7	332.9	1,051.9
daily notional (USD bn)	4.61	1.24	1.65	1.21	1.93	6.69	5.50	0.23	1.37	6.01
Mean trade size (USD mn)	17.24	6.97	16.84	7.44	4.05	4.54	3.71	5.27	4.12	5.71
Median trade size (USD mn)	1.00	2.00	10.00	3.00	1.00	1.00	1.00	2.00	1.00	1.00
P10 trade size (USD mn)	0.21	0.48	1.00	0.45	1.00	0.50	0.50	1.00	1.00	1.00
P90 trade size (USD mn)	50.00	19.00	34.00	19.00	10.00	9.50	4.99	12.00	10.00	15.00
SD trade size (USD mn)	53.52	19.05	34.69	18.19	13.04	19.35	19.48	8.75	12.21	18.53
<i>Panel B: Clearing-member statistics</i>										
Total active members	38	37	35	35	36	40	40	28	33	39
HHI of member trade-count shares	0.07	0.07	0.06	0.07	0.07	0.07	0.08	0.10	0.07	0.07
Top-5 share of notional (%)	50.0	44.4	45.9	46.0	40.0	39.1	41.4	61.4	45.2	42.7
Top-10 share of notional (%)	72.5	70.0	71.9	70.6	65.8	63.3	64.6	84.0	69.1	65.3
Average currencies traded per member	8.9	9.1	9.4	9.3	9.2	8.8	8.8	9.9	9.5	9.0

Notes. Summary statistics on LCH ForexClear cleared NDF transactions for the ten currency pairs in our sample, computed over 2013-01-01 to 2025-12-31. Trade counts and volumes are on a net basis, with each economic trade counted once. Averages pool the full sample period, and cleared volumes in recent years are well above the sample mean. Appendix C.3 reports statistics by subperiod.

Appendix A.1 reports additional evidence on the LCH data. Monthly cleared volume increased substantially over the sample period, reflecting both the growth of offshore NDF trading and the post-2016 increase in central clearing of OTC derivatives (Figure A.2). Clearing-member concentration, measured by the Herfindahl–Hirschman Index, declined modestly as the membership base broadened (Figure A.3), while Figure A.4 reports the maturity distribution of cleared contracts.

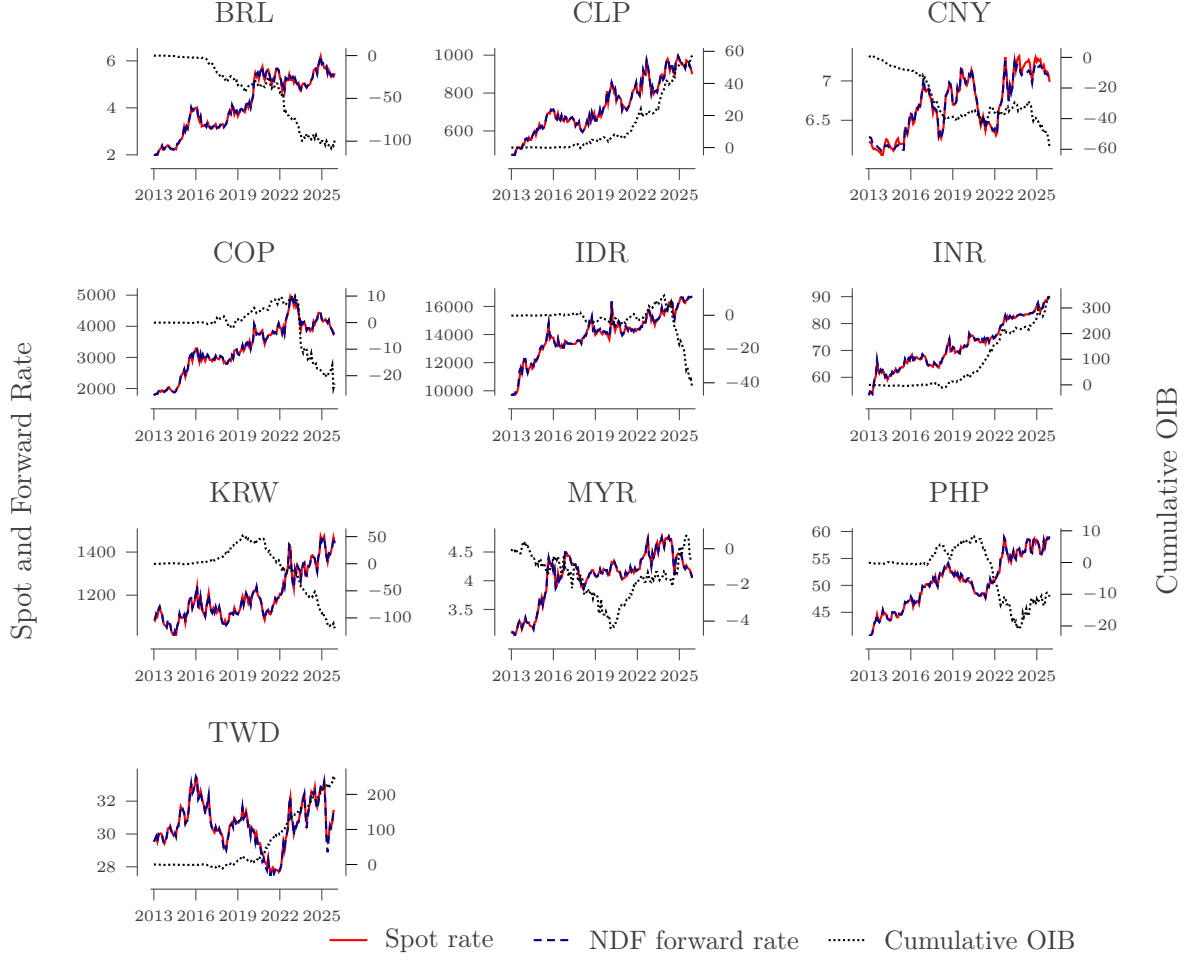
Price data. We combine the transaction data with price data from LSEG and Bloomberg. Throughout, the onshore spot rate is the *deliverable* spot rate of the onshore market, and the onshore forward is the deliverable forward traded onshore; both are distinct from the offshore NDF, which is cash-settled in U.S. dollars. All exchange rates are quoted as EM currency units per U.S. dollar. An increase in any rate therefore denotes a depreciation of the EM currency, and a positive order-flow imbalance denotes long-USD and short-EM pressure. For the high-frequency analysis, we use five-minute mid-quotes on offshore NDF and onshore spot rates from LSEG Tick History. Mid-quotes are computed as $(\text{bid} + \text{ask})/2$ at five-minute interval ends. We remove observations with implausibly wide bid–ask spreads and quotes that remain unchanged for more than five minutes. For the daily analysis, we obtain one-month outright onshore forward rates from Bloomberg. The outright forward rate is computed from forward points as

$$F_{i,t,t+n}^{\text{on}} = S_{i,t} + \frac{FP_{i,t,t+n}^{\text{on}}}{c_i},$$

where c_i is Bloomberg’s pair-specific point-scaling convention. Offshore one-month NDF rates are constructed in the same way from NDF forward points. The daily forward and spot panel covers January 2013 to December 2025. For the April 2026 India episode in Section 5.1.4, we extend the daily spot and forward series through May 2026; LCH transaction data are not available beyond December 2025.

Order flow. We use the transaction data to construct signed offshore NDF order flow. Each trade is signed using the algorithm of Lee and Ready (1991). We compare the transaction price with the bid–ask midpoint prevailing one second before its recorded LCH registration timestamp, using the latest quote available at or before that time from LSEG Tick History. A trade is classified as buyer-initiated if its price is above this midpoint and seller-initiated if it is below. Trades at the midpoint are classified using the tick test relative to the previous trade. Appendix C.2 examines sensitivity to alternative quote lags. We standardize all currency pairs to the EM-per-USD quotation before assigning trade direction, so that a buyer-initiated trade corresponds to a long-USD position and positive order-flow imbalance denotes long-USD and short-EM pressure. Buyer initiation is inferred from transaction prices and does not identify the type of trader behind the

Figure 2: Spot Rate, NDF Forward Rate, and Cumulative Order Imbalance by Currency



Notes. This figure plots spot rates, NDF forward rates, and cumulative LCH order imbalance by currency pair. Spot and NDF forward rates are on the left axis. Cumulative order imbalance is measured in USD billions and plotted on the right axis. The sample is from January 2013 to December 2025.

transaction.

For currency pair i and time interval t , order-flow imbalance is

$$OIB_{i,t} = \sum_{k \in \mathcal{K}(i,t)} (\mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]) \times V_k, \quad (2)$$

where $\mathcal{K}(i, t)$ indexes trades in currency pair i during interval t , $T_k \in \{B, S\}$ denotes the Lee–Ready buyer or seller initiation classification, and V_k is the trade notional in U.S. dollars. We aggregate $OIB_{i,t}$ at the five-minute frequency for the high-frequency VECM analysis and at the daily frequency for the daily VAR. Figure 2 plots cumulative order imbalance alongside spot and NDF rates for the ten currencies in our sample.

Offshore–onshore forward spread. We measure segmentation between offshore NDF and onshore forward markets using the offshore–onshore forward spread. We first compute the annualized one-month forward premium for currency i as

$$\rho_{i,t,t+n} = \frac{360}{n} \log \left(\frac{F_{i,t,t+n}}{S_{i,t}} \right), \quad (3)$$

separately for the offshore NDF rate, $\rho_{i,t,t+n}^{off}$, and the onshore forward rate, $\rho_{i,t,t+n}^{on}$, and express each premium in basis points. The offshore–onshore forward spread is

$$\text{FLOOP}_{i,t} \equiv \rho_{i,t,t+n}^{off} - \rho_{i,t,t+n}^{on}, \quad (4)$$

measured in annualized basis points. We refer to this variable as FLOOP in equations, tables, and figures and winsorize it at the 0.1% level to remove extreme observations.

We also construct offshore CIP deviations using one-month forward rates and corresponding interest rates. The construction of the cross-currency basis and the associated time-series evidence are reported in [Appendix A.2](#).

3.3 State Variables and Controls

Global risk factors. In the order-flow regressions, we control for two standard global risk factors, the broad U.S. dollar index from the Federal Reserve and the VIX implied volatility index. We also use the VIX as a state variable to examine whether the price impact of offshore order flow varies with global risk conditions.

Dealer FX positions. We construct an aggregate measure of gross dealer FX positions using the New York reporting-dealer panel. The data contain gross weekly FX positions of major U.S. FX-reporting banks in five advanced-economy currencies against the U.S. dollar. These are the Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), Japanese yen (JPY), and pound sterling (GBP). The reporting panel includes the same group of global FX-active primary dealers used in [He et al. \(2017\)](#). Following [Cenedese et al. \(2021\)](#), we restrict attention to the subset of primary dealers active in emerging-market currencies.⁸ We aggregate absolute long and short positions across the five currencies to obtain a single gross-position series. We use this series as a proxy for the scale of dealer risk-bearing activity. Because gross positions are equilibrium quantities rather than direct measures of unused balance-sheet capacity, we interpret the interaction results in [Section 5](#)

⁸The entities include BNP Paribas, Barclays, Bank of America, Citigroup, Credit Suisse, Deutsche Bank, Goldman Sachs, HSBC, JP Morgan, Morgan Stanley, Société Générale, Standard Chartered, State Street, and UBS. These banks are among the most active intermediaries in offshore FX markets, including the NDF market ([He et al., 2017](#); [Cenedese et al., 2021](#)). Panel composition changes over time. Credit Suisse, for example, ceased to operate as a separate institution after its acquisition by UBS in 2023.

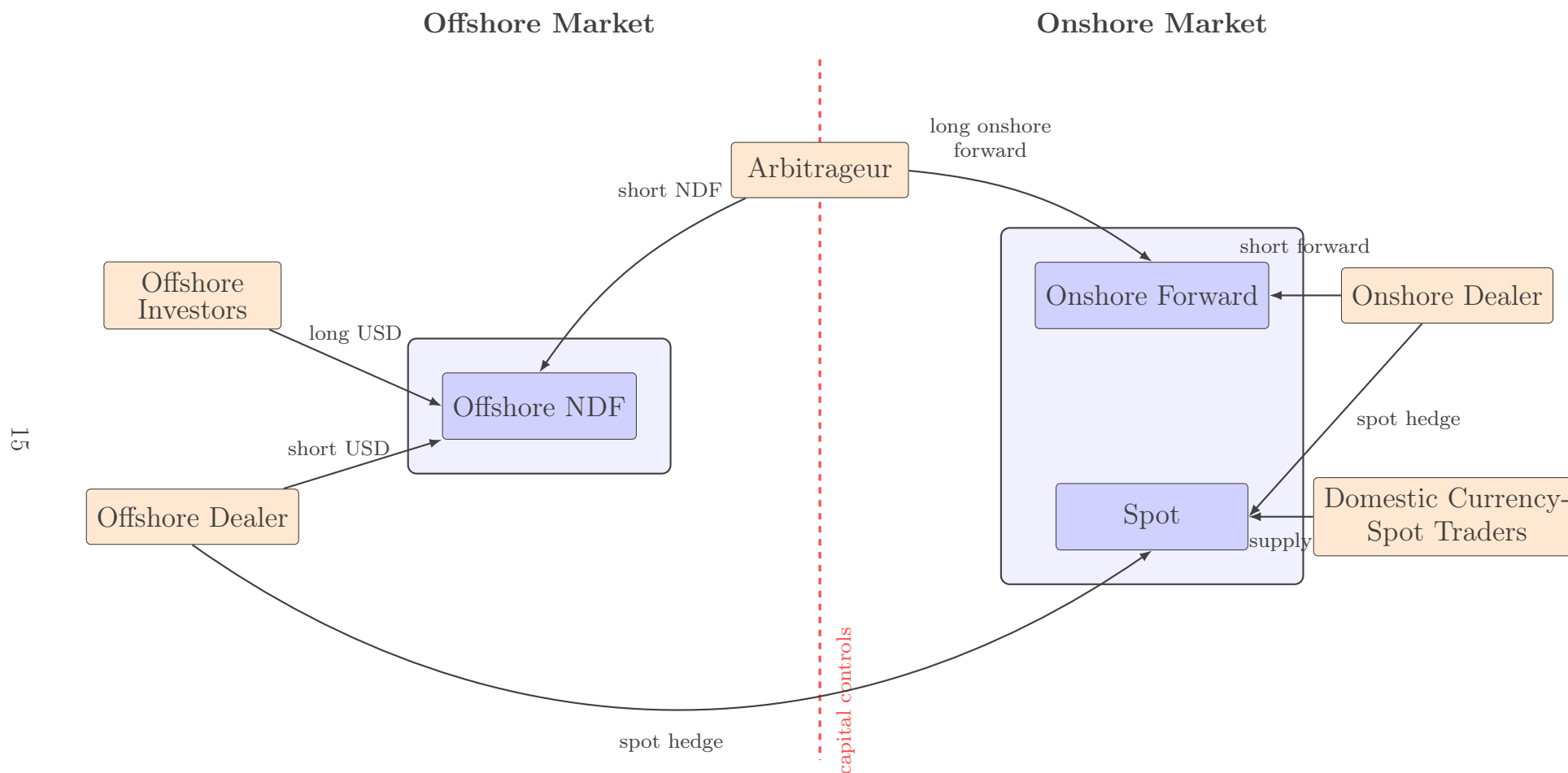
as evidence of state dependence rather than as a causal effect of intermediary capacity.

4 Model

We develop a simple model linking offshore demand pressure in NDF markets to exchange-rate movements in domestic spot markets. Capital controls segment offshore and onshore forward markets. Offshore demand pressure arises when offshore investors expect greater EM depreciation than domestic investors, generating signed long-USD NDF order flow. Dealers hedge this flow in the domestic spot market, while intermediary balance-sheet costs determine the offshore–onshore spread. Conditional on executed flow, tighter intermediation constraints widen the spread. In equilibrium, tighter constraints also reduce offshore flow and therefore weaken its effect on the domestic spot rate.

Five agents trade across offshore and onshore markets. *Offshore investors* generate net long-USD demand in the NDF market. An *offshore dealer* takes the other side and absorbs residual NDF inventory, which she hedges in the domestic spot market. An *arbitrageur* links offshore and onshore forward markets by taking offsetting positions, short NDF and long onshore forward in equal size. The position earns the offshore–onshore spread without FX risk but requires balance-sheet capacity. An *onshore dealer*, which is a domestic authorized dealer, takes the short side of the arbitrageur’s onshore forward position and hedges this exposure by buying U.S. dollars in spot. Finally, *domestic currency-spot traders* absorb the resulting spot demand at a market-clearing price. Offshore and domestic investors may hold different expectations of the terminal exchange rate. Variation in demand pressure arises from changes in offshore expectations relative to domestic expectations.

Figure 3: Agents, markets, and flows in the model



Notes. The offshore market contains the offshore NDF, while the onshore market contains the onshore forward and domestic spot markets. The two markets are separated by the capital-controls barrier. The five agents are offshore investors, the offshore dealer, the arbitrageur, the onshore dealer, and domestic currency-spot traders. Solid black arrows denote positions taken by each agent. Two flows cross the capital-controls barrier. The arbitrageur trades across the offshore and onshore forward markets, while the offshore dealer hedges residual NDF inventory in domestic spot.

4.1 Setup

There are two dates, $t = 0$ for trading and $t = 1$ for settlement. The terminal spot rate S_1 has variance σ^2 . We denote the offshore expectation by

$$\mu \equiv E^{off}[S_1],$$

while domestic investors hold the expectation $E^{dom}[S_1]$. Agents agree on the variance but may disagree about the expected terminal exchange rate. We model changes in offshore demand pressure as variation in the offshore expectation μ while holding the domestic expectation fixed.

All prices are quoted in EM currency per U.S. dollar, matching the convention of the empirical analysis, so a higher value represents an EM depreciation. Three prices are determined in equilibrium. These are the spot rate S_0 , the onshore forward rate F^{on} , and the offshore NDF rate F^{off} . The onshore forward rate is tied to the spot rate by covered interest parity,

$$F^{on} = S_0(1 + \rho), \quad 1 + \rho \equiv \frac{1 + i^{EM}}{1 + i^{USD}},$$

so that $\rho \simeq i^{EM} - i^{USD}$ under the EM-per-USD quotation.⁹

We define the offshore–onshore spread as

$$\Delta \equiv F^{off} - F^{on}. \quad (5)$$

Capital controls prevent offshore investors from directly accessing the onshore forward market. As a result, Δ can persist in equilibrium and measures segmentation between the two forward markets.¹⁰

4.2 Agents

Offshore Investors. Capital controls restrict offshore investors to the NDF market for their EM-currency exposure. They are mean-variance investors with risk aversion γ^S over the NDF payoff,

$$\max_{x^S} E^{off}[x^S(S_1 - F^{off})] - \frac{\gamma^S}{2} \text{Var}[x^S(S_1 - F^{off})] \quad \implies \quad x^S = \frac{\mu - F^{off}}{\gamma^S \sigma^2}. \quad (6)$$

⁹We assume CIP holds within the onshore market. Its only role is to determine the onshore forward price from the spot rate, since the paper focuses on the offshore–onshore spread. For emerging markets with local interest rates above USD rates, $\rho > 0$ and the onshore forward trades at a premium to spot under this quotation.

¹⁰The empirical counterpart of Δ is the offshore–onshore spread expressed in basis points. To first order, it corresponds to the normalized spread Δ/S_0 .

NDF demand therefore decreases with the NDF rate and increases with the offshore expectation μ .

Capital controls separate offshore and domestic investors and limit the trades that would otherwise reduce differences in their valuations. Offshore and domestic investors may therefore hold different expectations about exchange-rate fundamentals. When offshore investors expect greater EM depreciation than domestic investors, they increase their demand for U.S. dollars in the NDF market. We refer to the resulting net demand as *offshore demand pressure*. The same setup can be written as an additive demand shifter. Offshore demand can be expressed as

$$x^S = z + \frac{(1 + \rho)\bar{S} - F^{off}}{\gamma^S \sigma^2}, \quad z \equiv \frac{\mu - (1 + \rho)\bar{S}}{\gamma^S \sigma^2},$$

where $\bar{S}$ is the domestic valuation defined below. The difference in expectations is thus one microfoundation of offshore demand pressure, and any exogenous shift z in offshore demand, whether reflecting beliefs, hedging needs, or portfolio rebalancing, enters equilibrium prices identically.

The Offshore Dealer. The offshore dealer provides immediacy in the NDF market and takes the other side of offshore order flow that is not absorbed by the arbitrageur. Her residual inventory is

$$I_D = x^S - x^A, \tag{7}$$

where x^A is the arbitrageur's position defined below.

To hedge this exposure, she borrows EM currency, buys h units of U.S. dollars in the spot market, and holds the position over the trading period. At settlement, she receives the payoff on the short NDF position and unwinds the spot holding. With a short NDF position I_D and a spot holding h , her residual exchange-rate exposure is $(h - I_D)S_1$. A full hedge therefore requires

$$h = I_D. \tag{8}$$

The baseline model assumes that the offshore dealer can access the domestic spot market for hedging. Appendix B relaxes this assumption.

The hedged position has no FX risk and earns the spread per unit. Because the NDF is cash settled, the payoff on the short NDF position combined with the unwound spot holding financed at the onshore interest differential gives, by CIP, the cash flow

$$I_D(F^{off} - F^{on}) = \Delta I_D.$$

Carrying the position uses balance-sheet capacity. Following [Liao and Zhang \(2025\)](#), the dealer must set aside a haircut $\kappa_D h^2/2$ against the position, where $\kappa_D > 0$ determines the

size of the haircut. Capital committed to the position cannot be invested in an alternative opportunity $G_D(\cdot)$, with $G'_D > 0$ and $G''_D < 0$, out of initial wealth W_D .¹¹

The dealer therefore chooses inventory to maximize

$$\Delta I_D + G_D(W_D - \kappa_D I_D^2/2).$$

Under a local approximation around zero positions,

$$G'_D(W_D - \kappa_D I_D^2/2) \simeq G'_D(W_D),$$

the first-order condition gives the linear pricing rule¹²

$$F^{off} = F^{on} + \Lambda_D I_D, \quad \Lambda_D \equiv \kappa_D G'_D(W_D). \quad (9)$$

Here Λ_D is the dealer's *marginal cost of intermediation*. It increases with the haircut κ_D and decreases with dealer wealth W_D . The NDF therefore trades at a premium relative to the onshore forward to compensate the dealer for the balance-sheet cost of hedging residual inventory.

The Arbitrageur. The arbitrageur exploits a positive spread $\Delta > 0$ by taking offsetting forward positions. She shorts U.S. dollars in the NDF market and goes long U.S. dollars in the onshore forward market in equal size x^A . The position earns the spread without exchange-rate risk.¹³ For $\Delta < 0$, all positions reverse symmetrically.

As with the offshore dealer, the arbitrageur has initial wealth W and must set aside a haircut $\kappa(x^A)^2/2$ when committing capital to the trade. She invests the remaining wealth in an alternative opportunity $G(\cdot)$, with $G' > 0$ and $G'' < 0$,

$$\max_{x^A} \Delta x^A + G(W - \kappa(x^A)^2/2) \implies \Delta = \kappa G'(W - \kappa(x^A)^2/2)x^A. \quad (10)$$

The spread compensates the marginal opportunity cost of capital. Under the same local approximation,

$$G'(W - \kappa(x^A)^2/2) \simeq G'(W),$$

the supply of arbitrage capital is

$$x^A = \frac{\Delta}{\Gamma_A}, \quad \Gamma_A \equiv \kappa G'(W). \quad (11)$$

¹¹This is the quadratic case of the convex haircut $\kappa H(q)$ in [Liao and Zhang \(2025\)](#), who follow [Gârleanu and Pedersen \(2011\)](#) and [Ivashina et al. \(2015\)](#). Convexity may capture the increasing cost of holding a concentrated position in a single currency.

¹²Alternatively, with a linear opportunity cost $G_D(C) = r_D C$, where C denotes remaining wealth, the rule is exact.

¹³Even though the position has no exchange-rate risk, arbitrage of this kind may still be limited ([Shleifer and Vishny, 1997](#)).

Here Γ_A is the arbitrageur’s marginal cost of intermediation. It increases with the haircut κ and decreases with arbitrageur wealth W .

Arbitrage capacity is therefore determined by the slope $1/\Gamma_A$ rather than by a fixed position limit. A higher haircut or lower intermediary wealth reduces arbitrage capacity and leaves a larger share of offshore flow on the balance sheet of the offshore dealer.¹⁴

Common funding, volatility, and regulatory shocks may affect both intermediation costs, but the two costs remain distinct. The effective cost Λ defined below determines the spread generated by one unit of offshore flow. The allocation share a determines how this flow is divided between the offshore dealer and the arbitrageur.

The Onshore Dealer. The arbitrageur’s onshore forward position requires a counterparty. The *onshore dealer* is a domestic authorized dealer that takes the short side of the arbitrageur’s onshore forward position, $-x^A$, and hedges this exposure by buying x^A units of U.S. dollars in the domestic spot market,

$$h^{on} = x^A. \quad (12)$$

This provides the second channel through which offshore activity reaches the domestic spot market. Each unit of arbitrage activity generates one unit of spot demand.

Domestic Currency-Spot Traders. Local investors such as exporters, households, and domestic institutions can hold currency risk but are risk averse. Following [De Leo et al. \(2024\)](#), each investor takes a zero-capital spot position n , which is long USD funded by EM-currency borrowing or the reverse, and has mean-variance preferences over its excess return with risk aversion λ ,

$$\max_n n \left(E^{dom}[S_1] - (1 + \rho)S_0 \right) - \frac{\lambda}{2} \sigma^2 n^2. \quad (13)$$

Here $(1 + \rho)S_0$ is the opportunity cost of the funded position over the trading period. Their demand for EM currency in spot is

$$n = \frac{E^{dom}[S_1] - (1 + \rho)S_0}{\lambda \sigma^2}. \quad (14)$$

Demand falls as the spot price rises, with its sensitivity determined by $\lambda \sigma^2$.

We use the domestic expectation as the benchmark for domestic currency pricing.

¹⁴[Liao and Zhang \(2025\)](#) refer to this agent as a currency forward trader, or equivalently an FX swap trader, who uses capital to provide liquidity in forward markets. We use the term “arbitrageur” because the offshore–onshore position is a basis trade while retaining their constraint technology. The elastic supply of intermediation also resembles the local intermediaries in [De Leo et al. \(2024\)](#), whose position limits generate an upward-sloping forward supply schedule.

Define the domestic valuation

$$\bar{S} \equiv \frac{E^{dom}[S_1]}{1 + \rho}.$$

The supply of U.S. dollars in spot can then be written as

$$-n = \eta(S_0 - \bar{S}), \quad \eta \equiv \frac{1 + \rho}{\lambda \sigma^2}, \quad (15)$$

where η measures spot-market depth. A higher value implies a smaller price response to a given amount of spot demand.

4.3 Equilibrium

Forward Market Clearing and the Spread. The offshore NDF market clears when the net long position of offshore investors equals the combined short positions of the arbitrageur and offshore dealer. Residual dealer inventory is therefore $I_D = x^S - x^A$, as in (7). The onshore forward market clears through the onshore dealer, who takes the short side of the arbitrageur's long position.

Combining the dealer pricing rule in (9) with the arbitrageur's supply in (11) gives

$$\Delta = \Lambda x^S, \quad x^A = a x^S, \quad \Lambda \equiv \frac{\Lambda_D \Gamma_A}{\Lambda_D + \Gamma_A}, \quad a \equiv \frac{\Lambda_D}{\Lambda_D + \Gamma_A} \in (0, 1). \quad (16)$$

Here Λ is the *effective marginal cost of intermediation*. It measures the spread generated by one unit of offshore flow. The effective cost depends on both intermediary balance sheets. It increases with either Λ_D or Γ_A and converges to zero if either form of intermediation becomes frictionless. The share a of offshore flow intermediated by the arbitrageur increases with the offshore dealer's cost Λ_D and decreases with the arbitrageur's cost Γ_A .

Spot Market Clearing. Spot demand has two components. The offshore dealer hedges residual inventory $I_D = x^S - x^A$, while the onshore dealer hedges the arbitrageur's onshore forward position x^A . Together these positions equal total offshore flow,

$$(x^S - x^A) + x^A = x^S = \eta(S_0 - \bar{S}). \quad (17)$$

The equilibrium spot rate is therefore

$$S_0 = \bar{S} + \frac{x^S}{\eta}. \quad (18)$$

Every unit of offshore flow therefore generates one unit of spot demand. This is true whether the flow is absorbed by the offshore dealer and hedged directly in spot or absorbed by the arbitrageur and hedged through the onshore dealer.

Equilibrium Flow. Substituting (16) and (18), together with CIP, into offshore demand (6) gives

$$x^{S*} = \frac{\mu - (1 + \rho)\bar{S}}{\gamma^S \sigma^2 + \phi}, \quad (19)$$

where

$$\phi \equiv \frac{1 + \rho}{\eta} + \Lambda \quad (20)$$

combines spot price impact with the effective cost of intermediation.

Equilibrium flow increases with offshore demand pressure,

$$\mu - (1 + \rho)\bar{S} = E^{off}[S_1] - E^{dom}[S_1].$$

Offshore demand pressure is positive when offshore investors expect greater EM depreciation than domestic investors. Offshore risk aversion, spot price impact, and intermediation costs reduce the equilibrium position. We focus on positive demand pressure,

$$\mu - (1 + \rho)\bar{S} > 0,$$

so that $x^{S*} > 0$ and $\Delta^* > 0$.¹⁵

Equilibrium Forward Prices and Spread. Substituting x^{S*} into (18) and CIP gives the equilibrium spot and onshore forward rates. Substituting x^{S*} into (16) gives the equilibrium offshore–onshore spread,

$$\Delta^* = \frac{\Lambda}{\gamma^S \sigma^2 + \phi} [\mu - (1 + \rho)\bar{S}]. \quad (21)$$

The spread is positive when demand pressure is positive. It disappears if intermediation is frictionless, $\Lambda = 0$, or if offshore and domestic investors have the same expectation,

$$\mu = (1 + \rho)\bar{S}.$$

The equilibrium NDF rate is

$$F^{off*} = F^{on*} + \Delta^*.$$

4.4 Empirical Predictions

The model shares the quotation convention of the empirical analysis. Prices are EM currency per U.S. dollar, and positive offshore flow denotes long-USD, short-EM demand.

¹⁵Because the quadratic haircut is symmetric in the sign of the position, negative demand pressure generates short-USD flow and a negative spread, with the opposite price responses. We focus on positive pressure for simplicity.

Positive OIB therefore maps directly into x^S , and the predictions carry over to the data without any sign adjustment.

The model generates two main empirical predictions. Prediction 1 describes the response of the NDF rate, domestic spot rate, and offshore–onshore spread to greater offshore demand pressure. Prediction 2 describes the effect of tighter intermediation constraints on the offshore–onshore spread.

Changes in offshore expectations relative to domestic expectations generate offshore demand pressure. OIB measures the resulting executed signed flow x^{S*} . Regressions on OIB therefore estimate price responses conditional on realized flow rather than the total equilibrium response to a change in expectations.

Prediction 1 (Offshore demand pressure). *An increase in the offshore expectation μ , holding the domestic expectation fixed, raises the offshore NDF rate, the domestic spot rate, and the offshore–onshore spread,*

$$\frac{\partial F^{off*}}{\partial \mu} = \frac{\phi}{\gamma^S \sigma^2 + \phi} > 0, \quad (22)$$

$$\frac{\partial S_0^*}{\partial \mu} = \frac{1}{\eta(\gamma^S \sigma^2 + \phi)} > 0, \quad (23)$$

$$\frac{\partial \Delta^*}{\partial \mu} = \frac{\Lambda}{\gamma^S \sigma^2 + \phi} > 0. \quad (24)$$

Higher offshore demand pressure raises the NDF rate through two channels. Dealer hedging increases demand for U.S. dollars in the domestic spot market, raising the spot rate, an EM depreciation, and, through CIP, the onshore forward rate. In addition, the offshore dealer requires compensation for the balance-sheet cost of absorbing residual inventory, which raises the NDF rate relative to the onshore forward. The first channel determines the domestic spot response, while the second determines the offshore–onshore spread.

The offshore NDF always responds more strongly than the onshore forward,

$$\frac{\partial F^{off*}}{\partial \mu} - \frac{\partial F^{on*}}{\partial \mu} = \frac{\partial \Delta^*}{\partial \mu} > 0.$$

The comparison with spot also depends on the interest differential,

$$\frac{\partial F^{off*}}{\partial \mu} - \frac{\partial S_0^*}{\partial \mu} = \frac{\rho/\eta + \Lambda}{\gamma^S \sigma^2 + \phi}.$$

For emerging markets with local interest rates above USD rates, $\rho > 0$ under our convention, so the NDF always responds more strongly than spot. When $\rho < 0$, the stronger NDF response requires intermediation costs to be sufficiently large relative to the interest differential, $\Lambda > -\rho/\eta$.

Conditional on executed offshore flow x^S , the price impact of a unit of flow is

$$\frac{\partial S_0}{\partial x^S} = \frac{1}{\eta}, \quad \frac{\partial F^{on}}{\partial x^S} = \frac{1+\rho}{\eta}, \quad \frac{\partial \Delta}{\partial x^S} = \Lambda, \quad \frac{\partial F^{off}}{\partial x^S} = \frac{1+\rho}{\eta} + \Lambda = \phi. \quad (25)$$

These expressions map directly into the price-impact regressions of spot, onshore forward, and NDF returns, and of the spread, on OIB. Under full hedging, tighter intermediation raises the NDF and spread response per unit of flow through Λ but leaves the spot response $1/\eta$ unchanged. State dependence in spot price impact therefore requires variation in spot-market depth η or, as in Appendix B, variation in the offshore dealer's hedging access θ and the arbitrated share a .

Prediction 2 (Intermediation constraints and the spread). *Tighter intermediation constraints, represented by higher haircuts or lower intermediary wealth for either the offshore dealer or the arbitrageur, raise the effective cost Λ and widen the offshore–onshore spread,*

$$\frac{\partial \Delta^*}{\partial \Lambda} = \frac{\gamma^S \sigma^2 + (1+\rho)/\eta}{(\gamma^S \sigma^2 + \phi)^2} [\mu - (1+\rho)\bar{S}] > 0. \quad (26)$$

When haircuts rise or intermediary wealth falls, a given amount of demand pressure generates a larger offshore–onshore spread. This prediction motivates the empirical analysis of how the spread varies with intermediary conditions and changes in regulatory access.

Tighter intermediation constraints also affect equilibrium prices by reducing offshore flow. Under positive demand pressure, a higher Λ reduces the domestic spot response while raising the NDF rate and widening the offshore–onshore spread. Our empirical analysis focuses on the spread because it responds directly to changes in intermediation costs.

5 Empirical Evidence

We organize the empirical analysis in two parts. Section 5.1 presents four policy-event case studies that illustrate the two predictions of the model. The 2015 RMB central-parity reform is an episode of rising offshore demand pressure and maps onto Prediction 1. The 2016 Malaysian restrictions on offshore Ringgit NDF activity reduced offshore demand pressure and also limited domestic dealer participation in the offshore market. The observed compression of the offshore–onshore spread is consistent with the demand-pressure margin dominating, mapping the episode onto Prediction 1. The 2020 RBI opening of the offshore INR NDF market to Indian banks and the April 2026 RBI restrictions provide opposite changes in intermediation between offshore and onshore markets and map onto Prediction 2. Together, the four episodes illustrate how offshore

demand pressure and intermediation constraints affect the offshore–onshore spread and the domestic spot rate.

Section 5.2 then tests the model predictions across our panel of EM currencies using order-flow imbalance as a measure of executed offshore flow. We proceed in three steps. First, we estimate the price impact of order flow using daily regressions of exchange-rate returns on order-flow imbalance and examine how this price impact varies with global risk conditions and dealer balance-sheet activity. Second, we study price discovery using a cointegration model of offshore NDF and spot prices estimated at the five-minute frequency. Third, we test the effect of order flow on the offshore–onshore spread and show that offshore order flow widens the spread in addition to transmitting to the domestic spot rate.

5.1 Case Studies of NDF–Spot Transmission

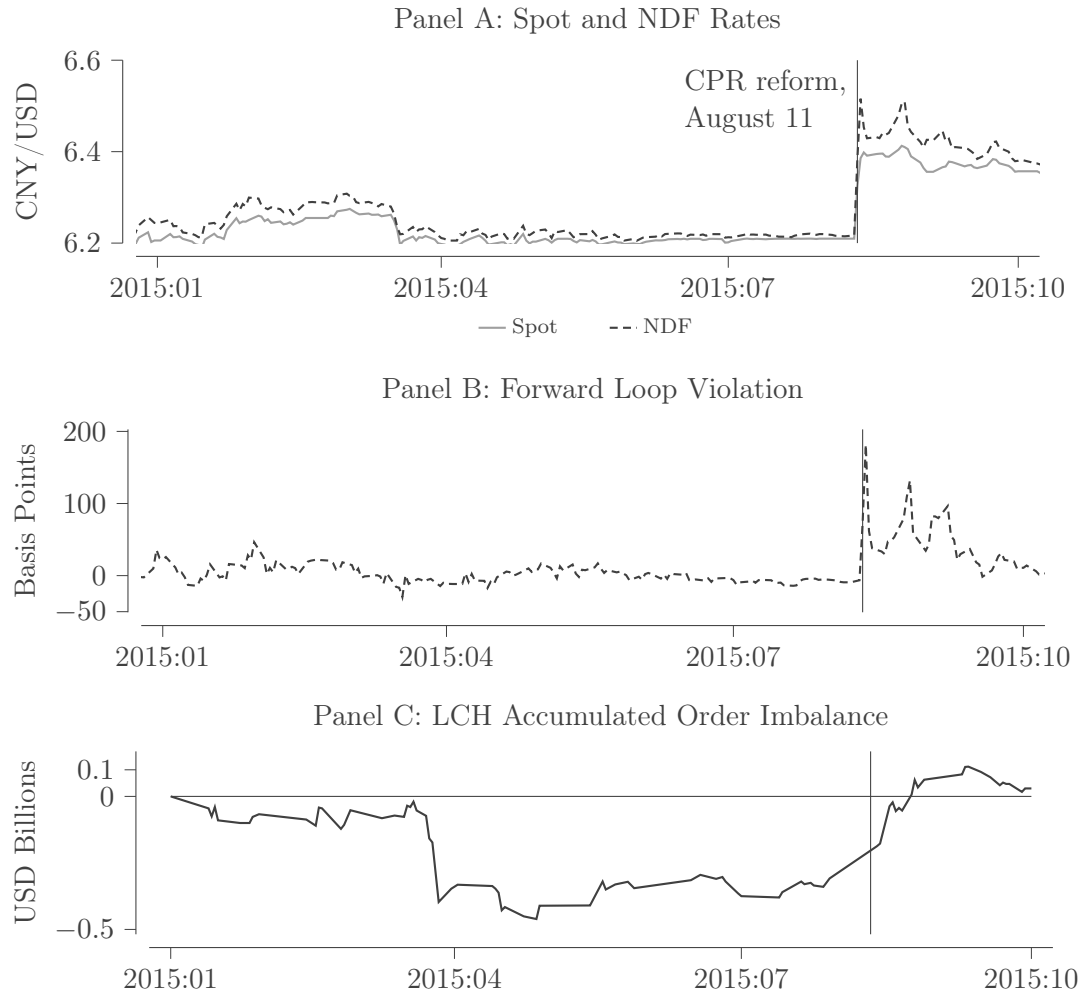
5.1.1 The 2015 RMB Central-Parity Reform

On August 11, 2015, the PBC changed the central parity rate formation mechanism, announcing that the daily fix would be set with reference to the previous business day’s interbank closing rate, supply and demand conditions in the foreign exchange market, and movements in major currencies rather than being directly administered. Although the PBC presented the reform as a move toward greater market determination of the Renminbi, market participants interpreted it as a signal that the authorities were prepared to tolerate further currency depreciation. The central parity rate moved by roughly 1.9% overnight, the largest single-day move on record, and offshore investors increased long-USD and short-CNY positions in the offshore NDF market.

Figure 4 reports the joint dynamics of the spot rate, the offshore–onshore spread, and cumulative offshore order imbalance around the reform. Three patterns stand out. First, the CNY/USD spot rate depreciated sharply on impact and continued to weaken over the following weeks. Second, the offshore forward spread widened by roughly 190 basis points within days of the reform and remained elevated. Third, cumulative offshore order imbalance moved sharply toward long-USD and short-CNY positions.

The joint response of spot depreciation, spread widening, and offshore position accumulation is consistent with Prediction 1. Stronger offshore demand pressure raises demand for long-USD and short-CNY positions, increases the inventory that intermediaries must absorb, and widens the spread between offshore and onshore forward rates. Dealer hedging then transmits part of this pressure to the domestic spot market.

Figure 4: 2015 RMB Central Parity Rate Reform

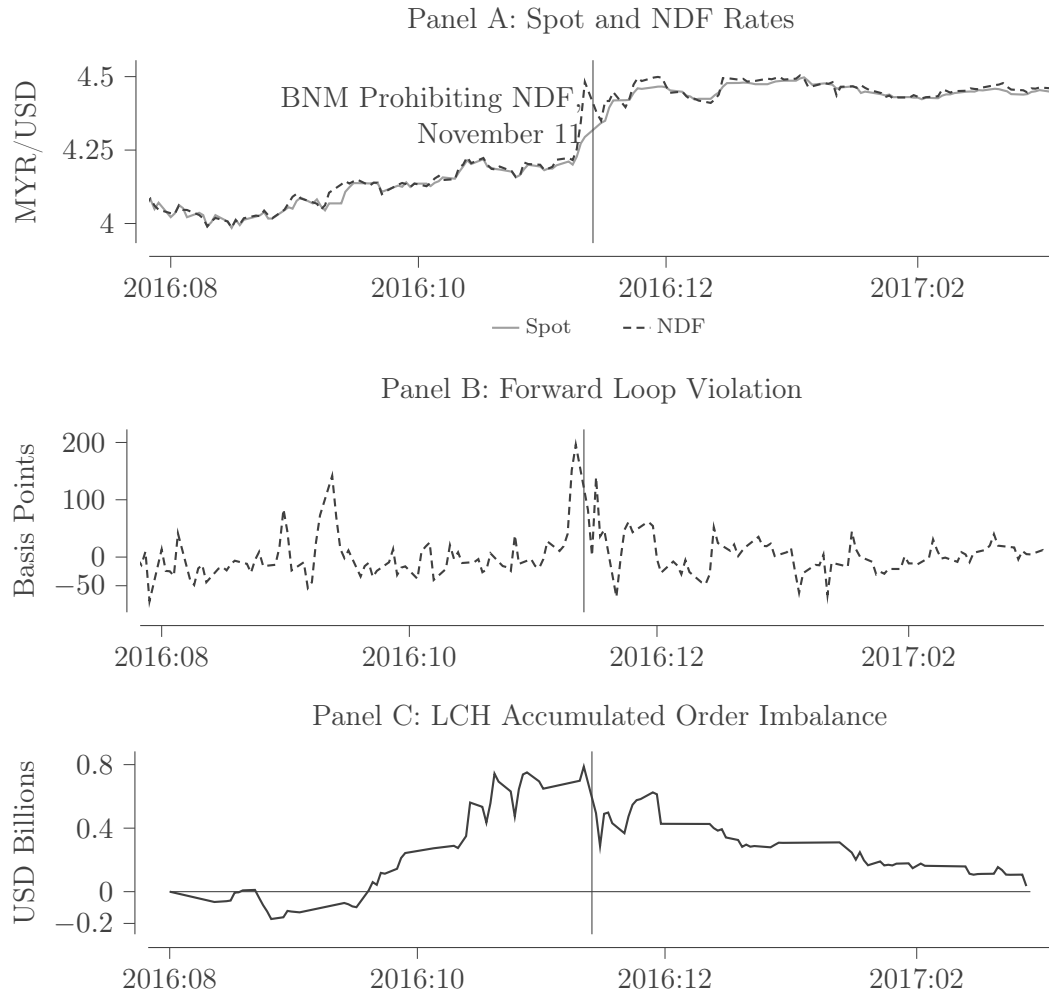


Notes. Panel A shows the CNY/USD spot rate (light solid) and one-month NDF rate (dashed). Panel B shows the CNY forward loop violation. On August 11, 2015, the PBC revised the central parity rate formation mechanism by linking it to the previous business day's closing rate. Panel C shows accumulated LCH order imbalance (in USD billions), constructed as the cumulative sum of daily order imbalance from January 1, 2015 to October 1, 2015.

5.1.2 Malaysia's 2016 NDF Crackdown

On November 11, 2016, BNM issued a statement titled *Prohibiting Facilitation of NDF Related Transactions*, instructing domestic financial institutions to stop facilitating Ringgit NDF transactions, including trades on behalf of offshore counterparties. The directive followed sustained pressure on the Ringgit after the November 2016 U.S. presidential election. In the days before the announcement, the offshore–onshore spread had widened sharply and the spot rate had depreciated. BNM presented the policy as part of a broader effort to limit offshore NDF activity and reduce its influence on domestic exchange-rate

Figure 5: Malaysia's 2016 NDF Crackdown



Notes. Panel A shows the MYR/USD spot rate (light solid) and NDF rate (dashed). Panel B shows the MYR forward loop violation. On November 11, 2016, BNM issues a press statement titled ‘Prohibiting Facilitation of NDF Related Transactions.’ Panel C shows accumulated LCH order imbalance (in USD billions), constructed as the cumulative sum of daily order imbalance from August 1, 2016 to March 1, 2017.

determination.¹⁶

Figure 5 reports the joint dynamics of the MYR/USD spot rate, the offshore–onshore spread, and cumulative offshore order imbalance around the restrictions. In the weeks leading up to the announcement, cumulative offshore NDF order imbalance increased sharply and the offshore–onshore spread widened. Following the announcement, the spread compressed rapidly and the spot rate stabilized, even though cumulative order imbalance did not immediately reverse.

The restrictions affect both forces in the model, with opposing implications for the spread. By prohibiting domestic institutions from facilitating ringgit NDF transactions,

¹⁶See Governor Muhammad Ibrahim’s speech of 18 November 2016, “Strengthening the financial market architecture” (<https://www.bis.org/review/r170117d.htm>).

the directive prevented the build-up of positions in the offshore NDF market and dampened offshore demand pressure, which compresses the spread (Prediction 1). At the same time, the restrictions weakened intermediation between offshore and onshore markets, which by itself would widen the spread (Prediction 2). The rapid compression of the offshore–onshore spread and the stabilization of the spot rate indicate that the demand-pressure margin dominated.

5.1.3 India’s 2020 NDF Market Opening

On March 27, 2020, the Reserve Bank of India announced that Indian banks would be permitted to participate in the offshore INR NDF market, reversing a long-standing restriction on Indian-bank participation in offshore Rupee NDFs. The reform became effective on June 1, 2020.¹⁷ The announcement came during the period of severe market stress associated with COVID-19, when the offshore–onshore spread had widened sharply and the Rupee had depreciated. Allowing Indian banks to access the offshore market was intended to improve price discovery and strengthen integration between offshore and onshore currency markets.

Figure 6 reports the joint dynamics of the INR/USD spot rate, the offshore–onshore spread, and cumulative offshore order imbalance around the March 27 announcement and June 1 implementation date. Before the announcement, the offshore forward spread widened sharply and the spot rate depreciated. Following the announcement, and particularly after the June 1 implementation, the offshore–onshore spread compressed substantially and the Rupee stabilized while cumulative offshore order imbalance resumed a gradual increase.

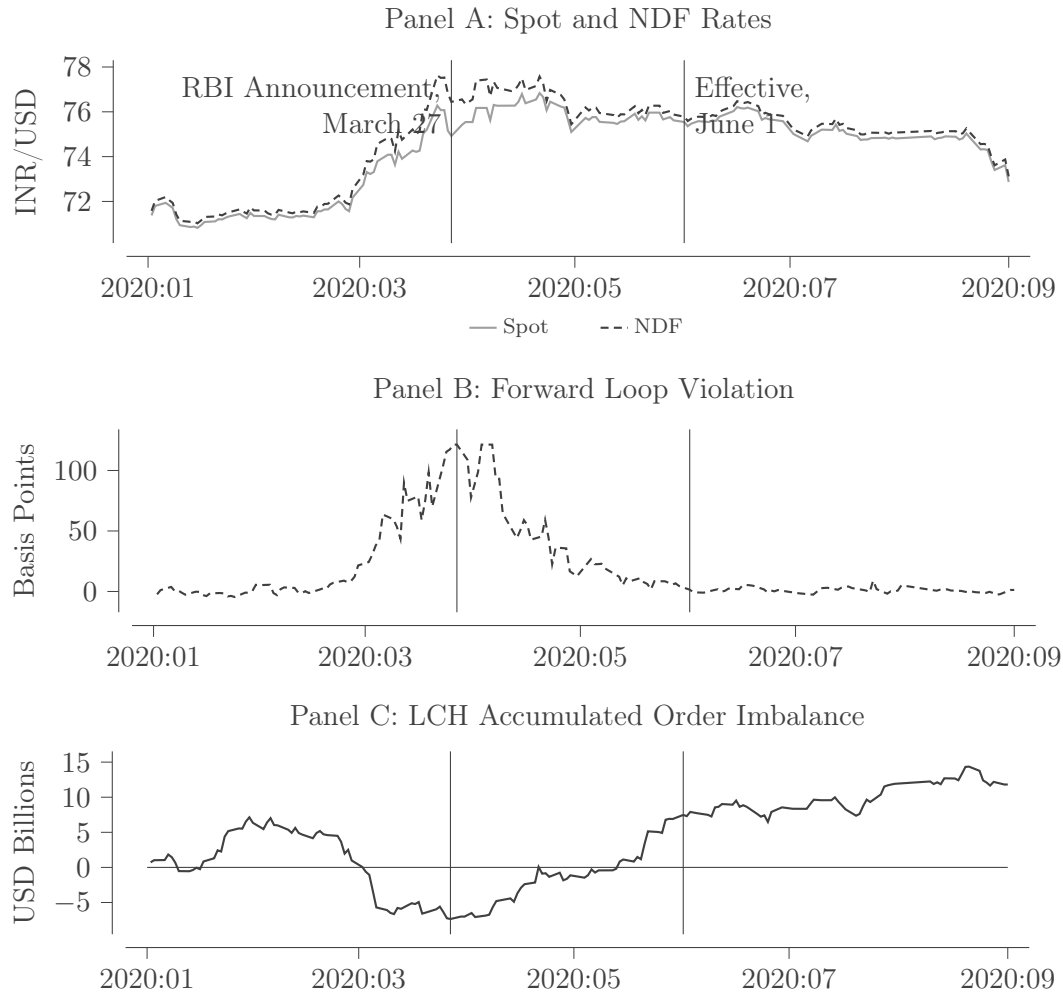
Allowing Indian banks to participate in offshore NDF markets increased the number of intermediaries able to operate across offshore and onshore markets. In the model, this reduces intermediation costs. Prediction 2 therefore implies a narrower offshore–onshore spread, consistent with the large compression following the reform. The model also implies that greater intermediation capacity allows offshore positions to be absorbed at a smaller spread.

5.1.4 India’s 2026 NDF Restriction

On April 1, 2026, the Reserve Bank of India announced restrictions on Indian banks’ offshore NDF activity in response to heightened Rupee volatility, partially reversing the 2020 liberalization. The directive limited the ability of domestic banks to facilitate offshore

¹⁷Eligibility was tied to the International Financial Services Centre (IFSC) at GIFT City: banks operating IFSC Banking Units were permitted to transact in rupee NDFs through their Indian branches, their foreign branches, or their IFSC units. The reform followed the recommendations of the RBI’s 2019 Task Force on Offshore Rupee Markets.

Figure 6: India's 2020 NDF Market Opening



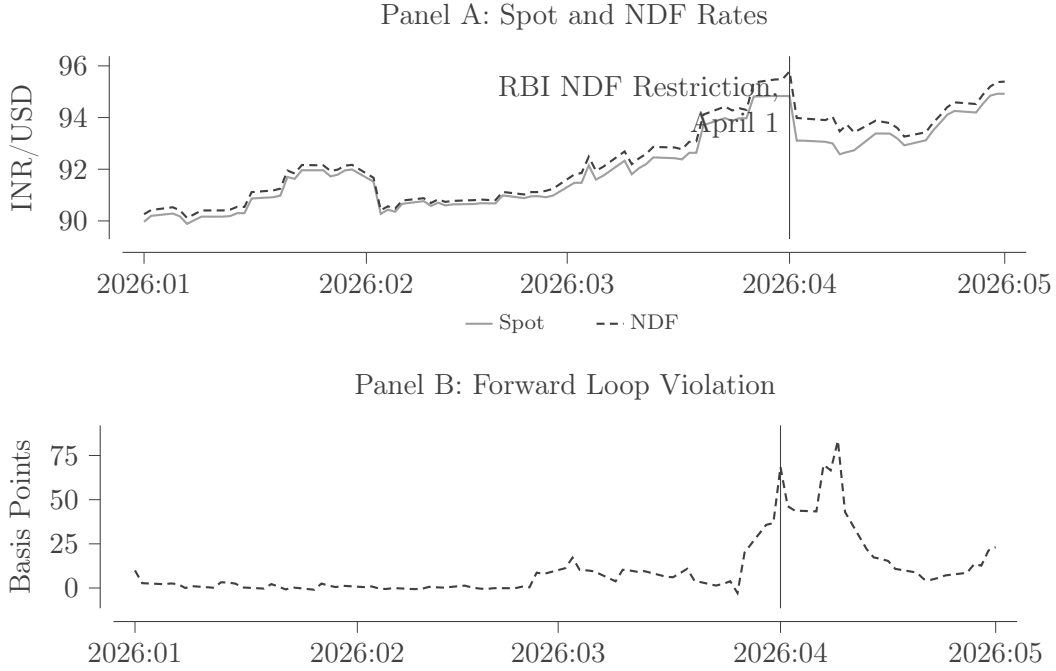
Notes. Panel A shows the INR/USD spot rate (light solid) and NDF rate (dashed). Panel B shows the INR forward loop violation. On March 27, 2020, the Reserve Bank of India announced that Indian banks would be permitted to participate in the offshore INR NDF/NDDC market; the reform became effective on June 1, 2020. Panel C shows accumulated LCH order imbalance (in USD billions), constructed as the cumulative sum of daily order imbalance from January 1, 2020 to September 1, 2020.

NDF trades for non-resident counterparties and reduced domestic dealer participation in the offshore market.

Figure 7 reports the joint dynamics of the INR/USD spot rate and the offshore–onshore spread around the April 1 announcement. The spread averaged around 3 basis points over the first quarter of 2020 before jumping to almost 40 basis points in the last days of March, as the spot rate depreciated sharply. Following the announcement, the spread widened further, peaking above 80 basis points, while the spot rate stabilized. We do not report cumulative order imbalance for this episode because order-flow data are not available for this period.

Restricting Indian-bank participation in the offshore NDF market raised the cost of

Figure 7: India’s 2026 NDF Restriction



Notes. Panel A shows the INR/USD spot rate (light solid) and NDF rate (dashed). Panel B shows the INR forward loop violation (NDF minus onshore forward, in basis points). On April 1, 2026, the Reserve Bank of India announced restrictions on Indian banks’ offshore NDF activity in response to heightened rupee volatility. The sample period runs from January 1, 2026 to May 1, 2026.

intermediating between offshore and onshore markets. Prediction 2 therefore implies a wider offshore–onshore spread, consistent with the data. The episode may also have reduced the amount of offshore flow transmitted to the domestic market by limiting the set of dealers able to operate across the two markets.

Taken together, the two India episodes provide opposite changes in offshore intermediation. The 2020 liberalization increased domestic dealer participation in the offshore market and was followed by a sharp compression of the offshore–onshore spread. The 2026 restrictions reduced this participation and were followed by a widening of the spread. Combined with the 2015 RMB reform and the 2016 Malaysian restrictions, the four episodes illustrate both demand-pressure and intermediation channels in the model.

As discussed in Section 5.1.2, the Malaysian and 2026 Indian restrictions operated on different margins, dampening offshore demand pressure in the Malaysian case and raising the cost of intermediation in the Indian case, with opposite spread responses. Trading volumes discriminate between the two margins. Consistent with the demand-side reading of the Malaysian episode, Patel and Xia (2019) report that total ringgit FX turnover fell by 48% between the April 2016 and April 2019 BIS Triennial Surveys, with offshore ringgit trading collapsing after the ban. Offshore rupee NDF trading, by contrast, continued after the April 2026 restrictions (Reuters, 2026), consistent with a supply-side change in

intermediation rather than a withdrawal of offshore demand.

5.2 Order Flow Price Impact

The case studies illustrate the model’s predictions in individual policy episodes. We now turn to formal tests across our full panel of ten EM currencies using order-flow imbalance as a measure of executed offshore flow. Section 5.2.1 estimates the price impact of order flow in daily regressions, following the FX microstructure literature. Section 5.2.2 examines how this price impact varies with global risk conditions and dealer balance-sheet activity. Section 5.2.3 studies price discovery in a cointegration model of offshore forward and spot prices at the five-minute frequency. Section 5.2.4 estimates a daily SVAR that adds the offshore forward spread and tests how order flow affects the spread in addition to the spot rate.

5.2.1 Contemporaneous Price Impact

We begin with the average price impact of order flow. A large FX microstructure literature shows that signed order flow explains a substantial share of exchange-rate movements through dealer inventory adjustment and information aggregation (Lyons, 1995; Evans and Lyons, 2002; Bjønnes and Rime, 2005; Rinaldo and Somogyi, 2021). Following this literature, we regress daily exchange-rate returns on contemporaneous order-flow imbalance,

$$r_{i,t}^m = \alpha_i + \beta OIB_{i,t} + \boldsymbol{\gamma}' \mathbf{X}_t + \varepsilon_{i,t}, \quad (27)$$

where $r_{i,t}^m$ is the daily log return in basis points on the onshore spot rate, offshore NDF rate, or onshore forward rate, α_i is a currency fixed effect, and $\mathbf{X}_t$ contains the global risk controls described in Section 3. $OIB_{i,t}$ is measured in U.S. billions, so the coefficients are basis points per USD billion of net buyer-initiated offshore flow. Standard errors are two-way clustered by currency and period in the panel regressions reported in Table 2 and use Newey–West HAC with 12 lags in the currency-by-currency regressions reported in Table 3.

Two patterns stand out. First, in the panel, a \$1 billion increase in long-USD and short-EM order flow depreciates the EM spot rate by roughly 9–11 basis points on impact (Table 2, columns 1–2). Onshore forwards move by a similar amount (columns 5–6). The offshore NDF response is larger, at roughly 18–19 basis points (columns 3–4), although it is estimated less precisely. This larger response is consistent with the model, in which the NDF response combines the domestic spot response with an offshore inventory premium. Adding changes in the VIX and the broad U.S. Dollar index leaves the OIB coefficient largely unchanged.

Second, the currency-level estimates in Table 3 show that the panel result is not

driven by a single market. The OIB coefficient on spot returns is positive and statistically significant for seven of the ten currencies, with especially large estimates for CLP and COP and precisely estimated slopes for BRL, CNY, KRW, INR, and PHP. The MYR and TWD estimates are positive but imprecise, and the IDR estimate is small and negative. NDF and onshore forward returns show a similar pattern.

These regressions estimate the association between order flow and returns rather than a causal price impact. Signed flow responds to the same news that moves prices, and feedback trading can generate reverse causality at the daily frequency. Three features of the analysis discipline the interpretation. First, the five-minute analysis in Section 5.2.3 identifies the order-flow innovation within a window in which feedback from returns to subsequent flow is limited, and delivers the same qualitative pattern as the daily estimates. Second, controlling for changes in the VIX and the broad U.S. dollar index leaves the OIB coefficient largely unchanged, so common global shocks do not appear to drive the association. Third, the model's predictions in equation (25) are stated conditional on executed flow, and we read the coefficients in the same way, as price responses per unit of realized offshore flow rather than as the total equilibrium effect of a change in offshore expectations.

Table 2: Order Imbalance and Exchange-Rate Returns

	r^{spot}		r^{NDF}		$r^{onshore}$	
<i>OIB</i>	10.73** (4.42)	10.06** (4.18)	18.46* (9.94)	18.06* (10.13)	10.52** (4.38)	9.91** (4.15)
ΔVIX		4.52*** (1.62)		2.53 (2.62)		4.05*** (1.48)
<i>Dollar</i>		0.05 (0.05)		0.02 (0.66)		0.06 (0.05)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes
N	34,168	32,397	34,168	32,397	31,241	29,658

Notes. Panel regressions of daily exchange-rate returns on contemporaneous offshore order-flow imbalance. The dependent variables are spot, NDF forward, and onshore forward returns, each measured in basis points. $OIB_{i,t}$ is measured in U.S. billions, so reported coefficients are basis points per USD billion of OIB. Columns labeled *OIB* include order imbalance and currency fixed effects. Columns labeled *OIB* + ΔVIX also include the daily change in the VIX and the broad U.S. Dollar index as global risk controls. Standard errors are two-way clustered by currency and period and reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

Table 3: Order Imbalance and Exchange-Rate Returns by Currency

	Currency pair									
	USD/BRL	USD/CLP	USD/CNY	USD/COP	USD/IDR	USD/INR	USD/KRW	USD/MYR	USD/PHP	USD/TWD
Panel A: Spot return (r^{spot})										
OIB	22.91*** (3.23)	72.22*** (9.98)	15.53*** (2.02)	56.52*** (6.95)	-4.15* (2.48)	3.44*** (0.61)	11.20*** (1.66)	18.32 (13.70)	13.83*** (3.62)	1.33 (0.88)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.09	0.10	0.05	0.09	0.01	0.02	0.03	0.01	0.01	0.01
N	3,176	3,247	3,245	3,247	3,247	3,247	3,247	3,247	3,247	3,247
Panel B: NDF forward return (r^{NDF})										
OIB	14.60*** (2.21)	71.95*** (10.00)	9.80* (5.60)	54.69*** (6.97)	-0.79 (14.56)	3.28*** (0.59)	65.15 (47.11)	51.68** (21.12)	20.77*** (3.82)	4.35** (1.81)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.00	0.10	0.01	0.09	0.00	0.02	0.00	0.01	0.00	0.03
N	3,176	3,247	3,245	3,247	3,247	3,247	3,247	3,247	3,247	3,247
Panel C: Onshore forward return ($r^{onshore}$)										
OIB	22.96*** (3.20)	71.10*** (9.87)	15.43*** (2.02)	58.58*** (7.77)	-4.20* (2.49)	3.35*** (0.60)	11.00*** (1.66)	18.48 (13.64)	13.64*** (3.66)	1.40 (0.88)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.09	0.10	0.05	0.10	0.01	0.02	0.03	0.01	0.01	0.01
N	3,176	2,104	3,245	1,651	3,247	3,247	3,247	3,247	3,247	3,247

Notes. Currency-by-currency time-series regressions of daily exchange-rate returns on contemporaneous offshore order-flow imbalance. The dependent variables are spot, NDF forward, and onshore forward returns, each measured in basis points and reported in separate panels. $OIB_{i,t}$ is measured in U.S. billions, so reported coefficients are basis points per USD billion of OIB. The row labeled Controls indicates that the daily change in the VIX and the broad U.S. dollar index are included. Newey–West HAC standard errors with 12 lags are reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

5.2.2 Dealer-Inventory State Dependence

The contemporaneous regressions establish that order flow moves prices on average. We next examine whether this price impact varies with market conditions. In the model, the spread and NDF responses per unit of flow increase with the effective cost of intermediation, while the spot response depends on spot-market depth and, in Appendix B, on offshore dealers’ access to spot hedging. We therefore test whether estimated price impact varies with global risk conditions and dealer balance-sheet activity, in the spirit of the intermediary asset-pricing channel of He et al. (2017).

We interact $OIB_{i,t}$ with three state variables and report the implied OIB pricing effect at low, average, and high values of each state, corresponding to one standard deviation below the mean, the mean, and one standard deviation above the mean. The first state variable is the VIX, which captures global risk conditions. The second is the aggregate gross foreign-exchange position of New York reporting dealers in five major currencies, CAD, CHF, EUR, JPY, and GBP, described in Section 3. We use this variable as a proxy for the scale of risk-bearing activity by global FX dealers. The third is the net-to-gross ratio of dealers’ open NDF positions at LCH ForexClear, a direct measure of how directional dealer inventories are, defined in Appendix D. All specifications include currency and period fixed effects, and standard errors are two-way clustered by currency

and period. Table 4 reports the results, including the response of the offshore–onshore forward spread in the final column.

Three patterns stand out. First, the OIB pricing effect on spot and onshore forward rates rises modestly with the VIX, from 8.24 to 9.25 basis points per \$1 billion, consistent with stronger price impact in risk-off periods. In the model, this can reflect lower spot-market depth or tighter intermediation conditions. Second, the OIB pricing effect decreases sharply with dealer gross positions. For the spot rate, the OIB effect falls from 17.8 basis points when dealer gross positions are one standard deviation below the mean to 7.1 basis points when they are one standard deviation above the mean. The onshore forward rate shows a similar pattern. The NDF response moves in the opposite direction across dealer-position states, although these estimates are imprecise. Third, the spot response rises with the net-to-gross ratio, from 7.3 basis points when the ratio is one standard deviation below its mean to 16.0 basis points when it is one standard deviation above, consistent with larger price impact when dealer inventories are more directional. The final column shows that the spread responses are small and statistically insignificant in all states, so the state dependence we identify operates through the spot and NDF responses rather than through the spread.

These results show that price impact varies with intermediary conditions, consistent with the intermediary asset-pricing evidence of He et al. (2017) and the G10 currency evidence of Cenedese et al. (2021). Because gross positions, the net-to-gross ratio, and the VIX are equilibrium variables rather than direct measures of intermediary constraints, we interpret the results as evidence of state dependence rather than as identifying a particular model parameter. Through the lens of the model, variation in spot price impact may reflect changes in spot-market depth or offshore dealers’ access to spot hedging, while variation in intermediation costs should appear most directly in the offshore–onshore spread.

5.2.3 Dynamic Price Impact at High Frequency

The regressions above estimate average price impact at the daily frequency. We next study price discovery directly. Offshore NDF and domestic spot prices are linked by the settlement of NDF contracts against onshore fixing rates, so the two log price series share a common stochastic trend and are cointegrated. A vector error correction model allows us to estimate how order flow affects each price and which market adjusts first.

We estimate a five-minute trivariate VECM for each currency pair i using

$$\mathbf{y}_{i,t} = (p_{i,t}^{\text{ndf}}, p_{i,t}^{\text{spot}}, OIB_{i,t})'.$$

The variables $p_{i,t}^{\text{ndf}}$ and $p_{i,t}^{\text{spot}}$ are log five-minute NDF and spot mid-quotes from LSEG Tick History, while $OIB_{i,t}$ is the signed order-flow imbalance from equation (2). Onshore

Table 4: State-Dependent OIB Pricing Effects

	r^{spot}	r^{NDF}	$r^{onshore}$	$\Delta FLOOP$
<i>Panel A: Conditioning on VIX</i>				
Low VIX (-1 sd)	8.24*** (2.87)	12.79 (8.07)	7.98*** (2.81)	-1.79 (1.32)
Average VIX	8.74*** (3.09)	18.39 (11.21)	8.65*** (3.08)	-1.07 (1.32)
High VIX (+1 sd)	9.25*** (3.56)	23.98* (14.50)	9.32*** (3.61)	-0.34 (1.55)
R-squared	0.01	0.00	0.01	0.00
N	33,244	33,244	30,411	30,411
<i>Panel B: Conditioning on dealer gross position</i>				
Low position (-1 sd)	17.77* (9.18)	-1.39 (16.38)	17.89* (9.17)	1.71 (4.14)
Average position	12.42** (5.37)	11.32* (6.32)	12.44** (5.37)	0.17 (2.45)
High position (+1 sd)	7.08*** (2.36)	24.02 (16.63)	7.00*** (2.36)	-1.38 (0.94)
R-squared	0.01	0.00	0.01	0.00
N	34,168	34,168	31,241	31,241
<i>Panel C: Conditioning on the dealer net-to-gross ratio</i>				
Low NGR (-1 sd)	7.28*** (2.52)	21.44 (14.04)	7.22*** (2.55)	-1.12 (1.15)
Average NGR	11.64*** (4.29)	16.85* (9.10)	11.63*** (4.24)	-0.40 (1.90)
High NGR (+1 sd)	16.01** (6.28)	12.26 (8.11)	16.04*** (6.15)	0.31 (2.83)
R-squared	0.01	0.00	0.01	0.00
N	33,802	33,802	30,887	30,887

Notes. Implied OIB pricing effects from panel regressions of daily exchange-rate returns on OIB interacted with a market-state variable. The dependent variables are spot, NDF forward, and onshore forward returns and the daily change in the onshore–offshore forward spread ($\Delta FLOOP$), each measured in basis points. OIB is measured in U.S. billions, so reported effects are basis points per USD billion of OIB. Panel A reports the implied effect at one standard deviation below the mean, at the mean, and one standard deviation above the mean of the VIX. Panel B reports the same effects conditioning on gross dealer positions in CAD, CHF, EUR, JPY, and GBP. Panel C conditions on the net-to-gross ratio of dealers’ open NDF positions at LCH ForexClear, pooled across the ten currencies and defined in Appendix D; a higher ratio means less netting within dealer books. Samples differ across panels with the availability of each state variable. All specifications include currency and period fixed effects; R-squared is the within R-squared. Standard errors are two-way clustered by currency and period and reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

forward prices are available only at the daily frequency, so the intraday system includes only the offshore NDF and spot prices. We add the onshore forward rate and offshore–onshore spread in the daily analysis of Section 5.2.4.

The VECM is

$$\Delta \mathbf{y}_{i,t} = \boldsymbol{\alpha}_i \boldsymbol{\beta}' \mathbf{y}_{i,t-1}^* + \sum_{\ell=1}^{k_i-1} \boldsymbol{\Gamma}_{i,\ell} \Delta \mathbf{y}_{i,t-\ell} + \mathbf{u}_{i,t}, \quad \mathbf{u}_{i,t} \sim (\mathbf{0}, \boldsymbol{\Sigma}_{u,i}), \quad (28)$$

with cointegration rank $r = 1$ on the price block, $\mathbf{y}_{i,t-1}^* \equiv (\mathbf{y}_{i,t-1}', 1)'$, and lag length k_i chosen by the Bayesian information criterion. We identify a structural OIB shock using a recursive Cholesky decomposition,

$$\boldsymbol{\Sigma}_{u,i} = \mathbf{P}_i \mathbf{P}_i',$$

under the ordering

$$OIB \succ p^{\text{ndf}} \succ p^{\text{spot}}.$$

This ordering follows the model. Order flow first affects offshore dealer inventory, the NDF rate adjusts next, and the spot rate responds through dealer hedging. Confidence bands use a moving-block residual bootstrap with a block length of 60 minutes and 500 replications.

Figure 8 reports the impulse responses of NDF and spot rates to a unit OIB shock. In nine of the ten currencies, a \$1 billion OIB shock generates a rapid and statistically significant increase in the offshore NDF rate within the first few minutes, with the response stabilizing at a positive level over the 30-minute horizon. The spot rate also increases, but adjusts more gradually. Both responses are consistent with Prediction 1. Offshore order flow moves the NDF rate directly, while dealer hedging transmits the effect to the domestic spot rate.

The VECM also allows us to examine where permanent price discovery occurs. We compute two standard decompositions of the permanent component of prices. Let $\boldsymbol{\alpha}_{i,p} = (\alpha_{i,\text{ndf}}, \alpha_{i,\text{spot}})'$ denote the price-equation loadings on the cointegration residual. The Gonzalo and Granger (1995) weights are

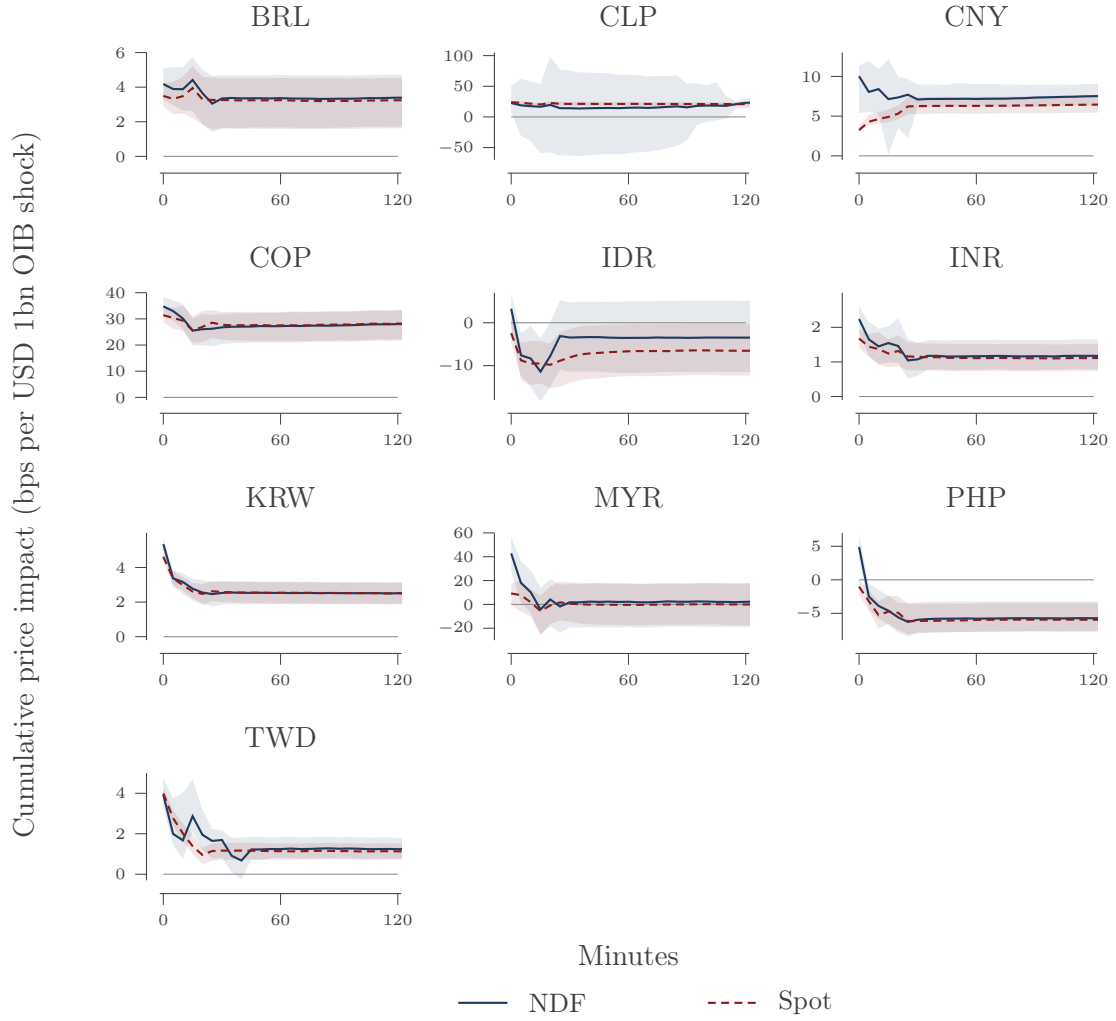
$$W_{i,\text{ndf}}^{\text{GG}} = \frac{\alpha_{i,\text{spot}}}{\alpha_{i,\text{spot}} - \alpha_{i,\text{ndf}}}, \quad W_{i,\text{spot}}^{\text{GG}} = 1 - W_{i,\text{ndf}}^{\text{GG}}. \quad (29)$$

The Hasbrouck (1995) information share of venue $j \in \{\text{ndf}, \text{spot}\}$ is

$$\text{IS}_{i,j} = \frac{([\boldsymbol{\psi}_i \mathbf{P}_i]_j)^2}{\boldsymbol{\psi}_i \boldsymbol{\Sigma}_{u,i}^p \boldsymbol{\psi}_i'}, \quad (30)$$

where $\boldsymbol{\Sigma}_{u,i}^p$ is the 2×2 price block of $\boldsymbol{\Sigma}_{u,i}$ and $\boldsymbol{\psi}_i$ is the long-run impact vector on the price block. Because the Hasbrouck decomposition depends on the ordering within the price block, we report each venue's information share as the interval spanned by the NDF-first and spot-first orderings, together with the midpoint.

Figure 8: VECM-X: Price Response to Order Imbalance by Currency

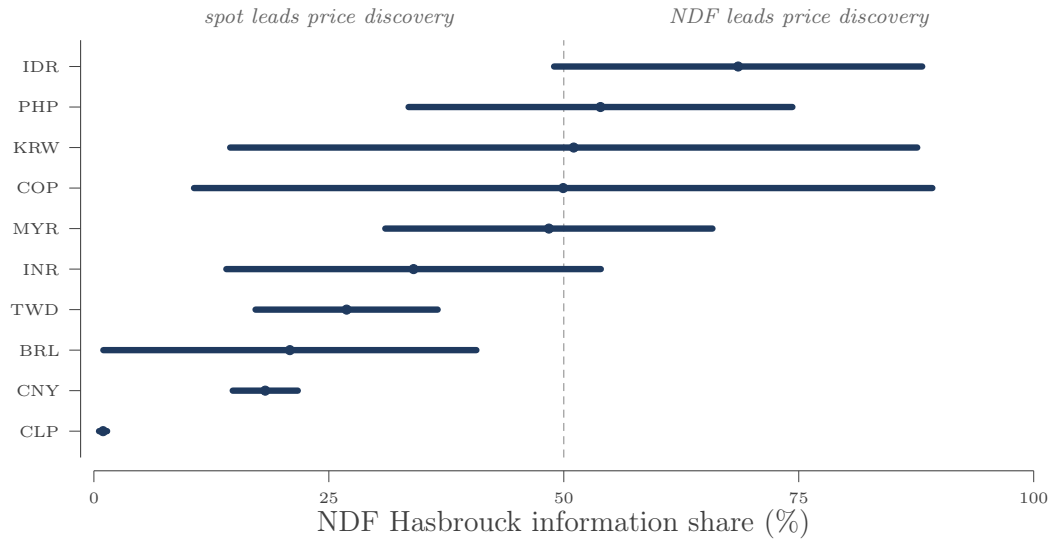


Notes. This figure plots cumulative NDF forward and spot price responses to a USD 1 billion order-flow imbalance shock in the five-minute VECM-X. Responses are in basis points and horizons are measured in minutes. Shaded areas denote pointwise bootstrap confidence bands.

Figure 9 reports the information shares. Price discovery is shared across venues, and the onshore market accounts for the larger share in the most actively traded pairs. Midpoint NDF information shares are below one half for seven of the ten currencies. They are lowest in the most actively traded pairs, at roughly 34% for INR and 27% for TWD, with KRW close to one half, and are highest in less actively traded pairs, at roughly 69% for IDR and 54% for PHP. The Gonzalo–Granger weights show a similar pattern. This pattern is consistent with deep onshore spot markets and fixing rates based on onshore trading concentrating permanent price discovery onshore, while the NDF contributes a material share in all currencies and a larger share where onshore markets are less active.

As a robustness check, we decompose OIB by clearing channel and separately estimate the VECM responses to client-cleared and house order flow, where client-cleared trades

Figure 9: NDF Information Share by Currency



Notes. This figure plots five-minute VECM-X Hasbrouck information shares for the NDF forward market. Points show midpoint NDF information shares in percent, and horizontal intervals show the lower and upper bounds spanned by the NDF-first and spot-first Cholesky orderings within the price block. Spot information share equals 100 minus the NDF information share.

are those of banks that clear through a client-clearing broker rather than through their own membership. On average, the price-impact estimates for client-cleared order flow are larger than those for house order flow, although the client-cleared estimates also show greater cross-sectional variation. Because all counterparties in the dataset are banks, the decomposition reflects the clearing channel rather than trading motives, which cannot be separated in our data. Full results are reported in Appendix C.

5.2.4 Structural VAR

The high-frequency VECM identifies the price impact of order flow within minutes, but it cannot include the onshore forward rate, which is available only at the daily frequency. We therefore move to daily data, where we can measure the offshore–onshore spread directly. We estimate a daily SVAR using order flow, the offshore–onshore spread, and the spot return and test whether offshore order flow widens the spread in addition to moving the domestic spot rate.

For each currency pair i , we estimate a structural VAR following [Hasbrouck \(1991\)](#) using

$$\mathbf{w}_{i,t} = (OIB_{i,t}, \text{FLOOP}_{i,t}, r_{i,t}^{\text{spot}})',$$

where $OIB_{i,t}$ is daily signed order-flow imbalance in billions of U.S. dollars, $\text{FLOOP}_{i,t}$ is the one-month offshore–onshore forward spread defined in equation (4), and $r_{i,t}^{\text{spot}} = \Delta \ln S_{i,t}$ is the daily log spot return. The structural form is

$$\mathbf{A}\mathbf{w}_{i,t} = \mathbf{a}_{0,i} + \sum_{\ell=1}^p \mathbf{A}_{\ell}\mathbf{w}_{i,t-\ell} + \boldsymbol{\varepsilon}_{i,t}, \quad \boldsymbol{\varepsilon}_{i,t} \sim (\mathbf{0}, \mathbf{D}), \quad (31)$$

where $\mathbf{A}$ is the matrix of contemporaneous structural coefficients, $\mathbf{D}$ is the diagonal covariance matrix of structural shocks, and $p = 10$ is the lag length. Pre-multiplying by $\mathbf{A}^{-1}$ gives the reduced form

$$\mathbf{w}_{i,t} = \mathbf{c}_i + \sum_{\ell=1}^p \mathbf{B}_{\ell}\mathbf{w}_{i,t-\ell} + \mathbf{u}_{i,t}, \quad \mathbf{u}_{i,t} \sim (\mathbf{0}, \boldsymbol{\Sigma}_{u,i}), \quad (32)$$

with

$$\mathbf{c}_i = \mathbf{A}^{-1}\mathbf{a}_{0,i}, \quad \mathbf{B}_{\ell} = \mathbf{A}^{-1}\mathbf{A}_{\ell}, \quad \mathbf{u}_{i,t} = \mathbf{A}^{-1}\boldsymbol{\varepsilon}_{i,t}.$$

We identify structural shocks using a recursive Cholesky decomposition of the reduced-form covariance,

$$\boldsymbol{\Sigma}_{u,i} = \mathbf{P}_i\mathbf{P}_i',$$

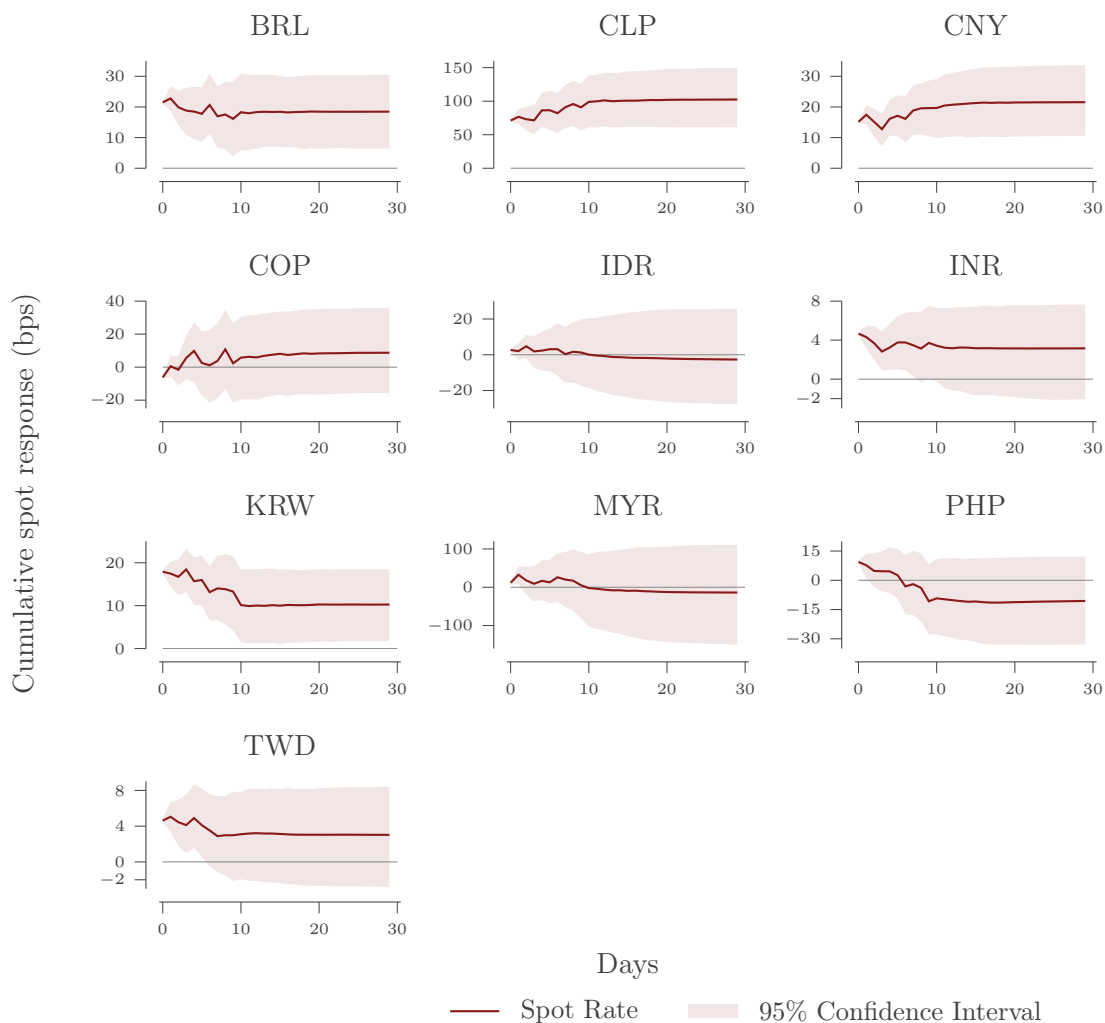
with $\mathbf{A}^{-1} = \mathbf{P}_i$ and the ordering

$$OIB \succ \text{FLOOP} \succ r^{\text{spot}}. \quad (33)$$

The ordering follows the model. Order flow is ordered first, the offshore–onshore spread responds as intermediaries price residual inventory, and the spot return responds through dealer hedging. Structural impulse responses at horizon h are $\boldsymbol{\Theta}_{i,h}\mathbf{P}_i$, where $\boldsymbol{\Theta}_{i,h}$ is the h -step moving-average coefficient matrix of the reduced form. We cumulate the spot-return response to obtain a spot-level response and report bootstrap confidence bands with 1,000 replications.

Figure 10 reports the cumulated response of the domestic spot rate to a unit OIB shock. The spot rate increases persistently, with the cumulated response stabilizing after roughly two weeks and remaining elevated through the 30-day horizon. This confirms the transmission of offshore order flow to domestic spot at the daily frequency, consistent with Prediction 1.

Figure 10: Daily VAR: Spot Rate Response to Order Imbalance

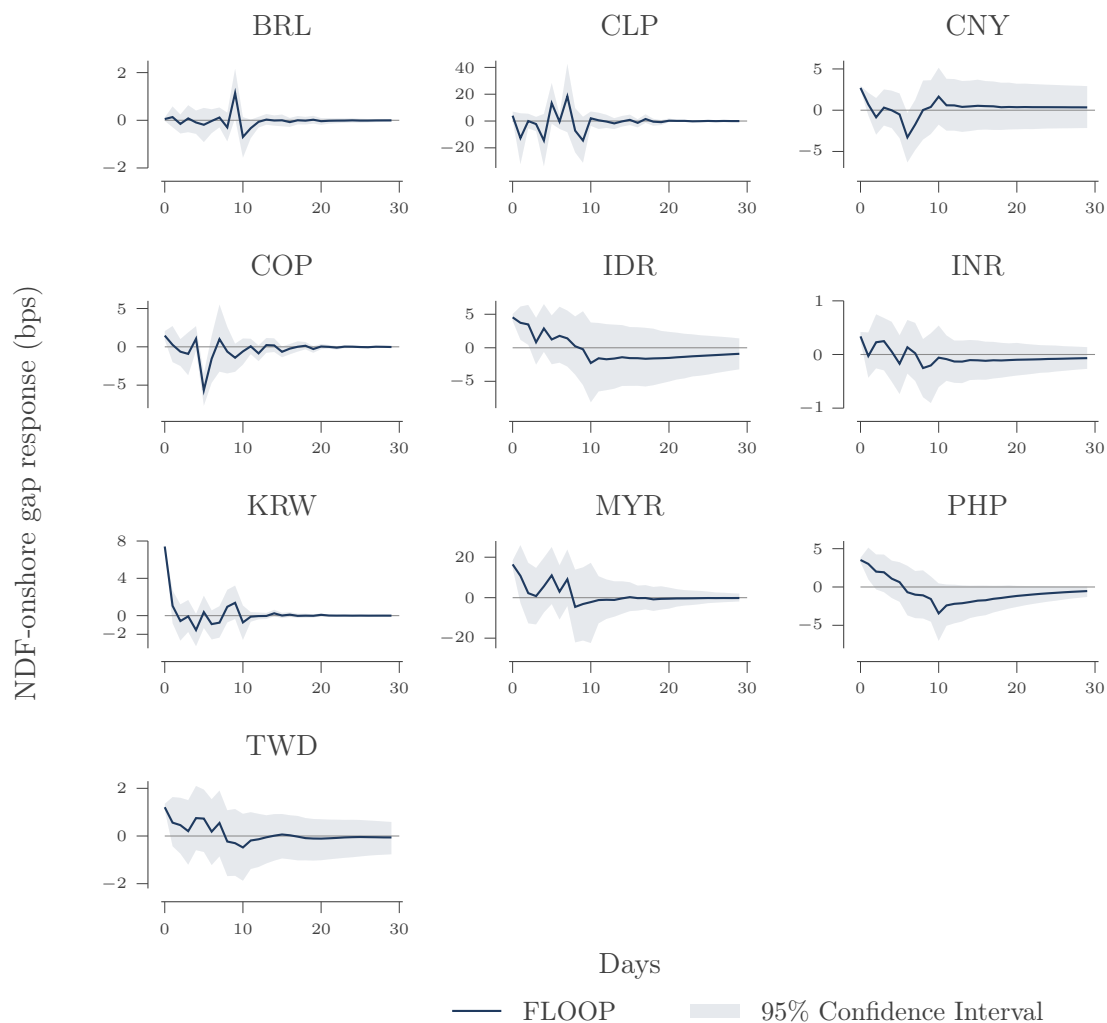


Notes. This figure plots the cumulative spot-rate response to a USD 1 billion order-imbalance shock in the daily VAR. Responses are converted from log units to basis points and horizons are measured in business days. Shaded areas denote pointwise bootstrap confidence bands.

Figure 11 reports the impulse response of the one-month offshore forward spread to the same OIB shock. A \$1 billion OIB shock widens the spread on impact in all ten currencies, significantly in nine. The response peaks within the first week and decays gradually over the following two to three weeks, with most currencies returning to baseline by 30 business days. Offshore order flow therefore widens the offshore–onshore spread in addition to moving the spot rate, consistent with Prediction 1. In the model, intermediaries require a

larger premium to absorb greater offshore inventory. The gradual mean reversion of the spread is also consistent with arbitrage capital absorbing the imbalance over time.

Figure 11: Daily VAR: NDF-Onshore Gap Response to Order Imbalance



Notes. This figure plots the impulse response of the NDF-onshore gap to a USD 1 billion order-imbalance shock in the daily VAR. Responses are in basis points and horizons are measured in business days. Shaded areas denote pointwise bootstrap confidence bands.

Taken together, the SVAR results show that offshore order flow moves the domestic spot rate and widens the offshore–onshore spread, with similar responses across the ten currencies. The spot result is the daily-frequency counterpart of the transmission identified in the high-frequency VECM, while the spread response is consistent with the pricing of offshore inventory by constrained intermediaries.

6 Conclusion

This paper studies how offshore NDF markets contribute to price discovery in emerging-market currencies. We develop a simple framework in which offshore demand pressure generates NDF order flow, dealers hedge the resulting inventory exposure through domestic markets, and capital controls limit arbitrage between offshore and onshore prices. Net long-USD positions depreciate the EM currency in both spot and NDF markets and widen the offshore–onshore forward spread. Tighter intermediation constraints widen the spread and reduce the transmission of offshore flow to the domestic spot market.

Four policy episodes illustrate these mechanisms. Following the August 2015 RMB reform, the renminbi depreciated sharply, the offshore–onshore spread widened, and speculators built long USD positions in anticipation of further depreciation. Malaysia’s 2016 restrictions reduced domestic-bank participation in offshore ringgit NDF activity and were followed by a compression of the offshore–onshore spread and reversing speculator flows. The 2020 RBI reform increased Indian-bank participation in offshore rupee NDF markets and was followed by a substantial narrowing of the offshore–onshore spread, while the April 2026 restrictions reduced this participation and were followed by a widening of the spread. These episodes illustrate the roles of offshore demand pressure and cross-market intermediation in linking offshore NDF and domestic currency markets.

Panel evidence from our transaction-level data on ten EM currencies over 2013–2025 supports these predictions. A \$1 billion increase in long-USD and short-EM order flow depreciates the domestic spot rate by approximately 10 basis points, while the offshore NDF response is approximately 18 basis points. At the five-minute frequency, offshore order flow affects both NDF and spot rates within minutes, and the offshore NDF contributes a material share of permanent price discovery, with the onshore market accounting for the larger share in the most actively traded pairs. At the daily frequency, offshore order flow also widens the offshore–onshore forward spread and generates a persistent response in the domestic spot rate.

In sum, our findings have implications for exchange-rate and capital-flow management in emerging markets. Offshore NDF markets transmit to domestic exchange rates even when capital controls restrict direct access to onshore markets. At the same time, these markets provide benefits in the form of price discovery, liquidity, and market access for investors facing capital controls. A key policy margin is the access of domestic banks to offshore markets. Expanding access increases arbitrage between offshore and onshore markets and narrows the offshore–onshore spread, while restrictions reduce cross-market intermediation and insulate domestic rates at the cost of wider spreads.

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Online Appendix to Offshore Forwards and Price Discovery in Emerging Market Currencies

Not for publication

We provide a roadmap of each section of the Appendix.

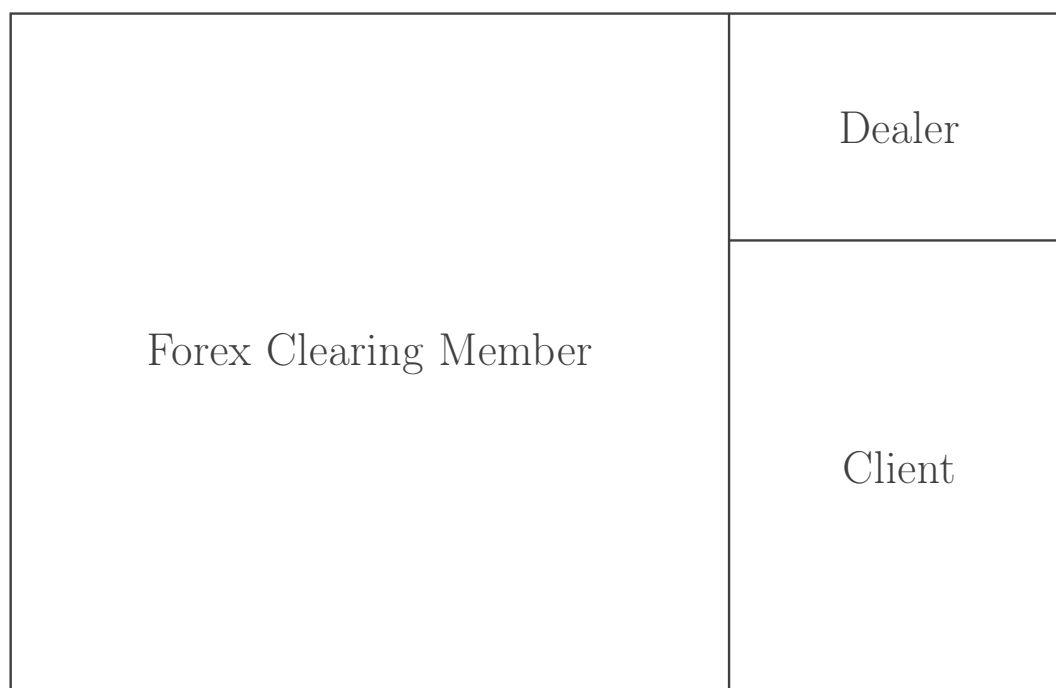
1. Appendix [A](#) describes the data. Appendix [A.1](#) provides additional detail on the LCH ForexClear transaction data, including variable definitions, counterparty classifications, monthly trading volume, clearing-member concentration, contract maturities, and intraday activity. Appendix [A.2](#) reports offshore–onshore forward spreads and offshore CIP deviations for the ten currencies in our sample.
2. Appendix [B](#) presents the model extension with partial offshore-dealer hedging. The extension allows the offshore dealer’s access to domestic spot hedging to affect the transmission of offshore demand pressure to the domestic spot rate.
3. Appendix [C](#) reports additional robustness tests, including the decomposition of high-frequency price impact into client-cleared and house order flow.
4. Appendix [D](#) describes the dealer-constraint measures used in the state-dependent analysis of Section [5.2.2](#) and reports OIB pricing effects conditioning on composite constraint indices.

A Data

A.1 LCH ForexClear Data

This appendix provides additional detail on the LCH ForexClear transaction data used in the main analysis. Table A.1 reports the variables observed in the cleared-trade records. Figure A.1 describes the counterparty classification used throughout the paper. Figure A.2 reports monthly cleared NDF volume by currency, Figure A.3 reports clearing-member concentration, Figure A.4 reports the maturity distribution of cleared contracts, Figure A.5 reports intraday trading activity, and Figure A.6 reports the quarterly distribution of clearing-member shares.

Figure A.1: LCH entity classifications

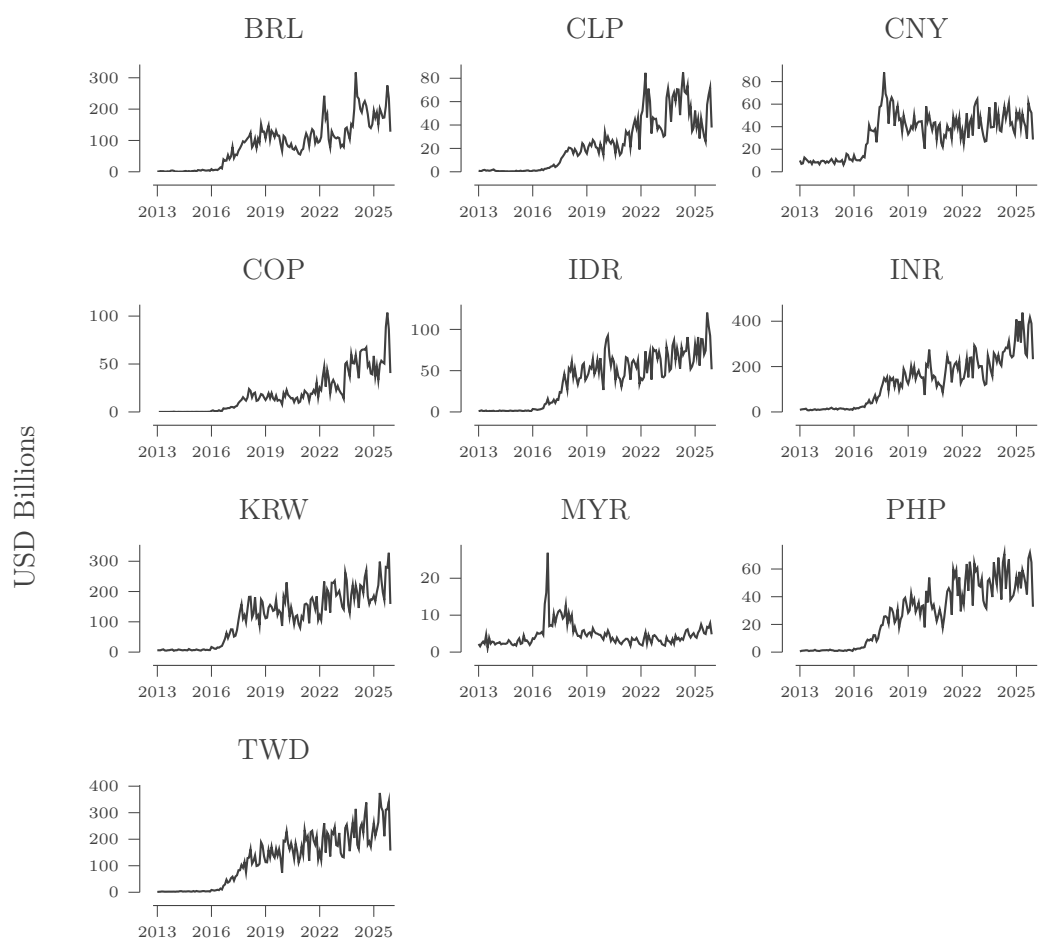


Notes. The figure reports the LCH counterparty classifications used in the paper. Forex clearing members hold direct membership of ForexClear. Dealers are affiliates of a member group that are authorized to trade NDFs and clear through the member. Clients clear indirectly through a Forex clearing member. Dealers and clients are not themselves Forex clearing members.

Table A.1: LCH Data Descriptions

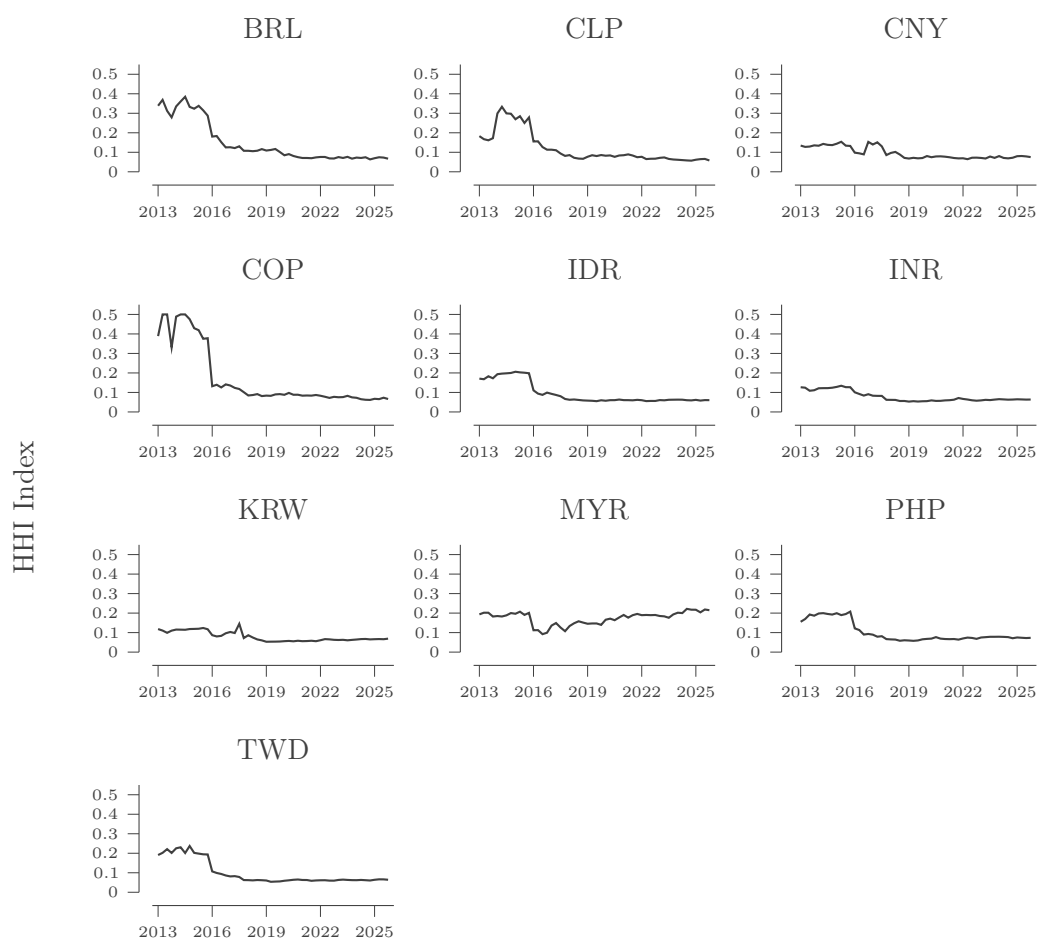
Names	Descriptions	Notes
Currency Pair	Currency pair of the NDF contract.	
Member ID	Unique identifier of the member executing the trade. Both legs of each trade are included in the dataset.	44 in total.
Member Flag	Indicates whether the entity is a clearing member of ForexClear.	A member may have multiple entities with different flags, including House and Dealer entities.
Dealer Flag	Indicates whether the entity is a dealer. A ForexClear dealer or affiliate is a member of, or affiliated firm within, a Member Group that is authorized to trade and clear FX products directly through ForexClear.	Dealers are not ForexClear clearing members.
Client Flag	Indicates whether the entity is a client that clears indirectly through a member.	Client trades are cleared through a ForexClear member.
Bank Flag	Indicates whether the entity is classified as a bank.	All entities in the dataset are classified as banks.
Counterparty	Identifier distinguishing clearing-member house activity from client activity and, where available, different client portfolios.	House or Client.
Trade Notional	Trade notional converted to U.S. dollars on the clearing date by ForexClear.	
Direction of Trade	Indicates whether the counterparty is on the long or short USD leg of the NDF contract.	
Trade Timestamp	Date and time at which the trade was registered in the ForexClear system.	
NDF Price	Price at which the trade is agreed between the counterparties.	
Spot Fixing Price	Spot fixing rate used to determine the settlement value of the NDF.	
Spot Price	Spot price associated with the NDF contract at the time of the transaction.	
Fixing Date	Date on which the reference spot rate used for NDF settlement is observed.	Typically 1–2 business days before maturity.
Maturity Date	Date on which the NDF cash flow settles.	

Figure A.2: LCH Monthly Trading Volume by Currency



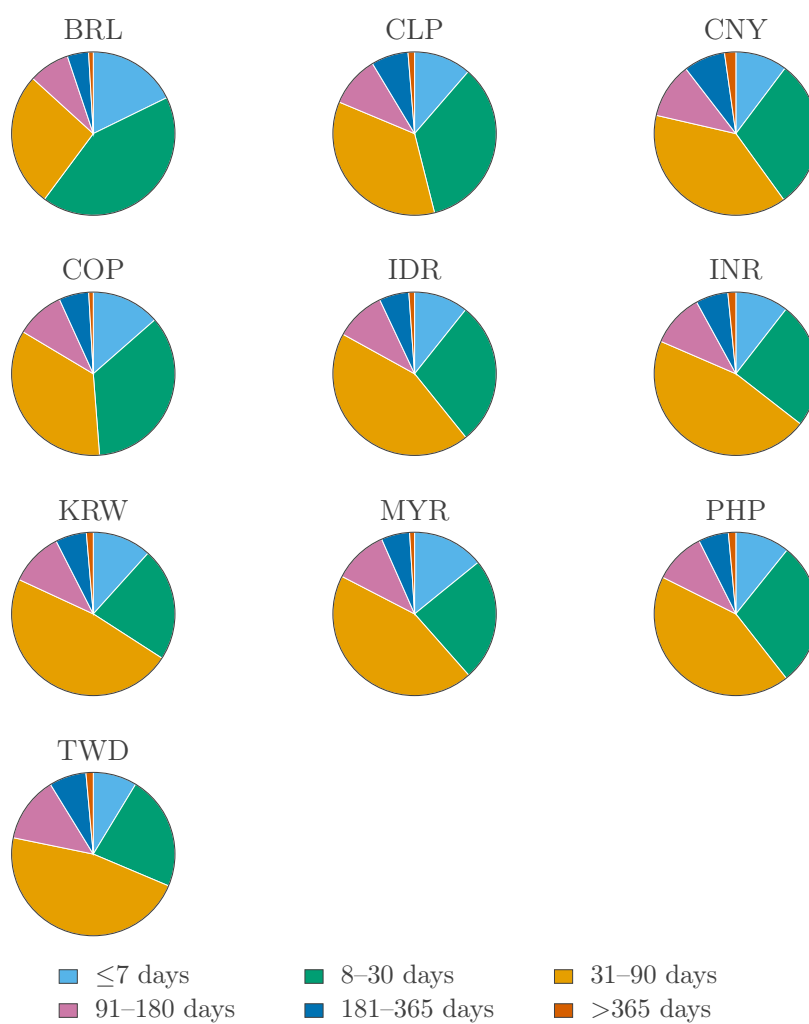
Notes. This figure plots monthly LCH trading volume by currency pair, measured as USD billions of notional volume. The sample is from January 2013 to December 2025.

Figure A.3: LCH Quarterly HHI by Currency



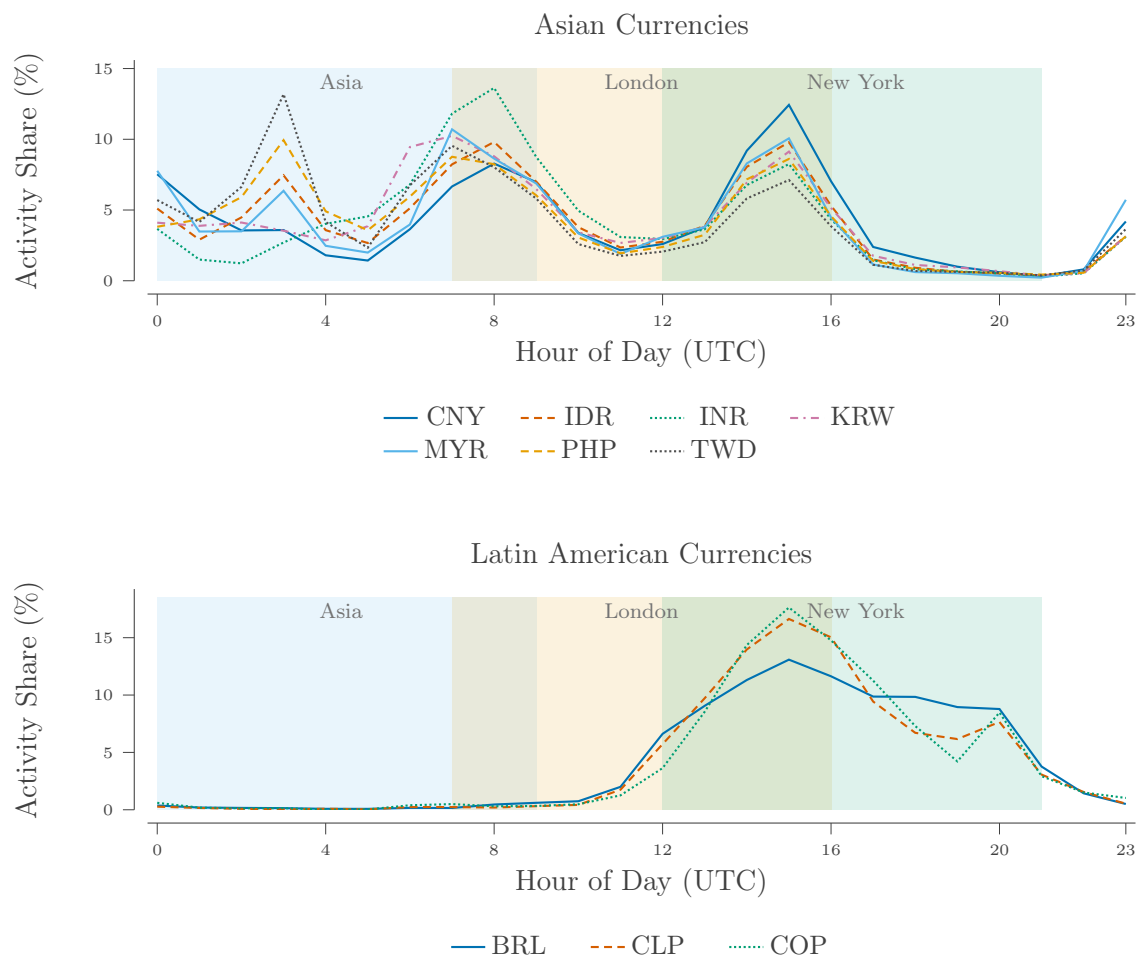
Notes. This figure plots the quarterly Herfindahl-Hirschman index of LCH notional trading shares by currency pair. The sample is from the first quarter of 2013 to the fourth quarter of 2025.

Figure A.4: LCH Maturity Tenor Shares by Currency



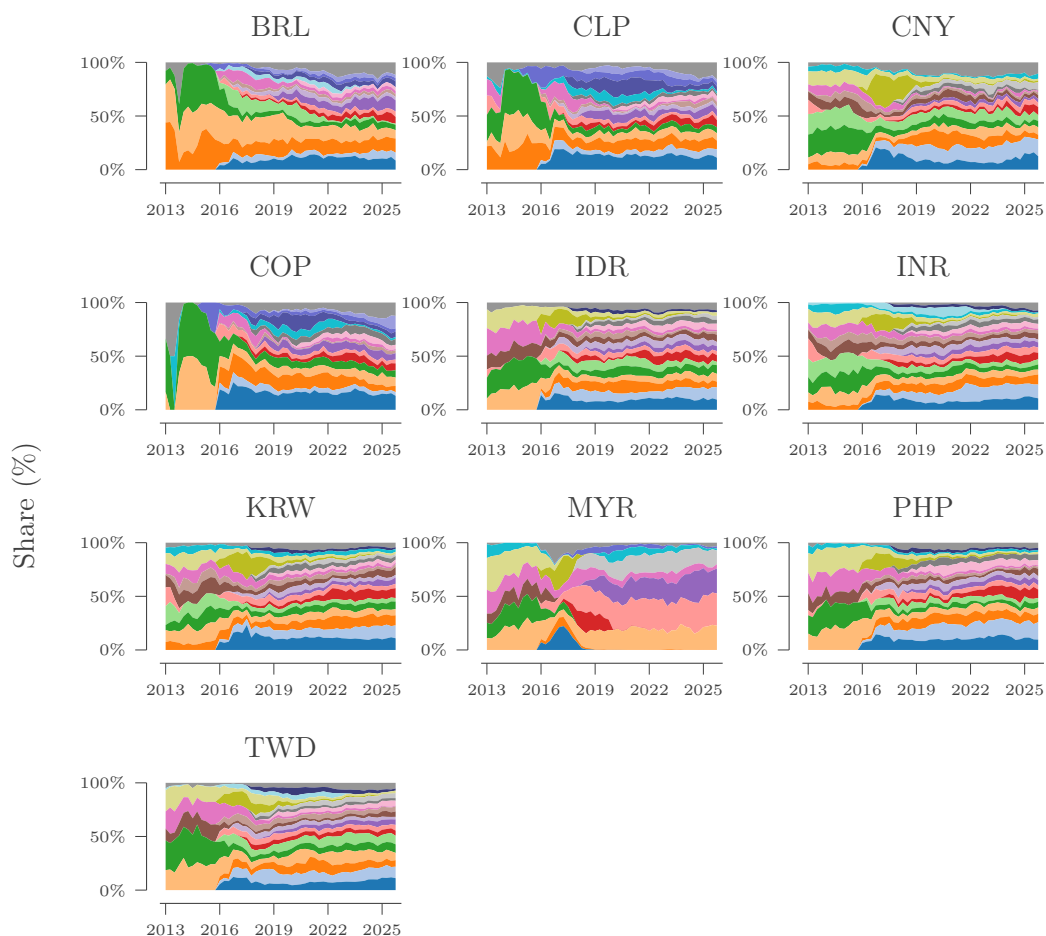
Notes. This figure reports the maturity-tenor composition of LCH notional trading volume by currency pair. Slices are based on each tenor bucket's share of total notional trading volume. The sample is from January 2013 to December 2025.

Figure A.5: Intraday LCH Activity Share by Currency



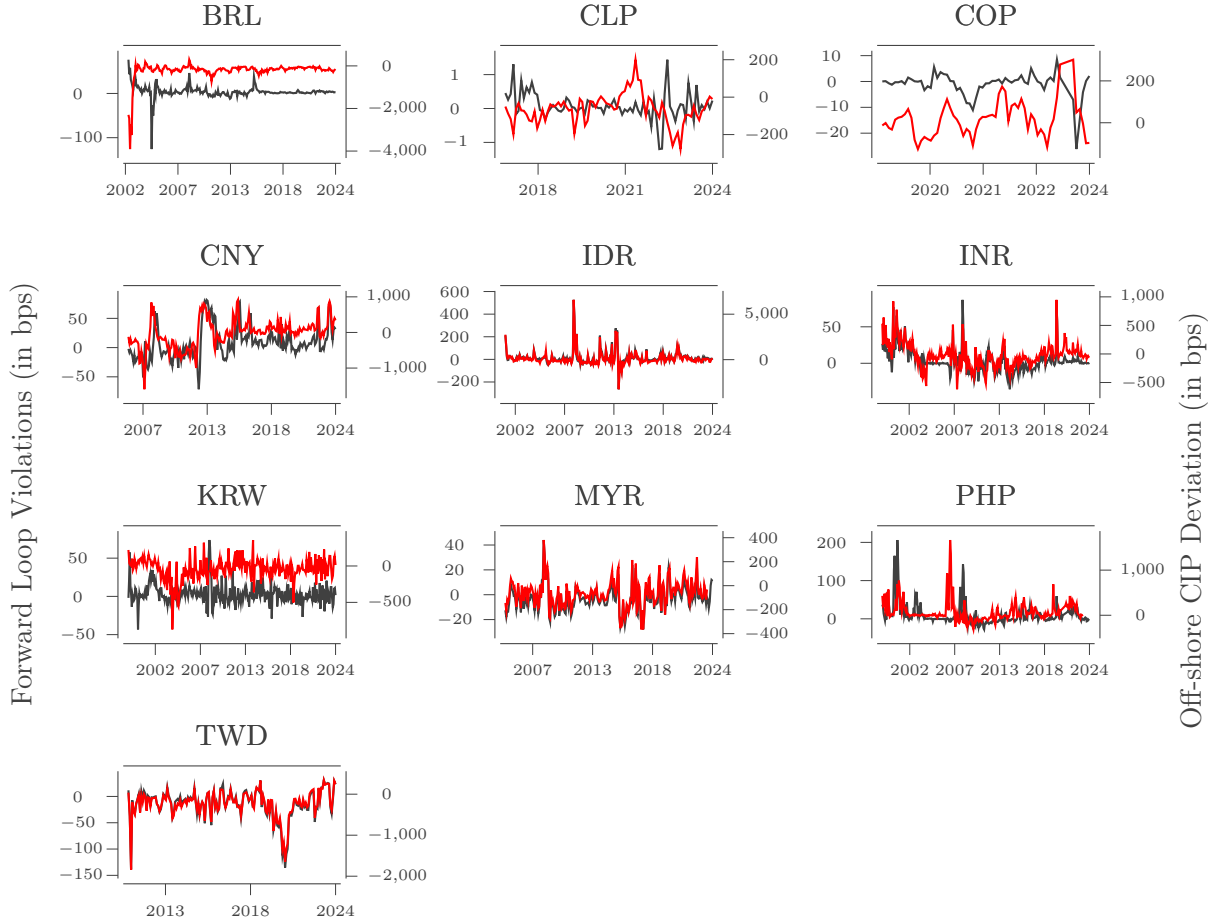
Notes. This figure plots the average intraday distribution of LCH notional trading activity by currency pair. For each currency, hourly values are the mean share of daily notional volume cleared in each UTC hour. Shaded regions denote Asian (00:00–09:00 UTC), London (07:00–16:00 UTC), and New York (12:00–21:00 UTC) trading sessions, respectively; darker regions indicate overlapping sessions. The sample is from January 2013 to December 2025.

Figure A.6: LCH Quarterly Member Trading Volume Shares by Currency



Notes. This figure plots quarterly member shares of LCH notional trading volume by currency pair. Shares are stacked within each currency-quarter and sum to 100 percent. Colors are fixed across panels and stack from Member 1 through Member 24, with grey denoting Others. The sample is from the first quarter of 2013 to the fourth quarter of 2025.

Figure A.7: The Forward Law of One Price Violations and Off-shore CIP Violations



Notes. This figure plots monthly average 1-month FL_t and off-shore CIP deviations for Brazil, Chile, Colombia, China, Indonesia, India, Korea, Malaysia, Philippines and Chinese Taipei. The black lines show the FL_t (left y-axis) and the red lines show the off-shore currency basis (right y-axis).

A.2 Offshore CIP Deviations

Figure A.7 reports the offshore–onshore forward spread together with the offshore cross-currency basis $x_{i,t}$ for the ten currencies in our sample. The offshore basis is constructed using NDF rates. The offshore CIP series closely tracks the offshore–onshore forward spread for most currencies, indicating that differences between offshore and onshore forward prices account for an important component of the offshore basis.

B Offshore Hedging and Spot Transmission

In the baseline model, the offshore dealer hedges all residual inventory in the domestic spot market. As a result, all offshore flow reaches the spot market one-for-one. In practice,

capital controls may also restrict offshore dealers' access to domestic spot markets. This appendix relaxes the full-hedging assumption and allows the offshore dealer's access to domestic spot hedging to affect the transmission of offshore demand pressure to the domestic spot rate.

Setup. The offshore dealer hedges a fraction $\theta \in [0, 1]$ of her residual inventory in the onshore spot market and leaves the remainder unhedged. This may reflect access through an onshore branch, FPI custody positions, or indirect access through domestic counterparties. A higher θ represents greater access to domestic spot hedging, and the baseline model is recovered when $\theta = 1$.¹⁸

We hold the offshore dealer's total marginal inventory cost fixed at Λ_D regardless of how the position is hedged. This isolates the effect of hedging access on spot-market transmission. The assumption is reduced form and does not require unhedged FX risk and a funded spot hedge to have the same marginal cost in practice. The dealer pricing rule in (9), and therefore Λ and a in (16), remain unchanged. Only spot-market clearing changes.

Equilibrium. Spot demand now consists of the offshore dealer's partial hedge $\theta(x^S - x^A)$ and the onshore dealer's full hedge x^A ,

$$\theta(x^S - x^A) + x^A = [\theta + (1 - \theta)a]x^S = \eta(S_0 - \bar{S}). \quad (34)$$

Only the fraction $\theta + (1 - \theta)a$ of offshore flow therefore reaches the domestic spot market. Solving for equilibrium flow as in the baseline gives

$$x^{S*} = \frac{\mu - (1 + \rho)\bar{S}}{\gamma^S \sigma^2 + \phi_\theta}, \quad \phi_\theta \equiv \frac{(1 + \rho)[\theta + (1 - \theta)a]}{\eta} + \Lambda. \quad (35)$$

The term ϕ_θ is the counterpart of ϕ in (20), with spot price impact scaled by the fraction of offshore flow that reaches the domestic market. When $\theta = 1$, $\phi_\theta = \phi$ and the baseline model is recovered. The equilibrium spot rate is

$$S_0^* = \bar{S} + \frac{[\theta + (1 - \theta)a]x^{S*}}{\eta}.$$

Prediction 1 (Hedging access and spot transmission). *Conditional on order flow, the*

¹⁸Only the offshore dealer hedges partially. The onshore dealer continues to hedge in full. The friction applies to the offshore dealer because she must access the domestic market to hedge, while the onshore dealer already operates in the domestic market. This is similar to De Leo et al. (2024), where local intermediaries cannot hold exchange-rate risk and offset forward positions one-for-one in spot. In practice, onshore net-open-position limits encourage domestic dealers to hedge, while capital controls may restrict the ability of offshore dealers to do so.

spot price impact of a unit of flow,

$$\frac{\partial S_0}{\partial x^S} = \frac{\theta + (1 - \theta)a}{\eta}, \quad (36)$$

is increasing in the offshore dealer's hedging access,

$$\frac{\partial^2 S_0}{\partial x^S \partial \theta} = \frac{1 - a}{\eta} > 0.$$

In equilibrium, the response of the spot rate to offshore demand pressure,

$$\frac{\partial S_0^*}{\partial \mu} = \frac{\theta + (1 - \theta)a}{\eta(\gamma^S \sigma^2 + \phi_\theta)}, \quad (37)$$

is also increasing in hedging access,

$$\frac{\partial^2 S_0^*}{\partial \mu \partial \theta} = \frac{(1 - a)(\gamma^S \sigma^2 + \Lambda)}{\eta(\gamma^S \sigma^2 + \phi_\theta)^2} > 0. \quad (38)$$

The first result follows directly from (34). The second follows from differentiating (37) with respect to θ , using

$$\begin{aligned} \frac{\partial[\theta + (1 - \theta)a]}{\partial \theta} &= 1 - a, \\ \frac{\partial \phi_\theta}{\partial \theta} &= \frac{(1 + \rho)(1 - a)}{\eta}, \end{aligned}$$

and

$$\phi_\theta - \frac{(1 + \rho)[\theta + (1 - \theta)a]}{\eta} = \Lambda.$$

The first result maps most directly into the empirical analysis. Conditional on observed order flow, greater hedging access raises the spot response to a given amount of OIB. The second result gives the corresponding equilibrium response to a change in offshore expectations. Capital controls that restrict offshore dealers' access to domestic spot hedging, represented by a lower θ , therefore reduce the transmission of offshore demand pressure to the domestic spot market.

The policy episodes provide related variation in the ability of intermediaries to operate across offshore and onshore markets. Restrictions on domestic-bank participation in offshore NDF markets, such as the Malaysian measures in 2016 and the April 2026 RBI restrictions, may reduce the ability of offshore positions to be intermediated back to the domestic market. In the model, one component of this effect can be represented by a decline in effective hedging access θ .

These policies are unlikely to affect only θ . Restrictions on domestic dealer participation may also raise Λ_D and Γ_A , changing both the effective intermediation cost Λ and the arbitrage share a . They may also affect offshore demand pressure itself. We therefore

interpret the policy episodes as broader changes in offshore intermediation rather than as isolated changes in a single model parameter.

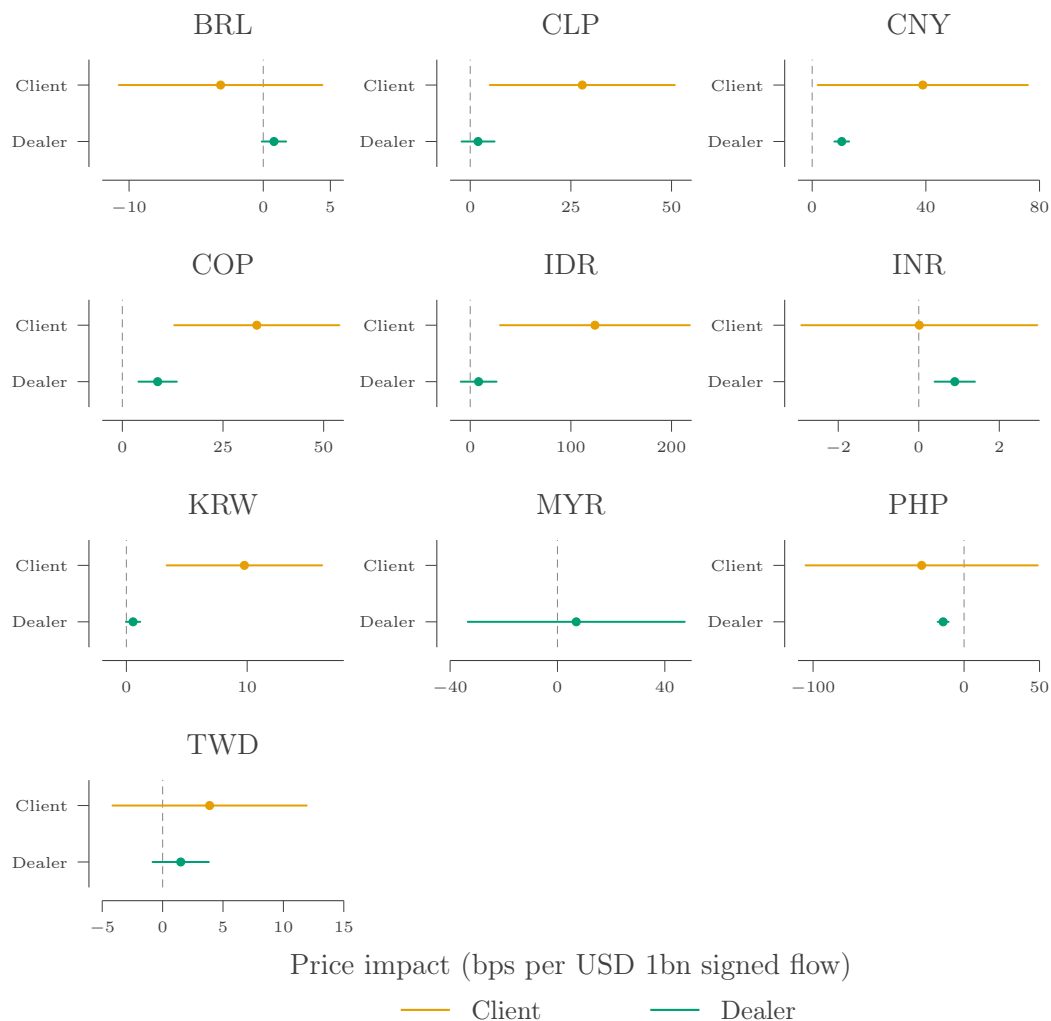
C Additional Tests

C.1 Client-Cleared versus House Order Flow

As a robustness test of the high-frequency VECM evidence in Section 5.2.3, we decompose order-flow imbalance by clearing channel and re-estimate the VECM responses separately for client-cleared and house order flow. Client-cleared trades are those of banks that do not hold direct clearing membership and clear through a client-clearing broker, while house trades are those of clearing members and their dealer affiliates. Figure C.1 reports the results by currency. The estimated price impact of client-cleared order flow is larger on average than that of house order flow for both the offshore NDF rate and the domestic spot rate, although the client-cleared estimates display greater cross-sectional variation.

This pattern is consistent with client-cleared order flow containing more directional information than house order flow. In the model, offshore investor demand generates the initial directional position x^S , while subsequent trading among intermediaries reflects the redistribution and hedging of this exposure. The decomposition reflects the clearing channel rather than the type of trader, however. All counterparties in the dataset are banks, and the classification does not identify the underlying motive for each trade. We therefore interpret the decomposition as evidence that the price impact of offshore order flow is concentrated in trades cleared outside clearing members' house books rather than as a direct measure of any particular trading motive.

Figure C.1: Member-Level Price Impact by Currency



Notes. This figure plots five-minute member-type OLS price-impact estimates at horizon $h = 5$. Points show coefficients in basis points per USD 1 billion of signed flow, and horizontal intervals denote 95% confidence intervals. X-axis ranges vary by currency. The MYR client estimate is omitted because the source file marks it as unavailable.

C.2 Alternative Quote Lags in the Lee–Ready Classification

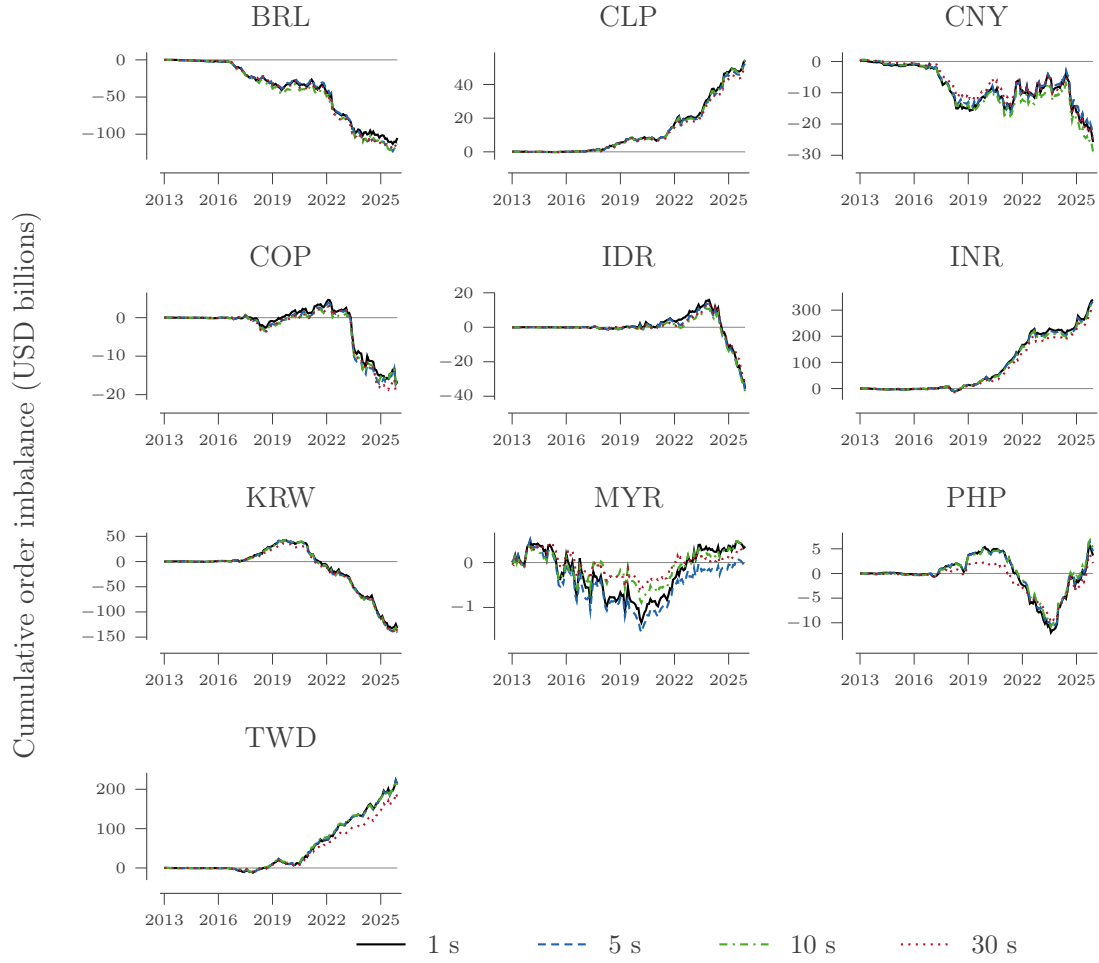
The LCH timestamps record registration in the clearing system, so the choice of reference quote may affect the classification of trade direction. In the baseline, we compare each transaction price with the bid–ask midpoint prevailing one second before its recorded registration timestamp. We examine sensitivity to this timing convention by using quote lags of 5, 10, and 30 seconds and re-estimating the daily regressions and five-minute price responses.

The daily estimates are similar across quote lags. Table C.1 reports the panel regressions of Table 2 for each lag. The spot coefficient declines modestly from 10.1 to 9.4 basis points per \$1 billion of order-flow imbalance between the one- and thirty-second lags. The NDF coefficient ranges from 17.7 to 18.1 basis points across the four specifications, and the onshore forward response remains close to the spot response. Figure C.2 also shows broadly similar movements in cumulative order imbalance across lags.

The intraday responses are also robust to quote timing. Figures C.3 and C.4 report the NDF and spot responses to a \$1 billion order-flow shock using the five-minute model of Section 5.2.3. For BRL, CLP, CNY, and COP, both responses remain positive across the four quote lags. For several other currencies, longer quote lags reduce the estimated responses and can reverse their sign. According to LCH, most transactions are registered automatically, suggesting that longer quote lags may match trades to quotes that substantially predate execution, causing the classification to reflect intervening price movements rather than trade direction.

These results support the association between offshore order flow and exchange-rate returns across alternative quote lags.

Figure C.2: Cumulative Order Imbalance by Currency and Quote Lag



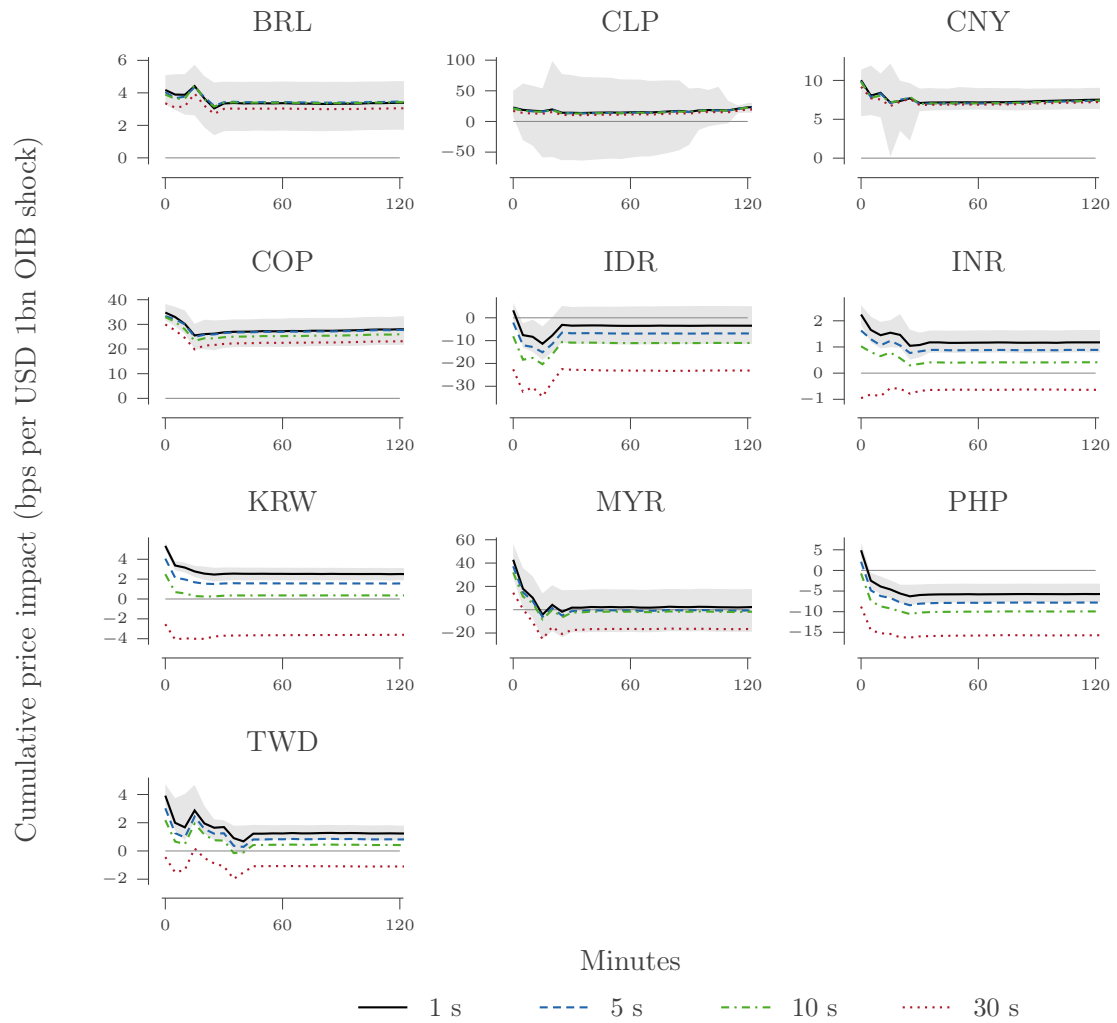
Notes. This figure plots cumulative LCH order imbalance by currency pair using alternative quote lags in the Lee–Ready classification. Trades are signed against the quote prevailing 1, 5, 10, or 30 seconds before the recorded trade timestamp. The one-second lag is the baseline used in the paper. Cumulative order imbalance is measured in USD billions at the end of each month, and positive values denote long-USD and short-EM pressure. The cumulative series include only trades with reference quotes no more than 60 seconds old. The sample is from January 2013 to December 2025.

Table C.1: Order Imbalance and Exchange-Rate Returns: Alternative Quote Lags

	r^{spot}		r^{NDF}		$r^{onshore}$	
<i>Panel A: Quote lag 1 second (baseline)</i>						
<i>OIB</i>	10.73** (4.42)	10.06** (4.18)	18.46* (9.94)	18.06* (10.13)	10.52** (4.38)	9.91** (4.15)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
<i>Panel B: Quote lag 5 seconds</i>						
<i>OIB</i>	10.61** (4.37)	9.94** (4.13)	18.96* (10.59)	18.57* (10.80)	10.41** (4.34)	9.80** (4.11)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
<i>Panel C: Quote lag 10 seconds</i>						
<i>OIB</i>	10.41** (4.39)	9.74** (4.13)	18.25* (10.11)	17.84* (10.31)	10.21** (4.35)	9.60** (4.11)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
<i>Panel D: Quote lag 30 seconds</i>						
<i>OIB</i>	10.06** (4.34)	9.42** (4.09)	18.02* (10.29)	17.65* (10.48)	9.84** (4.29)	9.25** (4.06)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
Controls	No	Yes	No	Yes	No	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes
N	34,168	32,397	34,168	32,397	31,241	29,658

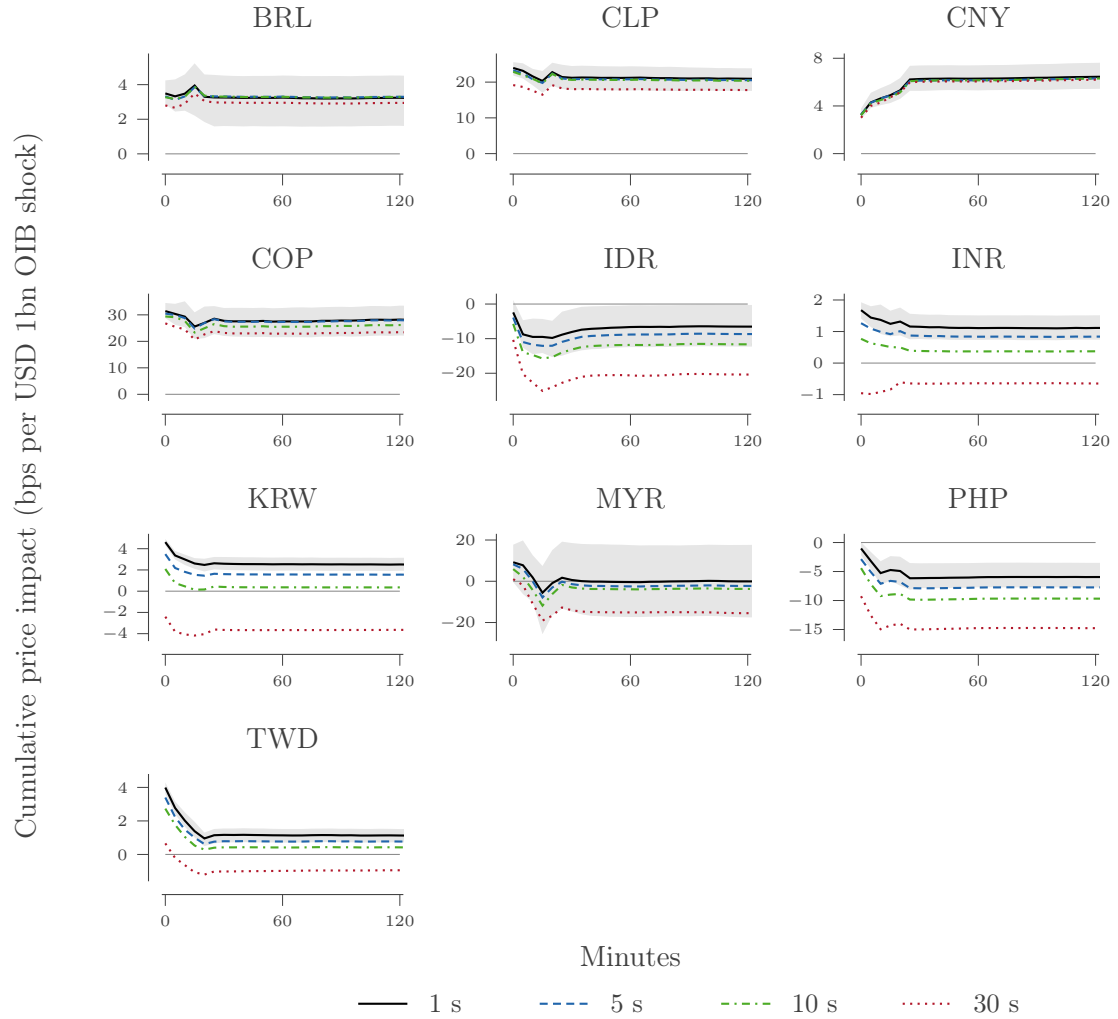
Notes. Panel regressions of daily exchange-rate returns on contemporaneous offshore order-flow imbalance, as in Table 2, using alternative quote lags in the Lee–Ready classification. Trades are signed against the quote prevailing 1 second (Panel A, the baseline), 5 seconds (Panel B), 10 seconds (Panel C), or 30 seconds (Panel D) before the recorded trade timestamp. The dependent variables are spot, NDF forward, and onshore forward returns, each measured in basis points. $OIB_{i,t}$ is measured in USD billions, so reported coefficients are basis points per USD billion of OIB. All columns include currency fixed effects. Columns marked Yes in the Controls row also include the daily change in the VIX and the broad U.S. dollar index as global risk controls. Standard errors are two-way clustered by currency and period and reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

Figure C.3: VECM-X: NDF Price Response to Order Imbalance by Currency and Quote Lag



Notes. This figure plots cumulative NDF forward price responses to a USD 1 billion order-flow imbalance shock in the five-minute VECM-X. Trades are signed using the Lee–Ready algorithm against the quote prevailing 1, 5, 10, or 30 seconds before the recorded trade timestamp. The one-second lag corresponds to the baseline specification in Figure 8; the sample and estimation procedure are otherwise unchanged. Responses are in basis points and horizons are measured in minutes. Shaded areas denote pointwise bootstrap confidence bands for the baseline specification.

Figure C.4: VECM-X: Spot Price Response to Order Imbalance by Currency and Quote Lag



Notes. This figure plots cumulative spot price responses to a USD 1 billion order-flow imbalance shock in the five-minute VECM-X. Trades are signed using the Lee–Ready algorithm against the quote prevailing 1, 5, 10, or 30 seconds before the recorded trade timestamp. The one-second lag corresponds to the baseline specification in Figure 8; the sample and estimation procedure are otherwise unchanged. Responses are in basis points and horizons are measured in minutes. Shaded areas denote pointwise bootstrap confidence bands for the baseline specification.

C.3 Sub-Sample Stability: Before and After 2019

Cleared NDF activity increased substantially over the sample, reflecting both market growth and the expansion of central clearing (Figure A.2). We examine whether the daily relation between offshore order flow and exchange-rate returns persists as the observed market changes. We split the sample at 2019 to compare the earlier period of lower cleared activity with the later period of higher activity. Tables C.2 and C.3 repeat the panel and currency-level regressions of Tables 2 and 3 for the two periods.

Two patterns stand out. First, the panel coefficients remain positive in both periods, but the estimated spot and onshore forward responses are larger before 2019. In the specifications without global risk controls, the spot coefficient is 18.5 basis points per \$1 billion of order-flow imbalance in the early period and 9.9 basis points in the later period, compared with 10.7 in the full sample. The onshore forward coefficient follows a similar pattern. The NDF coefficients are closer across periods, at 19.8 and 18.4 basis points, respectively. Adding the daily change in the VIX and the broad U.S. dollar index leaves these comparisons largely unchanged.

Second, the currency-level estimates show that the positive spot association is present across most markets in both periods. The spot coefficient is positive and significant at the 5% level for eight of the ten currencies before 2019 and seven afterwards. The estimated coefficient is larger in the early period for eight currencies. These results support the qualitative relation between offshore order flow and domestic spot returns across the two periods, while indicating variation in the estimated response per unit of flow.

Table C.4 places these estimates alongside changes in the cleared market. Across the ten currencies, daily cleared notional increases from about \$11 billion in 2013–2018 to \$47 billion in 2019–2025. Mean trade size falls for eight currencies, and the number of active clearing members rises for every currency except MYR. A fixed dollar imbalance therefore represents a smaller share of observed cleared volume in the later period. The lower spot coefficients coincide with this expansion in cleared activity, but the comparison does not distinguish changes in market depth from changes in the coverage and composition of cleared trading.

Table C.2: Order Imbalance and Exchange-Rate Returns: Before and After 2019

	r^{spot}		r^{NDF}		$r^{onshore}$	
<i>Panel A: Full sample, 2013–2025</i>						
<i>OIB</i>	10.73** (4.42)	10.06** (4.18)	18.46* (9.94)	18.06* (10.13)	10.52** (4.38)	9.91** (4.15)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
N	34,168	32,397	34,168	32,397	31,241	29,658
<i>Panel B: 2013–2018</i>						
<i>OIB</i>	18.52*** (7.16)	17.41** (7.12)	19.83*** (6.67)	19.10*** (6.37)	17.10** (6.82)	16.27** (6.79)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
N	15,609	14,534	15,609	14,534	12,842	11,955
<i>Panel C: 2019–2025</i>						
<i>OIB</i>	9.92** (4.14)	9.37** (3.91)	18.43* (10.42)	18.05* (10.63)	9.85** (4.15)	9.30** (3.92)
R-squared	0.01	0.03	0.00	0.00	0.01	0.03
N	18,559	17,863	18,559	17,863	18,399	17,703
Controls	No	Yes	No	Yes	No	Yes
Currency FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Panel regressions of daily exchange-rate returns on contemporaneous offshore order-flow imbalance, as in Table 2, estimated for the full sample, 2013–2025 (Panel A), and the sub-samples 2013–2018 (Panel B) and 2019–2025 (Panel C). The dependent variables are spot, NDF forward, and onshore forward returns, each measured in basis points. $OIB_{i,t}$ is measured in USD billions, so reported coefficients are basis points per USD billion of OIB. All columns include currency fixed effects. Columns marked Yes in the Controls row also include the daily change in the VIX and the broad U.S. dollar index as global risk controls. Standard errors are two-way clustered by currency and period and reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

Table C.3: Order Imbalance and Exchange-Rate Returns by Currency: Before and After 2019

	Currency pair									
	USD/BRL	USD/CLP	USD/CNY	USD/COP	USD/IDR	USD/INR	USD/KRW	USD/MYR	USD/PHP	USD/TWD
Panel A: Spot return (r^{spot})										
Full sample, 2013–2025	22.91*** (3.23)	72.22*** (9.98)	15.53*** (2.02)	56.52*** (6.95)	-4.15* (2.48)	3.44*** (0.61)	11.20*** (1.66)	18.32 (13.70)	13.83*** (3.62)	1.33 (0.88)
R-squared	0.09	0.10	0.05	0.09	0.01	0.02	0.03	0.01	0.01	0.01
N	3,176	3,247	3,245	3,247	3,247	3,247	3,247	3,247	3,247	3,247
2013–2018	46.96*** (6.86)	145.78*** (30.84)	18.13*** (3.03)	122.82*** (26.75)	20.33*** (7.64)	7.62*** (2.14)	10.72*** (3.95)	11.66 (21.05)	20.50** (9.70)	1.98 (2.04)
R-squared	0.08	0.09	0.05	0.08	0.03	0.02	0.02	0.02	0.02	0.02
N	1,441	1,455	1,453	1,455	1,455	1,455	1,455	1,455	1,455	1,455
2019–2025	20.53*** (3.12)	67.90*** (9.75)	14.75*** (2.39)	51.81*** (6.94)	-6.25** (2.56)	3.06*** (0.64)	11.53*** (1.80)	31.25* (16.04)	12.90*** (3.90)	1.29 (0.96)
R-squared	0.12	0.10	0.06	0.10	0.01	0.02	0.03	0.00	0.01	0.00
N	1,735	1,792	1,792	1,792	1,792	1,792	1,792	1,792	1,792	1,792
Panel B: NDF forward return (r^{NDF})										
Full sample, 2013–2025	14.60*** (2.21)	71.95*** (10.00)	9.80* (5.60)	54.69*** (6.97)	-0.79 (14.56)	3.28*** (0.59)	65.15 (47.11)	51.68** (21.12)	20.77*** (3.82)	4.35** (1.81)
R-squared	0.00	0.10	0.01	0.09	0.00	0.02	0.00	0.01	0.00	0.03
N	3,176	3,247	3,245	3,247	3,247	3,247	3,247	3,247	3,247	3,247
2013–2018	29.35*** (8.59)	147.14*** (30.83)	19.62*** (3.45)	123.77*** (27.05)	-112.44 (154.12)	7.78*** (2.24)	43.38** (19.93)	79.54** (31.88)	34.97** (14.57)	6.13*** (2.33)
R-squared	0.00	0.09	0.04	0.08	0.00	0.03	0.00	0.02	0.00	0.04
N	1,441	1,455	1,453	1,455	1,455	1,455	1,455	1,455	1,455	1,455
2019–2025	12.85*** (2.12)	67.53*** (9.75)	6.93 (6.96)	49.78*** (6.96)	7.65** (3.84)	2.86*** (0.61)	68.69 (53.89)	20.87 (17.45)	19.26*** (3.87)	4.22** (1.99)
R-squared	0.04	0.10	0.01	0.10	0.05	0.02	0.00	0.00	0.04	0.02
N	1,735	1,792	1,792	1,792	1,792	1,792	1,792	1,792	1,792	1,792
Panel C: Onshore forward return ($r^{onshore}$)										
Full sample, 2013–2025	22.96*** (3.20)	71.10*** (9.87)	15.43*** (2.02)	58.58*** (7.77)	-4.20* (2.49)	3.35*** (0.60)	11.00*** (1.66)	18.48 (13.64)	13.64*** (3.66)	1.40 (0.88)
R-squared	0.09	0.10	0.05	0.10	0.01	0.02	0.03	0.01	0.01	0.01
N	3,176	2,104	3,245	1,651	3,247	3,247	3,247	3,247	3,247	3,247
2013–2018	46.72*** (6.87)	141.45*** (34.24)	18.51*** (2.98)		20.92*** (7.77)	7.73*** (2.15)	10.60*** (3.95)	11.71 (20.97)	20.67** (9.74)	1.95 (2.03)
R-squared	0.08	0.15	0.05		0.03	0.03	0.02	0.02	0.02	0.02
N	1,441	312	1,453		1,455	1,455	1,455	1,455	1,455	1,455
2019–2025	20.61*** (3.09)	67.67*** (9.72)	14.52*** (2.39)	57.92*** (7.70)	-6.35** (2.57)	2.94*** (0.63)	11.33*** (1.80)	31.53** (15.98)	12.67*** (3.95)	1.36 (0.95)
R-squared	0.12	0.10	0.05	0.11	0.01	0.02	0.03	0.00	0.01	0.00
N	1,735	1,792	1,792	1,632	1,792	1,792	1,792	1,792	1,792	1,792

Notes. Currency-by-currency time-series regressions of daily exchange-rate returns on contemporaneous offshore order-flow imbalance, as in Table 3, estimated for the full sample, 2013–2025, and the sub-samples 2013–2018 and 2019–2025. The dependent variables are spot, NDF forward, and onshore forward returns, each measured in basis points and reported in separate panels. $OIB_{i,t}$ is measured in USD billions, so reported coefficients are basis points per USD billion of OIB. As in Table 3, each regression includes the daily change in the VIX and the broad U.S. dollar index as global risk controls. Estimates are omitted when fewer than 30 observations are available, as for COP onshore forward returns in 2013–2018. Newey–West HAC standard errors with 12 lags are reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

Table C.4: Transaction Statistics by Currency: Before and After 2019

	USD/BRL	USD/CLP	USD/CNY	USD/COP	USD/IDR	USD/INR	USD/KRW	USD/MYR	USD/PHP	USD/TWD
<i>Panel A: Trade characteristics, 2013–2018</i>										
Trades per trading day	53.9	30.7	75.4	51.4	123.5	395.9	413.0	46.4	96.1	251.6
daily notional (USD bn)	1.85	0.27	1.18	0.38	0.65	2.31	2.22	0.25	0.43	1.84
Mean trade size (USD mn)	34.23	8.95	15.68	7.39	5.22	5.84	5.38	5.49	4.49	7.31
Median trade size (USD mn)	15.00	4.00	10.00	3.00	2.00	1.00	1.00	2.00	1.00	1.00
P10 trade size (USD mn)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P90 trade size (USD mn)	100.00	20.00	33.00	17.00	13.00	15.00	9.00	13.00	10.00	20.00
SD trade size (USD mn)	53.69	15.79	21.37	14.02	10.99	16.87	26.83	8.54	10.60	18.14
<i>Panel B: Clearing-member statistics, 2013–2018</i>										
Total active members	29	24	26	24	26	26	27	23	26	26
HHI of member trade-count shares	0.11	0.08	0.08	0.10	0.07	0.08	0.08	0.09	0.07	0.07
Top-5 share of notional (%)	65.6	49.5	55.3	56.9	43.2	40.4	48.4	55.3	42.3	41.3
Top-10 share of notional (%)	86.9	78.1	81.4	82.6	71.9	69.4	74.7	85.2	73.0	70.5
Average currencies traded per member	8.6	9.7	9.6	9.7	9.6	9.6	9.3	9.9	9.6	9.6
<i>Panel C: Trade characteristics, 2019–2025</i>										
Trades per trading day	437.2	302.2	118.0	221.3	784.4	2,430.7	2,429.0	39.3	539.9	1,752.1
daily notional (USD bn)	6.81	2.06	2.06	1.65	3.05	10.58	8.41	0.20	2.19	9.65
Mean trade size (USD mn)	15.57	6.80	17.49	7.44	3.89	4.35	3.46	5.05	4.06	5.51
Median trade size (USD mn)	1.00	1.38	10.00	2.14	1.00	1.00	1.00	2.00	1.00	1.00
P10 trade size (USD mn)	0.20	0.40	1.00	0.40	0.88	0.50	0.50	1.00	0.80	1.00
P90 trade size (USD mn)	49.83	18.00	34.68	20.00	10.00	7.50	3.40	11.00	10.00	15.00
SD trade size (USD mn)	53.21	19.29	40.33	18.64	13.29	19.67	18.10	8.95	12.44	18.57
<i>Panel D: Clearing-member statistics, 2019–2025</i>										
Total active members	38	37	35	35	36	40	39	20	33	39
HHI of member trade-count shares	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.16	0.08	0.07
Top-5 share of notional (%)	49.8	44.4	48.6	45.4	40.0	40.3	43.2	87.3	47.5	43.8
Top-10 share of notional (%)	70.8	70.3	71.6	71.3	66.6	64.1	66.1	99.7	71.5	66.6
Average currencies traded per member	8.7	8.9	9.2	9.0	9.0	8.6	8.8	9.8	9.2	8.8

Notes. Summary statistics on LCH ForexClear cleared NDF transactions for the ten currency pairs in our sample, as in Table 1, computed separately for 2013–2018 (Panels A and B) and 2019–2025 (Panels C and D). Panels A and C report trade characteristics; Panels B and D report clearing-member statistics. Trade counts and volumes are on a net basis, with each economic trade counted once. Clearing-member statistics are computed using members active in each sub-sample.

D Dealer-Constraint Measures

This appendix describes the dealer-constraint measures behind Panel C of Table 4 and the composite indices of Table D.1. Public measures describe the balance sheets of the banks that are clearing members of LCH ForexClear, using regulatory filings and market prices. LCH measures are built from the members' cleared NDF positions. Every measure is signed so that a higher value indicates a tighter constraint and enters the regressions standardized to zero mean and unit variance.

Table D.1: State-Dependent OIB Pricing Effects: Composite Indices

	r^{spot}	r^{NDF}	$r^{onshore}$	$\Delta FLOOP$
<i>Panel A: Conditioning on the composite index (all measures)</i>				
Low index (-1 sd)	6.48** (2.56)	16.00 (10.31)	6.45** (2.57)	-1.15 (1.24)
Average index	8.75*** (3.09)	19.98* (12.04)	8.70*** (3.10)	-1.04 (1.46)
High index (+1 sd)	11.01*** (3.87)	23.97* (13.92)	10.95*** (3.86)	-0.93 (1.78)
R-squared	0.01	0.00	0.01	0.00
N	21,449	21,449	20,998	20,998
<i>Panel B: Conditioning on the composite index (public measures)</i>				
Low index (-1 sd)	6.83*** (2.41)	4.92** (2.47)	6.71*** (2.38)	-1.67 (1.24)
Average index	8.95*** (3.20)	21.62 (13.32)	8.91*** (3.20)	-0.97 (1.52)
High index (+1 sd)	11.07*** (4.15)	38.31 (26.69)	11.10*** (4.18)	-0.26 (1.99)
R-squared	0.01	0.00	0.01	0.00
N	21,449	21,449	20,998	20,998
<i>Panel C: Conditioning on the composite index (LCH measures)</i>				
Low index (-1 sd)	7.61** (3.12)	34.41 (25.78)	7.68** (3.17)	-0.33 (1.59)
Average index	8.63*** (3.14)	21.30 (13.48)	8.59*** (3.15)	-0.96 (1.46)
High index (+1 sd)	9.65*** (3.33)	8.19*** (2.41)	9.50*** (3.28)	-1.60 (1.54)
R-squared	0.01	0.00	0.01	0.00
N	21,989	21,989	21,440	21,440

Notes. Implied OIB pricing effects from panel regressions that interact OIB with a composite dealer-constraint index. The dependent variables are spot, NDF forward, and onshore forward returns and the daily change in the offshore–onshore forward spread ($\Delta FLOOP$), each measured in basis points. OIB is measured in USD billions, so reported effects are basis points per USD billion of OIB. Panels A, B, and C use all eleven measures, the four public measures, and the seven LCH measures described in this appendix, respectively. Each index is an equal-weighted average of standardized measures, computed on days when all component measures are observed and re-standardized to unit variance. Higher values indicate tighter dealer constraints. Effects are reported at one standard deviation below the mean, at the mean, and one standard deviation above the mean of each index. All specifications include currency and period fixed effects; R-squared is the within R-squared. Standard errors are two-way clustered by currency and period and reported in parentheses. Significance levels are *** 1%, ** 5%, and * 10%.

D.1 Public Measures

Trading-book value-at-risk. Following [Huang et al. \(2025\)](#), we collect from each member bank’s financial reports the quarterly average value-at-risk of its overall trading book, convert it to U.S. dollars on a 99% one-day basis, and average across the N_q reporting banks, $\text{VaR}_q = N_q^{-1} \sum_i \text{VaR}_{i,q}$. A higher VaR means that dealers hold more market risk against their capital. Quarterly, 2012–2025.

VaR breaches. The FFIEC 102 market-risk reports of the U.S. holding companies of up to twelve member banks record, for each quarter, the number of trading days on which the bank’s trading loss exceeded its regulatory VaR. We average these counts across banks, $\text{NVB}_q = N_q^{-1} \sum_i \text{NVB}_{i,q}$. Breaches raise the banks’ capital requirements. Quarterly, 2017Q4–2025.

Intermediary capital ratio. Following [He et al. \(2017\)](#), we compute the aggregate capital ratio of the member banks,

$$\eta_t = \frac{\sum_i E_{i,t}}{\sum_i (E_{i,t} + D_{i,t})},$$

where $E_{i,t}$ is bank i ’s market value of equity and $D_{i,t}$ its book debt, total assets less book equity, both in U.S. dollars from Bloomberg. A low ratio means little equity capital per unit of balance sheet, so the measure enters with a negative sign. Daily, 2012–2026.

CDS spreads. The equal-weighted average of the five-year senior CDS spreads of the member banks with quoted contracts, $\text{CDS}_t = N_t^{-1} \sum_i \text{CDS}_{i,t}$, from Bloomberg. Higher spreads indicate weaker credit and higher funding costs for dealers. Daily, 2012–2026.

D.2 LCH Measures

Open positions. For each dealer d , currency c , and day t we track the open long-dollar and short-dollar NDF notionals, $L_{d,c,t}$ and $S_{d,c,t}$, by adding each cleared trade’s notional on its trade date and removing it on its fixing date. The net position is $I_{d,c,t} = L_{d,c,t} - S_{d,c,t}$, positive when the dealer is long U.S. dollars, and the gross book is $G_{d,c,t} = L_{d,c,t} + S_{d,c,t}$. Dealers are the bank entities of [Figure A.1](#), clearing members and their dealer affiliates, and positions are their house books; the pooled series aggregate across the ten currencies. Daily, 2013–2025.

Dealer inventory. The net position that intermediating dealers accumulate from trades with clients and with directional members, $I_{c,t}^D = \sum_d I_{d,c,t}^{cf}$, where $I_{d,c,t}^{cf}$ counts only those trades and intermediating dealers are the members whose net-to-gross trading ratio lies

below the cross-sectional median. Because a large book of either sign ties up capital, the measure enters in absolute value.

Inventory at risk and capacity utilisation. Inventory at risk converts net positions into dollar risk, $\text{IaR}_{c,t} = \sum_d |I_{d,c,t}| \sigma_{c,t}$, where $\sigma_{c,t}$ is the standard deviation of daily spot returns over the previous 63 trading days. Capacity utilisation relates it to the largest risk dealers have carried to date, $U_{c,t} = \text{IaR}_{c,t} / \max_{s \leq t} \text{IaR}_{c,s}$, so values near one mean that dealers are close to their peak exposure.

Net-to-gross ratio. The share of dealers' gross books that is not netted,

$$\text{NGR}_{c,t} = \frac{\sum_d |L_{d,c,t} - S_{d,c,t}|}{\sum_d (L_{d,c,t} + S_{d,c,t})},$$

the gross-weighted average of the dealers' own ratios. A higher ratio means more directional exposure per unit of gross position, so netting provides less relief to dealer balance sheets (Atkeson et al., 2015).

Capital losses. The mark-to-market gain or loss on dealers' open NDF books from spot-rate moves, $\text{Rev}_t = \sum_{d,c} I_{d,c,t-1} \Delta \ln S_{c,t}$ (including the day's new trades), where $S_{c,t}$ is the spot rate in local currency per dollar. Losses deplete dealer capital, so the measure enters as the cumulative revaluation over the previous 21 trading days with a negative sign.

Quarter-end measures. Two measures capture the cost of carrying positions across reporting dates (Du et al., 2018). The crossing gap is the volume-weighted difference, within each quarter and maturity bucket k , between the annualised forward premium $fp = (F/S - 1) \times 365/\text{tenor}$ of contracts maturing after the quarter end and that of contracts maturing before it, $\text{Gap}_q = \sum_k w_{k,q} (\overline{fp}_{k,q}^{\text{cross}} - \overline{fp}_{k,q}^{\text{non}})$; a larger gap means dealers charge more for balance-sheet space at quarter-ends. Window dressing is the contraction of dealers' gross books in the last five trading days of the quarter relative to the quarter average, $\text{WD}_{d,q} = \overline{G}_{d,\text{last 5 days}} / \overline{G}_{d,q} - 1$, averaged across dealers; it enters with a negative sign so that a stronger contraction indicates a tighter constraint. Quarterly, 2013–2025.

Composite indices. Each composite is the equal-weighted average of its members' standardized, constraint-signed values on the days when all members are observed, re-standardized to unit variance. Panel A of Table D.1 uses all eleven measures, Panel B the four public measures, and Panel C the seven LCH measures. The samples run from October 2017 (Panels A and B, when VaR breaches become available) or December 2016 (Panel C) to December 2025.