Markups to Financial Intermediation in Foreign Exchange Markets*

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Abstract

On average from 2013 to 2020, foreign asset managers in net sold forward 1.1 trillion US dollars. This forward sale of dollars hedges the currency mismatch of foreign investment in US dollar assets. By accommodating this demand, US and European banks earn an arbitrage spread, a violation of covered interest rate parity. I document evidence that banks exercise market power in the pricing of the dollar forward rate. Prices are asymmetrically sensitive to interest rate spreads and arbitrage spreads increase in response to predictable decreases in competition. When competition is low, arbitrage spreads increase five-fold and US banks earn profits of 48-82 million dollars per week.

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1 Introduction

The foreign exchange derivatives markets are some of the deepest and most liquid financial markets. Prices in these markets are often used as an example of textbook arbitrage, covered interest rate parity (CIP). CIP is the no-arbitrage equivalence between the risk-free rate implied by spot and forward exchange rates and the risk-free rate spread between the two currencies. Recent literature has studied law of one price deviations to CIP.[1] This literature interprets the CIP basis as a bank balance sheet cost to arbitrage in a competitive market. In this paper, I document evidence of markups in the pricing of foreign exchange forwards and swaps. Due to these markups, CIP bases reflect both costs and markups. When competition is low due to a regulatory supply shifter that impacts European banks, US banks earn large markups: on average 70-108 bps and profit 48-82 million US dollars per week.

There are two necessary conditions for CIP deviations to exist: (i) investors need to have a preference for synthetic, rather than direct dollar borrowing and (ii) there is a limit to arbitrage. Synthetic dollar borrowing involves borrowing foreign currency and using foreign exchange (FX) derivatives to swap the foreign borrowing into US dollar funding. This synthetic dollar funding contrasts with directly borrowing US dollars from wholesale funding markets, such as US money market funds (MMFs). Using a novel dataset, I document that foreign asset managers (funds) borrowed on average 1.1 trillion US dollars of synthetic funding for each day from 2013 to 2020. US and European banks take the opposite side of this trade by lending synthetic dollars.[2]

The literature documents that the primary costs to CIP arbitrage are non-risk weighted capital requirements for global banks (Du et al., 2018; Boyarchenko et al., 2020) and dollar funding costs (Andersen et al., 2018; Rime et al., 2017). For a given amount of equity capital,

[1]CIP deviations were first documented by Du et al. (2018) and Rime et al. (2017). For a review of hte literature see Du and Schreger (2021).

[2]This interpretation equating forward sale of dollars and synthetic dollar funding is typical of the literature. Correa et al. (2020) document that US banks hedge their net derivative positions by holding foreign currency reserves at foreign central banks. I observe the derivative positions of banks and funds and infer that these derivative positions hedge US dollar investments, but I do not have direct evidence of US dollar investments by individual banks and funds.

a bank's targeted leverage ratio implies a fixed amount of balance sheet space. Arbitrage utilizes scarce bank balance sheet capacity. Therefore, there is a cost to bank balance sheet space, which I define as an annualized return in excess of the risk-free rate required for the use of a bank's balance sheet. Furthermore, CIP arbitrage requires that banks be able to borrow US dollar funding at near risk-free rates. Credit spreads to unsecured US dollar funding are a cost to CIP arbitrage.

The contribution of this paper is to document that imperfect competition is a limit to arbitrage free prices. Both imperfect competition and costly arbitrage contribute to arbitrage spreads. This 1.1 trillion dollar net demand increases the market clearing forward dollar exchange rate. For G10 currencies, except for the AUD and NZD, forward dollars are too expensive relative to the arbitrage-free price. The synthetic dollar funding rate (forward implied rate plus foreign risk-free rate) is greater than the cash dollar rate (US risk-free rate).[3] This spread between synthetic and cash dollar rates is an arbitrage spread, namely the CIP basis. Foreign funds pay the CIP basis when borrowing synthetic dollar funding, and banks earn the CIP basis when lending synthetic dollar funding.

I document two facts that show evidence of markups in CIP bases: banks do not competitively lend synthetic dollar funding. First, banks imperfectly passthrough cost shocks to the pricing of forward implied rates. This limited passthrough implies that banks price above marginal cost. Second, regulatory differences cause competition to predictably decrease near quarter-end. European banks pull back from the market and US banks are the low cost lender of synthetic dollar funding at quarter-end. For the four quarter-ends per year, CIP bases increase and US banks earn large markups: an annualized 108 bps, or profits of 82 million US dollars per week.

To assess the competitiveness of the FX derivatives market, I measure the passthrough of cost shocks to the pricing of forward implied rates. In supplying synthetic dollar funding,

[3] Borio et al. (2016) explains that high interest rate currencies, such as the AUD and NZD, tend to have smaller local depositor bases and receive dollar inflows for local currency investments. This contrasts with low interest rate currencies that experience outflows.

banks incur two costs: the cross-currency interest rate spread and a cost to arbitrage. The cost to arbitrage is unobservable and difficult to measure. However, the interest rate spread is directly observable in the data. In a perfectly competitive market, the passthrough of changes to interest rate spreads to forward implied rates depends on the covariance between the cost to arbitrage and the interest rate spread. If the cost to arbitrage is unrelated to the interest rate spread of G10 currencies, then passthrough is 1 in a competitive market.

Alternatively, in an imperfectly competitive market, the passthrough rate is less than 1 because markups negatively covary with cost shocks. Furthermore, the markups may be asymmetrically sensitive to cost shocks. Banks may passthrough cost increases quickly and cost decreases slowly. Such asymmetric passthrough of cost shocks has been documented for banks in other product markets, such as the deposit market. Duffie and Krishnamurthy (2016) explains that banks raise deposit rates slowly when the Fed Funds rate increases but decrease deposit rates quickly when the Fed Funds rate decreases.

Empirically, I find that the passthrough of interest rate spread changes to forward implied rates is less than 1 and asymmetric. When the interest rate spread changes by 100 bps, banks passthrough 81.3 bps to the forward implied rate. This imperfect passthrough is robust to the inclusion of time-fixed effects, which absorb all common variation in the cost to arbitrage and common variation in interest rate spreads (including changes to the US risk-free rate). Furthermore, this passthrough is asymmetric. When the US minus foreign risk-free rate spread increases, banks fully pass on these cost increases to the forward implied rate. However, when the interest rate spread decreases by 100 bps, banks only passthrough 74.6 bps. This asymmetric passthrough dissipates over a 2-month horizon.

This asymmetric passthrough implies that banks price above marginal cost, such that there are markups to the synthetic dollar funding rate. Therefore, the CIP basis includes markups in addition to the cost of arbitrage. After a 25 bps decrease in interest rate spreads, there is a 6.6 bps markup in the CIP basis that dissipates over 2 months. Evidence of imperfect passthrough is informative of the existence of markups, but this does not reveal the average level of markups in CIP bases.

To identify the size of markups in the CIP basis, I use a regulatory supply shifter that impacts European banks, but not US banks. European regulators enforce capital requirements based on a quarter-end snapshot. This incentivizes window dressing: European banks shrink their balance sheet at quarter-end in order to appear better capitalized. By contrast, US banks have quarter-average capital requirements. Quarter-end and quarter-average capital requirements imply different costs to arbitrage by whether the position crosses quarter-end and by its tenor.[4]

In a competitive market, banks behave as price takers and allocate scarce balance sheet capacity to earn the largest CIP basis. This price taking allocation equates the CIP basis to the marginal cost to arbitrage. This assumption of a unit mass of competitive financial intermediaries is standard in the literature (He and Krishnamurthy, 2018; Gromb and Vayanos, 2010, 2018). In such a competitive market, if the low cost supplier of synthetic dollar lending is a European bank, then CIP bases should be larger for lending that crosses quarter-end. The quarter-end increase in CIP bases should increase in tenor and match the amortization of a fixed quarter-end cost. Alternatively, if the low cost supplier of synthetic dollar lending is a US bank without a quarter-end cost, then CIP bases should not increase at quarter-end.

In an imperfectly competitive market, there are markups in the CIP basis. These markups increase when competition decreases. Since competition decreases at quarter-end because European banks become constrained, we expect CIP bases to increase at quarter-end. However, this increase need not match that of a quarter-end cost. Furthermore, US banks would appear to be misallocating balance sheet capacity: earning small CIP bases intra-quarter, rather than larger CIP bases at quarter-end. This differs from the price taking allocation but is consistent with US banks restricting supply when competition is low, in order to earn larger markups.

[4] Non-regulatory costs to arbitrage may include credit spreads (Andersen et al., 2018; van Binsbergen et al., 2022; Augustin et al., 2021), scarce dollar funding (Anderson et al., 2019). I focus on the regulatory balance sheet costs to arbitrage because I study short-horizon arbitrages (1-year or less) and quarter-end changes in the term-structure to CIP bases.

Empirically, I document that US banks are the low cost lenders of synthetic dollar funding across quarter-end. At quarter-end, European banks shrink their average synthetic dollar lending from about 650 billion to 600 billion, a decrease of 50 billion. This decrease in supply by European banks is offset by US banks and Asian banks. At quarter-end, US banks increase their synthetic dollar lending from about 386 billion to 426 billion, an increase of 40 billion. Correa et al. (2020) documents an internal transfer at quarter-end between the depository and broker-dealer subsidiaries of US banks, which is of similar magnitude to their quarter-end increase in synthetic dollar lending. Asian banks make up the remainder by increasing their lending by 10 billion.

In addition to lending more at quarter-end, US banks also have a larger market share of marginal demand by funds. Away from quarter-end, for a 1 dollar increase in demand for synthetic dollar borrowing by funds, European banks supply 0.64 dollars, US banks supply 0.31 dollars, and Asian banks supply 0.05 dollars. However, near quarter-end, European banks pull back from the market and the market share of US banks increases to 83 percent. According to the survey evidence, there are four major US banks and eight major European banks in the FX derivatives market.[5] Therefore, dominance of US banks at quarter-end decreases the number of competitors in the market from 12 to 4.

Despite US banks being the low cost supplier of synthetic dollar funding at quarter-end, CIP bases increase five-fold, on average, for the week that crosses quarter-end. For example, US banks could earn an additional 111 bps by shifting 1-week synthetic dollar lending against the EUR from within quarter to quarter-crossing. Insofar as US banks do not have quarter-end costs to arbitrage, the quarter-end increase to CIP bases is a markup. These markups are economically large. When competition from European banks is low, US banks limit the supply of synthetic dollar funding and earn average profits of 108 bps annualized or 82 million

[5] The 2018 EuroMoney FX survey covered 1,792 FX market customers, representing 46.87 trillion USD of demand in calendar year 2017. The four US banks comprise of 22% of FX swap market volume and include JP Morgan, Citigroup, Bank of America, and Goldman Sachs. The eight European banks comprise of 46% of the swap market volume and include UBS, Deutsche Bank, HSBC, Standard Chartered, Barclays, BNP Paribas, Credit Agricole, and Société Générale.

US dollars per week.

The existence of these markups assumes that US banks are not constrained in their ability to shift balance sheet capacity to quarter-end or have other quarter-end costs to arbitrage. To empirically test this assumption, I estimate the slope of the term-structure of quarter-end increases to CIP bases and test whether it is consistent with a quarter-end cost. A quarter-end cost is amortized over the tenor of the contract. For example, a quarter-end cost that is 1 bps for a 2-month tenor would be 2 bps for a 1-month tenor, and 8.7 bps for 1-week (there are 4.35 weeks in a month).

At year-end, December 31st, all Globally Systemically Important Banks (GSIBs) balance sheets are evaluated by the Bank of International Settlements to determine their next year's capital surcharge. Therefore, US and European banks have quarter-end costs for the 4th quarter. Empirically, I estimate the slope of the term-structure of increases to CIP bases at year-end. For the 4th quarter, the slope of the term-structure matches that of a quarter-end cost. A 1 bps year-end increase in the CIP basis of the 2-month tenor is associated with a 7.592 bps increase in the 1-week tenor. This term-structure slope is insignificantly different from the 8.69 bps implied by a quarter-end cost. When both US and European banks have quarter-end costs, I cannot rule out that the quarter-end increase to CIP bases is entirely due to a quarter-end cost.

However, for quarters 1-3, there is no regulatory quarter-end cost to arbitrage for US banks. Empirically, I estimate the slope of the term-structure for quarters 1-3 and find that the slope is too flat to be consistent with a quarter-end cost. A 1 bps quarter-end increase in the CIP basis of the 2-month tenor is associated with a 2.11 bps increase in the 1-week tenor. This slope is significantly flatter than what would be implied by a quarter-end cost. Therefore, the quarter-end increases in CIP bases for quarters 1-3 reflect markups. If we exclude year-end from the markup estimates, US banks earn a profit of 70 bps annualized, which is 48 million US dollars of profits per week.

The price and quantity responses of the foreign exchange derivatives market at quarter-end reveal that both demand and supply is inelastic. The 50 billion dollar decrease in supply by European banks at quarter-end is small compared to the average 1.3 trillion dollars of aggregate demand in the market. Despite this small decrease in European bank supply at quarter-end, CIP bases on average increase by 113 bps, nearly a five-fold increase.

On the demand side, funds are nearly entirely inelastic to the five-fold increase in synthetic dollar borrowing rates at quarter-end. This inelasticity of demand for predictable, but transitory, increases to price is consistent with foreign funds using synthetic dollar funding to invest in US dollar assets. Selling and repurchasing US dollar investments to avoid quarter-ends may be more costly than the elevated borrowing rate. Demand may be more elastic over longer horizons and for more permanent increases to synthetic dollar borrowing rates.

The supply of synthetic dollar funding is also inelastic. When European banks decrease their supply at quarter-end by an additional percent of aggregate demand, CIP bases increase by an additional 42 percent, or 11 bps. Variation in quarter-end changes to European bank supply explains 26 to 42 percent of the variation in the quarter-end increases to CIP bases. Market power by US banks contributes to the inelasticity of supply. In response to predictable European bank constraints at quarter-end and inelastic demand by foreign funds, US banks limit their supply of synthetic dollar funding and earn large markups. This finding contributes to a growing literature on the elasticity of demand in financial markets (Koijen and Yogo, 2019; Gabaix and Koijen, 2021; Haddad et al., 2021).

Imperfect competition and inelastic demand and supply for synthetic dollar funding can reconcile tensions within the CIP literature. The hypothesized costs to CIP arbitrage are balance sheet and funding costs (Boyarchenko et al., 2020; Andersen et al., 2018), which are both at the bank-level. However, a large empirical literature documents that currency-specific and idiosyncratic demand shocks explain variation in CIP bases. Aldasoro et al. (2019) finds that CIP bases are larger for currencies with more inelastic demand for dollar funding. Borio et al. (2016) shows that local hedging demand by foreign investors explains variation in local currency CIP bases. Liao and Zhang (2021) documents that variation in local hedging demand can explain cross-currency differences in the sensitivity of CIP bases to local and global currency volatility. Viswanath-Natraj (2020) shows that quantitative easing by the local central bank increases CIP bases for the local currency. The price impact of local currency demand shocks on local CIP bases is inconsistent with a global, competitive market to arbitrage. Price taking global banks would reallocate scarce balance sheet capacity or dollar funding in response to local demand shocks. However, this can be explained with imperfect competition: the markups to CIP bases respond to local demand shocks.

Following the introduction, I describe prices and quantities derived from a novel dataset on net FX derivative positions in Section 2. Section 3 presents evidence of imperfect passthrough of cost shocks. Section 4 presents evidence of markups at quarter-end, when European banks are constrained. Section 5 documents evidence of inelastic demand and supply in the FX derivatives market. Section 6 concludes.

2 Prices and Quantities

2.1 Prices

From Bloomberg, I source data on foreign exchange rates and risk-free rates. Denote the spot exchange rate as $S_{c,t}$ for S US dollars for 1 unit of foreign currency c at time t. Denote the τ year forward exchange rate as $F_{c,t,\tau}$ US dollars for 1 unit of foreign currency c at time $t+\tau$. Thus, a higher spot or forward foreign exchange rate means a stronger foreign currency or weaker US dollar. For risk-free rates, I follow the literature convention in using overnight index swap (OIS) rates.[6] Let $i_{c,t,\tau}$ denote the continuously compounded τ-year risk-free rate of currency c.

[6] OIS rates are not available for the DKK and NOK and have limited availability for CHF. For the DKK and NOK, I use LIBOR rates.

Covered interest rate parity (CIP) implies

$$e^{\tau i_{c,t,\tau}} \frac{F_{c,t,\tau}}{S_{c,t}} = e^{\tau i_{\$,t,\tau}}$$

or in logs, where lower case $s_{c,t}$ and $f_{c,t,\tau}$ are the log of their upper case counterparts

$$\tau^{-1}(f_{c,t,\tau} - s_{c,t}) = i_{\$,t,\tau} - i_{c,t,\tau}.$$

Empirically, CIP does not hold (Du et al., 2018) and there is a basis

$$\overbrace{\tau^{-1}(f_{c,t,\tau} - s_{c,t})}^{\text{Forward Implied Rate}} = \overbrace{i_{\$,t,\tau} - i_{c,t,\tau}}^{\text{Interest Rate Spread}} + \overbrace{b_{c,t,\tau}}^{\text{Basis}}.$$

Denote the forward implied rate $\rho_{c,t,\tau}$ and the interest rate spread $\delta_{c,t,\tau}$. Then, we have the expression:

$$\rho_{c,t,\tau} = \delta_{c,t,\tau} + b_{c,t,\tau} \tag{1}$$

and this basis is generally positive ($b_{c,t,\tau} > 0$) for G10 currencies, except for AUD and NZD, as shown in the rightmost column of Table 1. Note that this basis is defined as minus the CIP basis in Du et al. (2018). This notation is convenient because all terms are generally positive- the forward implied rate, interest rate spread, and basis. This convention will be helpful for interpreting supply and demand.

2.2 Quantities

An empirical challenge in studying cross-currency dollar funding is the limited data on quantities. Working with a large foreign exchange settlement firm, I constructed a unique dataset on net positions of FX derivatives. Regulatory capital requirements permit banks to net offsetting long and short FX derivatives trades with the same currency and maturity. Through multilateral netting, banks may shrink their margin funding requirements and decrease the size of their balance sheet. The firm settles more than 6 trillion dollars per day for 70+ settlement members, which spans nearly all GSIB banks, and more than 28,000 funds.[7] This effectively covers the universe of bank intermediation of cross-currency dollar funding in the FX derivatives market.

I define net position to be the cumulative outstanding forward purchases of foreign currency for US dollars less the forward sale of foreign currency for US dollars. Synthetic dollar lending is a negative net position and synthetic dollar borrowing is a positive net position. By this convention, demand for synthetic dollar funding is a positive quantity.

Denote $NP^B_{r,c,t}$ as the net position of banks in region r for foreign currency c and day t. Similarly, denote $NP^F_{r,c,t}$ as the net position of funds. Regions include the Americas, EMEA (Europe, Middle East, and Africa), and APAC (Asia-Pacific). I refer to banks headquartered within the Americas as US banks, banks within EMEA as European Banks, and banks within APAC (Asia-Pacific) as Asian banks. I similarly refer to funds as US, European, or Asian funds. The currencies include G10 currencies paired with the US dollar.[8] The sample is at the daily frequency from January 1st, 2013 through December 31st 2020.

Foreign exchange derivatives are in zero net supply. For each dollar of synthetic funding borrowed, there is a dollar lent. Therefore, the market clearing condition is that

$$\sum_r \left(NP^B_{r,c,t} + NP^F_{r,c,t} \right) = 0$$

for each foreign currency c and day t.

I infer demand for synthetic dollar funding from positive net FX derivative positions: forward purchase of foreign currency c and sale of US dollars. For example, a fund with $NP^F_{r,c,t} > 0$ demands synthetic dollar funding and pays the CIP basis $b_{c,t,\tau}$. Similarly, I infer supply for synthetic dollar from negative net FX derivative positions. For example, a bank with $NP^B_{r,c,t} < 0$ supplies synthetic dollar funding and earns the CIP basis $b_{c,t,\tau}$.

[7] Of the 30 GSIB banks as of 2020, only 3 Chinese banks are not settlement members: Industrial and Commercial Bank of China Limited, Agricultural Bank of China, and China Construction Bank

[8] G10 currencies include Australian Dollar (AUD), Canadian Dollar (CAD), Euro (EUR), Japanese Yen (JPY), New Zealand Dollar (NZD), Norwegian Krone (NOK), Pound Sterling (GBP), Swedish Krona (SEK), Swiss Franc (CHF), and US Dollar (USD).

Let $Q_{c,t}$ be the aggregate demand for synthetic dollar funding. By market clearing, I can measure aggregate demand as the size of outstanding FX derivative net positions (divided by two so as to not double count long and short net positions):

$$Q_{c,t} = \frac{1}{2} \sum_r \Big(|NP^B_{r,c,t}| + |NP^F_{r,c,t}| \Big).$$

Table 1 shows the average net positions of banks and funds by region. US banks have an average net position of -362 billion, from which I infer that they supply 362 billion synthetic dollars of funding. US banks do so predominantly by converting EUR funding (247 billion) and GBP funding (65 billion) into US dollar funding. European banks on average supply 574 billion synthetic dollars of funding. European banks do so predominantly by converting JPY funding (223 billion) and GBP funding (127 billion) into US dollar funding. Asian banks are a more mixed case: Asian banks lend 117 billion synthetic dollars against EUR and GBP funding but borrow 156 billion against JPY funding.

European funds have an average net position of 986, from which I infer that they borrow 986 billion synthetic dollars of funding. European funds predominantly borrow against EUR funding (567 billion) and GBP funding (293 billion). Asian funds borrow 113 billion synthetic dollars of funding, primarily against AUD. US funds are a more mixed case: US funds borrow 129 billion dollars against JPY and CAD funding and lend 280 billion against EUR and GBP funding.

Figure 2a shows the time trends in aggregate net positions of banks and funds by region. Over time, quantities have increased: net synthetic borrowing by funds has increased from 462 billion in 2013 to 1.6 trillion in 2020. Furthermore, US funds have transitioned from a net supplier of synthetic dollar funding to a nearly zero net position. Asian banks have transitioned from borrowers of synthetic dollar funding to suppliers.

Figure 2b shows the time trends in demand for synthetic dollar funding by currency. The positive time trend to demand for synthetic dollar funding is common across many currencies.

From 2013 to 2020, demand on average increased by 12% annually for synthetic dollar funding against the EUR, 16% for GBP, and 9% for JPY.

3 The Passthrough of Interest Rate Spreads to Forward Discount Rates

To evaluate the competitiveness of the market, I measure the passthrough of changes to interest rate spreads to FX forward implied rates. If banks were behaving competitively in lending synthetic dollars, then they would pass on changes to interest rate spreads one for one to the forward implied rate. However, in an imperfectly competitive market, I expect passthrough rates to be less than 1. Furthermore, with imperfect competition passthrough rates may be asymmetric, depending on whether they are cost increases or decreases.

In a perfectly competitive market, the forward implied rate is equal to the interest rate spread and the marginal cost to arbitrage. With perfect competition, the CIP basis ($b_{c,t,\tau}$) is the marginal cost to arbitrage ($mc_{c,t,\tau}$) such that we may rewrite equation (1) as

$$\rho_{c,t,\tau} = \delta_{c,t,\tau} + mc_{c,t,\tau}.$$

In changes, we have

$$\Delta\rho_{c,t,\tau} = \Delta\delta_{c,t,\tau} + \Delta mc_{c,t,\tau}. \tag{2}$$

Projecting $\Delta\delta_{c,t,\tau}$ onto both sides of equation (2) yields:

$$\overbrace{\frac{Cov(\Delta\rho_{c,t,\tau}, \Delta\delta_{c,t,\tau})}{Var(\Delta\delta_{c,t,\tau})}}^{\text{Passthrough Rate}} = 1 + \frac{Cov(\Delta mc_{c,t,\tau}, \Delta\delta_{c,t,\tau})}{Var(\Delta\delta_{c,t,\tau})} \tag{3}$$

Denote the passthrough rate of changes to interest rate spreads to changes in the forward implied rate $\beta_{\Delta\delta}$.

Insofar as the marginal cost to arbitrage does not covary with interest rate spreads, then in a perfectly competitive market, then changes in interest rate spreads have a passthrough of 1 to the forward implied rate. In Section 3.1 we relax the assumption that marginal cost does not covary with interest rate spreads and discuss its empirical plausibility.

Alternatively, in an imperfectly competitive market, price is equal to marginal cost and markup. I define an additive markup $\varphi_{c,t,\tau}$ to the forward implied rate:

$$\rho_{c,t,\tau} = \delta_{c,t,\tau} + mc_{c,t,\tau} + \varphi_{c,t,\tau}. \tag{4}$$

Keeping with the assumption that the marginal cost to arbitrage does not covary with interest rate spreads ($Cov(\Delta mc_{c,t,\tau}, \Delta\delta_{c,t,\tau}) = 0$), we may similarly derive

$$\beta_{\Delta\delta} = 1 + \frac{Cov(\Delta\varphi_{c,t,\tau}, \Delta\delta_{c,t,\tau})}{Var(\Delta\delta_{c,t,\tau})}.$$

A large theoretical and empirical literature characterizes how markups covary with changes to cost. Generally, the covariance is negative: markups fall in response to cost increases due to a downward sloping demand curve. This negative covariance causes a passthrough rate less than 1. However, the covariance has also been documented to exhibit asymmetries. For example, Tappata (2009) shows that market power and limited consumer information can explain why prices rise quickly in response to cost increases but fall slowly in response to cost decreases. In financial markets, Duffie and Krishnamurthy (2016) show that inattentive customers and market power can explain why deposit rates asymmetrically respond to changes in the Fed funds rate. Deposit rates rise quickly in response to increases to the Fed funds rate, but deposit rates fall slowly in response to decreases to the Fed funds rate.

3.1 Empirical Estimates of Passthrough Rates

I estimate how the forward implied rate changes in response to changes in the interest rate spread:

$$\Delta\rho_{c,t,\tau} = \alpha_t + \beta_{\Delta\delta}\Delta\delta_{c,t,\tau} + \epsilon_{c,t,\tau}$$

for tenors ranging from 3-months to 12-months.[9] The coefficient estimate of interest is $\beta_{\Delta\delta}$, the passthrough rate of changes in interest rate spreads to forward implied rates.

Column 1 of Table 2 shows that a 100 bps change in the interest rate spread is associated with an 81.3 bps change in the forward implied rate at a 1-week horizon. We can reject the null of a passthrough rate of 1 at all conventional levels of significance. This finding is robust to the inclusion of a time-fixed effect (column 2), which absorbs all common variation in interest rate spreads (including changes to the US risk-free rate).

The passthrough of interest rate spread changes is asymmetric. Column 3 of Table 2 shows that when US risk-free rates increase relative to foreign risk-free rates, the passthrough rate is nearly 1. For a 100 bps increase in the interest rate spread, forward implied rates increase by 99.2 bps. This increase in the interest rate spread is an increase in the cost to supplying synthetic dollar funding (hedging the forward sale of US dollars). Banks fully passthrough cost increases to the pricing of forward implied rates.

However, when US risk-free rates decrease relative to foreign risk-free rates, the passthrough rate is significantly smaller. For a 100 bps decrease in the interest rate spread, forward implied rates decrease by 73.6 bps ($= 0.992 - 0.256$). This decrease in the interest rate spread is a decrease in the cost to supplying synthetic dollar funding. Banks partially passthrough cost savings to the pricing of forward implied rates.

This asymmetry in the passthrough of interest rate spread changes dissipates at the 2-month horizon. Column 5 of Table 2 shows that for 2-month changes, the passthrough rate is nearly 1 and not asymmetric.

In a perfectly competitive market, the passthrough rate differs from 1 due to a covariance between the marginal cost of arbitrage and interest rate spreads (equation (3)). To explain a passthrough less than 1, the marginal cost of cost of arbitrage would need to be negatively related to interest rate spreads. One economic mechanism for such a negative correlation would be if during periods of financial distress interest rate spreads decreased and the marginal

[9] The exclusion of short-term tenors is due to significant quarter-end variation related to changes in European bank shadow balance sheet costs. This is explored in much greater detail in the Section 4.

cost to arbitrage increased. For interest rate spreads to decrease, US risk-free rates would need to fall by more than foreign risk-free rates. Time fixed effects absorbs this source of negative correlation by absorbing all variation in US risk-free rates and common variation in financial conditions. Passthrough rates less than 1 are difficult to explain in perfectly competitive markets. Furthermore, asymmetric passthrough is especially difficult to explain.

In an imperfectly competitive market, cost shocks may asymmetrically passthrough to prices (equation (4)). Increases to interest rate spreads increase the cost to lending synthetic dollars and banks fully passthrough these costs. Decreases to interest rate spreads decrease the cost to lending synthetic dollars and banks partially passthrough these cost savings. Markups increase when interest rate spreads decrease. Therefore, after a 25 bps decrease in interest rate spreads, there is a 6.6 bps markup in the CIP basis that dissipates over 2 months.[10] The passthrough of interest rate spread changes to the forward implied rate reveals that there are time-varying markups in the CIP basis.

4 European Bank Window Dressing and US Bank Market Power

In addition to imperfect passthrough, prices increase in response to decreased competition. In the global foreign exchange market, competing banks operate under different regulatory requirements. Due to differences in the enforcement of regulatory capital requirements,Due to differences in the enforcement of regulatory capital requirements, European banks systematically deleverage at quarter-end (window dress), but US banks do not. This deleveraging by European banks is predictable and has been occurring in the foreign exchange market at each quarter-end since 2015. This quarter-end deleveraging coincides with reporting requirements for their compliance with the supplementary leverage ratio (SLR). The SLR required banks

[10] For a 25 bps decrease in interest rate spreads, 18.4 bps (=25(0.992 − 0.256)) is passed through to the forward implied rate, which leaves a 6.6 bps markup.

to hold capital against all balance sheet exposures, including FX derivatives positions.[11] The deleveraging of European, but not US banks, presents an ideal laboratory to study competition effects on quantities and prices in the foreign exchange market.

4.1 Regulatory Differences and Competitive Behavior

Basel III requires that national regulators minimally enforce quarter-end capital ratio compliance (Basel Committee on Banking Supervision, 2014). European regulators enforce quarter-end capital requirements for European banks.[12] This snapshot approach incentivizes European banks to window dress: shrink their balance sheet at quarter-end in order to appear better capitalized.

To explain this window dressing incentive, I show how annualized balance sheet costs steeply increase with a fixed quarter-end cost. Define the marginal cost to overnight synthetic dollar lending as $mc_{c,t}$ for currency c and time t. This marginal cost can be decomposed into a common component ($\kappa_{c,t}$) and quarter-end component ($\lambda_{c,t}^{QE}$):

$$mc_{c,t} = \begin{cases} \kappa_{c,t} & \text{if intra-quarter} \\ \kappa_{c,t} + \lambda_{c,t}^{QE} & \text{if quarter-end} \end{cases}$$

where $\kappa_{c,t}$ applies for all t and $\lambda_{c,t}^{QE}$ is an additional cost when t is at quarter-end: March 31st, June 30th, September 30th, and December 31st. For a European bank with a quarter-end balance sheet cost, the marginal cost to synthetic dollar lending for tenors that cross

[11] Basel III requires banks to meet a 3% non-risk-weighted capital ratio (Basel Committee on Banking Supervision, 2014). US banks have a supplementary leverage ratio (SLR) of 2% if they are G-SIBs. These capital requirements pertain to total balance sheet exposure, including on- and off-balance-sheet items, irrespective of risk. Compliance with the SLR became mandatory in January 2018. However, Klingler and Sundaresan (2020) shows an impact of the SLR in bank Treasury holdings after January 2015, when banks were required to publicly disclose their SLR.

[12] As of January 2017, UK bank capital requirements are evaluated at month-end, but other European banks continue to be evaluated at quarter-end.

quarter-end (T) and are less than or equal to 3-months is

$$mc_{c,t,\tau} = \bar{\kappa}_{c,t,\tau} + \frac{1}{4\tau}\lambda^{QE}_{c,T} \tag{5}$$

where $\bar{\kappa}_{c,t,\tau}$ is the average of the common component to marginal cost from t to $t + \tau$ and $\frac{1}{4\tau}\lambda^{QE}_{c,T}$ is the annualized fixed quarter-end cost.[13] For simplicity, I assume that the bank knows its future balance sheet cost. This assumption is plausible for the short horizons of arbitrage: 1-week to 3-months.[14]

As quarter-end approaches, more synthetic dollar lending spans quarter-end and $\lambda^{QE}_{c,t}$ is amortized over shorter tenors τ. For a European bank with a quarter-end cost, the annualized marginal cost to arbitrage over quarter-end is inversely related to the tenor of the contract. For example, suppose that the fixed quarter-end cost is 1 bps when amortized over 2-months.[15] This same quarter-end cost would be 2 bps for a 1-month contract, 4.35 bps for a 2-week contract, and 8.69 bps for a 1-week contract. A fixed quarter-end cost amortized over short-term synthetic dollar lending has a large effect on the annualized lending cost.

By contrast, US regulators enforce quarter-average capital requirements for US banks. Without a quarter-end cost ($\lambda^{QE}_{c,t} = 0$), the marginal cost to synthetic dollar lending simplifies to

$$mc_{c,t,\tau} = \bar{\kappa}_{c,t,\tau}.$$

In a competitive market, the CIP basis is equal to the marginal cost to arbitrage. Banks behave as price-takers in allocating scarce balance sheet capacity such as to earn the largest CIP basis. Due to this regulatory difference, there are two potential functional forms to marginal cost that depend on tenor and whether the contract crosses quarter-end. If the

[13] The tenor τ is scaled by 4 when annualizing the fixed cost because there are 4 quarter-ends to a year.

[14] Du et al. (2020) shows that the risk-premium to this uncertainty is small, 1.35 bps for the EUR against the USD from July 1, 2010 to August 31, 2018 (see their Table 2). This risk-premium is larger for other currency pairs, and peaks for synthetic AUD lending against the JPY at 14.27 bps. We will see that this is small relative to the quarter-end increases to CIP bases.

[15] This would be an overnight quarter-crossing cost that is about 60 basis points because 60 bps amortized over about 60 days in two months increases the marginal cost to lending 2-month synthetic dollar funding by 1 bps.

low cost supplier of synthetic dollar lending is a European banks with quarter-end balance sheet costs, we expect a quarter-end increase to CIP bases that steeply increases as the tenor decreases. If the low cost supplier of synthetic dollar lending is a US bank with a quarter-average balance sheet cost, we expect no quarter-end increase to CIP bases.

In an imperfectly competitive market, the CIP basis is both marginal cost and markup. Over quarter-end, when European banks are more constrained than US banks, competition decreases and markups increase. Even if the low cost supplier of synthetic dollar lending is a US bank, CIP bases may increase at quarter-end due to the decrease in competition. US banks without a quarter-end balance sheet cost may restrict supply when competition is low, which increases markups and the CIP basis. A unique prediction of imperfectly competitive markets is that we expect to see what appears to be misallocation. US banks expend scarce balance sheet capacity to earn smaller CIP bases, rather than larger CIP bases. This allocation is due to US banks exercising market power; US banks restrict supply when competition is low- in this case, when European banks are constrained at quarter-end.

4.2 US Banks are the Low Cost Suppliers at Quarter-End

At quarter-end, European banks decrease their supply of synthetic dollar funding by about 50 billion dollars. Figure 4c shows the cumulative change in European banks' net position around quarter-end. For the two weeks prior to quarter-end, European banks decrease their supply of synthetic dollar funding. This reverses precisely after quarter-end and the cumulative change is insignificant after 1-week from quarter-end.

Despite the regulatory supply shifter that impacted European banks, aggregate quantity is nearly unchanged at quarter-end. On average, US banks offset European bank window dressing by supplying an additional $40 billion at quarter-end. Asian banks also supply approximately $10 billion to offset European bank window dressing. Figure 4 provides an event study illustration of the cumulative change in quarter-end synthetic dollar funding for aggregate demand, fund demand, European bank supply and US bank supply.

In addition to offsetting the window dressing of European banks, US banks also have a greater market share of funds' demand for synthetic dollar borrowing. Fund demand is the sum of the net positions of US, European and Asian funds ($NP^F_{c,t} = \sum_r NP^F_{r,c,t}$). I identify fund demand shocks by sign restriction: an increase in demand involves an increase in quantity ($\Delta NP^F_{c,t} > 0$) and price (CIP bases, $\Delta b_{c,t} > 0$); a decrease in fund demand involves a decrease in quantity ($\Delta NP^F_{c,t} < 0$) and price (CIP bases, $\Delta b_{c,t} < 0$).[16] I regress changes to net positions of banks on fund demand shocks:

$$\Delta NP^B_{r,c,t} = \alpha + \gamma_{r,c} QE_t + \beta_{r,c} \Delta NP^F_{c,t} + \varphi_{r,c}(\Delta NP^F_{c,t} \times QE_t) + \epsilon_{r,c,t}$$

where QE_t is an indicator for the two-weeks leading up to quarter-end. If funds demand an additional dollar of synthetic funding, then by market clearing, banks supply an additional dollar: $\sum_r \beta_{r,c} = -1$.

Table 3 shows that away from quarter-end, US banks have a 31 percent market share of fund demand, European banks have a 64 percent market share and Asian banks have a 5 percent market share. However, for the 2-weeks leading up to quarter-end, European banks' market share is nearly zero; US banks' market share is about 82 percent and Asian banks' market share is about 18 percent. When European banks are window dressing, they pull back from intermediating the market for synthetic dollar funding.

Near quarter-end, US banks are the dominant, low cost supplier of synthetic dollar funding. The pullback of the European banks from the market is a large decrease in competition. According to the Euromoney FX survey, 8 of the 12 global banks with large market share in the FX derivatives market are European. Therefore, this shift in market share to US banks decreases the number of competitors from 12 down to 4.

[16]This reduced form approach is motivated by Uhlig (2017) who shows that sign restrictions can estimate supply and demand shocks using a structural vector autoregression. I use the 3-month CIP basis for each currency and time as the price measure.

4.3 Quarter-End Increases to CIP Bases

Despite US banks being the low cost supplier of synthetic dollar funding at quarter-end, CIP bases increase at quarter-end. Du et al. (2018) first documented that CIP bases increase at quarter-end. Figure 3a shows that these quarter-end increases in CIP bases occur precisely when contracts transition from intra-quarter to quarter-crossing. Prices reflect that the market anticipates the quarter-end increase in CIP bases.

Figure 3b shows the term structure of synthetic dollar borrowing for tenors 1-week to 3-months by whether the contract crosses quarter-end (in red) or is intra-quarter (in black). The shaded area is the 95% confidence bound for the average CIP basis by tenor and quarter-crossing. These quarter-end increases to CIP bases are economically large. 1-week synthetic dollar borrowing against the EUR is on average 143 bps when crossing quarter-end and 32 bps when intra-quarter. These quarter-end increases are present for all G10 currencies, besides the AUD and NZD (see Table 5).

For 1-week synthetic dollar lending, US banks could earn on average an additional 111 bps by shifting a synthetic dollar lent against EUR from intra-quarter to quarter-end. Assuming price taking in a competitive market, this is a misallocation. If US banks were price-takers they would only engage in short-term synthetic dollar lending over quarter-end. However, US bank do a similar level of synthetic dollar lending within quarter and at quarter-end (see Figure 2a). On average for the 3-days about quarter-end, US banks synthetically lend 426 billion, and on other days, US banks synthetically lend about 386 billion.

This misallocation is present across all possible tenors by which US banks engage in synthetic dollar lending within the quarter. Consider the opposite extreme to the 1-week tenor, where US banks only lent over the full quarter (3-month tenor). US banks can maintain the same average balance sheet size by reallocating 3-month synthetic dollar lending to 1-week synthetic dollar lending over quarter-end. A marginal such reallocation would increase US banks returns by 98 bps.[17] Furthermore, the misallocation is present for all currencies that

[17]From 2015 to 2020, the 3-month EUR CIP basis was on average 45 bps. The 98 bps gain is the 1-week

exhibit quarter-end increases to CIP bases.

Therefore, US banks do not behave as price-takers in their supply of synthetic dollar funding. US banks exercise market power in limiting the supply of synthetic dollar funding at quarter-end, when competition is low. Insofar as US banks do not have quarter-end costs to arbitrage, the quarter-end increase to CIP bases is a markup. At quarter-end, US banks earn markups on 1-week synthetic dollar lending ranging from 37 bps for CAD and 170 bps for JPY. The dollar weighted average of these markups is an annualized 108 bps. In dollar terms, over the four weeks of the year when competition is low, US banks on average earned profits of 82 million US dollars per week.

Although US banks are the low cost supplier at quarter-end, other regulations or constraints may cause US banks to have a quarter-end cost to arbitrage. I empirically test whether the term-structure of quarter-end increases to CIP bases is consistent with the term-structure implied by a quarter-end cost (equation (5)).

I estimate the slope of the term structure of quarter-end increases the CIP bases:

$$\Delta b_{c,t,\tau} = \alpha_c + \alpha_\tau + \beta_\tau \Delta b_{c,t,2M} + \epsilon_{c,t,\tau}$$

where $\Delta b_{c,t,\tau}$ is the quarter-end increase in the CIP basis for currency c, quarter-end t and tenor τ, α_c is a currency fixed effect, α_τ is a tenor fixed effect, and $\Delta b_{c,t,2M}$ is the corresponding quarter-end increase of 2-month CIP bases. I empirically test whether the slope of the term structure matches the slope implied by a quarter-end cost for two sub-periods, quarters 1-3 and quarter 4 for years 2015-2020.

I separately estimate the term-structure for quarters 1-3 and quarter 4 because of the year-end GSIB capital requirements. At year-end, in addition to their usual capital requirements, US and European banks are also evaluated for their GSIB capital surcharge. This evaluation

EUR CIP basis that crosses quarter end (143 bps) minus the 3-month EUR CIP basis (45 bps), which is 98 bps. To maintain the same quarter-average balance sheet size, US banks would increase 1-week synthetic dollar lending about quarter-end by 13 units for each unit decrease in 3-month synthetic dollar lending over the full quarter.

occurs based on their December 31st balance sheets. This year-end snapshot introduces an additional fixed 4th quarter-end cost to both US and European bank balance sheets.

For quarter 4, the slope of the term structure to quarter-end increases to CIP bases is consistent with a quarter-end cost. The estimated coefficients are significantly different from zero but insignificantly different from what is implied by a quarter-end cost. A 1 bps increase in the 2-month CIP basis corresponds to a 1.9 bps increase in the 1-month CIP basis, which is insignificantly different from the 2 bps implied by a quarter-end cost. Similarly, the 1-week CIP basis increases by 7.6 bps, which is insignificantly different from the 8.7 bps implied by a quarter-end cost. When both US and European banks have quarter-end balance sheet costs, the term structure of synthetic dollar borrowing rates closely matches that of marginal cost. By matching the slope of a quarter-end cost, I fail to rule out competitive pricing at year-end.

For quarters 1-3, the slope of the term structure to quarter-end increases to CIP bases is too flat to be consistent with a quarter-end cost. Table 4 shows that a 1 bps increase in the 2-month CIP basis corresponds to a 1.2 bps increase in the 1-month CIP basis, which is significantly smaller than the 2 bps implied by a quarter-end cost. Similarly, the 1-week CIP basis increases by 2.11 bps, which is significantly smaller than the 8.7 bps implied by a quarter-end cost. Therefore, the term structure to the quarter-end price for synthetic dollar funding is too flat to be that of a quarter-end cost to arbitrage. This positive, but rather flat slope is consistent with US banks earnings markups due to imperfect competition.

The quarter 4 term structure slope estimates mitigate the concern that the flatness of the quarter 1-3 term structure is due to noise. Measurement error may attenuate the coefficients toward zero, resulting in incorrectly rejecting the null that the term structure is sufficiently steep to be that of a quarter-end cost. However, such measurement error would need to differ between quarters 1-3 and quarter 4. I further mitigate this concern by estimating the term structure for quarters where the 2-month increase in CIP bases is large.[18] For above median,

[18] When the 2-month quarter-end increase is large due to more European bank window-dressing, the relative size of measurement error in the forward premium or risk-free rate is likely to be smaller fraction of variation in the quarter-end increase to CIP bases. Therefore, attenuation of these estimated coefficients would be smaller.

2-month quarter-end increases, the third and fourth columns of Q1-3 of Table 4 shows the term structure is flatter, but not significantly different from that of the full sample.

Excluding year-end from the markup estimates decreases the dollar weighted average of US markups to an annualized 70 bps and 48 million US dollars for three weeks of the year.

5 Inelastic Supply and Demand

The quarter-end responses of prices and quantities to predictable decreases in European bank supply reveal that both supply and demand is inelastic.

Fund demand for synthetic dollar funding is entirely inelastic to the quarter-end increases in CIP bases. For the 1-week about quarter-end, funds borrow at an average annualized rate that is 95 bps higher. For the four quarter-end weeks of the year, funds pay an additional 183 million US dollars for synthetic dollar borrowing relative to other weeks of the year. In relative terms, this is a five-fold increase in synthetic dollar borrowing costs. Despite this large, predictable increase in cost at quarter-end, Figure 4 shows that on average the quarter-end change in net fund demand is nearly zero. Furthermore, with 95% confidence, net demand by funds did not decrease by more than 10 billion. This response by funds is small compared to the level of their synthetic borrowing: on average about 1 trillion US dollars.

The inelastic response of fund demand is consistent with funds using short-term synthetic dollar funding to invest in long-term US dollar assets. To funds do not respond to predictable, but short-lived increases to CIP bases, because liquidating their US dollar investments prior to quarter-end and repurchasing them afterwards may be more costly. Alternatively, funds could go unhedged over quarter-end, bearing currency mismatch risk. However, fund risk-aversion may prevent them from bearing currency risk, even over short periods of time.

In addition to demand being inelastic, supply is also inelastic. Weighted by aggregate demand, the average CIP basis increases by about five-fold at quarter-end; European banks on average decrease their supply of synthetic dollar funding by 2.6 percent of aggregate demand. This implies that supply by US and Asian banks is very inelastic to decreases in European bank supply. Market power contributes to this inelasticity of supply: US banks earn large markups by limiting their supply of synthetic dollar lending at quarter-end. To document this inelasticity, I show that quarter-end increases to CIP bases are highly sensitive to variation in how much European banks decrease supply.

For each currency and quarter-end, I measure the decrease in European banks supply ($s^B_{E,c,t}$) as a fraction of aggregate demand:

$$\Delta s^B_{E,c,t} = \frac{-\Delta NP^B_{E,c,t}}{\bar{Q}_{c,t}} \tag{6}$$

for currency c and quarter-end t. This is minus the change in net position because a synthetic dollar lending involves a negative net position. For the quarter-end change in supply, I take the average supply for a 3 day window about quarter-end and subtract a 3 day average of supply from two-weeks earlier. Figure 4c shows that this measure captures the timing of the decline in European bank synthetic dollar lending. I divide this quarter-end change in supply by a 1-month moving average of aggregate demand from two-weeks earlier ($\bar{Q}_{c,t}$). Dividing by lagged aggregate demand scales the decrease in European bank supply by market size. This scaling accounts for the positive time-trend in aggregate demand for synthetic dollar funding. Summing over all G10 currencies, at quarter-end, European banks decrease their synthetic dollar lending by 2.6 percent of aggregate demand (Table 5).

The quarter-end decrease in European bank supply varies by currency. In the cross-section of currencies, Table 5 shows the average European bank decrease in quantity and the increase in the CIP basis at quarter-end. For the JPY, European banks shrink their supply by 8.4 percent of aggregate demand and the 1-week quarter-end increase to the CIP basis is on average 170 bps. For the EUR, European bank supply decreases by 2.1 percent of aggregate demand and the 1-week quarter-end increase is on average 111 bps. For the AUD and NZD, European banks have nearly zero decrease in supply at quarter-end and the 1-week CIP basis does not increase at quarter-end. For the NOK and SEK, European banks do not decrease supply, but there is an increase to 1-week to CIP bases.

In the time-series, quarter-end increases in CIP bases are larger when European banks decrease their supply by more. For each intra-quarter tenor, I regress the size of quarter-end increase to CIP bases on the quarter-end change in European bank supply in aggregate and by currency:

$$\Delta ln(b_{c,t,\tau}) = \alpha + \beta_\tau \Delta s^B_{E,t} + \gamma_\tau \Delta s^B_{E,c,t} + \epsilon_{c,t,\tau} \tag{7}$$

The intra-quarter tenors span from 1-week to 2-months.[19] The sample of currencies (CAD, EUR, GBP, JPY, and SEK) is limited to those for which I have a full term structure of short-term CIP bases; I also exclude the AUD and NZD because European banks do not window dress and the synthetic dollar borrowing rate does not predictably increase at quarter-end. Column 1 of Table 6a shows that when European banks decrease their supply by 1 percent of aggregate demand, the quarter-end increase in CIP bases is on average 42 percent larger for the 1-week tenor. In contrast to this aggregate effect, I find no evidence that currency-specific changes in European bank supply effect quarter-end increases to CIP bases. Figure 5 illustrates the relationship between quarter-end increases to CIP bases and the quarter-end decrease in European bank supply. Changes in European bank supply explains 42 percent of the variation in the quarter-end increases to CIP bases.

Although there is an exogenous regulatory supply shifter at quarter-end, the quantity to which European banks decrease supply at quarter-end is endogenous to prices. To mitigate this endogeneity concern, I use the forward implied, rather than actual, quarter-end increase to CIP bases. The quarter-end change to forward implied CIP bases reflect the market's expectation of the future quarter-end increase in CIP bases.[20] Following Du et al. (2020),

[19] The 3-month to 12-month tenors always cross quarter-end and do not exhibit quarter-end increases.

[20] Du et al. (2020) shows that the risk-premium to forward implied CIP bases are small compared to the quarter-end increase in CIP bases. See footnote 14.

define the h period forward CIP basis as

$$b_{c,t,\tau,h} = \frac{h+\tau}{\tau} b_{c,t,\tau+h} - \frac{h}{\tau} b_{c,t,h} \tag{8}$$

For each intra-quarter tenor, I construct a forward CIP basis that crosses quarter-end. I re-estimate equation (7) using increases in the forward CIP basis, rather than the realized quarter-end increases in the CIP basis. The identifying assumption is that markets price the regulatory supply shifter that decreases European bank supply in the forward basis, but that other supply or demand shocks that occur at quarter-end are unanticipated. This would be violated if there were predictable fund demand shocks at quarter-end: the forward CIP basis would vary with expected demand in addition to the expected decrease in European bank supply. This concern is mitigated by earlier evidence that aggregate demand is nearly entirely inelastic to the quarter-end increase to CIP bases.

Table 6b shows that realized quarter-end decreases in European bank supply also explains variation in the anticipated component of quarter-end increases to CIP bases. When European banks decrease their supply by 1 percent of aggregate demand, the forward CIP basis is on average 26 percent larger for the 1-week tenor.

6 Concluding Discussion

Even in the largest financial markets, there are markups to prices. In the foreign exchange derivatives market, foreign funds net demanded to borrow an average 1.1 trillion US dollars of synthetic funding per day. US and European banks took the opposite side of this trade by lending synthetic dollar funding. The forward implied rate that cleared this market included a CIP basis. Banks earn the CIP basis as an arbitrage spread to the supply of synthetic dollar funding. I show that this arbitrage spread is comprised of both cost and markup.

These markups are large, when competition is low. Due to quarter-end capital requirements, European banks pull back from the market near quarter-end. European banks window dress to appear better capitalized to regulators by decreasing their supply of synthetic dollar funding by 60 billion at quarter-end. During this period, US banks market share of marginal demand increases from 31 percent to 83 percent. Due in part to markups, the 1-week CIP basis, the price the synthetic dollar borrowing, increases five-fold over quarter-end.

This regulatory quarter-end supply-shifter is an ideal laboratory to study the effects of bank deleveraging on US dollar funding. These quarter-end events are predictable, frequent, and impact European banks but not US banks. By contrast, deleveraging due to financial crises tends to be unpredictable, rare and impact all banks. The insights learned in this quarter-end laboratory are potentially informative about more general periods of distress in dollar funding markets. During crises, dollar funding is both scarce and concentrated among a few, well-capitalized banks. Inelastic demand, market power, and scarcity may jointly explain the large spikes in short-term dollar borrowing rates during periods of financial distress.

Policymakers intervene in this market for synthetic dollar funding during periods of distress. The Federal Reserve lent 580 billion dollars to foreign central banks through swap facilities during the financial crisis of 2008 and another 459 billion during the Covid-19 pandemic (Obstfeld et al., 2009; Aldasoro et al., 2020). Furthermore, policymakers are increasingly aware of the window-dressing incentives of quarter-end capital requirements. The BIS has urged national regulators to adopt quarter-average capital requirements (BIS, 2018). Switching from quarter-end to quarter-average capital requirements would address US bank market power at quarter-end; quarter-end increases to CIP bases would flatten. However, European banks would face larger intra-quarter balance sheet costs, which may raise the average level of CIP bases.

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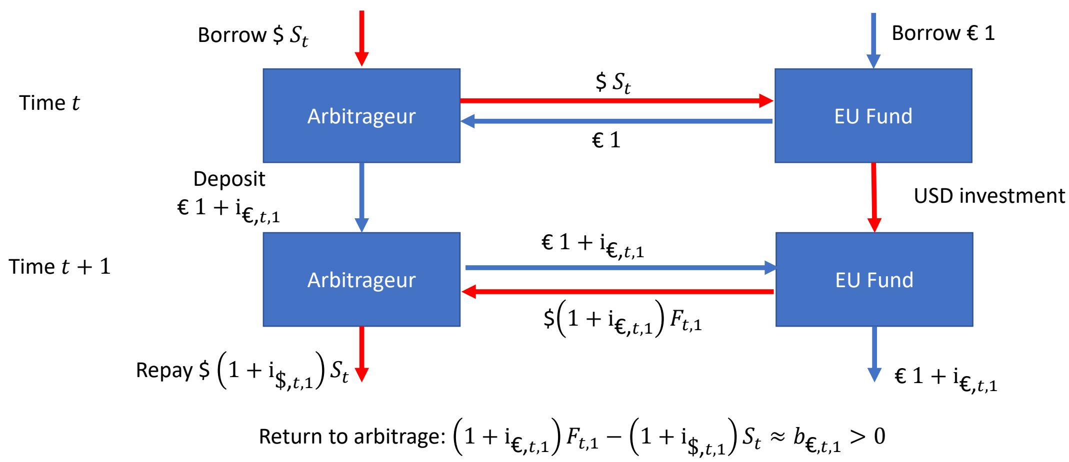
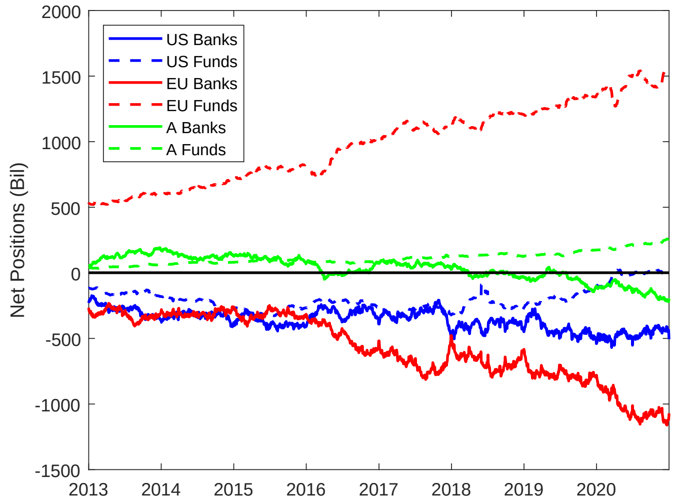
Figure 1: Synthetic Dollar Borrowing and Lending

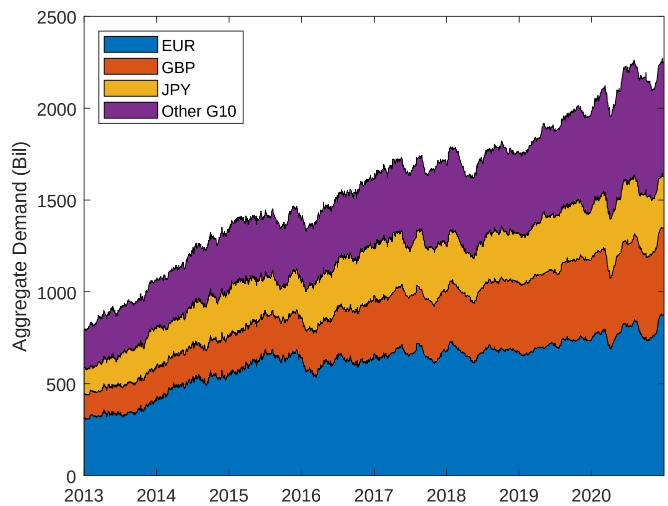


Notes: This figure illustrates synthetic dollar funding against the EUR. The red arrows trace the movement of USD and the blue arrows trace the movement of EUR. At t, the synthetic dollar lender (arbitrageur) borrows S_t dollars at the US risk-free rate $i_{\$,t,1}$ at time t for 1 period. The arbitrageur spot exchanges S_t dollar for 1 EUR and deposits at the EUR risk-free rate $i_{\epsilon,t,1}$. Simultaneously, the arbitrageur sells $1 + i_{\epsilon,t,1}$ EUR forward in exchange for $(1 + i_{\epsilon,t,1})F_{t,1}$ dollars. At $t + 1$, the arbitrageur repays the dollar lender $(1 + i_{\$,t,1})S_t$. Summing the arbitrageur cash flows reveals a return of $(1 + i_{\epsilon,t,1})F_{t,1} - (1 + i_{\$,t,1})S_t \approx b_{\epsilon,t,1}$. The borrower (EU fund) takes the opposite side of these trades in order to borrow synthetic dollar funding.

Figure 2: Net Synthetic Dollar Positions



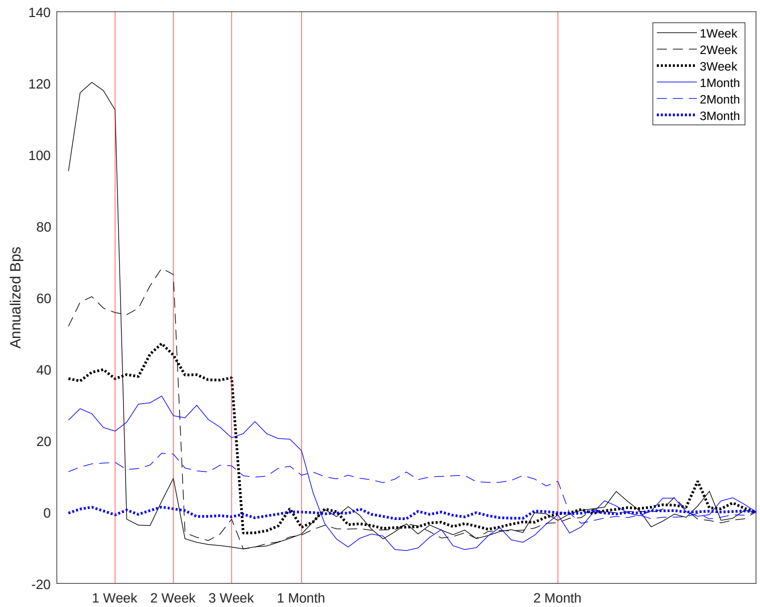
(a) By Geography-Institution



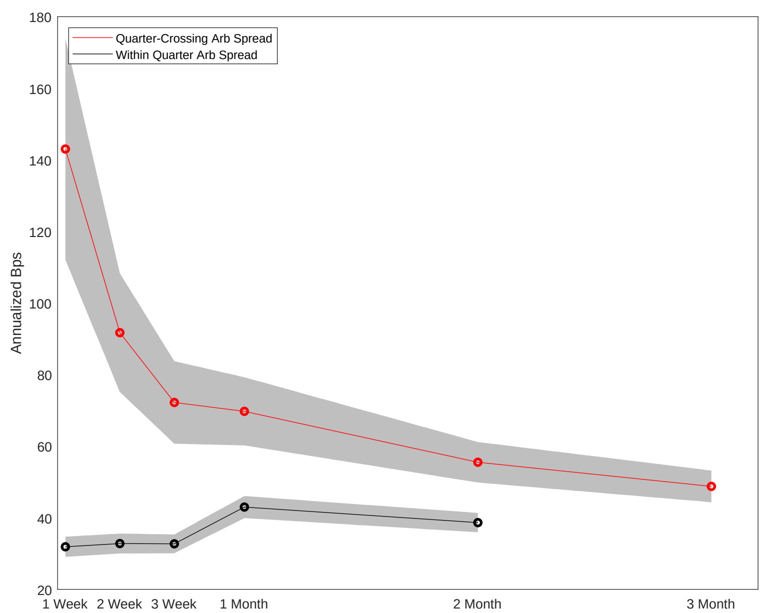
(b) By Currency

Notes: Net position is the net sum of all dollars sold forward. I infer that negative net positions reflect synthetic dollar lending and positive net positions reflect synthetic dollar borrowing. Figure 2a plots the net positions aggregated over G10 currencies of institution groups (US, European, and Asian banks and funds) from January 2013 to December 2020. European funds are the predominant synthetic dollar borrowers and US and European banks are the predominant lenders. Figure 2b plots the aggregate demand for synthetic dollar funding by currency over time. The three largest net positions (EUR, GBP, and JPY) are shown separately and the remaining G10 currencies are aggregated into Other G10.

Figure 3: Quarter-end Increases to CIP Arbitrage Spreads



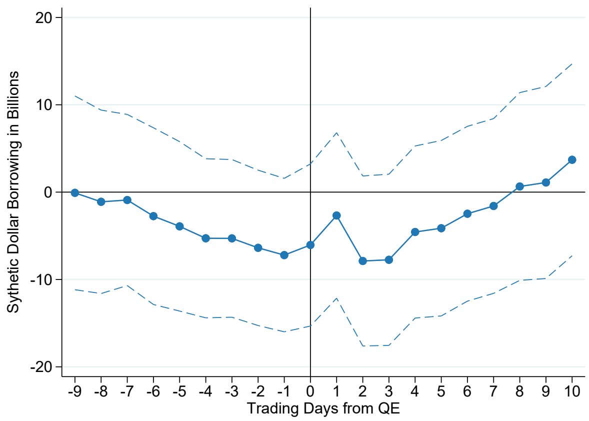
(a) EUR Arbitrage Spreads by Time to Quarter-End



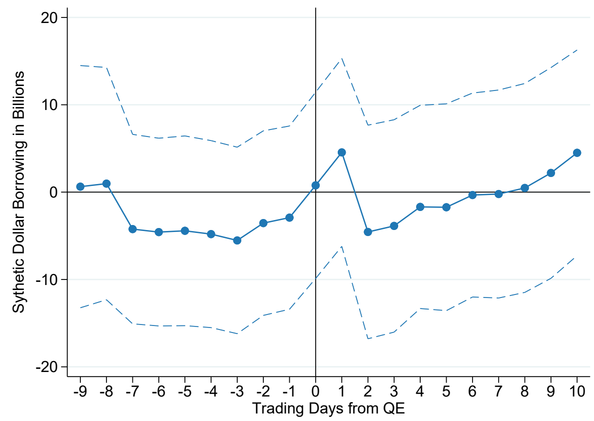
(b) EUR Arbitrage Spread Term Structure

Notes: Figure 3a plots the average CIP arbitrage spread for EUR synthetic dollar lending by time to quarter-end and contract tenor. The tenors span from 1-week to 2-months. The vertical red lines illustrate when contracts cross from intra-quarter to quarter-crossing and coincided with increases in the arbitrage spread. Figure 3b plots the term-structure of EUR CIP arbitrage spreads by tenor and quarter-crossing. The red (black) line is of average quarter-crossing (intra-quarter) arbitrage spreads. The shaded regions is of the 95 percent confidence interval. The sample is from January 2015 to December 2020.

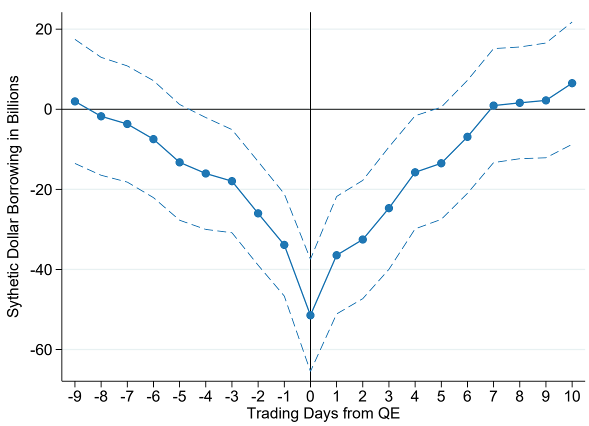
Figure 4: Quarter-end Effects on Synthetic Dollar Funding Intermediation



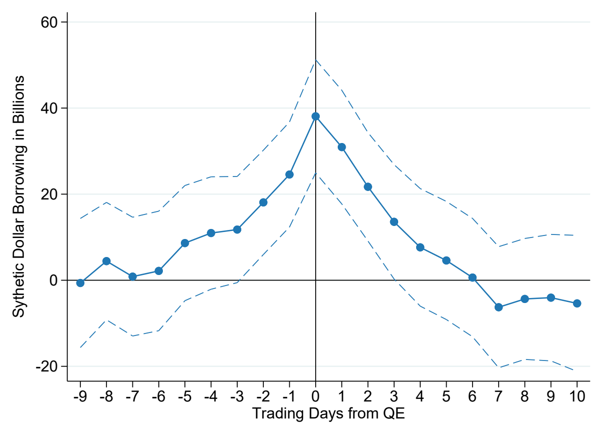
(a) Aggregate Demand



(b) Fund Demand



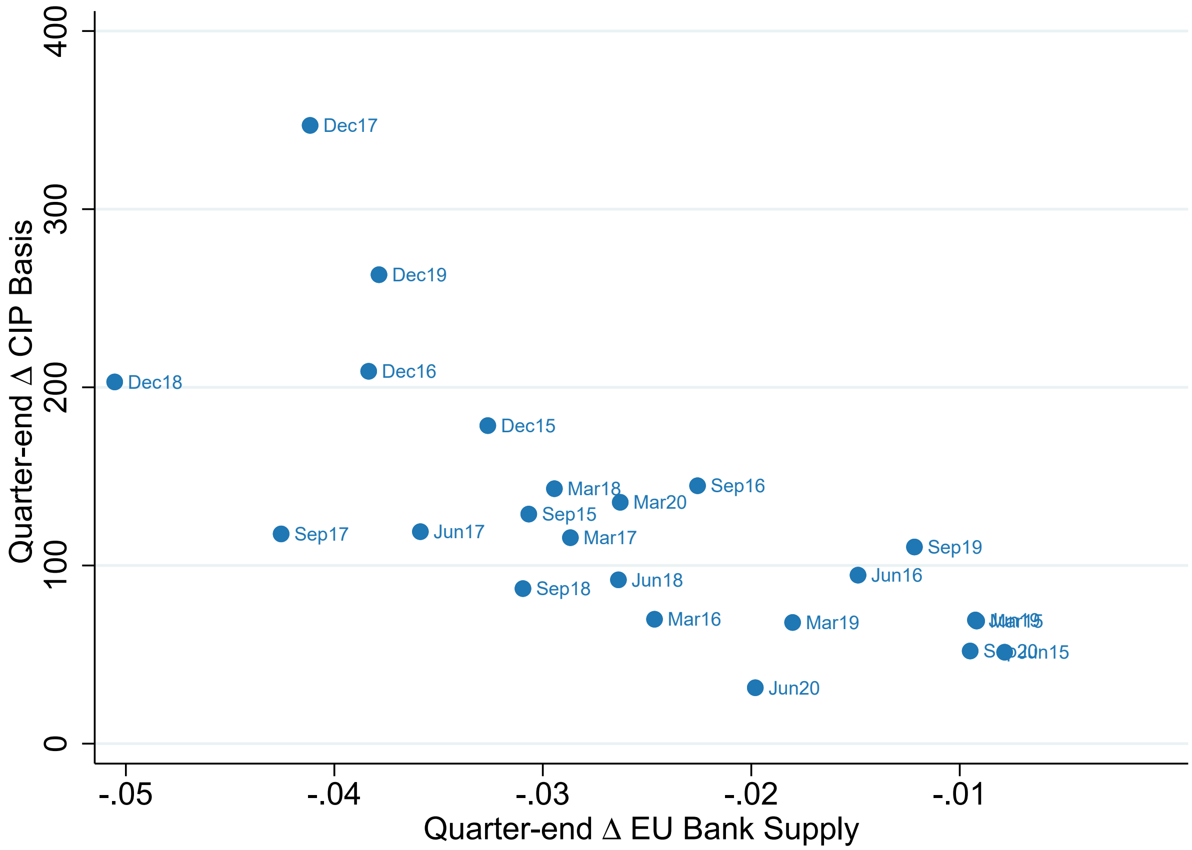
(c) EU Bank Supply



(d) US Bank Supply

Notes: This figure plots the average cumulative change in synthetic dollar funding relative to 10-trading days prior to quarter-end. Synthetic dollar borrowing is equal to net position and synthetic dollar lending is equal to minus net position as defined in Section 2.2. The solid line plots the cumulative change in synthetic dollar funding for the 2-weeks (20 trading days) about quarter-end for aggregate demand (Figure 4a), fund demand (Figure 4b), EU bank supply (Figure 4c), and US bank supply (Figure 4d). The dashed lines plot the 95 percent confidence interval of average cumulative changes for robust standard errors. The quarter-end event studies show that aggregate demand and fund demand insignificantly changes about quarter-end. By contrast, EU banks decrease their supply by about 50 billion at quarter-end and US banks increase their supply by about 40 billion.

Figure 5: Quarter-end Increase to the 1 Week CIP Basis and EU Bank Balance Sheet Constraints



Notes: This figure plots on the y-axis the quarter-end change in 1-week arbitrage spreads averaged over all G10 currencies, except for AUD and NZD, which do not exhibit quarter-end increases, and on the x-axis the quarter-end window dressing of European banks as defined in Equation (6). Each observation is a quarter-end and labeled on the figure. Variation in European bank window dressing explains 46 percent of the variation in quarter-end increases to CIP arbitrage spreads.

Table 1: Synthetic Dollar Funding by Currency and Institution and 3-month CIP Bases

	Demand	US Bank	EU Bank	AS Bank	US Fund	EU Fund	AS Fund	CIP Arb
Aggregate	1132	-362	-574	34	-197	986	112	31
AUD	128	-6	-77	-10	-27	-8	128	-9
CAD	58	0	-42	-7	56	-9	1	16
CHF	55	-17	-26	-0	-10	55	-2	58
DKK	29	-4	-17	-2	-5	29	-1	69
EUR	567	-247	-1	-79	-224	567	-16	37
GBP	293	-65	-127	-38	-56	293	-7	20
JPY	237	8	-223	156	73	-9	-5	51
NOK	23	-1	-21	-0	1	21	1	41
NZD	29	-18	-4	17	-3	-4	11	-9
SEK	50	-10	-35	-2	-3	50	1	34

Notes: This table display the average net positions in billions of institutions by currency from January 2013 to December 2020. For example, US banks had an average daily net EUR position of -247 billion, which means their average daily synthetic dollar lending against the EUR was 247 billion dollars. Demand is the sum of the absolute value of net positions across banks and funds divided by two so as to not double count long and short positions. Demand for synthetic dollar funding was in aggregate 1.1 trillion dollars. Aggregate is the sum of the net position by institution over all G10 currency pairs with respect to the US dollar. For example, European banks have an average daily net position of -574 billion, which means their average daily synthetic dollar lending against all G10 currencies was 574 billion. CIP Arb is the average 3-month CIP basis by currency.

Table 2: Changes to CIP Bases and and Interest Rate Spreads

	Dep Variable: Δ Forward Implied Rate				
	(1)	(2)	(3)	(4)	(5)
Horizon	1W	1W	1W	1M	2M
Δ Interest Rate Spread	0.813**	0.857**	0.992**	1.036**	0.982**
	(0.05)	(0.04)	(0.03)	(0.03)	(0.02)
Δ Interest Rate Spread x $1_{\Delta<0}$			-0.256**	-0.281**	0.009
			(0.10)	(0.09)	(0.03)
Time FE	N	Y	Y	Y	Y
Adjusted R^2	0.42	0.58	0.59	0.76	0.88
N	8,715	8,715	8,715	1,995	1,008

Notes: Table 2 shows the how the forward implied rate responds to changes in cross-currency interest rate spreads. The dependent variables is the change in the forward implied rate by currency for horizons of 1-week, 1-month, and 2-months. The explanatory variable is the change in interest rate spread (foreign minus US risk-free rate) for the corresponding horizon. A unit of observation is a change in the CIP basis for time t, currency c, and tenor τ. Standard errors are clustered by currency-tenor.

Table 3: Quarter-Crossing Change in Bank Net Position Responses to Changes in Fund Net Positions

	Dep Variable: Δ Net Position					
	US Bank		EU Bank		AS Bank	
QE	-0.310**		0.310		-0.001	
	(0.11)		(0.27)		(0.06)	
Δ Fund Net Pos	-0.311**	-0.309**	-0.638**	-0.639**	-0.052**	-0.053**
	(0.05)	(0.06)	(0.05)	(0.06)	(0.02)	(0.02)
Δ Fund Net Pos x QE	-0.515**	-0.540**	0.644**	0.645**	-0.129**	-0.107*
	(0.12)	(0.13)	(0.10)	(0.14)	(0.06)	(0.06)
Time FE	N	Y	N	Y	N	Y
Currency FE	Y	Y	Y	Y	Y	Y
Adjusted R^2	0.03	0.02	0.06	0.05	0.00	0.00
N	7,974	7,958	7,974	7,958	7,974	7,958

Notes: This table shows the difference in marginal market shares for synthetic dollar funding demanded by funds near quarter-end. I estimate marginal market shares by using 1-day changes in fund demand for synthetic dollar funding. The supply response of US, European and Asian banks differs depending on proximity to quarter-end. For intra-quarter variation in fund demand, US banks have a marginal market share of 31 percent. For the two-weeks leading up to quarter-end, US bank marginal market share increases by 52 percentage points. One unit of observation is a change in fund demand for synthetic dollar funding by currency and time. The marginal market shares are similar, when I include quarter and currency fixed effects. Standard errors are clustered by time.

Table 4: Quarter-end Increase to CIP Bases Ratios

Sample	Dep Variable: QE Δ CIP Basis						
		Q4		Q1-3			
	QE Cost	Coeff	Diff	Coeff	Diff	Coeff	Diff
Δ 2M x 1W Tenor	8.690	7.592**	-1.098	2.114**	-6.576**	1.718**	-6.972**
		(0.58)	(0.58)	(0.61)	(0.61)	(0.45)	(0.45)
Δ 2M x 2W Tenor	4.350	4.059**	-0.291	1.631**	-2.719**	1.465**	-2.885**
		(0.24)	(0.24)	(0.24)	(0.24)	(0.19)	(0.19)
Δ 2M x 3W Tenor	2.900	2.666**	-0.234	1.234**	-1.666**	1.185**	-1.715**
		(0.18)	(0.18)	(0.07)	(0.07)	(0.09)	(0.09)
Δ 2M x 1M Tenor	2.000	1.903**	-0.097	1.167**	-0.833**	1.118**	-0.882**
		(0.15)	(0.15)	(0.05)	(0.05)	(0.09)	(0.09)
Δ 2M x 2M Tenor	1.000						
Large Subsample		N		N		Y	
Currency FE		Y		Y		Y	
Tenor FE		Y		Y		Y	
Adjusted R^2		0.94		0.70		0.70	
N		100		360		180	

Notes: This table shows the term-structure of the quarter-end increases in CIP bases. The dependent variable is a change in quarter-end CIP basis for currency c and tenors 1-week to 1-month. The explanatory variable is the change in the same-currency 2-month quarter-end CIP basis. The coefficients report the effect for each tenor of a 1 bps increase in the 2-month quarter-end change in CIP basis. Each unit of observation is a quarter-end change in CIP basis by currency. I report the estimated coefficients in the columns labeled "Coeff" and a significance test of the difference, columns labeled "Diff", between the estimated term-structure slope and what would be implied by a quarter-end cost, column labeled "QE Cost" (see Section 4.1 for further details on the quarter-end cost slope to the term-structure). I estimate the slope of the term-structure to quarter-end changes in the CIP basis for quarters 1-3 in columns labeled "Q1-3" and for quarter 4 in columns labeled "Q4". Standard errors are clustered by time (each quarter-end event).

Table 5: Quarter-Crossing Change in Net Position and Arbitrage Spreads

Dep Variable:	QE Δ Quantity / Aggregate Demand				QE Δ CIP Basis
	Fund	US Bank	EU Bank	AS Bank	1 Week
Aggregate	-0.148	2.001**	-2.606**	0.452**	81.620**
	(0.30)	(0.34)	(0.25)	(0.18)	(24.72)
AUD	-0.330	-0.814	-0.248	0.707	4.544
	(0.57)	(0.84)	(0.72)	(0.60)	(5.14)
CAD	1.234	2.596	-0.480	-0.883*	37.047**
	(1.69)	(2.01)	(1.03)	(0.46)	(11.94)
CHF	-1.017*	4.601**	-5.281**	-0.337	144.169**
	(0.59)	(1.36)	(1.54)	(0.44)	(42.13)
DKK	-2.336**	2.420**	-4.692**	-0.065	103.882**
	(1.07)	(1.05)	(1.73)	(0.24)	(36.70)
EUR	-0.057	1.964**	-2.110**	0.085	111.270**
	(0.56)	(0.48)	(0.47)	(0.20)	(34.14)
GBP	-0.002	1.582**	-0.983	-0.600**	91.521**
	(0.40)	(0.70)	(0.74)	(0.29)	(27.29)
JPY	-0.618	4.177**	-8.403**	3.608**	169.798**
	(0.60)	(1.18)	(0.88)	(0.97)	(35.64)
NOK	0.417	0.040	0.250	0.126	66.718**
	(0.52)	(1.10)	(1.12)	(0.25)	(27.16)
NZD	-1.407**	-0.162	0.653	-1.956	-9.528**
	(0.53)	(1.07)	(1.13)	(1.34)	(3.69)
SEK	0.417	0.111	0.847	-0.541**	96.776**
	(0.46)	(0.85)	(0.98)	(0.19)	(35.09)

Notes: Table 5 shows the quantity and price changes over quarter-end by institution and currency. The quarter-end change in quantity computation is described in Section 5. In aggregate over the G10 currencies, European banks decrease their supply of synthetic dollar funding by 2.6 percent of aggregate demand at each quarter-end. The change in prices is the 1-week change in CIP basis at quarter-end as described in Section 4.2. On average, the 1-week CIP basis is 81.6 bps larger when it crosses quarter-end, relative to when it does not. Each unit of observation is a quarter-end. Standard errors are robust.

Table 6: Quarter-end Changes in CIP Bases and EU Bank Supply

(a) Effect on Quarter-end CIP Bases

	Dep Variable: QE Δ ln(CIP Basis)				
Tenor	1 Week	2 Weeks	3 Weeks	1 Month	2 Month
Δ EU Bank Supply	-0.421**	-0.348**	-0.278**	-0.223**	-0.217**
	(0.11)	(0.10)	(0.09)	(0.07)	(0.06)
Δ EU Bank Supply by Currency	0.012	0.018	0.013	0.011	0.006
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Adjusted R^2	0.42	0.35	0.27	0.26	0.34
N	113	114	114	115	115

(b) Effect on Forward Quarter-end CIP Bases

	Dep Variable: QE Δ ln(CIP Basis)				
Tenor	1 Week	2 Weeks	3 Weeks	1 Month	2 Month
Horizon	1 Week	1 Week	1 Week	1 Month	1 Month
Δ EU Bank Supply	-0.262**	-0.168**	-0.268**	-0.209**	-0.087**
	(0.08)	(0.07)	(0.08)	(0.08)	(0.04)
Δ EU Bank Supply by Currency	0.024**	0.025**	0.008	-0.002	-0.009
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Adjusted R^2	0.31	0.20	0.23	0.21	0.18
N	115	115	112	114	115

Notes: Table 6a shows the effect of European bank window dressing in aggregate and by currency on the quarter-end change in CIP bases. If at quarter-end European banks shrink their supply of synthetic dollar funding by an additional percent of aggregate demand, then the 1-week CIP bases increases by on average 42 percent. The specific currency in which European banks window dress has an insignificant effect on quarter-end increases to synthetic dollar funding rates. The effect is estimated separately by tenor (1-week to 2-months). Similarly, Table 6b shows the association between European bank window dressing and the forward CIP basis (see equation (8)). Each unit of observation is a quarter-end change in CIP basis by currency. Standard errors are clustered by time.