# Price-setting in the Foreign Exchange Swap Market: Evidence from Order Flow

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**Abstract**

Using transaction level data from the inter-dealer market, we find that the price impact of one standard deviation change in FX swap order flow has increased from less than one basis point prior to 2008 to about five basis points after 2008. However, the increase in price impact is confined to periods of elevated dispersion in funding costs and over quarter-ends. Central bank swap lines reduce the order flow into USD, subsequently affecting the FX forward rate. In contrast, over quarter-ends and after monetary policy announcements we observe that dealers immediately adjust prices to curb order flow.

Keywords: interest rate parity, exchange rates, currency swaps, order flow, dollar funding

JEL Classifications: E43, F31, G15

# 1 Introduction

Foreign Exchange (FX) swaps allow market participants to exchange currencies at the spot exchange rate with an agreement to reverse the transaction at a predetermined forward rate in the future. FX swaps are frequently used to hedge exchange rate risk arising from currency mismatch between assets and liabilities. After growing steadily over the past decade, FX swaps are now the most traded instrument in the global FX market, with a daily turnover of approximately USD 3.2 trillion according to the 2019 BIS triennial survey. In theory, the pricing of FX swaps is pinned down by Covered Interest Parity (CIP) — a well-known no-arbitrage relationship in international finance. CIP states that the rate of return on equivalent domestic and foreign assets should equalize after covering the exchange rate risk with an FX swap contract. However, the FX swap market has been subject to considerable scrutiny since the onset of the Global Financial Crisis (GFC) in 2008, as the pricing no longer obeys the iron law of CIP. Since 2008, CIP deviations have been large and persistent, implying a systematic premium to swap EUR, CHF and JPY into USD via FX swaps. In this paper, we examine the mechanisms that govern the price-setting in the FX swap market.

While much of the recent literature focuses on why CIP deviations exist, with explanations ranging from limits on the supply of USD due to bank regulations and funding constraints (Du et al., 2018; Cenedese et al., 2020; Bräuning and Puria, 2017; Rime et al., 2022; Liao, 2020), to factors that lead to an excess demand for USD in the FX swap market (Borio et al., 2016; Sushko et al., 2016), less is understood about the role of price-setting in the FX swap market. This paper aims to fill this gap. To this end, we examine order flow — the net of buyer- and seller-initiated transactions — from the FX swap market as a fundamental signal used by dealers to update the forward rate of the FX swap contract. In particular, we analyze the price impact of order flow before and after the GFC and how order flow responds to various types of information.

We construct a measure of order flow from a novel data set of FX swap transactions conducted on the Thomson Reuters (TR) D3000-2 platform.[1] This platform registers inter-dealer transactions in the FX swap market where each trade is signed as either a buyer- or a seller-initiated transaction. In our sign convention, a positive order flow means net buying pressure to obtain USD through FX swaps. Due to superior market depth, we use 1-week maturity as our preferred tenor and base our empirical analysis on the 1-week FX swap order flow and 1-week deviation from CIP.[2]

[1] This data set was first used by Rime et al. (2022). While the focus in Rime et al. (2022) is to measure and explain the persistence of CIP arbitrage, our focus is solely on the microstructure of the FX swap market.

[2] Note that our aim is not to precisely measure CIP arbitrage opportunities, but rather the price-setting in

Prior to the GFC, money markets were characterized by low dispersion in short-term funding costs across banks and tight risk premiums. In this environment, the London Interbank Offered Rate (Libor) acted as an accurate representation of banks' marginal cost across currencies. Consequently, FX swap dealers could simply price the FX swap according to the Libor interest rates. The dealer then sets the FX forward rate according to CIP based on Libor so that the returns were equalized after covering the exchange rate risk. Moreover, less stringent regulatory requirements allowed banks to flexibly use their balance sheet to take advantage of arbitrage opportunities. When a no-arbitrage condition such as CIP holds closely, the role of order flow in price setting is expected to be small and short-lived. Hence, we expect that the price impact of order flow is small prior to 2008 where minor price changes were sufficient to attract opposite flows.

In contrast, the post-2008 period is characterized by episodes of large dispersion in funding costs and tighter regulatory constraints on banks' balance sheets. This makes it more difficult for dealers to determine the equilibrium price in the FX swap market. Consequently, our hypothesis is that dealers actively use order flow as a signal to set the forward rate in the post-crisis period. We exploit time variation in the dispersion in funding costs across banks and the regulatory reporting regime to examine how these factors affect the price impact of order flow.

As a starting point, we develop a stylized microstructural model of the FX swap market inspired by the model in Evans and Lyons (2002). The model has three key agents: customers, arbitrageurs and dealers. Customers manage the currency exposure on their balance sheets, for example by swapping foreign currency into USD. Arbitrageurs provide funds through the FX swap market when arbitrage opportunities appear. Dealers act as intermediaries and match the flows of customers and arbitrageurs and typically try to keep their positions flat to avoid inventories (Lyons, 1995; Bjønnes and Rime, 2005; Rime et al., 2022). There are three trading rounds. In round 1, customers have a net demand for USD at the spot leg of FX swaps. Dealers learn about the aggregate demand in round 1 from inter-dealer trading in round 2. The aggregation of dealer imbalances is equal to inter-dealer order flow, which measures the public's net demand for USD at the spot leg of the FX swap. In round 3, dealers set prices to elicit a supply of USD by arbitrageurs that is sufficient to clear their inventories. We derive a price-setting condition in which the FX forward rate is set to correct order imbalances.

The model's primary contribution is to map a linear relationship between order flow and the price-setting of FX swaps. We use this framework to study how the price impact

the FX swap market. We therefore use 1-week Libor rates as the benchmark rate in our CIP calculation. Importantly, by examining CIP deviations instead of the forward rate directly, we control for movements in the forward rate that relates to changes in the interest rate differential.

of order flow is governed by shocks to arbitrageurs. For example, the model predicts that a tightening of funding and balance sheet constraints leads to an inelastic supply of arbitrage capital, with dealers adjusting the price substantially to avoid order imbalances that may lead to large inventories.

Guided by our model, we first investigate the price impact of order flow, and find it has increased substantially in the post-2008 period. Since 2008, a one standard deviation positive shock to order flow, suggesting increased demand for USD through the FX swap market, causes a widening of CIP deviations by up to five basis points. This stands in sharp contrast to the pre-2008 period where a one standard deviation increase in order flow is associated with less than half a basis point widening of CIP deviations.

We then investigate the post-2008 increase in the price impact of order flow by examining periods when the heterogeneity in US funding costs is large and when balance sheet expansion is particularly costly for banks.[3] Our estimates reveal that up to 80 per cent of the increased price impact can be attributed to periods when funding heterogeneity in USD is high, and when the FX swap contract crosses regulatory reporting dates at quarter-ends. Higher funding heterogeneity reduces the number of potential arbitrageurs as an increasing share of market participants face funding costs exceeding the threshold necessary to reap arbitrage profit. Similarly, regulatory reporting at quarter-ends gives arbitrageurs incentives to reduce their provision of arbitrage capital. Consequently, a larger price adjustment is necessary for dealers to balance inventories.

We also test whether news is impounded in the price contemporaneously, or through trading.[4] We hypothesize that *private* information is revealed through order flow, meaning that prices adjust as a result of trading activity. For example, in response to a shock to its access to direct USD funding, a euro area bank obtains USD via the FX swap market. If this information is private and not known to the dealers before the order appears, these excess demands translate into order flow in the inter-dealer market, which can then be used by dealers to update the forward rate. In contrast, we hypothesize that *public* information is impounded in the price contemporaneously. For instance, in a scheduled monetary policy announcement by a central bank, the outcomes of the meeting are conveyed to all market participants simultaneously. If the announcement implies a change in the interest rate differential between two currencies, the dealer can reset the forward rate to match the change in the interest differential. In this setting, the monetary news is impounded in the price immediately, suggestive of efficient price-setting in the FX swap market.

We test whether the public or private information view is relevant in the price-setting

[3] We define periods of funding heterogeneity by the daily cross sectional dispersion in 3-month US Libor panel quotes. Note that we use the terms funding heterogeneity and funding dispersion interchangeably throughout the paper.

[4] See Evans and Lyons (2005) for a similar analysis of the FX spot market.

by studying three different types of events. First, we examine the effect of Federal Reserve swap lines during the period 2008-2010. The swap lines allowed foreign central banks to provide USD funding directly to their own eligible counterparties. By doing so, a larger set of counterparties were able to access USD directly from the central bank rather than via the FX swap market.[5] Although it is publicly announced when these auctions take place, the dealers do not have detailed information on whether individual counterparties would draw on the swap line.[6] Therefore, we expect swap lines will reduce the demand for USD through FX swaps and lower the order flow into USD. Second, we look at dates when the FX swap contract crosses quarter-ends. A large number of banks report quarter-end balance sheet snapshots to regulators. This implies incentives to reduce the size of the balance sheet, leading to a more inelastic supply of arbitrage capital and significant price effects over reporting dates, as documented in Du et al. (2018). Given that quarter-ends are public information and known to dealers in advance, we hypothesize a contemporaneous price adjustment. Third, we identify monetary policy surprises to test whether the adjustment in the forward rate following monetary policy announcements happens through order flow. Following our example of a monetary policy announcement constituting public information, our theory points towards monetary news being impounded in the FX forward rate contemporaneously.

In our empirical tests, we find evidence that the Federal Reserve swap lines reduced the order flow into USD which in turn affected the forward rate, supporting the private information hypothesis. In response to quarter-ends, we utilize high frequency data on forward rates to show a large contemporaneous price adjustment exactly at the hour the FX swap contract crosses quarter-ends, with the full price adjustment occurring within two hours. Finally, in line with the hypothesis of public information, we find no effect on order flow of monetary policy announcements. These results highlight that dealers – also after the GFC – efficiently adjust the price according to publicly available information.

The paper is outlined as follows. Section 2 provides an overview of related literature. In section 3, we outline definitions of CIP, FX swaps and order flow and describe the data. In section 4, we develop a model of the microstructure of the FX swap market and derive a price-setting rule that relates the forward rate of the swap to order flow observed in the inter-dealer market. In section 5, we examine the price impact of order flow, while in section

[5] Alternatively, the swap line also relaxes arbitrageur balance sheet constraints and increases arbitrageurs' ability to supply USD in the FX swap market. The effects on both customers and dealers will have an equivalent effect of reducing the relative demand for USD funding in the FX swap market.

[6] We stress that the private information is not the announcement of the swap line itself, which is known to dealers, but the details of counterparties that use the swap line. For example, only a subset of banks that draw on the swap line may have previously been relying on USD funding via FX swaps. Similarly, banks may supply the USD in the FX swap market. Both of these outcomes are unanticipated by dealers until they are revealed as positive order flow.

6 we investigate the microstructure hypotheses of how prices are determined in response to public and private sources of information, using the response of the FX swap prices over quarter-ends and the announcements of central bank swap lines. Section 7 summarizes the conclusions of the analysis.

## 2 Related literature

The recent literature on CIP naturally centers on the supply and demand fundamentals in the FX swap market that can explain the persistent violations of CIP observed after the GFC. Theories on limits on the supply of USD in the FX swap market include rising balance sheet costs and regulatory requirements (Du et al., 2018; Liao, 2020; Bräuning and Puria, 2017), USD funding constraints (Rime et al., 2022), and the role of the USD exchange rate in constraining leverage (Avdjiev et al., 2019). Other studies have looked at related factors such as rising bid/ask spreads due to limited dealer capacity (Pinnington and Shamloo, 2016), costs to leverage such as shareholder risk (Andersen et al., 2019) and rising counterparty or liquidity risk (Baba and Packer, 2009; Mancini Griffoli and Ranaldo, 2009). On the demand for USD in the FX swap market, the focus has been on the deterioration in bank quality, strains in USD short-term funding markets, unconventional monetary policies, and central bank swap lines (Borio et al., 2016; Sushko et al., 2016; Bahaj and Reis, 2021; Ivashina et al., 2015; Iida et al., 2018). This paper contributes to the understanding of CIP violations by examining how constraints on the supply of USD in the FX swap market can lead to price discovery through order flow. This is a critical component of the FX swap market microstructure and we show empirically how dealers use order flow as a fundamental signal to update the forward rate of the FX swap.

The seminal work on market microstructure in FX has typically examined the price impact of order flow on spot foreign exchange markets (Evans and Lyons, 2002, 2005, 2006; Berger et al., 2008; Rime et al., 2010; Kozhan and Salmon, 2012; Ranaldo and Somogyi, 2021). Evans and Lyons (2002) use simultaneous trade models in which dealers set prices, and use inter-dealer order flow following a trading round as information to reset prices. In developing our model framework of the FX swap market, although we share many of the elements in trading, we note two clear differences in FX swaps. The first is that customers in the FX swap market first and foremost trade for hedging purposes. In contrast, investors in the FX spot market are composed of informed and uninformed traders, with informed traders having an information advantage in the price of the spot exchange rate, which is treated as a speculative asset. Second, we add arbitrageurs to the framework as they attempt to make systematic profits from the mispricing of the forward rate. Using our framework, we derive a price-setting relationship in which the price adjustment of the FX swap rate is linearly related to order flow. We use deviations from CIP as our preferred measure for the price adjustments in the FX swap market as CIP deviations implicitly control for changes in the interest rate differential.

Finally, our paper relates to a recent interest in understanding the microstructure and impact of order flow in the FX swap market. Krohn and Sushko (2022) examine how the market structure of the FX swap market has led to a reduction in market liquidity and rising bid/ask spreads during quarter-end periods. Cenedese et al. (2020) and Rime et al. (2022) find evidence that order flow has price impact in the post-crisis period. We extend their work in several ways. Through a model framework, we derive the price impact of order flow on the FX swap market through an inter-dealer market that sets the forward rate to minimize inventory accumulation. Our model framework enables us to link increased dispersion in USD funding costs and the tightening of leverage constraints to the price impact of order flow. These two factors explain up to 80 per cent of the increased price impact we empirically observe in the post-crisis period. We also find that the source of information matters: in response to public announcements, dealers set the forward rate contemporaneously. In contrast, order flow plays a significant role in price-setting of the forward rate in response to private information, and this is substantiated through the allotment of central bank swap lines by the Federal Reserve in the period 2008-2010.

# 3 Definitions and data

## 3.1 Foreign exchange swaps

Foreign exchange (FX) swaps, also known as spot-forward contracts, are used by banks and corporations to hedge exchange rate risk and manage their liquidity across currencies. Banks tend to hedge their FX exposure stemming from a currency mismatch between assets or liabilities, for instance as shown in Borio et al. (2016), where Japanese banks have significantly higher USD assets than liabilities.[7] We illustrate the legs of a EUR/USD FX swap in Figure 2. In the first leg of the contract, the customer exchanges a principal of 1 EUR at the current spot rate $S$ USD per EUR. The customer receives $S$ USD. Both parties then agree to re-exchange the principals at maturity at a specified forward rate, this is known as the forward leg of the contract. The customer receives their 1 EUR, and the dealer then receives $F$ USD, where $F$ is the FX forward rate of the contract.

In our empirical analysis we focus on short-term FX swaps with a 1-week maturity. We choose this maturity because the majority of the platform trading in FX swaps happens at

[7] Similarly, a corporate may hedge the currency mismatch of their cash flows, for example if a European corporate has profits in USD from their offshore activities, they will hedge the foreign exchange risk by swapping their USD receivables with EUR.

short maturities. At longer maturities, the use of brokers and telephone-based trading is more common.

## 3.2 Covered Interest Parity

Covered Interest Parity (CIP) states that two assets with identical characteristics in terms of credit risk and maturity, but denominated in different currencies, have the same rate of return after accounting for exchange rate risk using a forward contract. The CIP deviation — which should be (close to) zero if CIP holds — is defined as the difference between the direct and synthetic USD borrowing cost. This can be formally stated as:

$$\Delta = \underbrace{1 + r_{\$}^{f}}_{\text{direct}} - \underbrace{\frac{F}{S}(1 + r_{d}^{f})}_{\text{synthetic}} \tag{1}$$

Our measure of CIP deviations, $\Delta$, is expressed as the difference between the local USD borrowing rate less the synthetic USD borrowing rate as in equation (1), where $r_{\$}^{f}$ is the US interest rate, $r_{d}^{f}$ is the base interest rate (denominated in EUR, CHF or JPY in our empirical analysis), $S$ is the spot rate and $F$ is the forward rate, calculated as the mid-point using bid and ask quotes.[8,9] A negative $\Delta$ indicates that synthetic USD borrowing costs exceed local borrowing costs. For a measure of interest rates, we use 1-week Libor in the quoting and base currencies. In constructing the CIP deviation, we convert our forward premium $\frac{F}{S}$ to annualized basis points in order to construct a measure of 1-week CIP deviations in annualized terms.[10] To compute CIP deviations at the 1-week maturity, we use Thomson Reuters Tick History which contains historical data on spot and 1-week FX forward rates of the EUR/USD, CHF/USD and JPY/USD pairs measured at 5 pm London time.[11]

Since 2008, the cost of borrowing USD through the FX swap market from EUR, CHF and JPY has been higher than the corresponding direct funding cost in USD. In our notation this means that the CIP deviation is negative as the synthetic USD rate is higher than the direct USD rate. The CIP deviations can therefore be interpreted as a synthetic USD borrowing premium. We document this in Figure 1, which plots 1-week CIP deviations for

[8]To calculate the mid spot rate, we average the spot rates at ask and bid, $S = \frac{S_a + S_b}{2}$. Similarly, the forward rate is calculated as the mid point of bid and ask quotes, $F = \frac{F_a + F_b}{2}$.

[9]For simplicity, we drop the time (t) and maturity (m) subscript. CIP deviations can be calculated for all maturities, m, at time t. The FX forward rate and the interest rates must have the the same time to maturity at time t.

[10]We account for the exact number of trading days by properly adjusting for bank holidays in the respective currency pairs.

[11]Note that for simplicity we refer to EUR, CHF and JPY as the base currencies. However, in all calculations we take into account the standard market conventions where USD is the base currency in the USD/CHF and JPY/USD pairs, while EUR is the base currency in the EUR/USD pair.

the EUR/USD, CHF/USD and JPY/USD pairs.

When we refer to price-setting of the FX swap, we specifically refer to a dealer setting the FX forward rate, taking interest rates and the FX spot rate as inputs. Dealers in the FX swap market always take the prevailing FX spot rate as given. In a situation where CIP holds, the FX forward leg in the FX swap matches the interest rate differential for a given spot rate as depicted in equation (2). Prior to 2008, CIP deviations were rather small and $\Delta_{pre-crisis} \approx 0$, meaning that the FX forward rate was consistent with CIP holding closely (Akram et al., 2008). However, an FX forward rate consistent with no CIP deviations relies on arbitrageurs immediately exploiting any mispricing given the interest rates these arbitrageurs are facing in the two currencies. After the GFC, the deviations from CIP make it difficult for dealers to set the FX forward rate. In this case, order flow may provide important information for FX swap dealers when determining the FX forward rate.

$$\Delta_{pre-crisis} \approx 0 \implies F = S\frac{1+r^f_\$}{1+r^f_d} \tag{2}$$

Summary statistics for the EUR/USD, CHF/USD and JPY/USD pairs are provided in Table 1. Prior to 2008, the CIP deviations are close to zero.[12] CIP deviations widen substantially in the post-2008 period, with an average of minus 25 to minus 30 basis points for all pairs. Negative deviations suggest that the US Libor rate is below the synthetic Libor rate based on borrowing in EUR, CHF or JPY swapped for USD using FX swaps. The range of CIP deviations also increases significantly with measured spikes of up to -500 basis points. These spikes correspond to quarter-end periods, which we investigate empirically in the following sections. CIP deviations exhibit considerable persistence. Running a simple AR(1) specification (no constant) on CIP deviation in the post-2008 sample, we find an estimate for the autoregressive coefficient of 0.58. This translates to a half-life of approximately 1.3 days.[13]

## 3.3 Order Flow

Order flow is defined as the net of buyer-initiated transactions. We define a transaction as buyer-initiated if it is initiated by a counterparty swapping EUR, CHF or JPY into USD,

[12] To account for outliers potentially driving our results in the pre-2008 period we trim CIP deviations in excess of 25 basis points in absolute terms. The reason for trimming the pre-2008 period is that the high frequent data contains some noise in the early part of the sample when the Tick History database started its recording of FX swaps, in particularly for the JPY/USD pair. In order to make sure that we are not removing data points that are correct, we both compare the data points we remove and the remaining sample with the daily average from the high frequent data and daily close from Bloomberg. We also present supplementary results using the un-trimmed measure of CIP deviations in Internet Appendix A.4. As expected when removing incorrect data, using the trimmed measure we obtain more precise regression results. The coefficients, however, are of similar magnitude.

[13] The half-life formula for an AR(1) process $CIP_t = \rho CIP_{t-1} + \epsilon_t$ is $\frac{log(0.5)}{log(\rho)}$.

i.e. buying USD spot and selling USD forward. Conversely, a transaction is seller-initiated if the transaction is swapping USD into foreign currency.

To measure order flow at short-term maturities, we use the TR D3000-2 trading platform, which contains inter-dealer trades from 1 January 2005 to 1 September 2017 in FX swaps for the EUR/USD, CHF/USD and JPY/USD pairs.[14] We use the 1-week maturity as it is the most liquid and traded pair at maturities above one day. The data set includes quotes in the inter-dealer market, with columns indicating bid price, ask price, a timestamp of the quote to the nearest second, and a column for the market price when a trade has occurred. Additionally, our data set has a column indicating if the trade was buyer- or seller-initiated. Using this data, we can construct a measure of order flow. The measure of order flow is then given as the net of buyer-initiated transactions over a trading day, where buyer-initiated transactions are signed +1 and seller-initiated transactions are signed -1. We exclude days when no inter-dealer trades are recorded. The order flow for 1-week FX swaps are measured in counts as we do not have trade volume in the TR D3000-2 database.[15]

$$OF_t^{count} = \sum_{k=t}^{k=t+1} \mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]$$

Summary statistics of order flow using the inter-dealer trades are provided in Table 2. The mean of net buyer-initiated trades is close to zero, and the standard deviation of trades ranges from 2 to 4 net buyer transactions per day. The EUR/USD pair has the highest range of order flow, with a range of [-30,+30]. We provide plots of daily order flow in Figure 3. Given that order flow reflects private information, and dealers aim to minimize the accumulation of order imbalances over time, the persistence in order flow should be minimal. Indeed, we find little persistence in order flow with an AR(1) coefficient of 0.04, yielding a half-life of 0.2 days. This suggests the inter-dealer market reset prices at a high frequency to balance the market, supporting models of the FX market at the daily frequency (Evans and Lyons, 2002).

## 3.4 Other data

In our empirical investigation we construct several variables. First, we calculate the daily dispersion in the 3-month Libor contributions as a proxy for funding heterogeneity.

[14] The data covers FX swaps exclusively, that is transactions where the counterparties simultaneously exchange currencies spot and agree on the FX forward rate in the future. We provide supplementary information on data fields in the TR D3000-2 platform in Internet Appendix A.1

[15] We define a trading day from 00:00 GMT to 23:59 GMT. Note that the common way of measuring order flow is to follow the algorithm provided in Lee and Ready (1991), which sign transactions as buyer- or seller-initiated based on bid and ask quotes. In our data we are able to sign all trades correctly since the direction of the trade is already indicated.

The measure is computed as the difference between the highest and lowest daily submission by the contributing panel banks. A higher value indicates larger dispersion in funding costs among the panel banks. Data until 1 February 2014 for individual Libor submissions is obtained from Bloomberg. After this date Intercontinental Exchange (ICE) took over as Libor administrator from British Bankers Association (BBA) and we obtain the data from ICE. Figure 4 shows the dispersion in 3-month Libor during our sample period ranging from 1 January 2005 to 1 September 2017.

We exploit high frequency (hourly) data from the Thomson Reuters Tick History to create bid/ask spreads and to identify the price response in the FX swap market around quarter ends. Bid/ask spreads are constructed as the daily intraday average of the bid and ask for 1-week FX swap prices in each currency pair, and are plotted in Figure 5. Moreover, we construct a measure of monetary policy surprises by identifying the change in 1-month overnight indexed swaps right before and 30 minutes after a monetary policy release from Thomson Reuters Tick History data.

Finally, detailed data on the Federal Reserve swap lines available from the New York Federal Reserve contain details on the amount, currency, tenor and receiving central bank of each swap line auction. Using this, we can construct a measure of outstanding swap line amounts lent to the European Central Bank, Bank of Japan and Swiss National Bank.

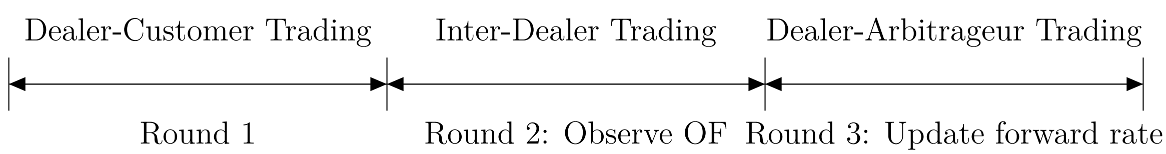
# 4 Model

Before turning to the empirical analysis, we develop a simple model to shed light on the main mechanisms in which order flow may affect price-setting in the FX swap market. As a starting point, we introduce three types of agents: customers, dealers and arbitrageurs. Customers include financial institutions and non-financial institutions that manage currency mismatch between assets and liabilities by hedging their positions via FX swaps. Dealers set the forward rate of the FX swap. The objective of dealers is to match flows from customers to earn the intermediation spread (bid/ask spread). Any unmatched flows are observed as order flow in the inter-dealer market. Arbitrageurs can step in and supply funds in the FX swap market to earn arbitrage profits from mispricing of the forward rate in response to underlying demand from customer flows. The primary contribution of the model is in deriving a relationship between order flow and price-setting of the FX forward rate. We identify two types of shocks to arbitrage capital in the form of heterogeneous funding costs across market participants and leverage constraints that increase the price impact of order flow.

In our model, dealers match flows in the FX swap market and strive to end the trading day without inventory (i.e. with no positions funded on their own books). As a result, the model clearly distinguishes between dealers and arbitrageurs. All the dealers in the FX swap market are affiliated with large banks that are well positioned to arbitrage deviations from CIP due to their global presence and superior access to short-term funding markets across currencies. However, while dealers may act as arbitrageurs, they are subject to the same funding costs, investment opportunities and regulatory constraints as the bank they are affiliated with. This is due to the common practice of Funds Transfer Pricing (FTP), where the Treasury department of the bank determines the internal price of funds and deposits to its units (including the dealer arm) based on the market conditions and balance sheet constraints of the bank.[16] Hence, without loss of generality we can distinguish between the bank acting as a dealer and the bank acting as an arbitrageur or customer in the model. This way, the dealer problem in the model is reduced to minimizing inventory. Other units of the bank may, however, separately act as customers or arbitrageurs.

## 4.1 Timing

The setup follows the timing for FX spot trading in the portfolio shifts model of Evans and Lyons (2002). Within a trading day there are three trading rounds. In round 1, customers have a net demand for USD at the spot leg of FX swaps. Dealers learn about the aggregate demand in round 1 from interdealer trading in round 2. The aggregation of dealer imbalances is equal to inter-dealer order flow, which measures the public's net demand for USD at the spot leg of the FX swap. In round 3, dealers off-load the aggregate inventory imbalances.[17] Dealers set prices in round 3 so that they elicit a supply of USD by arbitrageurs that is sufficient to clear their inventories.




We note three departures from the portfolio shifts model. First, we take the FX spot rate as given, with the dealer adjusting the forward rate in response to inter-dealer order flow. This is consistent with market practice in the FX swap market. Second, we assume that spot and forward markets are segmented, meaning that order flow in the spot market is separate from the order flow observed in the inter-dealer market for FX swaps. Third, the public absorption of inter-dealer order flow occurs through arbitrageurs. Dealers set the FX forward rate to elicit sufficient arbitrage capital to clear their inventories. In the

[16] See Rime et al. (2022) for further discussion of FTP.

[17] This is consistent with theories of market micro structure where dealers are sufficiently averse to holding the risk of inventory, see Lyons (1995) and Bjønnes and Rime (2005) for empirical evidence on dealers minimizing inventory.

portfolio shifts model, adjustment of the spot rate induces a change in speculator demands for the currency.

## 4.2 Customers

Customers use the FX swap market to finance assets denominated in USD. Customer demand is a function of counterparty quality $\theta$. All else equal, counterparties with higher quality are more likely to obtain USD directly via commercial paper markets or other money market instruments. In a continuum of [0,1] $x_t^D = \int_0^1 f(\theta)d\theta$ gives an aggregate measure of the net demand for USD at the spot leg of the FX swap. Given a functional form $f(\theta) = \tilde{a}_t\theta$, where $\tilde{a}_t$ is a shock to hedging demands with $\mathbb{E}[\tilde{a}_t] = 0$. The aggregate demand is given by:

$$x_t^D = \frac{\tilde{a}_t}{2} \tag{3}$$

## 4.3 Arbitrageurs

We model a risk-neutral arbitrageur that decides to lend $x_{j,t}$ USD in the FX swap market. The supply of USD by arbitrageurs is a function of the deviations from CIP. In logarithmic form, the CIP deviation ($\Delta_t$) is the difference between the forward premium ($f_t - s_t$) and the interest rate differential, $\Delta_t = f_t - s_t - (r_\$^f - r_d^f)$, where $r_\$^f$ is the risk-free rate in USD and $r_d^f$ is the risk-free rate in domestic currency.[18]

The individual arbitrageur faces a funding spread over the risk-free rate. We model funding costs $c_{j,t}$ in the continuum $[0, c_H]$.[19] We can write the evolution of wealth in the next period as the sum of returns on initial wealth, CIP arbitrage profits net of USD funding spreads.

$$W_{t+1} = \underbrace{W_t(1 + r_\$^f)}_{\text{return on wealth}} + \underbrace{x_{j,t}\Delta_t}_{\text{cip arbitrage}} - \underbrace{x_{j,t}c_{j,t}}_{\text{funding spreads}} \tag{4}$$

In addition, we capture costs to arbitrageur leverage by imposing a constraint $x_{j,t} \leq \Gamma W_t$. This is a stylized way of capturing regulatory factors such as requirements on a minimum level of core capital to assets, and other costs of scaling the balance sheet to conduct CIP arbitrage.[20]

[18] Note that the definition of the CIP deviations in the model is the negative of the CIP deviations expressed in the empirical evidence. We flip the sign in the model as we take the perspective of an arbitrageur supplying USD in the FX swap market profiting from situations where the direct USD rate is lower than the synthetic USD rate in the FX swap market.

[19] Note that we use the Libor fixings to calculate the CIP deviations in the empirical part of the paper. This is strictly speaking not accurate, but our mission in this paper is to investigate the price-setting in FX swaps, not to precisely measure arbitrage opportunities.

[20] Empirical evidence on the funding constraints for banks is detailed in Rime et al. (2022). Evidence for leverage constraints is found during quarter-end periods, for example see Bräuning and Puria (2017); Du et al. (2018); Cenedese et al. (2020).

The arbitrageur maximizes CIP arbitrage profits less the funding cost of the position, subject to the leverage constraint.

$$\max_{x^*_{j,t}} \left(W_t(1+r^f_\$) + x_{j,t}\Delta_t - x_{j,t}c_{j,t}\right) \tag{5}$$

Subject to

$$x^*_{j,t} \le \Gamma W_t \tag{6}$$

In equation (7), for arbitrageurs with sufficiently low funding spreads ($c_{j,t} < \Delta_t$), the supply of USD in the FX swap market is capped at $\Gamma W_t$. If funding spreads are higher than CIP arbitrage profits, it is optimal to refrain from supplying USD in the FX swap market.

$$x^*_{j,t} = \begin{cases} \Gamma W_t & , \Delta_t > c_{j,t} \\ 0 & , \Delta_t \le c_{j,t} \end{cases} \tag{7}$$

We aggregate the arbitrageurs' supply of USD across the continuum of funding spreads in equation (8). The fraction of arbitrageurs that are able to conduct arbitrage in the market is equal to $\frac{\Delta_{t,1}}{c_H}$. Arbitrageur supply is a positive function of CIP profits and negatively related to USD funding spreads. When funding dispersion, as measured by $c_H$, increases, there is a lower fraction of arbitrageurs that provide USD in the FX swap market.

$$\frac{1}{c_H}\int_0^{\Delta_t} x_{j,t}dc_{j,t} = \Gamma W_t \frac{\Delta_t}{c_H} \tag{8}$$

## 4.4 Dealers

Customers and arbitrageurs are price-takers, and turn to a market-maker to find a counterparty to take the other side of the trade. The market-maker is the dealer in our model. In round 1, there are $N$ dealers, and each dealer has a net supply of $D^j_{t,1}$ to customers. The aggregate supply of USD by dealers match net customer demands for USD in the FX swap market in equation (9).

$$\sum_{j=1}^{N} D^j_{t,1} = \int_0^1 f(\theta)d\theta \tag{9}$$

In round 2, dealers trade in the inter-dealer market to square individual dealer positions arising from customer trades. Aggregation of dealer demands results in inter-dealer order flow $OF_{t,2}$. This is observable and measures the net demand for USD by customers at the spot leg of FX swaps.

$$\sum_{j=1}^{N} D_{t,1}^{j} = OF_{t,2} \tag{10}$$

In round 3, market clearing requires that the inter-dealer order flow from the second round is equal to the supply of USD by both dealers and arbitrageurs in the third trading round.

$$OF_{t,2} = \sum_{j=1}^{N} D_{t,3}^{j} + x_{t,3}^{*} \tag{11}$$

As explained at the outset of this section, we make the simplifying assumption that dealers end the trading day with zero inventory, $D_{t,3}^{j} = 0$. This also matches the empirical fact that FX dealers aim to minimize inventory over the trading day (Lyons, 1995; Bjønnes and Rime, 2005; Wu, 2012) and gives a market clearing price of the forward rate, which balances customer demands in round 1 with arbitrageur supply of USD in round 3. Therefore, dealers set an attractive enough FX forward rate, and consequently the CIP deviation $\Delta$, for arbitrageurs to absorb dealer imbalances observed in the inter-dealer market in round 2. The The market clearing price $\Delta_{t,3}$ is based on parameters governing the supply of arbitrage capital and net hedging demands by customers.[21]

$$\Delta_{t,3} = \frac{c_H}{\Gamma W} \frac{\tilde{a}_t}{2} \tag{12}$$

## 4.5 Testable Implications

### Price impact of order flow

Using the market clearing condition in period $t-1$, we can express the first difference of $\Delta_t$ in equation (13).

$$\Delta_{t,3} - \Delta_{t-1,3} = \frac{c_H}{\Gamma W} \left( \frac{\tilde{a}_t}{2} - \frac{\tilde{a}_{t-1}}{2} \right) \tag{13}$$

Under the assumption that customers are perfectly hedged in period $t-1$, and $\tilde{a}_{t-1} = 0$, we can derive a linear relationship between price-setting of the forward rate and order flow in equation (14), which we test empirically. The price impact of order flow is defined by the coefficient $\beta = \frac{c_H}{\Gamma W}$. The forward premium is set to attract a supply of USD by arbitrageurs

[21] The equilibrium price $\Delta_{t,3}$ is common to all dealers. This is a reasonable assumption, as if dealers set different prices, this would not be a sustainable equilibrium as other dealers will only execute swap trades with the dealer that sets the most favorable rate. Moreover, inter-dealer trades are secured by daily margining, practically eliminating potential differences in counterparty risk across dealers.

that is sufficient to match order flows in the inter-dealer market.

$$\Delta_{t,3} - \Delta_{t-1,3} = \beta OF_{t,2} \tag{14}$$

The price impact of order flow increases in the dispersion of funding costs, which is consistent with the empirical findings of Rime et al. (2022). Through the lens of the model, high funding cost dispersion leads to a smaller fraction of arbitrageurs that supply USD in the FX swap market. The inter-dealer market then needs to set the forward rate more aggressively to attract arbitrage capital to take the other side of customer trades, minimizing inventory and matching flows.

The price impact decreases in the amount of arbitrageur capital. When there is a tightening of leverage constraints, for example through a decrease in $\Gamma$, less arbitrage capital is available to match customer demands and offset order flow. In response, the inter-dealer market sets the forward rate more aggressively to attract arbitrage capital and minimize inventory. The tightening of leverage constraints maps to an empirical test of whether the price impact of order flow increases during quarter-end regulatory reporting (Du et al., 2018; Cenedese et al., 2020).

**Determinants of Order Flow**

Order imbalances can be due to a change in the stock of inventory, or unexpected shocks to customers. Through the lens of the model, one determinant of order flow is unexpected shocks to customer hedging demands, given by $f(\theta) = \tilde{a}\theta$. An example of a shock that may affect hedging demand is the central bank swap line auctions where central banks provide USD funding to non-US banks. As the customers that receive swap line funding is private information, we hypothesize that banks receiving swap line funding reduce demands for USD in the FX swap market. This would result in a decline in order flow, causing a reduction in the forward premium in the FX swap market.

We also examine if public sources of information, such as monetary policy announcements and quarter-end reporting requirements, are anticipated by dealers. For instance, if dealers anticipate the shock to arbitrage capital stemming from regulatory reporting obligations, the forward rate will immediately adjust when the FX forward contract crosses a quarter-end. In such a situation, we do not expect any significant impact on order flow. Similarly, monetary policy announcements are available to all market participants simultaneously, and changes in the risk-free rate should result in dealers adjusting the forward premium to maintain market clearing in the FX swap market.[22]

[22]For illustration, the CIP deviation can be expressed as the difference between the forward premium and risk-free rates across the two currencies. $\Delta_{t,3} = f_{t,3} - s_t - (r^f_\$ - r^f_d)$. A change in the risk-free rate due to monetary policy announcements will cause an offsetting change in the forward rate.

To conclude, the model provides a simple framework through which price-setting in the FX swap is mapped linearly to order flow. In the following two sections, we empirically examine the price impact of order flow and how central bank swap lines, quarter-ends and monetary announcements affect order flow in the FX swap market.

# 5 Estimating the Price Impact of FX Swap Order Flow

## 5.1 Baseline specification

In this section, we examine the price impact of FX swap order flow. Our model framework suggests that an increase in order flow into USD is consistent with an increase in the forward premium and a widening of CIP deviations. As dealers are averse to holding inventory, the inter-dealer market resets the forward rate to offset order flow. Our baseline specification for testing the price impact of order flow is outlined in equation (15).

$$\Delta CIP_t = \alpha + \beta_1 OF_t + \beta_j x_{j,t} + \epsilon_t \tag{15}$$

The outcome variable is the daily change in 1-week CIP deviations, where negative values indicate that it becomes more costly to obtain USD through FX swaps relative to the direct interest rate in USD. Our variable of interest, $\beta_1$, measures the price impact of order flow (OF). X is a vector of control variables including the change in the Libor-OIS spreads for 1-week and 3-month maturities in USD, the VIX index, and the USD trade weighted exchange rate. We run the specification for all currency pairs as a panel and for the EUR/USD, CHF/USD and JPY/USD pairs separately, and divide our sample into two periods, a pre-2008 period (January 2005 to December 2007), and a post-2008 period (January 2008 to September 2017).

Before 2008, the deviations from CIP were small, indicating an elastic supply of arbitrage capital. Hence, we expect a relatively small price impact of order flow in this period. This is in line with the empirical evidence in Akram et al. (2008). In contrast, the post-2008 period is characterized by large and persistent CIP deviations, tighter balance sheet constraints and periods of significant dispersion in funding costs across market participants (see Figure 4). We hypothesize that dealers need to adjust prices more aggressively during this period to attract the necessary arbitrage capital to balance inventories.

We present the results of the baseline specification in Table 3. Columns (1) through to (4) depict the price impact of order flow in the pre-2008 period, and columns (5) through to (8) illustrate the corresponding price impact in the post-2008 period. We find that order flow has significant price impact in the post-2008 period for all three pairs, with a one standard deviation change in order flow widening CIP violations by up to 5 basis points based on the panel specification in column (5). In contrast, the order flow coefficient is at most around 0.6 basis points in our pre-2008 period.

The coefficients are remarkably similar across currencies in both periods. As expected, the point estimates for the price impact are small prior to 2008. In line with the empirical evidence in Akram et al. (2008), these results indicate that dealers could confidently apply common measures of the interest rate differential like Libor when determining the FX swap price and rely on minor price adjustments to elicit the opposite flow to square inventories.

In the post-2008 period, a one standard deviation increase in order flow into USD leads to between 3.8 and 5.7 basis points wider (more negative) CIP deviations. Consistent with EUR/USD being the most liquid FX swap market of the three currency pairs, this pair has the smallest estimated price impact. The price impact for CHF/USD and JPY/USD are similar in magnitude and both above 5 basis points. The results are statistically different from zero at the 1 percent significance level. Higher demand for USD borrowing through FX swaps (positive order flow) leads to an increase in the synthetic USD rate implied from the FX swap market relative to the direct USD rate (i.e. more negative CIP deviations) as dealers need to adjust the forward rate aggressively to attract opposite flows.

**Dynamic effects**

In addition to the contemporaneous price impact of order flow, we test for dynamic effects using a structural vector autoregression (VAR) framework. Following the work of Hasbrouck (1991) and Ranaldo and Somogyi (2021), we estimate the following bivariate VAR of order flow $OF$ and the first difference in CIP deviations $\Delta CIP$, illustrated in equations (16) and (17). In equation (16), a contemporaneous shock to daily order flow is impounded in the price the same day, which is consistent with the price-setting equation derived in our model framework. In contrast, we allow for shocks to prices to affect order flow with a lag. The identification assumption is consistent with causality running from order flow to price-setting of the FX swap. Our baseline specification contains $L = 7$ lags.

$$\Delta CIP_t = \alpha_1 + \sum_{k=1}^{L} \gamma_{1,k} \Delta CIP_{t-k} + \sum_{k=0}^{L} \beta_{1,k} OF_{t-k} + \epsilon_{1,t} \quad (16)$$

$$OF_t = \alpha_2 + \sum_{k=1}^{L} \gamma_{2,k} \Delta CIP_{t-k} + \sum_{k=1}^{L} \beta_{2,k} OF_{t-k} + \epsilon_{2,t} \quad (17)$$

We test the effects of a one standard deviation shock to order flow on the CIP deviations in Figure 6. In the left-hand panel, we test for effects during the pre-2008 period, and observe a contemporaneous effect of order flow on the CIP deviation for the EUR/USD and CHF/USD of approximately 0.5 basis points. In line with the results presented in

Table 3, we find the contemporaneous change in the CIP deviation is approximately 5 basis points, with insignificant price changes in the days following the shock.

## 5.2 Dispersion in funding costs and quarter-ends

We now turn to two factors that can quantitatively explain the time variation in price impact; i) funding cost heterogeneity, and ii) regulatory constraints due to quarter-end reporting. When dispersion in USD funding costs increases, it becomes more difficult for the FX swap dealers to determine the forward rate as market participants face increasingly different interest rate differentials. Higher funding costs for a number of potential arbitrageurs may lead to less arbitrage capital as the remaining arbitrageurs are subject to funding and balance sheet constraints that prevent the arbitrageur from scaling up the trade.

In a number of developed jurisdictions, including euro area countries, Japan and Switzerland, banks report quarter-end snapshots of their balance sheets to regulatory authorities. These snapshots provide the basis for banks' key regulatory capital metrics such as the leverage ratio and the ratio of core capital to risk-weighted assets. Hence, banks are particularly leverage constrained over quarter-ends.

Based on our model framework, funding cost heterogeneity and quarter-end reporting require dealers to adjust the FX forward rate more aggressively to attract the necessary arbitrage capital to match customer flows and minimize inventory. As a result, the price impact of order flow increases.

To jointly test these hypotheses, we run the regression specification outlined in equation (18). The variables $D_{FundingHet}$ and $Qend$ represent dummy variables for funding cost heterogeneity and quarter-ends, respectively. The dummy variable $D_{FundingHet}$ captures days with high cross-sectional dispersion among US Libor panel banks in their individual submissions.[23] The dummy variable $Qend$ takes the value 1 on days when the 1-week FX swap contract crosses quarter-ends. When the settlement of the FX swap contract is before quarter-end while the contract matures after, the arbitrageur increases its leverage at the reporting day. Hence, the $Qend$ dummy captures an increase in banks' balance sheet constraints. The interaction between order flow and these variables measures the price impact of an increase in funding costs and when the FX swap contract crosses quarter-ends.

$$\Delta CIP_t = \alpha + \beta_1 OF_t + \beta_2 OF_t \times D_{FundingHet,t} + \beta_3 OF_t \times Qend_t + \beta_j x_{j,t} + \epsilon_t \tag{18}$$

[23] The dispersion dummy takes the value 1 when the cross-sectional dispersion (difference between the maximum and the minimum submitted quote) is within the highest quartile of the distribution on the respective day and zero otherwise.

The results are depicted in Table 4. As in the baseline specification above, columns (1) to (4) of Table 4 measures the price impact of order flow in the period prior to 2008, while columns (5) to (8) measure the price impact of order flow from the beginning of 2008 to the end of our sample in 2017. Consistent with our model framework, we find an increase in the price impact of order flow during periods of high dispersion in Libor quotes in the post-2008 period. In the panel specification in column (5), we estimate a 5.6 basis point increase in the price impact of order flow during periods of high funding heterogeneity.

We also note a substantial increase in price impact during quarter-end periods. In the panel specification in column (5), we estimate a 11 basis point increase in the price impact of order flow during quarter-end periods. Quarter-ends limit capital to conduct CIP arbitrage trades, reducing the supply of arbitrage capital in the FX swap market. This is consistent with our theory of a more inelastic supply of arbitrage capital when balance sheet constraints are more binding. Market makers must adjust the forward rate more aggressively to elicit the necessary supply by arbitrageurs.

The unconditional price impact of a one standard deviation order flow shock is approximately 5 basis points in the baseline specification. After controlling for elevated funding heterogeneity and quarter-ends, the coefficient $\beta_1 \approx 1$, implying that approximately 80 per cent of price impact stems from periods of high dispersion in funding costs and when the FX swap contract crosses regulatory reporting dates.

Table 4 uncovers two important differences in price impact between the currency pairs. First, there is no additional price impact during periods of high funding dispersion for the CHF/USD pair. This stands in sharp contrast to the two other currency pairs where dispersion in USD funding costs explains a large portion of the post-2008 price impact. For the EUR/USD and JPY/USD currency pairs, the price impact is respectively 5.2 and 8.1 basis points larger (more negative) than the average effect in periods of high funding heterogeneity. As a result, the average price impact is large and statistically significant for the CHF/USD pair (3.54 basis points). Second, the additional price impact over quarter-ends is large for both the CHF/USD and the JPY/USD pairs (14.3 and 20.9 basis points, respectively), while the effect is substantially smaller and statistically insignificant for the EUR/USD pair. We discuss potential explanations for these cross currency differences in subsection 5.5.

### 5.3 Direction of order flow

We now test if there is an asymmetric price impact of order flow depending on the direction of the flow. We hypothesize that the price impact of order flow is larger when order flow is positive, i.e. there is net pressure for swapping domestic currency into USD in the inter-dealer market. This is because high funding cost heterogeneity in USD leads to a shortage of arbitrage capital in USD. For negative shocks to order flow, the availability of funding in other currencies is what matters for price impact, which has been ample since the GFC (Rime et al., 2022).

We present our results in Table 5. Columns (1) through to (4) depict the results from regressing positive and negative order flow on changes in CIP deviations and these two variables interacted with a dummy that takes the value of 1 after 2008, and zero otherwise. As expected, neither positive nor negative order flow have substantial price impact prior to 2008. After 2008, we observe an asymmetry in price impact. Positive order flow has a quantitatively more significant price impact across all currencies. This serves as an indication that funding strains in USD is an important constraint after 2008.

In addition, we run a similar regression as specified in equation (18) on the panel of currencies, but now with the order flow split between positive and negative order flow. Columns (5) and (6) depict the pre- and post-2008 results respectively. In the post-2008 sample, shown in column (6), the price impact of positive order flow is negative and significant. The price impact of negative order flow is statistically insignificant with a coefficient near zero. We observe the asymmetry is stronger during periods when funding heterogeneity is high. This is consistent with our hypothesis that high funding cost heterogeneity in USD leads to a shortage of arbitrage capital in USD, making dealers more sensitive to positive order flow (net demand for swapping domestic currencies into USD) in the FX swap market.

In line with the results presented in Table 4, the CHF/USD pair stands out with no difference in the coefficients for positive and negative order flow. This result is consistent with the lack of additional price impact in periods of elevated USD funding dispersion. Since funding dispersion is USD-specific and limits the availability of arbitrage capital, it is reasonable that it affects the price impact of order flow into USD. Given the lack of additional price impact in periods of higher funding dispersion for the CHF/USD pair, there is no reason to expect a strong difference in the price impact between positive and negative order flow for this currency pair.

During quarter-ends, we find that both positive and negative order flow have a large price impact (although not statistically significant, potentially due to the reduction in observations after splitting order flow into positive and and negative values). This means that dealers use order flow as a signal to update the forward rate of the FX swap in periods when balance sheets are particularly constrained and they need to aggressively adjust the price to balance order flow independent of the direction of the flow.

## 5.4 Bid/ask spreads

Bid/ask spreads typically widen in response to a deterioration in market liquidity and higher costs of holding inventory. Consequently, we hypothesize that bid/ask spreads increase during periods of funding heterogeneity and when the FX swap contract trades over quarter-ends. Table 6 presents the results from regressing the bid/ask spread on the quarter-end and funding heterogeneity variables used in specification (18). In columns (1) through to (3) we test for effects in the pre-crisis period. Columns (4) to (9) show the results for the post-crisis period, with additional dummies capturing the post-2015 period. First, the constant in the regression indicates that the bid/ask spreads are lowest for EUR/USD and highest for CHF/USD pairs. This is in line with the interpretation that the EUR/USD is the most liquid currency pair while the CHF/USD is the least liquid.

Bid/ask spreads are generally higher when funding heterogeneity is high. This is particularly pronounced for EUR/USD and JPY/USD. After 2015, bid/ask spreads have also widened during quarter-ends, consistent with empirical evidence in Krohn and Sushko (2022).[24]

We now turn to whether the increased illiquidity in the inter-dealer market leads to an increase in the price impact of order flow. We run a regression specification in equation (19). $D_{spread}$ is an indicator for bid-ask spreads that take a value of 1 for values in the top 25 percentiles (upper quartile) over the post-2008 sample from 1 January 2008 to 1 September 2017.[25]

$$\Delta CIP_t = \alpha + \beta_1 OF_t + \beta_2 OF_t \times D_{spread,t} + \beta_3 OF_t \times Qend_t + \beta_j x_{j,t} + \epsilon_t \tag{19}$$

In Table 7 we present the results of each specification. Columns (1) to (4) depict the price impact of order flow in periods of the 25 per cent of the largest values of bid/ask spreads. Consistent with our theory, we find that the price impact of order flow is fully absorbed by periods of high bid/ask spreads. This is evident in $\beta_1 \approx 0$, and the coefficient on order flow interacted with $D_{spreads}$ being quantitatively significant, with a one standard deviation order flow widening CIP deviations by approximately 6 basis points. The results suggest a deterioration in market liquidity, as indicated by widening bid/ask spreads, implying that dealers are more sensitive to a change in inventories. The inter-dealer market sets the forward rate more aggressively to balance the market.

Importantly, the results illustrate the relationship between market liquidity and funding

[24] Krohn and Sushko (2022) make an additional point that market structure matters for dealer pricing. In particular, the role of smaller dealers providing arbitrage capital during quarter-ends leads to an increase in the observed bid/ask spreads.

[25] Similar results for our regression specification are obtained using the full sample of 1 January 2005 to 1 September 2017.

dispersion in USD. For the two main currency pairs, EUR/USD and JPY/USD, table 6 illustrates that the relationship between high funding dispersion and high bid/ask spreads is particularly strong and explain much of the price impact of order flow.[26]

## 5.5 Differences in price impact across currencies

Table 4 shows that the increase in the price impact for the CHF/USD pair is not confined to periods of high funding dispersion in USD. However, the price impact of order flow and bid/ask spreads are closely connected across all three currency pairs (see Table 7). Hence, the evolution of bid/ask spreads may reveal important information about the underlying drivers of the price impact of order flow for the CHF/USD pair.

One distinct difference between the CHF and the other two currencies (EUR and JPY) is the appreciation pressure the Swiss currency has been under since 2010. The first wave of appreciation pressure appeared with the escalation of the euro-area sovereign debt crisis in May 2010. In August 2011, the CHF came under renewed pressure as the euro-crisis intensified. On 6 September 2011, the Swiss National Bank (SNB) set a minimum floor for the EUR/CHF exchange rate at 1.20.[27] On January 15, 2015, the SNB surprisingly discontinued the minimum floor. The discontinuation of the exchange rate floor caused immediate and large fluctuations in the exchange rate.

Before setting the minimum floor for the EUR/CHF in September 2011, the SNB took various measures to contain the appreciation of the exchange rate through CHF-providing repo transactions and direct interventions in the FX swap market. These measures contributed to increased volatility in both the FX spot and FX swap market and consequently led to higher inventory risk for dealers. As a result, bid/ask spreads widened and the price impact of order flow increased. Not surprisingly, the sudden removal of the minimum floor in January 2015 also caused higher risk for dealers and a surge in bid/ask spreads.[28] Figure 7 illustrates these events and the corresponding response in bid/ask spreads.

The appreciation pressure on the Swiss exchange rate and the corresponding response by the SNB may explain why the increase in the price impact of order flow for the CHF/USD pair is less concentrated to periods of elevated funding heterogeneity in USD as these CHF-specific led to higher bid/ask spreads and increased inventory risk for dealers in the

[26] In Internet Appendix A.2, we also estimate rolling regressions over time, and rolling regressions sorted on the dispersion of LIBOR quotes and bid/ask spreads. Our results confirm that price impact of order flow is significant post-2008, and is confined to periods of high dispersion in LIBOR quotes and bid/ask spreads.

[27] In the press release on 6 September 2011 the SNB says: "With immediate effect, it will no longer tolerate a EUR/CHF exchange rate below the minimum rate of CHF 1.20. The SNB will enforce this minimum rate with the utmost determination and is prepared to buy foreign currency in unlimited quantities."

[28] The removal of the minimum floor for the exchange rate can also be observed in the order flow data depicted in Figure 3, where noticeable spikes in both directions take place on 15 and 16 January in 2015.

CHF/USD pair. This explanation is further supported by the results depicted in Table 5. In periods of elevated funding heterogeneity in USD, we expect that flows into USD (positive order flow) have a stronger price impact than flows out of USD (negative order flow). This is indeed the case for EUR/USD and JPY/USD, but not for CHF/USD. If the price impact in CHF/USD is driven by CHF-specific events connected to the exchange rate appreciation, there is no reason to expect a substantial difference between positive and negative order flow for CHF/USD.

We also note that the price impact over quarter-ends is substantially smaller for the EUR/USD pair than the other two currency pairs. There may be various reasons for this. First, the EUR/USD pair is the most liquid in the world, both for FX swaps and FX spot, and bid/ask spreads are also generally tightest for the EUR/USD. Second, deeper money markets and the presence of a larger range of market participants, in particular global banks with physical presence in the euro area, may favor the EUR/USD cross when arbitrage capital is particularly scarce. As can be gleaned from Table 9, the contemporaneous price adjustment when the FX swap contract crosses quarter-ends is more precise for the EUR/USD with the full adjustment taking place the first hour after the contract trades over quarter-ends.

# 6 Public vs Private Information Shocks

In this section, we empirically test the microstructural hypotheses of public and private information. We examine how price-setting in the FX swap market is determined in response to central bank swap lines, quarter-end reporting requirements and monetary policy surprises.

## 6.1 Central Bank Swap Lines

A currency swap line is an agreement between two central banks to exchange currencies. A source central bank, for example the Federal Reserve, exchanges USD for the domicile currency of the counterparty central bank. The counterparty central bank can then auction the USD currency they receive to domestic banks. Federal Reserve swap lines can alleviate market dysfunction by reducing dollar constrained institutionsâ reliance on the FX market for dollar funding, and enable top-tier banks to borrow dollars close to the risk-free rate and lend in the FX market to conduct arbitrage.

We turn to Federal Reserve swap lines to test how price-setting is determined in the FX swap market. We hypothesize that the swap lines constitute private information. While the date of swap line auctions are publicly known, the details of which commercial banks that accessed the swap lines are unknown to dealers.[29] Banks that have access to USD via a central bank swap line may reduce their demand for USD funding in the FX swap market. Alternatively, if the central bank swap lines are instead allocated to arbitrageurs supplying USD in the FX swap market, we expect an increase in seller-initiated transactions for USD. In either case, we predict an increase in allotments to reduce order flow.

To test our hypothesis, we construct a global measure of total amounts outstanding for lines extended to the ECB, BOJ and SNB. Using data on Federal Reserve swap line allotments to other central banks during the period of 2008-2010, we compute the total stock of allotments as the total amount of all loans made by the Federal Reserve to counterparty central banks, less any loans that have matured. At the height of the crisis, in October 2008, allotments peaked at approximately 250 billion USD to the ECB, and approximately 100 billion USD to the BOJ. The daily change in stocks provides us with a flow measure of allotments. This is the most direct measure of incremental liquidity provided by the Federal Reserve to foreign (non-US) banks.

We test for the impact of swap line allotment flows on the CIP deviations and order flow. The multivariate VAR framework is summarized in equations (20), (21) and (22). We continue to use data on 1-week FX swaps as the majority of swap allotments are of a 1-week maturity. As well as the measure of the first difference in CIP deviations $\Delta CIP_t$ and order flow $OF_t$, we augment the bivariate VAR in section 5.1 with a measure of swap allotment flows $A_t$. The identifying assumption is that shocks to swap line allotments can have contemporaneous effects on the CIP deviations and order flow. In contrast, swap line allotments are only affected by lagged order flow and CIP deviations. We hypothesize that a positive shock to swap line allotments causes a decline in order flow, as banks substitute toward the swap line for additional USD funding. Similarly, banks that now receive USD funding can use their arbitrage capital by supplying USD in the FX swap market. The decline in order flow then narrows the CIP deviations.

$$\Delta CIP_t = \alpha_1 + \sum_{k=1}^{L} \gamma_{1,k} \Delta CIP_{t-k} + \sum_{k=0}^{L} \beta_{1,k} OF_{t-k} + \sum_{k=0}^{L} \delta_{1,k} A_{t-k} + \epsilon_{1,t} \tag{20}$$

$$OF_t = \alpha_2 + \sum_{k=1}^{L} \gamma_{2,k} \Delta CIP_{t-k} + \sum_{k=1}^{L} \beta_{2,k} OF_{t-k} + \sum_{k=0}^{L} \delta_{2,k} A_{t-k} + \epsilon_{2,t} \tag{21}$$

$$A_t = \alpha_3 + \sum_{k=1}^{L} \gamma_{3,k} \Delta CIP_{t-k} + \sum_{k=1}^{L} \beta_{3,k} OF_{t-k} + \sum_{k=1}^{L} \delta_{3,k} A_{t-k} + \epsilon_{3,t} \tag{22}$$

In our baseline specification, we use $L = 7$ lags. We document the impulse response to

[29] If the details of the swap line auctions are public information, the FX swap price should adjust contemporaneously.

a one standard deviation shock in swap line allotment flows in Figure 8. Consistent with our hypothesis, there is a contemporaneous decline in order flow for the EUR/USD and JPY/USD pairs. The effect on order flow is strongest for the EUR/USD. This is intuitive, given the majority of swap line allotments were extended to the ECB, which then auctioned funds to European banks that relied on USD funding in the EUR/USD FX swap market. A number of European banks suffered credit downgrades in this period. Consequently, these banks experienced higher funding costs and difficulties raising funding directly in US money markets. The direct allotment of USD by the ECB through the swap line arrangement gave lower-rated banks an opportunity to raise USD funding from their own central bank.

Examining the price effects, we see that there is a peak in the reduction of CIP deviations by 5 basis points for each currency pair, with the peak effect occurring 2-3 days following the swap line shock. The delayed price adjustment is attributed to the timing of swap line allotments: allotments occur in periods of extreme dislocation in FX swap markets, and respond to periods of low liquidity, high counterparty risk, and significant strains in US money markets. While the effect of swap lines on reducing CIP deviations has been the focus of Bahaj and Reis (2021), we contribute to this literature by showing that the price impact of central bank swap lines occurs through the channel of order flow.

Adding to the dynamic effects of the swap lines on order flow and CIP, we run a simple regression where we regress order flow on a dummy for the days when the results of the swap line auctions are announced. As in our previous regressions, we include the dummies for funding heterogeneity and quarter-ends, and control for changes in Libor-OIS spreads (1-week and 3-month maturity), VIX and broad USD index. The sample runs from 1 January 2008 to 31 December 2009, the period when the banks actively drew on the swap lines. Table 8 reports the finding that order flow is substantially lower (less pressure to borrow USD in the FX swap market) on the days when USD liquidity is provided by the swap lines.[30]

## 6.2 Quarter-end effects

Quarter-end reporting can impact both customers and arbitrageurs in the FX swap market. First, there is an incentive for financial institutions to window-dress balance sheets in order to meet leverage requirements imposed by the new regulatory framework for banks (Basel III). By limiting the capital to conduct CIP arbitrage trades, this reduces the supply of USD in the FX swap market. Quarter-end reporting can also affect bank demands for

[30] We also investigate whether the price impact of order flow is significantly affected during periods of swap line allotments. In table IA.I in Internet Appendix A.3 we show that the price impact of order flow is attenuated on days of swap line auctions for EUR/USD and JPY/USD (although not statistically significant). This is consistent with swap lines not only affecting the demand for USD through FX swaps, but also relaxing constraints on USD funding for arbitrageurs.

USD funding in the FX swap market. There is evidence that the large increase in excess reserves in the banking systems of euro area, Japan and Switzerland during the post-2008 period increases the incentive to use FX swaps as an alternative source of USD funding during quarter-ends.[31] Consistent with quarter-ends being public information, we find evidence of contemporaneous price-setting by dealers. Figure 9 shows the reaction of the 1-week CIP deviation for the EUR/USD, CHF/USD and JPY/USD pairs in September 2016. Once the quarter-end period ends, the forward rate contemporaneously adjusts back to its level observed prior to quarter-end.

We then examine the speed of adjustment of the forward rate over quarter-ends using high frequency tick data from Thomson Reuters Tick History. For each currency pair we look at the hourly change in the FX swapped USD rate (the synthetic USD rate swapped from the respective currency 1-week Libor rate) from five hours before to five hours after the contract crosses quarter-ends. Table 9 reports the results, averaging across all quarter-ends. The contemporaneous adjustment is strong across all currency pairs, in particular after 2015 when the leverage ratio was introduced. A large part of the adjustment happens at exactly the hour when the contract first trades over quarter-end. However, for CHF/USD and JPY/USD there is further adjustment in the same direction up to two hours following the quarter-end. Moreover, for JPY, the currency where the central bank engaged in various forms of quantitative easing (and hence provided excess reserves to banking system) before 2008, there is evidence of a large contemporaneous price adjustment over quarter-ends (11 basis points) even prior to the GFC.

In addition to contemporaneous adjustment of the forward rate, we also test for effects on order flow. The results in section 5 suggest that the price impact of order flow is particularly large during quarter-ends. Through the lens of our theoretical framework, the regulatory balance sheet constraints force dealers to make larger price concessions to attract opposite flows during these periods. On the other hand, the large contemporaneous price adjustment that happens when the FX swap contract crosses quarter-ends is necessary to avoid directional order flow into USD. Given that participants face heterogeneous balance sheet constraints, the contemporaneous adjustment could be too large or too small. In theory, this means that a potential effect on order flow could be in both directions.[32] We test for systematic effects on order flow by simply regressing order flow on our dummy for dates when the 1-week FX swap contract crosses quarter-ends. Table 10 depicts the results.

We find that although order flow increases (i.e., more flow into USD) during quarter-

[31] This is due to FX swaps being *off balance sheet*, in contrast to short-term direct USD funding that increases a bank's leverage, see Rime et al. (2022) for more details.

[32] For example, if dealers overshoot in their expectations of the tightness of leverage constraints, then this will result in a negative order flow. Conversely, if dealers underestimate the tightening of leverage constraints, this will result in positive order flow.

end periods for all currency pairs in the post-2008 sample, for JPY/USD the effect is not statistically significant. Furthermore, we do not find that the effect on order flow changes after the leverage ratio was introduced in 2015. These results indicate that there is a general tendency that the contemporaneous adjustment around quarter-end is not large enough to curb order imbalances. Interestingly, for the JPY/USD pair, where the contemporaneous price adjustment is largest, the effect on order flow is smallest. Taken together, our results suggest that dealers contemporaneously adjust prices to curb order flow as a result of publicly known effects of quarter-ends.

Our results indicate that order flow into USD is larger when the FX swap contract crosses quarter-ends. This increase in order flow should fade quickly as dealers adjust prices. To further investigate the effect on order flow during quarter-ends, we distinguish between the first day when the contract crosses quarter-end and the remaining days when the contract trades over quarter-ends. Table IA.VI in Internet Appendix A.4 shows that the majority of the effect on order flow during quarter-end periods occur on the first day the contract crosses the quarter-end. After the first day, dealers have fully adjusted prices to avoid excess order flow in one direction.

## 6.3 Monetary Policy Announcements

Central bank interest rate announcements are public information and we expect dealers to respond by adjusting the forward rate contemporaneously. CIP deviations are decomposed into a forward premium and the interest rate differential. In response to a change in the risk-free rate, our hypothesis is that the forward premium reacts in a systematic way to offset the change in the interest rate differential. We illustrate this hypothesis in equation (23), where a decline in the risk-free rate $r_d^f$ is met by an offsetting increase in the forward premium, preserving the synthetic USD rate of swapping EUR into USD.

$$\Delta = \underbrace{1 + r_{\$}^f}_{\text{direct}} - \underbrace{\frac{F \uparrow}{S}(1 + r_d^f \downarrow)}_{\text{synthetic}} \tag{23}$$

Figure 10 plots the forward premium of the EUR/USD, CHF/USD and JPY/USD currency pairs in response to the scheduled monetary policy announcements of the ECB, SNB and BOJ respectively. The ECB announcement we consider is the 14 September 2014 announcement where the ECB lowered the deposit facility rate by 10 basis points.[33] The SNB policy announcement is on 15 January 2015, when the interest rate target is lowered by 50 basis points to -0.75%, and the SNB lifts the floor on the CHF/EUR exchange

[33]The ECB monetary policy decision: https://www.ecb.europa.eu/press/pr/date/2014/html/pr140904.en.html

rate.[34] Finally, on 29 January 2016 the BOJ applies a negative interest rate of minus 10 basis points on current accounts that financial institutions hold at the central bank.[35] For each announcement, we observe a widening of the forward premium of approximately a similar magnitude to the surprise change in the interest rate, with most of the adjustment occurring within an intra-day window of the announcement. The increase in the forward premium in response to a decline in the risk-free rate is intuitive: dealers offset the change in the risk-free rate with a change in the forward premium, keeping the synthetic USD rate constant.

We test our hypothesis in equation (23) more concretely through an event study analysis of scheduled monetary policy announcements. For our measure of monetary surprises, we calculate the high frequency (30-minute window) change in the 1-month overnight index swap (OIS) rate. The surprise rate is a proxy for the surprise component of the interest rate change around monetary policy announcements based on a measure of the risk-free rate. We run the following event study for days of scheduled announcements, by regressing order flow on the surprise measure of interest rates. Our event study results in Table 11 show that monetary policy announcements have no statistical effect on order flow.[36] The results are consistent with contemporaneous adjustment of the forward premium as dealers offset changes to the interest rate differential.

# 7 Conclusion

In this paper we identify FX swap order flow — the net of buyer- and seller-initiated transactions — as a fundamental signal used by dealers to update the price of the FX swap. Our key finding is that order flow has significant price impact after 2008, with negligible effect before 2008. We explore two factors that restrict arbitrage capital and account for the increase in price impact: i) the increased heterogeneity of USD funding costs, and ii) periods where the FX swap contract crosses quarter-ends.

We first provide a model framework of the FX swap market. Agents supply USD for CIP arbitrage, and demand USD to hedge balance sheet currency risk. Dealers are the market-maker, and set a forward rate that equates customers net demand for USD in the FX swap market with the supply of USD of agents with arbitrage capital. We derive a price-setting rule in which dealers use order flow to update the forward rate of the swap.

We then test the framework empirically. Based on transaction level data for 1-week FX swaps in the inter-dealer market, we document a significant price impact of order flow in

[34] The SNB press release: https://www.snb.ch/en/mmr/reference/pre_20150115/source/pre_20150115.en.pdf

[35] The BOJ press release: https://www.boj.or.jp/en/announcements/release_2016/k160129a.pdf

[36] In line with this, we find no effect of monetary policy announcements on the price impact of order flow, see table IA.II in Internet Appendix A.3.

the post crisis-period, with a one standard deviation OF leading to a 5 basis point widening of CIP deviations. We estimate up to 80 per cent of the observed price impact is explained by an increase in the heterogeneity of USD funding costs, and when the FX swap crosses quarter-end periods. Through the lens of the model, these factors lead to a reduction in arbitrage capital, requiring dealers to increase the forward premium more aggressively to elicit the necessary supply by arbitrageurs to match flows and balance inventories.

Our second empirical contribution is to distinguish between public and private information in the FX swap market. We find evidence of contemporaneous price-setting during quarter-ends and monetary policy announcements. During quarter-ends, we document a high-frequency jump in the forward premium that corresponds to the hour during which the FX swap contract crosses quarter-ends. This suggests that dealers price the effects of quarter-ends on arbitrage capital, consistent with public information. We also show gradual price adjustment through order flow in response to swap line allotments, consistent with dealers updating the forward rate in response to private information.

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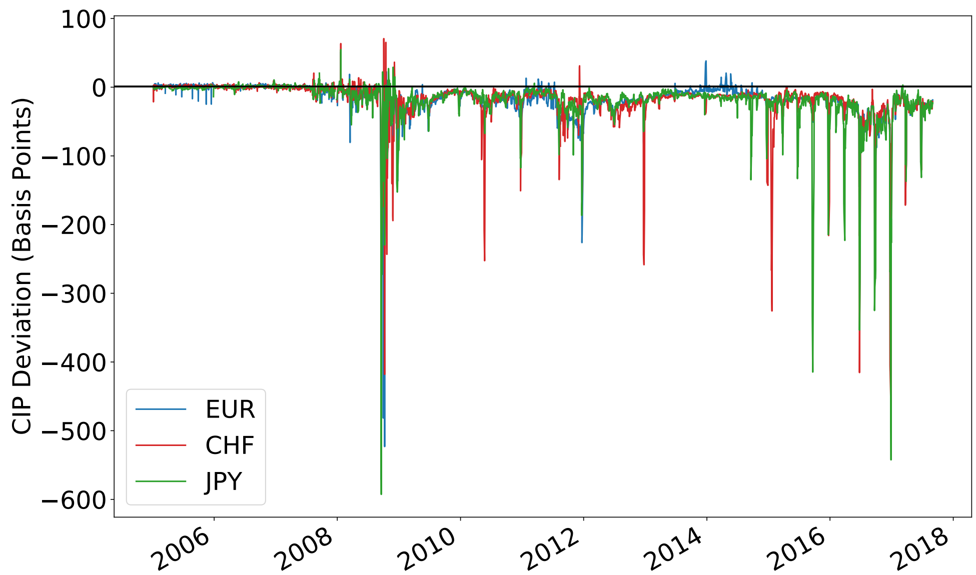
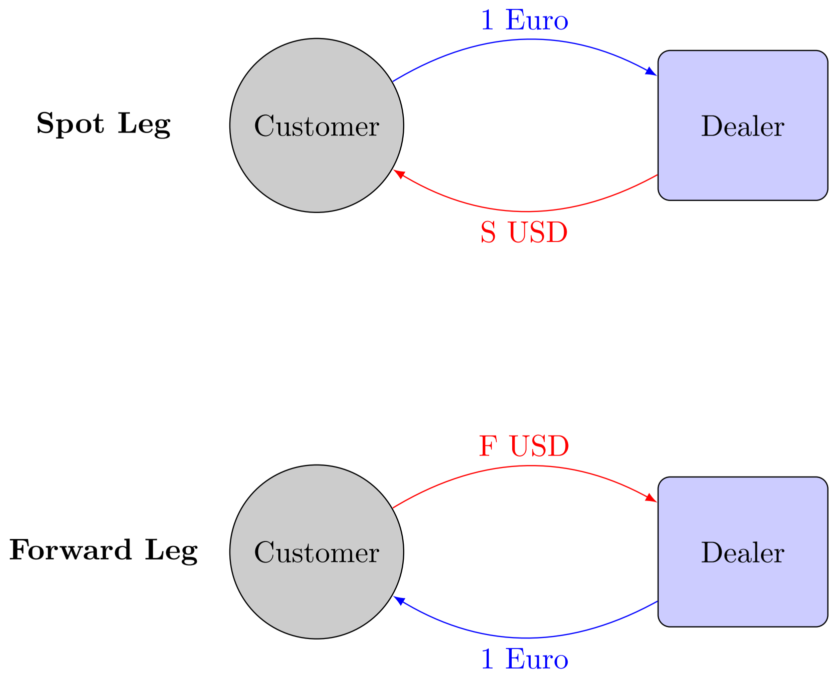
# Figures

Figure 1: 1-week CIP deviations



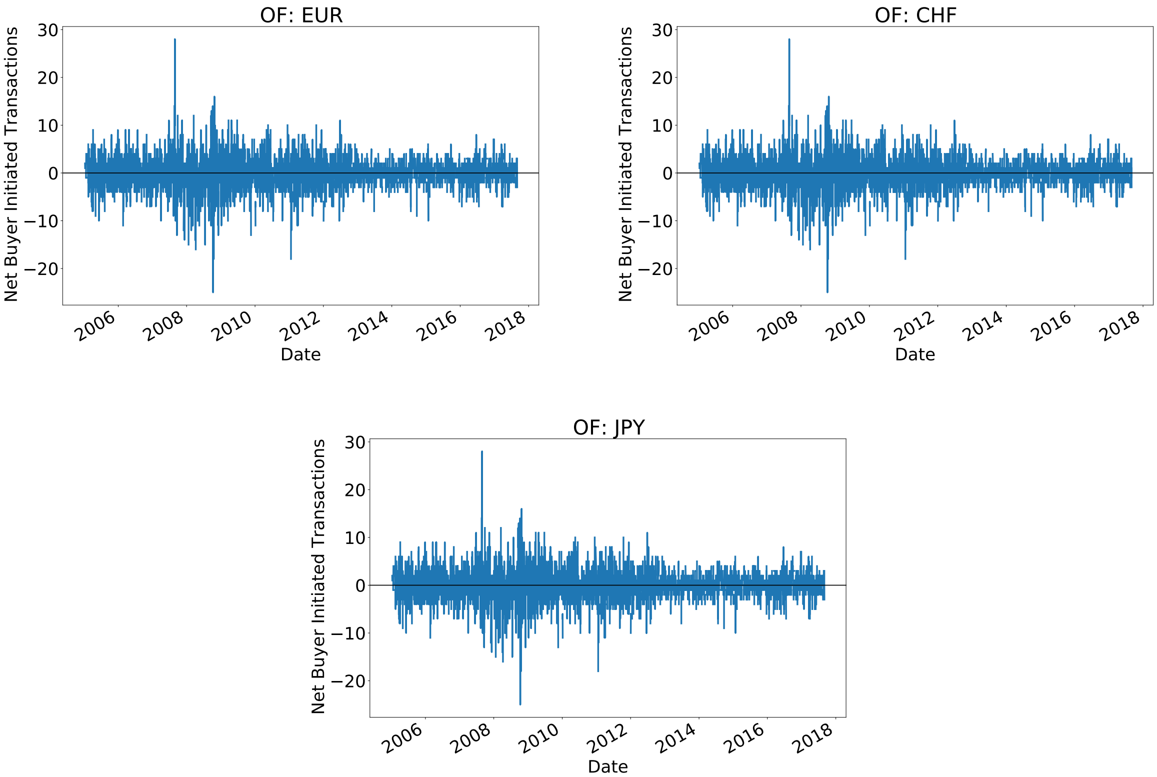

*Note: This figure plots the 1-week CIP deviation measured in basis points, obtained from Thomson Reuters Tick History. This provides a measure of CIP deviations based on 1-week Libor rates. Negative deviations indicate a USD borrowing premium for the EUR/USD, CHF/USD and JPY/USD pairs. Sample period is 1 January 2005 to 1 September 2017.*

Figure 2: Foreign exchange swap



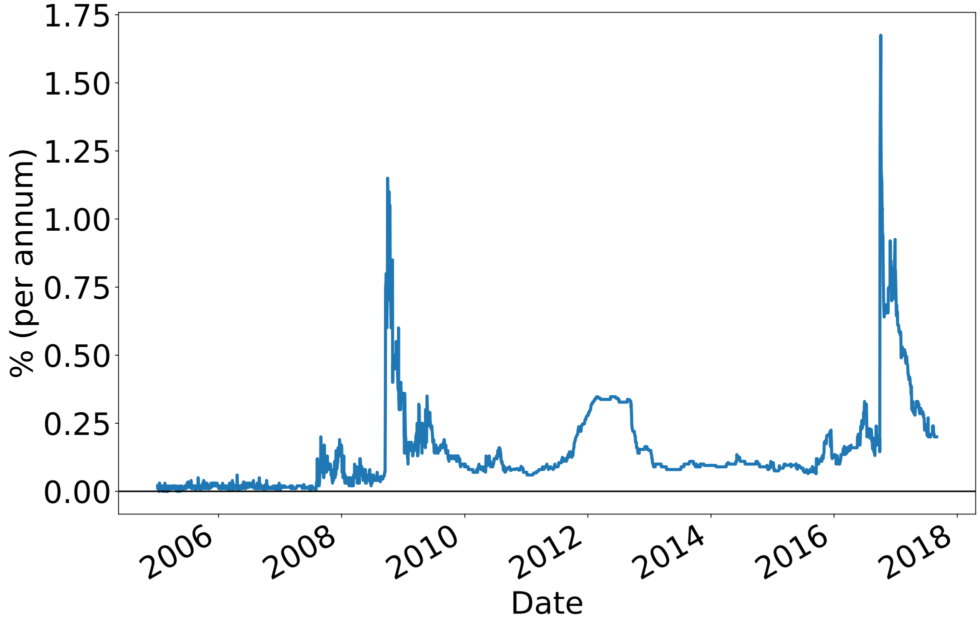

*Note: FX swap is typically for maturities at less than three months. At the spot leg, domestic currency and USD are swapped at the prevailing spot rate. The principals are then re-exchanged at maturity at the forward rate.*

Figure 3: Order flow



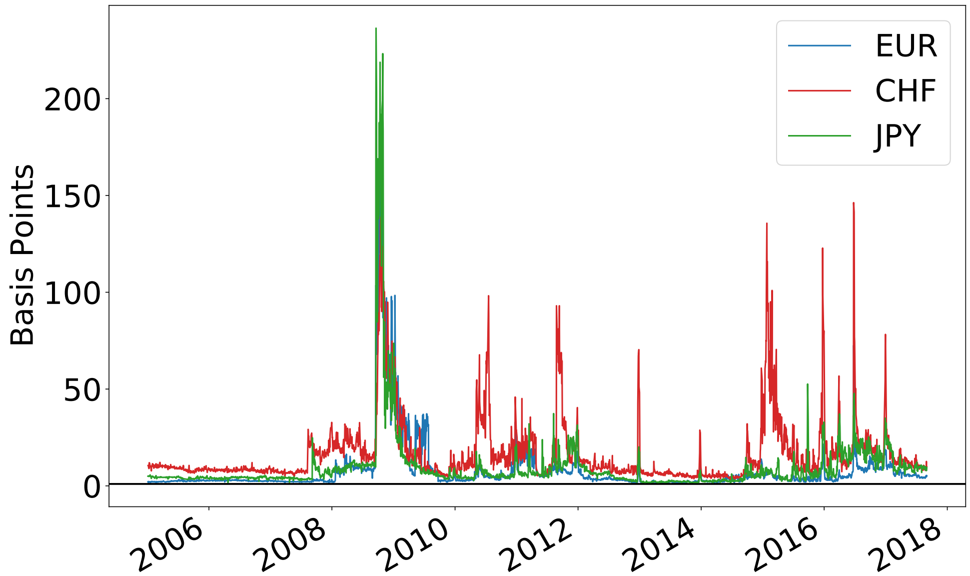

*Note: Daily count order flow for EUR/USD, JPY/USD and CHF/USD pairs using the TR D3000-2, for 1-week FX swap maturities. Order flow is given as the net of buyer- initiated transactions, where buyer-initiated transactions are signed +1 and seller-initiated transactions are signed −1.* $OF_t^{count} = \sum_{k=t_0}^{k=t_0+1} \mathbb{1}[T_k = B] - \mathbb{1}[T_k = S]$. *Sample period is 1 January 2005 to 1 September 2017.*

Figure 4: Range of Libor fixing quotes



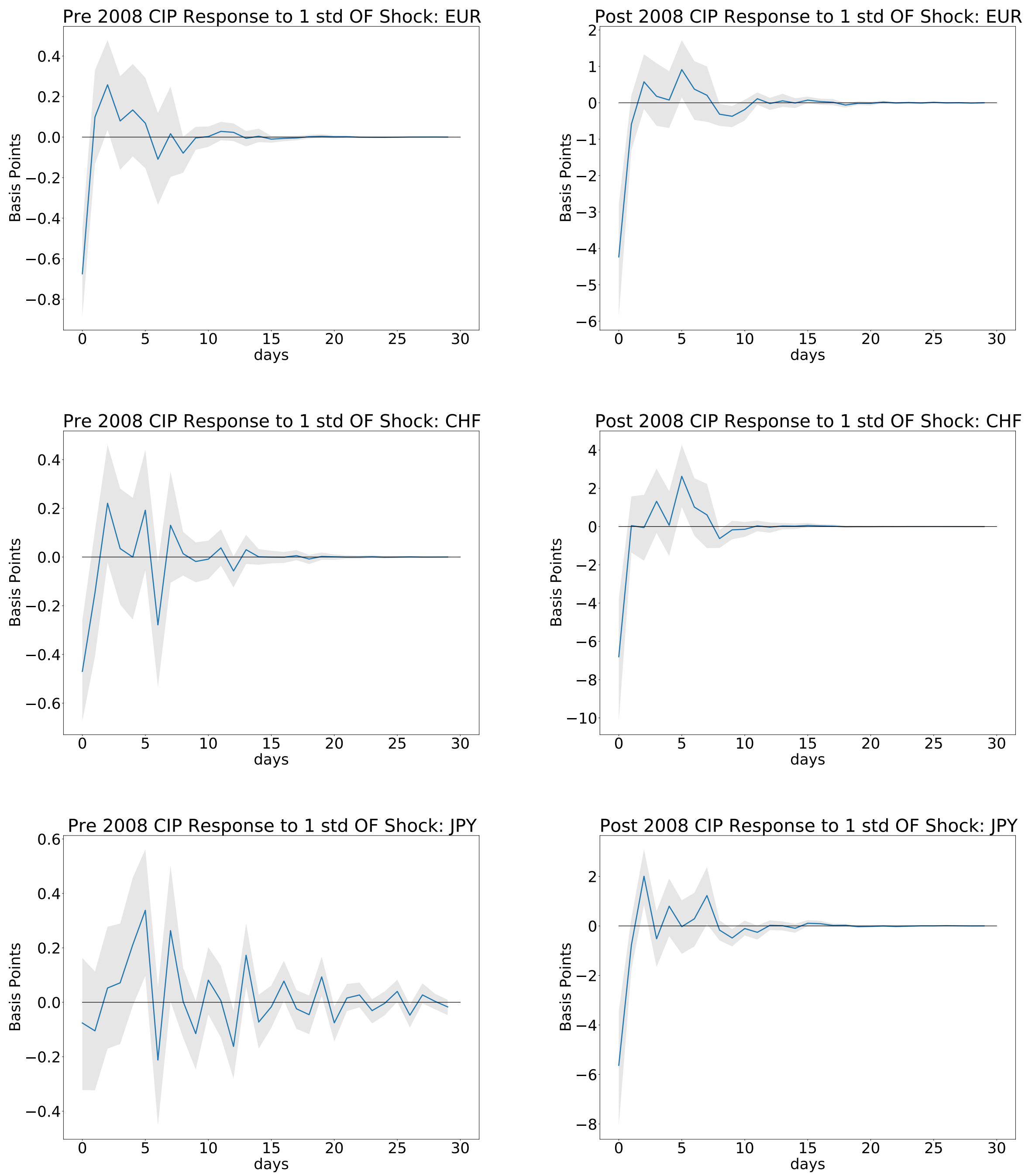

*Note: The figure depicts the daily difference in percentage points between the highest and lowest submission among the contributing banks in 3-month USD Libor. The data are obtained from Bloomberg and Intercontinental Exchange (ICE). Sample period is 1 January 2005 to 1 September 2017.*

Figure 5: Bid/ask spreads for 1-week FX swaps



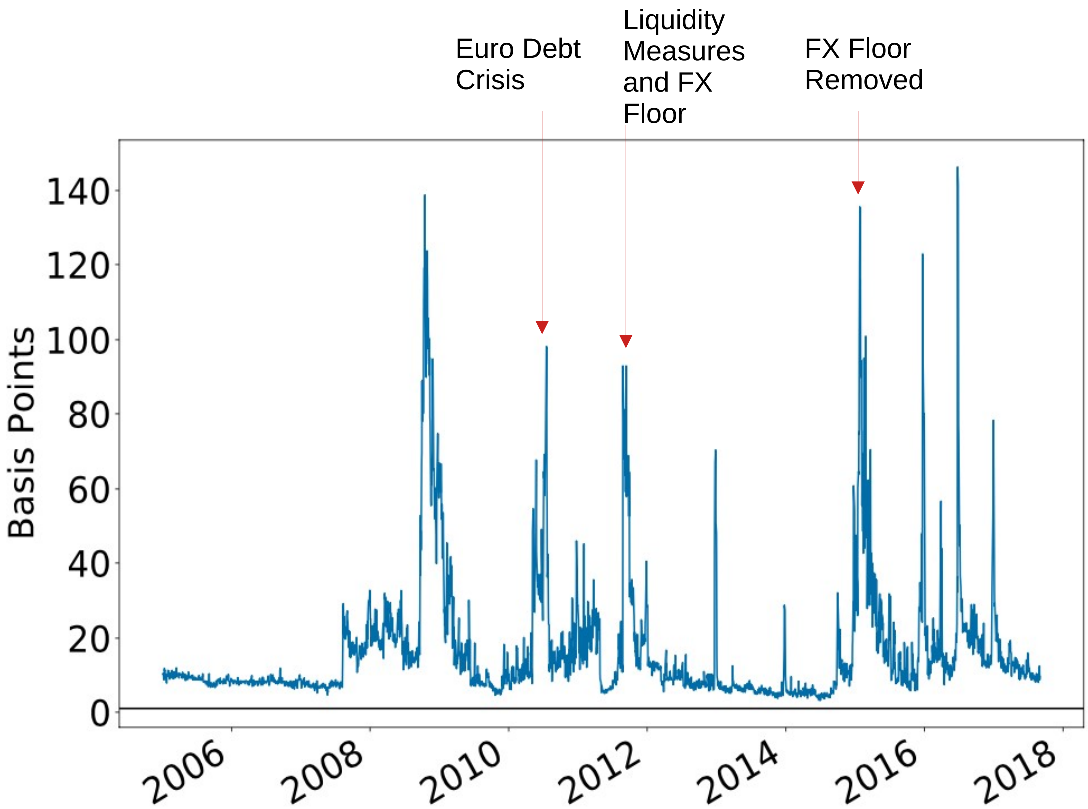

*Note: The figure shows the daily average between the bid and the ask quotation based on hourly data from Thomson Reuters Tick History. The bid/ask spread is expressed in basis points. Sample period is 1 January 2005 to 1 September 2017.*

Figure 6: Response of 1-week CIP deviations to a 1 standard deviation shock in order flow



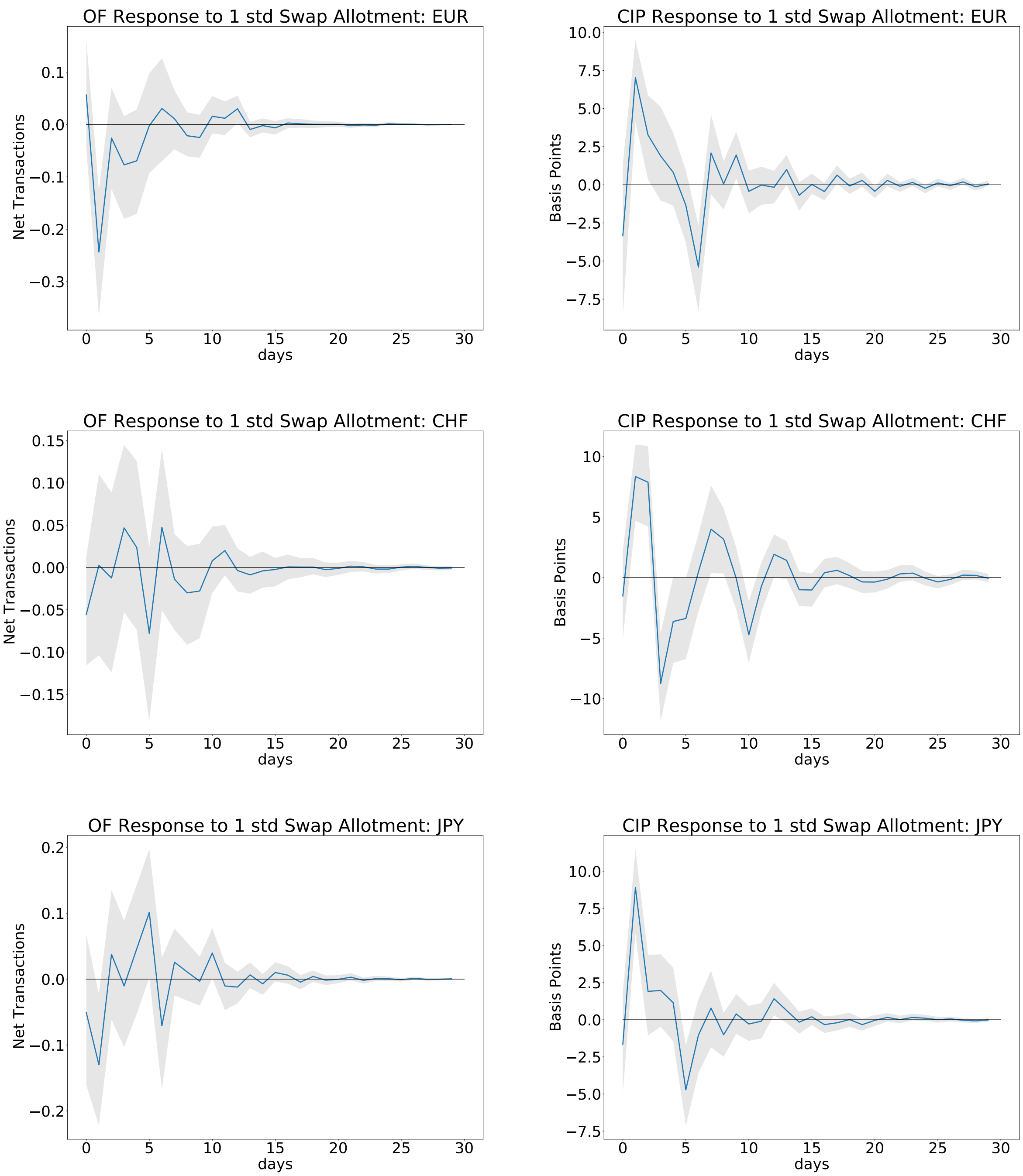

*Note: This figure plots the impulse response of the change in CIP deviations to a 1 standard deviation shock to order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps, based on a bivariate VAR following Hasbrouck (1991) and Ranaldo and Somogyi (2021). Standardized order flow OF is measuring the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades, and CIP deviation is calculated using Thomson Reuters Tick History quotes on 1-week FX swap points. We condition our sample into two periods based on pre-2008 (1 January 2005 to 31 December 2007) and a post-2008 (1 January 2008 to 1 September 2017) period. The left-hand panel shows the response of EUR/USD, CHF/USD and JPY/USD in the pre-2008 period, and the right-hand panel shows the response in the post-2008 period. Total sample period is from 1 January 2005 to 1 September 2017. Gray area denotes a standard error band equivalent for statistical significance at the 10% level.*

Figure 7: Bid/ask spreads for 1-week CHF/USD FX swaps



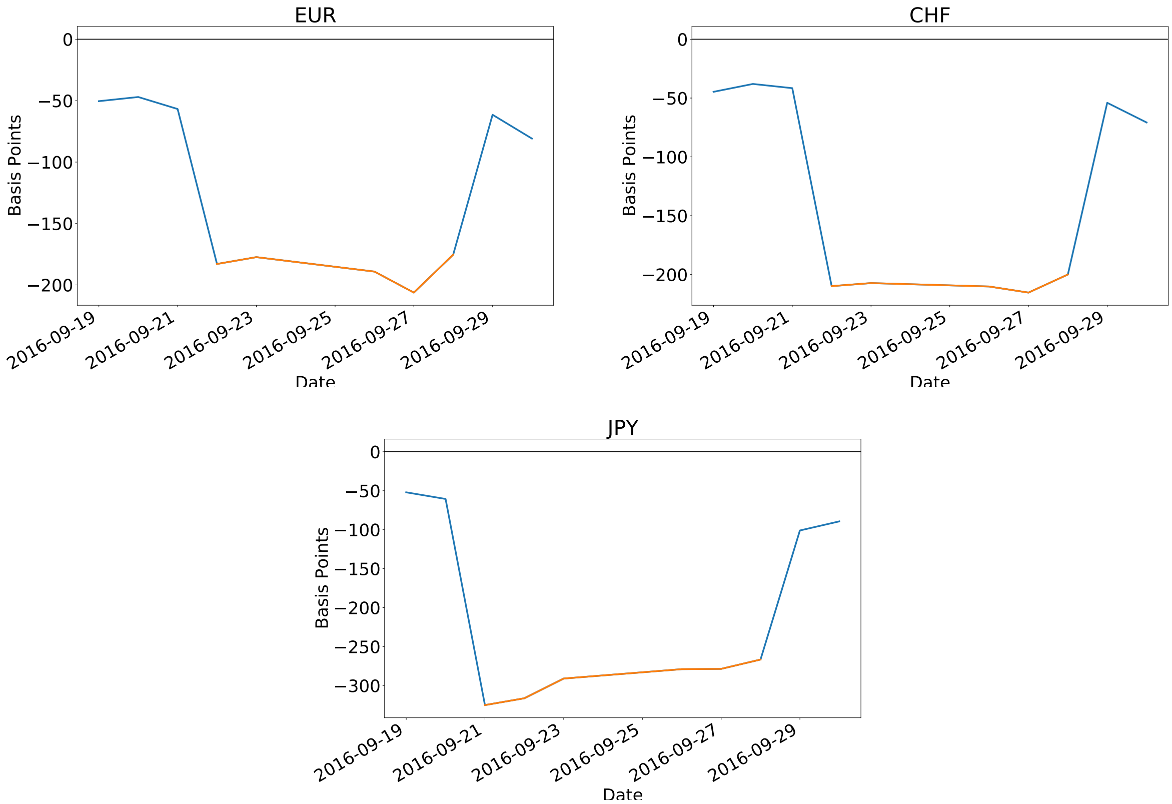

*Note: The figure shows the daily average between the bid and the ask quotation for CHF/USD FX swap rates based on hourly data from Thomson Reuters Tick History. The bid/ask spread is expressed in basis points. Sample period is 1 January 2005- 1 September 2017.*

Figure 8: Response of order flow and 1-week CIP deviations to a one standard deviation shock in swap line allotments



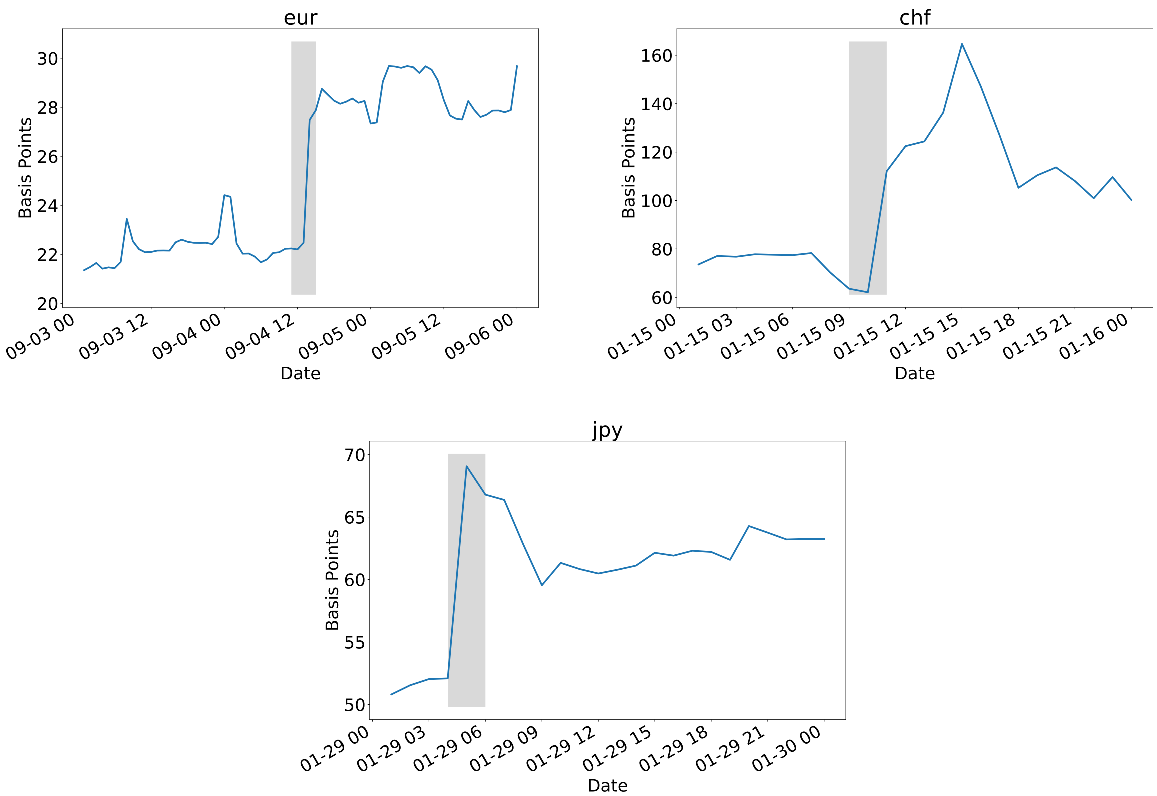

*Note: This figure plots the impulse response of the change in CIP deviations and order flow to a 1 standard deviation shock in swap line allotments for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps, based on a multivariate VAR following Hasbrouck (1991) and Ranaldo and Somogyi (2021). Standardized order flow OF is measuring the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades, and CIP deviation is calculated using Thomson Reuters Tick History quotes on 1-week FX swap points. Swap line allotments measure aggregate flows of USD loans from the Federal Reserve to counterparty central banks. The left panel shows order flow and the right panel shows the response of CIP deviations of EUR/USD, CHF/USD and JPY/USD, respectively. Total sample period is from 1 January 2007- 31 December 2011. Gray area denotes a standard error band equivalent for statistical significance at the 10% level.*

Figure 9: 1-week CIP deviations during quarter-end in September 2016




*Note: This figure examines 1-week CIP deviations for the EUR/USD, CHF/USD and JPY/USD pairs around the quarter-end period in September 2016, with contemporaneous adjustment of the forward premium as the FX swap contract enters the quarter-end period. The CIP deviations are computed using the 1-week FX forward rate and FX spot, using intra-day data from Thomson Reuters Tick History, and 1-week LIBOR rates.*

Figure 10: Response of the forward premium to scheduled monetary policy announcements




*Note: This figure shows the response of the 1-week forward premium in EUR/USD, CHF/USD and JPY/USD around scheduled monetary policy announcements of the ECB, SNB and BOJ, respectively. Grey area denotes an intra-day window around the scheduled monetary announcement. In each case, the scheduled announcement changed the central bank policy rate and caused dealers to contemporaneously adjust the forward premium. The forward premium is computed using 1-week forward and spot rates, using intra-day data from Thomson Reuters Tick History.*

# Tables

Table 1: Summary statistics for 1-week CIP deviations

| | Pre 2008 | | | | | Post 2008 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | observations | mean | sd | min | max | observations | mean | sd | min | max |
| EUR/USD | 667 | 0.9 | 3.9 | -24.8 | 6.2 | 1921 | -24.6 | 36.2 | -571.1 | 38.2 |
| CHF/USD | 391 | -0.2 | 3.3 | -21.5 | 20.5 | 821 | -25.9 | 41.1 | -415.5 | 70.7 |
| JPY/USD | 395 | -0.5 | 3.9 | -23.4 | 12.3 | 1363 | -27.8 | 45.6 | -592.7 | 27.1 |

*Note: This table records summary statistics of daily 1-week CIP deviations in EUR/USD, CHF/USD and JPY/USD. CIP deviations are annualized and expressed in basis points. Data on 1-week forward and spot rates are taken from Thomson Reuters Tick History. The interest rates used to calculated the CIP deviations are 1-week Libor rates. The full sample period is from 1 January 2005 to 1 September 2017, and is divided into pre and post 2008 periods.*

Table 2: Summary statistics order flow

| | Pre 2008 | | | | | Post 2008 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | observations | mean | sd | min | max | observations | mean | sd | min | max |
| EUR/USD | 667 | -0.2 | 3.6 | -14 | 14 | 1921 | -0.1 | 3.6 | -25 | 18 |
| CHF/USD | 391 | 0.4 | 2.1 | -6 | 7 | 821 | 0.4 | 1.7 | -10 | 8 |
| JPY/USD | 395 | 0.1 | 2.1 | -9 | 7 | 1363 | 0.1 | 2.1 | -11 | 9 |

*Note: This table records summary statistics of daily order flow based on trades in 1-week FX swaps using inter-dealer trades in Thomson Reuters D3000-2 Platform. Order flow is constructed as the net of buyer-initiated transactions, where a transaction is signed +1 if it is swapping EUR, CHF and JPY into USD at the spot leg of the FX swap contract. The sample period is from 1 January 2005 to 1 September 2017.*

Table 3: Price impact of order flow before and after 2008

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | |
| | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ |
| OF | -0.42*** | -0.60*** | -0.49*** | -0.17 | -4.67*** | -3.77*** | -5.01*** | -5.73*** |
| | (0.09) | (0.14) | (0.12) | (0.12) | (0.85) | (0.97) | (1.36) | (1.35) |
| Constant | -0.01 | -0.03 | 0.13 | -0.13 | -0.19 | -0.27 | 0.51 | -0.39 |
| | (0.09) | (0.14) | (0.14) | (0.16) | (0.49) | (0.52) | (0.90) | (0.66) |
| Observations | 1,453 | 667 | 391 | 395 | 4,105 | 1,921 | 821 | 1,363 |
| R-squared | 0.04 | 0.10 | 0.13 | 0.03 | 0.10 | 0.12 | 0.05 | 0.12 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Note: This table presents the results of regressing order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on 1-week Libor rates. Standardized order flow $OF$ is measuring the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and FX spot rates with close at 5 pm London time. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, and the USD Trade weighted exchange rate. The full sample runs from 1 January 2005 to 1 September 2017 and is split into pre and post 2008. Data is daily. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table 4: Price impact of order flow; funding constraints and quarter-ends

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | |
| | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ |
| OF | -0.42*** | -0.66*** | -0.46*** | -0.12 | -1.27** | -1.30** | -3.60** | 0.02 |
| | (0.10) | (0.15) | (0.13) | (0.13) | (0.58) | (0.51) | (1.68) | (0.77) |
| Qend $\times OF$ | 0.05 | 0.62 | 0.11 | -0.60* | -10.99*** | -3.03 | -14.35* | -20.86*** |
| | (0.23) | (0.42) | (0.42) | (0.32) | (4.19) | (3.20) | (8.63) | (7.82) |
| OF $\times \mathrm{D}_{fundinghet}$ | | | | | -5.57*** | -5.25** | -0.29 | -8.15*** |
| | | | | | (1.92) | (2.35) | (2.48) | (2.16) |
| Constant | 0.05 | -0.01 | 0.19 | -0.03 | 0.37 | 0.33 | 2.02** | -0.20 |
| | (0.09) | (0.14) | (0.14) | (0.15) | (0.34) | (0.33) | (0.79) | (0.57) |
| Observations | 1,453 | 667 | 391 | 395 | 4,105 | 1,921 | 821 | 1,363 |
| R-squared | 0.04 | 0.11 | 0.17 | 0.11 | 0.13 | 0.14 | 0.09 | 0.21 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | No | No | No | No | Yes | Yes | Yes | Yes |

*Note: This table presents the results of regressing order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on 1-week Libor rates. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and the FX spot rates with close at 5 pm London time.* $D_{FundingHet}$ *is a dummy variable that takes the value 1 when the daily dispersion in individual panel bank's 3-month Libor quotes is among the 25 per cent largest values, and zero otherwise. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD Trade weighted exchange rate. Additionally, the following variables are included in the regression specification but not shown in the Table; Qend and* $D_{FundingHet}$*. Data is daily. The sample runs from 1 January 2005 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table 5: Price impact of order flow; direction of flow

| | (1) $\Delta CIP_{panel}$ | (2) $\Delta CIP_{eur}$ | (3) $\Delta CIP_{chf}$ | (4) $\Delta CIP_{jpy}$ | (5) $\Delta CIP_{panel}$ | (6) $\Delta CIP_{panel}$ |
|---|---|---|---|---|---|---|
| OF × $\mathbb{1}[OF > 0]$ | -0.45 | -1.10 | -0.32 | 0.23 | -0.50** | -2.17* |
| | (0.32) | (0.69) | (0.28) | (0.55) | (0.21) | (1.12) |
| OF × $\mathbb{1}[OF < 0]$ | 0.14 | -0.26 | -0.43 | 1.25* | -0.34* | -0.44 |
| | (0.39) | (0.50) | (0.36) | (0.72) | (0.17) | (1.17) |
| OF × $\mathbb{1}[OF > 0]$ × post2008 | -6.12*** | -6.09** | -4.51 | -6.61** | | |
| | (2.08) | (2.69) | (3.15) | (2.90) | | |
| OF × $\mathbb{1}[OF < 0]$ × post2008 | -3.06* | -0.75 | -4.82* | -6.39 | | |
| | (1.65) | (1.24) | (2.78) | (3.95) | | |
| OF × $\mathbb{1}[OF > 0]$ × Qend | | | | | 0.12 | -6.31 |
| | | | | | (0.42) | (6.70) |
| OF × $\mathbb{1}[OF < 0]$ × Qend | | | | | -0.01 | -16.22 |
| | | | | | (0.41) | (10.06) |
| OF × $\mathbb{1}[OF > 0]$ × $D_{FundingHet}$ | | | | | | -7.51* |
| | | | | | | (4.40) |
| OF × $\mathbb{1}[OF < 0]$ × $D_{FundingHet}$ | | | | | | -3.56 |
| | | | | | | (3.03) |
| Constant | 0.06 | 0.07 | -0.02 | 0.11 | 0.11 | 1.01 |
| | (0.28) | (0.41) | (0.38) | (0.46) | (0.15) | (0.66) |
| Observations | 5,558 | 2,588 | 1,212 | 1,758 | 1,453 | 4,105 |
| R-squared | 0.09 | 0.11 | 0.05 | 0.12 | 0.04 | 0.14 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | | | | | No | Yes |

*Note: This table presents the results of regressing order flow for 1 week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Standardized order flow $OF$ measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and FX spot rates with close at 5 pm London time. $\mathbb{1}[OF > 0]$ takes the order flow value if the order flow is positive, zero otherwise. Positive order flow implies a pressure to obtain USD spot and sell USD forward (i.e. borrow USD). $\mathbb{1}[OF < 0]$ takes the order flow value if the order flow is negative, zero otherwise. $D_{FundingHet}$ is a dummy variable that takes the value 1 when the daily dispersion in individual panel bank's 3-month Libor quotes is among the 25 per cent largest values, and zero otherwise. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Post 2008 is a dummy that takes the value 1 after 1 January 2008, and zero otherwise. The table only shows the relevant coefficients. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD Trade weighted exchange rate. Additionally, the dummies for $D_{FundingHet}$, Qend and Post2008 are included, but not shown. Data is daily. The sample runs from 1 January 2005 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table 6: Bid/ask spreads

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | Post 2008 | | | | | |
| | EUR | CHF | JPY | EUR | CHF | JPY | EUR | CHF | JPY |
| $D_{FundingHet}$ | 0.02 | 14.05*** | 2.21** | 10.95*** | 5.07*** | 13.39*** | 12.93*** | 4.21*** | 14.21*** |
| | (0.19) | (2.08) | (1.09) | (0.95) | (0.89) | (1.13) | (1.08) | (1.04) | (1.33) |
| Qend | 0.01 | -0.41 | 0.27 | 3.64*** | 3.59** | 4.81** | 2.75* | 0.74 | 3.28 |
| | (0.05) | (0.53) | (0.34) | (1.33) | (1.70) | (1.91) | (1.67) | (1.48) | (2.47) |
| post2015 | | | | | | | -8.18*** | 2.81*** | -3.68*** |
| | | | | | | | (0.76) | (1.04) | (0.91) |
| post2015 × Qend | | | | | | | 3.03 | 10.97** | 5.76* |
| | | | | | | | (2.36) | (4.92) | (3.11) |
| Constant | 2.51*** | 9.56*** | 4.52*** | 5.61*** | 16.54*** | 6.11*** | 7.21*** | 16.05*** | 6.86*** |
| | (0.01) | (0.15) | (0.07) | (0.18) | (0.42) | (0.19) | (0.25) | (0.40) | (0.27) |
| Observations | 756 | 745 | 691 | 2,434 | 2,437 | 2,438 | 2,434 | 2,437 | 2,438 |
| R-squared | 0.00 | 0.12 | 0.02 | 0.10 | 0.02 | 0.10 | 0.14 | 0.03 | 0.11 |

*Note: This table presents the results of regressing bid/ask spreads for 1-week FX swap quotes based on high frequency data from Thomson Reuters Tick History database on dummies for Funding Heterogeneity ($D_{FundingHet}$) and dates when the 1 week contract crosses quarter-ends (Qends) for three currency pairs (EUR/USD, CHF/USD and JPY/USD). Column (1) to (3) depict the results from a sample that runs from 1 January 2005 to 31 December 2007, while column (4) to (6) are based on a sample period that runs from 1 January 2008 to 1 September 2017. In column (7) to (9) the interaction terms between a dummy that takes the value 1 from January 1, 2005 and onwards (zero otherwise) and funding heterogeneity and quarter-ends are added. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses.*

Table 7: Price impact of order flow; bid/ask spreads

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Bid-ask spreads | | | |
| | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ |
| OF | -0.34 | -1.18*** | 0.16 | 0.17 |
| | (0.43) | (0.43) | (0.85) | (0.71) |
| OF $\times D_{spread}$ | -5.94*** | -4.01** | -7.32*** | -7.34*** |
| | (1.23) | (1.79) | (2.46) | (1.83) |
| Qend | -5.41** | -5.20* | -8.59* | -2.78 |
| | (2.57) | (2.87) | (4.87) | (5.07) |
| OF $\times Qend$ | -11.26*** | -3.26 | -15.15* | -20.83*** |
| | (4.12) | (3.23) | (8.09) | (8.03) |
| Constant | 0.54** | 0.53* | 1.33** | 0.21 |
| | (0.24) | (0.27) | (0.57) | (0.45) |
| Observations | 4,106 | 1,922 | 821 | 1,363 |
| R-squared | 0.14 | 0.13 | 0.11 | 0.20 |
| Controls | Yes | Yes | Yes | Yes |
| Post2008 | Yes | Yes | Yes | Yes |

*Note: This table presents the results of regressing order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Standardized order flow $OF$ measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using Thomson Reuters Tick History quotes on 1-week spot and forward rates with close at 5 pm London time. $D_{spread}$ is a dummy variable that takes the value 1 when the daily forward rate bid-ask spread is among the 25 per cent largest values, and zero otherwise. $D_{vol}$ is a dummy variable that takes the value 1 when the daily intra-day volatility of the forward rate is among the 25 per cent largest values, and zero otherwise. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Data is daily. The sample runs from 1 January 2008 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. Standard errors for the panel specification is clustered at the time level. White heteroscedasticity-robust standard errors are reported in parentheses.*

Table 8: Effect on order flow: swap lines

| | (1) $OF_{panel}$ | (2) $OF_{eur}$ | (3) $OF_{chf}$ | (4) $OF_{jpy}$ |
|---|---|---|---|---|
| $D_{swapline}$ | -0.23** | -0.26* | -0.07 | -0.51* |
| | (0.10) | (0.13) | (0.18) | (0.27) |
| Constant | 0.01 | -0.13* | 0.25*** | 0.08 |
| | (0.05) | (0.08) | (0.09) | (0.07) |
| Observations | 1,099 | 473 | 253 | 373 |
| R-squared | 0.03 | 0.06 | 0.02 | 0.05 |
| Controls | Yes | Yes | Yes | Yes |

*Note: This table illustrates the impact of quarter-end on 1-week order flow. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps.* $D_{swapline}$ *is a dummy variable that takes the value 1 on days when there was initial take up in any of the swap lines between the Fed and foreign central banks, zero otherwise. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Data is daily. The sample runs from 1 January 2008 to 31 December 2009. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specification is clustered at the time level.*

Table 9: Price adjustment quarter-end for EUR/USD, CHF/USD and JPY/USD

| | EUR/USD | | | | CHF/USD | | | | JPY/USD | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | 2005-2007 | 2008-2012 | 2013-2014 | 2015-2017 | 2005-2007 | 2008-2012 | 2013-2014 | 2015-2017 | 2005-2007 | 2008-2012 | 2013-2014 | 2015-2017 |
| -5 | 0.1 | 0.2 | 0.0 | 0.1 | 0.1 | 0.4 | 0.0 | 0.1 | -0.1 | -0.9 | -0.4 | -0.1 |
| -4 | 0.1 | 0.7 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | -0.1 | -0.2 | 0.5 | -0.4 | 0.0 |
| -3 | 0.0 | 0.7 | 0.0 | 0.1 | 0.4 | -0.7 | 0.0 | -0.2 | -0.7 | 1.2 | 0.0 | 0.0 |
| -2 | 0.1 | -0.2 | 0.5 | 0.2 | -0.2 | 0.6 | 1.3 | 0.0 | -0.1 | 1.8 | 0.1 | 8.0 |
| -1 | -0.1 | -1.3 | 1.9 | 3.3 | 1.0 | -1.5 | 1.2 | 10.7 | 1.2 | 1.2 | 1.4 | 18.4 |
| **0** | **0.1** | **1.6** | **-2.4** | **40.1** | **-2.3** | **1.4** | **-1.9** | **15.7** | **11.5** | **0.1** | **26.9** | **59.4** |
| 1 | 1.8 | -0.8 | -0.9 | 0.2 | -0.1 | 1.1 | 0.4 | 23.0 | -2.1 | 8.5 | -0.7 | 62.7 |
| 2 | 0.1 | 1.8 | -0.3 | 0.3 | 0.8 | 1.2 | 0.4 | 9.5 | -0.8 | 7.8 | 1.9 | 2.5 |
| 3 | 0.4 | 0.3 | -0.1 | -0.1 | 0.3 | -0.8 | -0.8 | 1.5 | 0.0 | -8.1 | 0.2 | 1.7 |
| 4 | 0.1 | 0.0 | -0.2 | -0.5 | -0.5 | 0.1 | 0.5 | 0.2 | -0.3 | -11.0 | 0.7 | -3.1 |
| 5 | -0.3 | -0.5 | 0.1 | -0.9 | 0.0 | 2.2 | -0.4 | -1.5 | 0.0 | -4.8 | 0.7 | 2.2 |

*Note: This table illustrates the hourly change in the FX swapped (synthetic) USD rate calculated from Libor from 5 hours before to 5 hours after the 1-week FX swap contract matures after quarter-end. 0 denotes the hour when the contract first matures after quarter-end. The numbers are in basis points and represent the average of all quarter-ends within the sample period. Data is obtained from Thomson Reuters Tick History quotes. The sample period runs from 1 January 2005 to 1 September 2017.*

Table 10: Effect on order flow: quarter-ends

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | | |
| | $OF_{panel}$ | $OF_{eur}$ | $OF_{chf}$ | $OF_{jpy}$ | $OF_{panel}$ | $OF_{eur}$ | $OF_{chf}$ | $OF_{jpy}$ | $OF_{panel}$ |
| Qend | 0.12 | -0.03 | 0.64*** | -0.24 | 0.15** | 0.15* | 0.22** | 0.11 | 0.16** |
| | (0.10) | (0.15) | (0.19) | (0.21) | (0.06) | (0.09) | (0.10) | (0.10) | (0.07) |
| post2015 | | | | | | | | | 0.01 |
| | | | | | | | | | (0.04) |
| post2015 × Qend | | | | | | | | | -0.03 |
| | | | | | | | | | (0.12) |
| Constant | 0.05* | -0.04 | 0.15*** | 0.10** | 0.03 | -0.04* | 0.18*** | 0.03 | 0.02 |
| | (0.03) | (0.04) | (0.05) | (0.05) | (0.02) | (0.02) | (0.04) | (0.03) | (0.02) |
| Observations | 1,534 | 697 | 409 | 428 | 4,120 | 1,924 | 826 | 1,370 | 4,120 |
| R-squared | 0.01 | 0.01 | 0.05 | 0.06 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Note: This table illustrates the impact of quarter-end on 1-week order flow. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end, zero otherwise. Post2015 is a dummy variable that is 1 from 1 January 2015, zero otherwise. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Data is daily. The sample runs from 1 January 2008 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table 11: Effect on order flow: monetary policy surprises

| | (1) $OF_{panel}$ | (2) $OF_{eur}$ | (3) $OF_{chf}$ | (4) $OF_{jpy}$ |
|---|---|---|---|---|
| $\Delta_{ois}$ | -1.92 | -3.51 | -1.29 | 1.91 |
| | (1.70) | (3.33) | (3.40) | (9.04) |
| Constant | -0.12** | -0.14* | -0.34 | -0.07 |
| | (0.06) | (0.08) | (0.22) | (0.10) |
| Observations | 243 | 117 | 26 | 100 |
| R-squared | 0.05 | 0.03 | 0.13 | 0.07 |
| Controls | Yes | Yes | Yes | Yes |

*Note: This table illustrates the impact of monetary policy surprises on 1-week order flow. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. $\Delta OIS$ is the 30 min change in the 1-month OIS rate (Overnight Index Swaps - a proxy for the risk-free rate) in the respective currency around the central bank policy announcement. Monetary policy announcements in EUR, CHF, JPY and USD are considered. In the case of US announcements the sign of the change in the OIS is switched so that a positive change in the OIS always proxy an increase in the interest rate differential towards the US (i.e foreign currency rate minus the US rate). Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Data is daily. The sample runs from January 1, 2008 to September 1, 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specification is clustered at the time level.*

*Supplementary Internet Appendix to accompany*

# Price-setting in the Foreign Exchange Swap Market: Evidence from Order Flow

(Not for publication)

## A.1 FX swap and order flow

We collect FX swap data from the Thomson Reuters D3000-2 database with the following tickers: EURSW=D3, CHFSW=D3 and JPYSW=D3. The data is based on high frequency data from an electronic limit order book where each actual trade is marked and signed as either buy or sell. We only collect data for 1-week FX swaps between EUR, CHF and JPY against USD. If the sign indicates buying USD on the spot leg of the FX swap transaction the trade is allocated +1, and -1 otherwise. To create the order flow measure, the counts are summarized over the calendar date.

We use the tickers EURSW=, CHFSW= and JPYSW= from Thomson Reuters Tick History to obtain high frequency 1-week FX swap data (quotes). We use hourly data by taking the last hourly observation. The measure of CIP deviations is calculated by using the last observation the preceding hour at 5 pm London time, the FX spot rate at the same time, the exact number of trading days for the 1-week FX swap from Thomson Reuters and the 1-week Libor rates for each currency. The bid/ask spreads are calculated as the daily average over the trading day from hourly bid and ask prices. Daily data on the 1-week and 3-month Libor, the VIX-index, OIS-rates and the USD trade weighted exchange rate are sourced from Bloomberg.

## A.2 Rolling Regressions of Price Impact

### A.2.1 Rolling regressions show structural break in 2008

Evidence for price impact variation over time is estimated using a method of rolling regressions. We present the results in Figure IA.1. We plot the price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. We use a series of controls based on the baseline specification (exchange rate, VIX, Libor-OIS spread) and quarter-end periods. A rolling window of 180 days is used in the baseline specification. The price impact estimates show a structural break; with insignificant estimates in the pre-2008 period, that becomes persistently significant during the post-2008 period.

### A.2.2 Rolling regressions sorted on funding cost dispersion: bid/ask spreads

We estimate rolling regressions sorted on the variables that govern price impact, which include the dispersion of LIBOR quotes and bid/ask spreads. We outline the general steps of our procedure, with respect to a sorting variable $Z_t$.[37]

1. Create a dataset $DS_t$ which includes the sorting variable $Z_t$, the daily change in CIP deviations $\Delta CIP_t$, order flow $OF_t$ and control variables $X_t$, which includes daily changes in the VIX, trade weighted exchange rate, and Libor-OIS spreads. $DS_t = [Z_t, \Delta CIP_t, OF_t, X_t]$

2. Re-sort observations by $j = 1, 2, ..., N$, in ascending order of the sorting variable $Z$, $Z_1 < Z_2 < .... < Z_N$.

3. Re-sort observations of $\Delta CIP_t$, $OF$ and control variables according to $j = 1, 2, ..., N$. The new dataset $DS_j$ is now sorted in ascending order of the sorting variable $Z_j$.

4. Run order flow specification $\Delta CIP_j = \alpha + \beta OF_j + X_j + \epsilon_j$, with a rolling window of 180 periods ($[k, k + 180]$, where $k = 1, 2, ..., N - 180$)

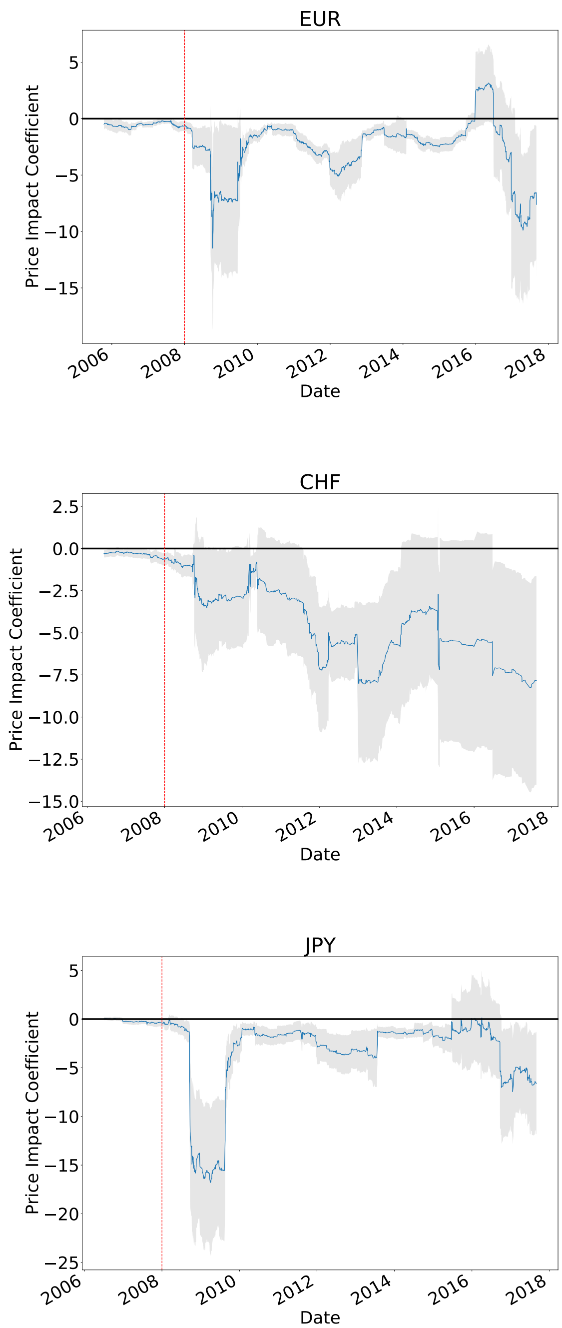
Following the procedure, we first sort the data set in ascending order of dispersion in Libor quotes. Price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. We use a series of controls based on the baseline specification

[37] The procedure is based on Payne (2003), which uses a VAR structure to study the impact of order flow on quote revisions in the spot foreign exchange market. In the paper, a VAR including order flow and spot quotes is sorted on variables that measure market liquidity (eg. trading volume). The procedure was then used to show how the price impact of trades changes across low and high volume states.

(exchange rate, VIX, Libor-OIS spreads) and quarter-end periods. A rolling window of 180 days is used in the baseline specification.

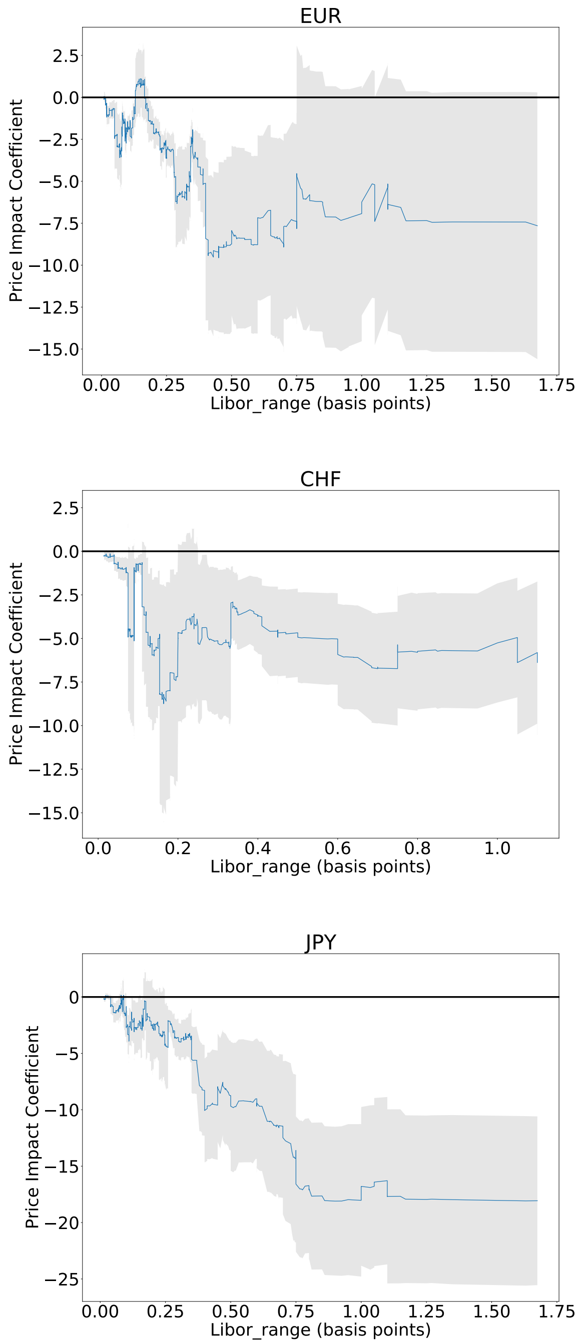
We present the results for price impact variation for Libor quotes and bid-ask spreads in Figures IA.2 and IA.3. We plot the price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. We use a series of controls based on the baseline specification (exchange rate, VIX, Libor-ois spreads) and quarter-end periods. A rolling window of 180 days is used in the baseline specification. Consistent with our theory of increased price impact due to constraints in USD funding to arbitrage trades, the price impact estimates increase continuously from periods of small to large dispersion in funding costs, from periods of small to large bid/ask spread, and from periods of low to high volatility of the forward rate. In summary, the analysis confirms that the price impact of order flow is confined to periods of high dispersion in Libor quotes, bid/ask spreads.

Figure IA.1: Rolling regressions plot of price impact coefficients over time. Red dotted line indicates the post-2008 period.



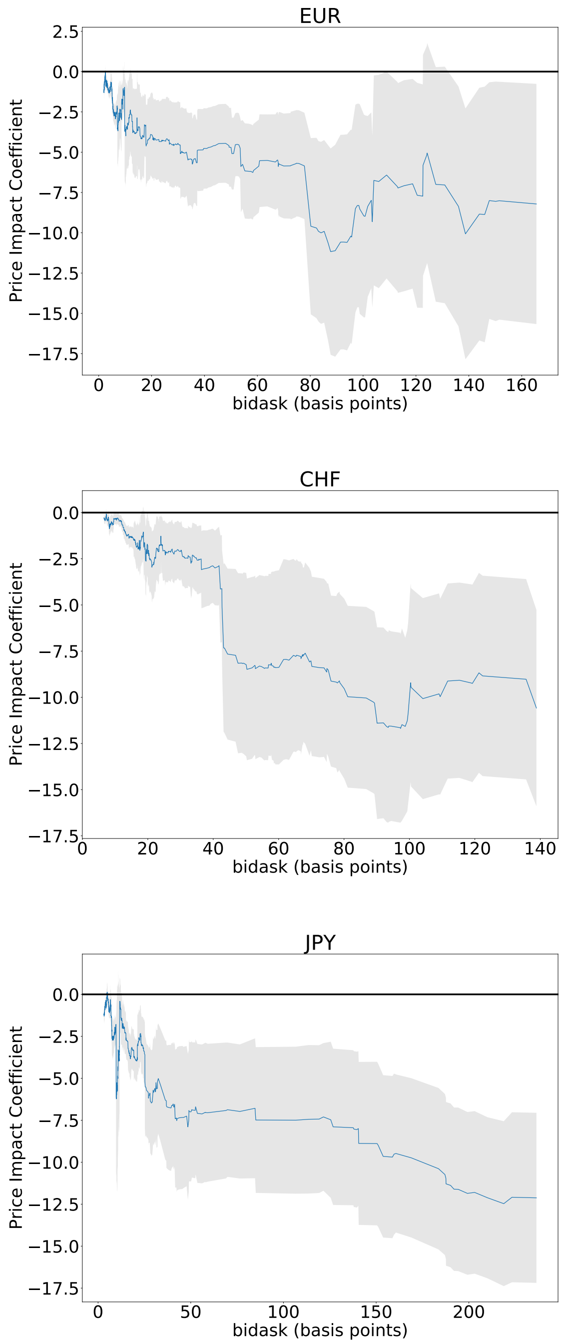

*Note: This figure plots the price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Rolling regressions are estimated using a window of 180 days. Red dotted line for 1 January 2008 divides time periods into pre-2008 and post-2008. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate, and a dummy for periods when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Gray area denotes 90% confidence interval using White heteroscedasticity-robust standard errors.*

Figure IA.2: Rolling regressions sorted on the range of LIBOR quotes: plot of price impact coefficients




*Note: This figure plots the price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Rolling regressions are estimated using a window of 180 days. Data is sorted in ascending order by funding heterogeneity, which measures daily dispersion in individual panel banks 3-month Libor quotes. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate, and a dummy for periods when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Gray area denotes 90% confidence interval using White heteroscedasticity-robust standard errors.*

Figure IA.3: Rolling regressions sorted on bid-ask spreads: plot of price impact coefficients




*Note: This figure plots the price impact coefficients of rolling regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Rolling regressions are estimated using a window of 180 days. Data is sorted in ascending order by bid-ask spreads. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD Trade weighted exchange rate, and a dummy for periods when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Gray area denotes 90% confidence interval using White heteroscedasticity-robust standard errors.*

## A.3 Price Impact of Order Flow: Swap Lines and Monetary Policy Announcements

### A.3.1 Swap lines

To test the effect of central bank swap lines on price impact, we run the following regression specification in equation (IA.1). $D_{swapline}$ is a dummy variable that takes the value 1 on days when there was settlement of any swap lines between the Fed and foreign central banks, zero otherwise. We restrict our sample to the period of swap lines in 2008 and 2009, and use a series of controls based on the baseline specification (exchange rate, VIX, Libor-OIS spreads) and quarter-end periods. The interaction of the dummy variable with order flow measures the extent to which price impact fundamentally changes due to the provision of swap lines.

$$\Delta CIP_t = \alpha + \beta_1 OF_t + \beta_2 OF_t \times D_{Swapline,t} + \beta_j x_{j,t} + \epsilon_t \qquad \text{(IA.1)}$$

Table IA.I presents the results. Columns (1) to (4) present our baseline results. For our panel specification, we find that the price impact of order flow is 6.6 basis points, and is higher than our post-2008 estimate of 5 basis points. However the additional price impact due to swap lines captured by the interaction of order flow with $D_{swapline}$ is insignificant. Individual currency pairs in columns (2), (3) and (4) also find an attenuation of the price impact coefficient on days with central bank swap lines. In columns (5) to (8), we account for additional variables that govern price impact, where $D_{FundingHet}$ and $Qend$ represent dummy variables for funding cost heterogeneity and quarter-ends respectively. We find quantitatively that the time variation in price impact during the period of swap lines is explained by funding heterogeneity and quarter-end periods. In the panel specification, the price impact estimate due to quarter-ends is -12.5 basis points, and on days with high funding cost dispersion we estimate a -6.8 basis point change in funding costs. Examining individual currency pairs, the price impact explained by these factors is strongest for JPY/USD.

The net price impact due to swap lines, which is the sum of coefficients $\beta_1$ and $\beta_2$, is reported in Table IA.I.[38] The price impact is attenuated during the period of swap lines. To explain this results, we note that swap lines in 2008 and 2009 correspond to a period of excess volatility in the FX swap market, with dealers pricing FX swaps due to high counterparty risk. For example, our results in Internet Appendix A.2 on rolling regressions show that there is considerable dispersion in price impact during this period for all pairs.

[38] Specifically the row that is titled $Swapline_{PriceImpact}$

Second, we hypothesize that swap lines relax arbitrage constraints for market participants. This would reduce price impact as dealers do not need to adjust forward rates as much to elicit the necessary supply of USD by arbitrageurs. Third, we note that after accounting for quarter-end periods and periods of high funding dispersion in columns (5) to (8), the price impact of order flow is insignificant for all currency pairs, suggesting these factors dominate the explanation of time-variation in price impact during this period.

### A.3.2 Monetary policy announcements

We repeat the exercise for scheduled monetary policy announcements. We run the following regression specification in equation (IA.2). $D_{MP}$ is a dummy variable that takes the value 1 on days when there was a scheduled monetary policy announcement of the central banks of the ECB, BOJ and SNB, and zero otherwise.[39] We use a series of controls based on the baseline specification (exchange rate, VIX, Libor-OIS spreads) and quarter-end periods. We consider only the post-2008 period. The interaction of the dummy variable with order flow measures the extent to which price impact fundamentally changes due to scheduled monetary announcements.

$$\Delta CIP_t = \alpha + \beta_1 OF_t + \beta_2 OF_t \times D_{MP,t} + \beta_j x_{j,t} + \epsilon_t \tag{IA.2}$$

Table IA.II presents the results. Columns (1) to (4) present our baseline results for the post-2008 period. For our panel specification, we find that the price impact of order flow is 4.7 basis points. The additional price impact due to monetary policy announcements captured by the interaction of order flow with $D_{MP}$ is insignificant. The results are robust to adding quarter-ends and funding dispersion in columns (5) to (8). The net price impact due to monetary policy announcements, which is the sum of coefficients $\beta_1$ and $\beta_2$, is also reported. The price impact is attenuated during days of scheduled monetary policy announcements. This is intuitive as monetary policy announcements are public information, dealers reset prices contemporaneously and not through order flow during these periods.

[39] For the EUR/USD pair we use ECB announcements, for the JPY/USD pair we use BOJ announcements, and for the CHF/USD pair we use SNB announcements.

Table IA.I: Price impact of order flow: swap lines

| | (1) $\Delta CIP_{panel}$ | (2) $\Delta CIP_{eur}$ | (3) $\Delta CIP_{chf}$ | (4) $\Delta CIP_{jpy}$ | (5) $\Delta CIP_{panel}$ | (6) $\Delta CIP_{eur}$ | (7) $\Delta CIP_{chf}$ | (8) $\Delta CIP_{jpy}$ |
|---|---|---|---|---|---|---|---|---|
| OF | -6.55*** | -5.26* | -1.32* | -10.23*** | -1.60** | -3.35* | -1.05 | 0.25 |
| | (1.86) | (2.78) | (0.76) | (3.27) | (0.81) | (1.77) | (0.88) | (1.02) |
| OF $\times D_{swapline}$ | 1.43 | 0.59 | -4.89 | 5.27 | 4.92 | 6.09 | -5.10 | 6.44 |
| | (3.47) | (4.66) | (4.86) | (4.35) | (3.79) | (6.93) | (4.72) | (4.69) |
| OF $\times D_{fundinghet}$ | | | | | -9.46*** | -9.25 | -0.77 | -12.68*** |
| | | | | | (2.87) | (6.15) | (1.74) | (4.08) |
| OF $\times Qend$ | | | | | -13.20* | 2.51 | 12.70 | -27.33*** |
| | | | | | (7.63) | (5.46) | (10.24) | (8.43) |
| Constant | 0.15 | -0.87 | 1.01 | -0.18 | -0.41 | -0.56 | 0.42 | -1.52* |
| | (0.87) | (1.41) | (1.13) | (1.59) | (0.56) | (1.08) | (0.96) | (0.81) |
| Observations | 1,098 | 472 | 253 | 373 | 1,098 | 472 | 253 | 373 |
| R-squared | 0.14 | 0.14 | 0.05 | 0.28 | 0.18 | 0.16 | 0.06 | 0.47 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Price impact$_{Swapline}$ | -5.12* | -4.67 | -6.20 | -4.96 | 3.32 | 2.74 | -6.15 | 6.69 |
| | (2.74) | (3.33) | (4.78) | (3.15) | (3.46) | (5.66) | (4.53) | (4.52) |

*Note: This table presents regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Standardized order flow $OF$ measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week spot and forward rates with close at 5 pm London time. $D_{swapline}$ is a dummy variable that takes the value 1 on days when there was settlement of any swap lines between the Fed and foreign central banks, zero otherwise. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD Trade weighted exchange rate, $D_{FundingHet}$, OF*$D_{FundingHet}$, Qend, Qend*OF. Data is daily. The sample runs from 1 January 2008 to 31 December 2009. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. For the panel specifications they are clustered at the time level.*

Table IA.II: Price impact of order flow: monetary policy announcements

| | (1) $\Delta CIP_{panel}$ | (2) $\Delta CIP_{eur}$ | (3) $\Delta CIP_{chf}$ | (4) $\Delta CIP_{jpy}$ | (5) $\Delta CIP_{panel}$ | (6) $\Delta CIP_{eur}$ | (7) $\Delta CIP_{chf}$ | (8) $\Delta CIP_{jpy}$ |
|---|---|---|---|---|---|---|---|---|
| OF | -4.61*** | -3.87*** | -5.13*** | -5.39*** | -1.17* | -1.37*** | -3.77** | 0.35 |
| | (0.71) | (1.00) | (1.38) | (1.39) | (0.60) | (0.53) | (1.72) | (0.89) |
| OF $\times D_{MP}$ | -2.92 | 4.04 | 4.90** | -8.11 | -3.43 | 3.17 | 4.52* | -8.00 |
| | (5.53) | (2.93) | (2.44) | (9.65) | (4.80) | (2.98) | (2.56) | (7.34) |
| OF $\times D_{fundinghet}$ | | | | | -5.57*** | -5.24** | -0.14 | -8.11*** |
| | | | | | (1.54) | (2.35) | (2.50) | (2.15) |
| OF $\times Qend$ | | | | | -11.03*** | -2.95 | -14.23 | -20.86*** |
| | | | | | (4.11) | (3.22) | (8.65) | (7.79) |
| Constant | -0.17 | -0.38 | 0.64 | -0.25 | 0.38 | 0.24 | 2.18*** | -0.16 |
| | (0.38) | (0.55) | (0.92) | (0.67) | (0.31) | (0.35) | (0.81) | (0.61) |
| Observations | 4,079 | 1,895 | 821 | 1,363 | 4,079 | 1,895 | 821 | 1,363 |
| R-squared | 0.10 | 0.12 | 0.05 | 0.13 | 0.13 | 0.14 | 0.09 | 0.21 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Price impact$_{MP}$ | -7.53 | 0.18 | -0.22 | -13.50 | -4.61 | 1.79 | 0.75 | -7.65 |
| | (5.47) | (2.71) | (1.94) | (9.42) | (4.59) | (2.88) | (2.04) | (6.89) |

*Note: This table presents regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Standardized order flow $OF$ measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week spot and forward rates with close at 5 pm London time. MP is a dummy variable that takes the value 1 on days when the central bank disseminates its monetary policy decision, and zero otherwise. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate, $D_{FundingHet}$, OF*$D_{FundingHet}$, Qend, Qend*OF. Data is daily. The sample runs from 1 January 2008 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. For the panel specifications they are clustered at the time level.*

## A.4 Additional Tables

Table IA.III, IA.IV and IA.V replicate table 3, 4 and 5 using an un-trimmed measure of CIP deviations. Table IA.VI is identical to table 10 except that the quarter-end dummy is split between the first day when the contract crosses quarter ends (QendFirstDay) and the remaining days when the contract crosses quarter ends (QendRest).

Table IA.III: Price impact of order flow before and after the GFC

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | |
| | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ |
| OF | -0.19 | -0.42** | -0.63 | 0.10 | -4.67*** | -3.77*** | -5.01*** | -5.73*** |
| | (0.41) | (0.19) | (0.59) | (1.21) | (0.85) | (0.97) | (1.36) | (1.35) |
| Constant | -0.04 | -0.12 | 0.40 | -0.28 | -0.18 | -0.26 | 0.51 | -0.39 |
| | (0.36) | (0.24) | (0.78) | (0.95) | (0.49) | (0.52) | (0.90) | (0.66) |
| Observations | 1,523 | 686 | 409 | 428 | 4,106 | 1,922 | 821 | 1,363 |
| R-squared | 0.00 | 0.03 | 0.01 | 0.01 | 0.10 | 0.12 | 0.05 | 0.12 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Note: This table presents regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on 1-week Libor rates. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and FX spot rates with close at 5 pm London time. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, and the USD trade weighted exchange rate. The full sample runs from 1 January 2005 to 1 September 2017 and is split into pre and post 2008. Data is daily. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table IA.IV: Price impact of order flow: funding constraints and quarter-ends

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | |
| | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ | $\Delta CIP_{panel}$ | $\Delta CIP_{eur}$ | $\Delta CIP_{chf}$ | $\Delta CIP_{jpy}$ |
| OF | -0.50 | -0.45** | -0.73 | -0.72 | -1.27** | -1.30** | -3.60** | 0.02 |
| | (0.41) | (0.20) | (0.63) | (1.14) | (0.58) | (0.51) | (1.68) | (0.77) |
| Qend $\times OF$ | 2.35 | 0.33 | 0.50 | 4.90 | -11.00*** | -3.03 | -14.35* | -20.86*** |
| | (1.67) | (0.44) | (0.75) | (4.67) | (4.19) | (3.20) | (8.63) | (7.82) |
| OF $\times D_{fundinghet}$ | | | | | -5.57*** | -5.24** | -0.29 | -8.15*** |
| | | | | | (1.92) | (2.35) | (2.48) | (2.16) |
| Constant | 0.06 | -0.07 | 0.35 | 0.08 | 0.38 | 0.33 | 2.02** | -0.20 |
| | (0.35) | (0.25) | (0.82) | (0.88) | (0.34) | (0.33) | (0.79) | (0.57) |
| Observations | 1,523 | 686 | 409 | 428 | 4,106 | 1,922 | 821 | 1,363 |
| R-squared | 0.01 | 0.03 | 0.01 | 0.02 | 0.13 | 0.14 | 0.09 | 0.21 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | No | No | No | No | Yes | Yes | Yes | Yes |

*Note: This table presents regressions of order flow for 1-week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on 1-week Libor rates. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and the FX spot rates with close at 5 pm London time.* $D_{FundingHet}$ *is a dummy variable that takes the value 1 when the daily dispersion in individual panel bank's 3-month Libor quotes is among the 25 per cent largest values, and zero otherwise. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Additionally, the following variables are included in the regression specification but not shown in the Table; Qend and* $D_{FundingHet}$*. Data is daily. The sample runs from 1 January 2005 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table IA.V: Price impact of order flow: direction of flow

| | (1) $\Delta CIP_{panel}$ | (2) $\Delta CIP_{eur}$ | (3) $\Delta CIP_{chf}$ | (4) $\Delta CIP_{jpy}$ | (5) $\Delta CIP_{panel}$ | (6) $\Delta CIP_{panel}$ |
|---|---|---|---|---|---|---|
| OF × $\mathbb{1}[OF < 0]$ | 0.44 | -0.02 | 0.15 | 1.13 | 0.21 | -0.44 |
| | (0.58) | (0.53) | (1.16) | (1.31) | (0.56) | (1.17) |
| OF × $\mathbb{1}[OF > 0]$ | -0.23 | -1.21* | -0.89 | 1.62 | -1.16 | -2.17* |
| | (0.85) | (0.70) | (0.63) | (2.91) | (0.77) | (1.12) |
| OF × $\mathbb{1}[OF < 0]$ × post2008 | -3.45** | -1.07 | -5.40* | -6.41 | | |
| | (1.71) | (1.23) | (2.99) | (4.15) | | |
| OF × $\mathbb{1}[OF > 0]$ × post2008 | -6.37*** | -5.97** | -3.96 | -8.12* | | |
| | (2.26) | (2.68) | (3.20) | (4.16) | | |
| OF × $\mathbb{1}[OF > 0]$ × Qend | | | | | 4.82 | -6.31 |
| | | | | | (2.98) | (6.69) |
| OF × $\mathbb{1}[OF < 0]$ × Qend | | | | | -0.40 | -16.22 |
| | | | | | (1.67) | (10.06) |
| OF × $\mathbb{1}[OF > 0]$ × $D_{FundingHet}$ | | | | | | -7.51* |
| | | | | | | (4.40) |
| OF × $\mathbb{1}[OF < 0]$ × $D_{FundingHet}$ | | | | | | -3.56 |
| | | | | | | (3.03) |
| Constant | 0.16 | 0.31 | 0.66 | -0.58 | 0.57 | 1.01 |
| | (0.61) | (0.53) | (0.92) | (1.72) | (0.61) | (0.66) |
| Observations | 5,629 | 2,608 | 1,230 | 1,791 | 1,523 | 4,106 |
| R-squared | 0.08 | 0.10 | 0.05 | 0.08 | 0.01 | 0.14 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Post2008 | | | | | No | Yes |

*Note: This table presents regressions of order flow for 1 week EUR/USD, CHF/USD and JPY/USD FX swaps on daily changes in 1-week CIP deviations based on Libor rates. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. The 1-week CIP deviation is calculated using TR tick history quotes on 1-week forward rates and FX spot rates with close at 5 pm London time.* $\mathbb{1}[OF > 0]$ *takes the order flow value if the order flow is positive, zero otherwise. Positive order flow implies a pressure to obtain USD spot and sell USD forward (i.e. borrow USD).* $\mathbb{1}[OF < 0]$ *takes the order flow value if the order flow is negative, zero otherwise.* $D_{FundingHet}$ *is a dummy variable that takes the value 1 when the daily dispersion in individual panel bank's 3-month Libor quotes is among the 25 per cent largest values, and zero otherwise. Qend is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end and matures after quarter-end. Post 2008 is a dummy that takes the value 1 after January 1, 2008, and zero otherwise. The table only shows the relevant coefficients. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Additionally, the dummies for* $D_{FundingHet}$*, Qend and Post2008 are included, but not shown. Data is daily. The sample runs from 1 January 2005 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level. White heteroscedasticity-robust standard errors are reported in parentheses. Standard errors for the panel specifications are clustered at the time level.*

Table IA.VI: Effect on order flow: quarter-end separation

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| | Pre 2008 | | | | Post 2008 | | | | |
| | $OF_{panel}$ | $OF_{eur}$ | $OF_{chf}$ | $OF_{jpy}$ | $OF_{panel}$ | $OF_{eur}$ | $OF_{chf}$ | $OF_{jpy}$ | $OF_{panel}$ |
| QendFirstDay | 0.21 | -0.16 | 0.37* | 0.37 | 0.36*** | 0.33*** | 0.55*** | 0.27 | 0.39*** |
| | (0.21) | (0.44) | (0.20) | (0.39) | (0.12) | (0.11) | (0.16) | (0.30) | (0.14) |
| QendRest | 0.10 | -0.00 | 0.72*** | -0.35 | 0.10 | 0.11 | 0.15 | 0.07 | 0.10 |
| | (0.11) | (0.15) | (0.23) | (0.23) | (0.07) | (0.11) | (0.12) | (0.09) | (0.09) |
| post2015 | | | | | | | | | 0.01 |
| | | | | | | | | | (0.04) |
| post2015 × QendFirstDay | | | | | | | | | -0.13 |
| | | | | | | | | | (0.30) |
| post2015 × QendRest | | | | | | | | | 0.00 |
| | | | | | | | | (0.13) | |
| Constant | 0.05* | -0.04 | 0.15*** | 0.10** | 0.03 | -0.04* | 0.18*** | 0.03 | 0.02 |
| | (0.03) | (0.04) | (0.05) | (0.05) | (0.02) | (0.02) | (0.04) | (0.03) | (0.02) |
| Observations | 1,534 | 697 | 409 | 428 | 4,120 | 1,924 | 826 | 1,370 | 4,120 |
| R-squared | 0.01 | 0.01 | 0.05 | 0.07 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

*Note: This table illustrates the impact of quarter-end on 1-week order flow. Standardized order flow OF measures the net buyer transactions of swapping EUR, CHF and JPY into USD, and is sourced from TR D3000-2 inter-dealer trades for 1-week FX swaps. QendFirstDay is a dummy variable taking the value 1 when the 1-week contract is settled on the first day prior to quarter-end the matures after quarter-end, zero otherwise. QendRest is a dummy variable taking the value 1 when the 1-week contract is settled prior to quarter-end but matures after quarter-end except the day captured by QendFirstDay, zero otherwise. Post2015 is a dummy variable that is January 1, 2015, zero otherwise. Controls include the changes in USD Libor-OIS spreads for 1-week and 3-month maturities, the VIX index, the USD trade weighted exchange rate. Data is daily. The sample runs from 1 January 2008 to 1 September 2017. *** denotes significance at the 1 percent level, ** at the 5 percent level, and * at the 10 percent level.Standard errors for the panel specifications are clustered at the time level.*