

# Markups to Financial Intermediation in Foreign Exchange Markets\*

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## **Abstract**

Even in deep, liquid asset markets, financial intermediaries may have market power. To identify the effects of market power on asset prices, I study foreign exchange market arbitrages implied by deviations from covered interest rate parity. Previous literature equates these arbitrages to the shadow price of a balance sheet constraint on foreign exchange dealer banks. My work identifies cross-sectional variation in arbitrage returns that is inconsistent with the standard balance sheet constraint channel. My identification strategy relies on cross-country differences in the enforcement of capital constraints that decrease competition near quarter-end. Using a model of imperfect competition, I decompose CIP arbitrage returns into balance sheet cost and markup. Markups explain a significant portion of CIP arbitrage returns.

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# 1 Introduction

To what extent do foreign exchange (FX) dealer banks have market power? For identification, I study arbitrages implied by deviations from covered interest rate parity (CIP). [Du, Tepper, and Verdelhan \(2018\)](#) document the existence of large, persistent deviations between US dollar borrowing rates and the synthetic dollar rate implied by FX markets. This difference is an arbitrage opportunity and implies a friction to risk-free financial intermediation. [Ivashina, Scharfstein, and Stein \(2015\)](#) explain how regulatory capital constraints may generate a CIP arbitrage equal to the shadow price of bank balance sheet space. The extant literature’s economic intuition is that price-taking FX dealer banks intermediate synthetic dollar demand until the CIP arbitrage is equal to their marginal balance sheet cost. My contribution is to highlight the ability of FX dealer banks to price above marginal cost. I identify this behavior using a regulatory supply shift that decreases the number of low cost FX dealer banks from 12 to 4 near quarter-end. This decrease occurs in the cross-section of tenors that span the quarter-end regulatory capital reporting date. As competition decreases, the JPY-USD arbitrage increases from on average 55 bps to 160 bps. This evidence suggests that markups due to imperfect competition may explain a significant portion of CIP arbitrage.

The leading explanation of CIP arbitrage is bank balance sheet constraints. The cost to arbitrage is expanding the size of the bank’s balance sheet. Non-US banks need to meet a minimum leverage ratio of 3% and US banks have a 5-6% requirement with the supplementary leverage ratio (SLR) ([BIS \(2014\)](#)). Due to costly equity financing, these capital constraints bind. One such cost to equity financing is debt overhang. [Admati, DeMarzo, Hellwig, and Pfleiderer \(2018\)](#) explain how banks prefer to shrink balance sheet exposure rather than raise equity to meet capital requirements. For a given amount of capital, a bank’s targeted leverage ratio implies a fixed amount of balance sheet space. The shadow price or cost to bank balance sheet space is the annualized return in excess of the risk-free rate required for the use of a bank’s balance sheet.

Under the assumption of perfect competition in asset markets, the cost to bank balance sheet space is an upper bound to arbitrage. Any price-taking bank would supply balance sheet space for a price (arbitrage) above cost. This interpretation is prevalent in the literature. In standard models of intermediary asset pricing, arbitrageurs are modeled as a unit mass of competitive agents ([He and Krishnamurthy \(2018\)](#) and [Gromb and Vayanos \(2010\)](#)). The literature has sought to identify sufficiently large balance sheet costs that may rule out the existence of profitable arbitrage. For example, [Andersen, Duffie, and Song \(2019\)](#) explain that short-term credit spreads make CIP arbitrage for many currency pairs unprofitable. Similarly, [van Binsbergen, Diamond, and Grotteria \(2019\)](#) estimate an interest

rate implied by SP 500 index put-call parity. They find that CIP arbitrage is about 40 bps smaller when adjusting for the spread between risk-free rates and the rate implied by put-call parity. Research on CIP arbitrage, such as [Du et al. \(2018\)](#), [Avdjiev, Du, Koch, and Shin \(2017\)](#), [Borio, Iqbal, McCauley, McGuire, and Sushko \(2018\)](#), interpret CIP arbitrage to be equal to the balance sheet cost of FX dealer banks.

The contribution of my paper is to nuance this equivalence between arbitrage and balance sheet cost. I hypothesize that banks marginal in CIP arbitrage have heterogeneous balance sheet costs. There are high-cost banks with balance sheet costs that are near-equal to CIP arbitrage. However, there are also well-capitalized banks with balance sheet costs below that of CIP arbitrage. These low-cost banks earn a positive spread in CIP arbitrage due to imperfect competition.

To empirically identify imperfect competition, I use a regulatory difference between the enforcement of US and non-US bank capital requirements. At a minimum, Basel III requires capital requirements to be enforced at quarter-end. However, more frequent calculations (month-end or daily averages) are permitted. US regulators enforce quarter-average capital requirements for US banks. In contrast, non-US bank regulators enforce quarter-end capital requirements. For a 3-month arbitrage held to maturity, there is no difference between a quarter-end or quarter-average capital requirement. The 3-month arbitrage has the same balance sheet effect. Alternatively, consider the effect of 1 unit of balance sheet allocated to a 1-week arbitrage that crosses quarter-end. The quarter-end balance sheet of the non-US bank increases by 1-unit. The quarter-average balance sheet of a US bank increases by 1/13th of a unit. Short-term CIP arbitrage that crosses quarter-end has a much smaller effect on the regulatory balance sheets of US banks than non-US bank. These regulatory differences imply distinct term-structures to US and non-US balance sheet cost.

The first contribution of this paper is to empirically test whether banks perfectly compete in supplying balance sheet capacity to CIP arbitrage. The null hypothesis is that CIP arbitrage is equal to the marginal bank's balance sheet cost. I test this hypothesis for CIP arbitrages in the JPY-USD and EUR-USD currency pairs. These currency pairs are the most liquid in the FX derivatives market and also tend to have one of the largest CIP bases ([BIS \(2019\)](#)). I consider tenors spanning from 1-week, 2-week, 3-weeks, 1-month, 2-month, and 3-months. This term-structure is important because quarter-average and quarter-end implied balance sheet costs differ across these tenors. The sample spans from 2014 Q3 through 2018 Q3. This sample covers the implementation of non-risk-weighted capital requirements under Basel III. I treat fourth quarters separately in a discussion in Appendix A because of year-end globally systemically important bank (G-SIB) capital assessments.

Is the term-structure to CIP arbitrage returns consistent with perfect competition? No.

The JPY-USD and EUR-USD CIP arbitrage returns have term-structures that are inconsistent with either US or non-US bank balance sheet cost. The quarter-crossing CIP arbitrages are too steep for US banks and too flat for non-US banks. If US banks are price takers, then US banks maximize profit by allocating balance sheet space to the largest CIP arbitrage return. The 1-week quarter-crossing JPY-USD CIP arbitrage is statistically significantly larger than all other JPY-USD and EUR-USD tenors. The quarter-crossing CIP arbitrages are upward sloping in tenor and therefore too steep for US bank balance sheet cost. Non-US banks have balance sheet costs that are amortized over contract maturity. If non-US banks are price takers, then they would allocate balance sheet space to the arbitrage with the largest spread (difference between return and balance sheet cost). The slope to quarter-crossing arbitrage returns is statistically significantly flatter than the slope to balance sheet cost for non-US banks. Therefore, price-taking non-US banks would only be active in the 3-month JPY-USD quarter-crossing CIP arbitrage.

Across currency, JPY-USD CIP arbitrages are on average statistically significantly larger than that of EUR-USD CIP arbitrage. Given 1 unit of scarce balance sheet space, a price-taking arbitrageur would prefer the JPY-USD CIP arbitrage. Under perfect competition, neither US banks nor non-US banks could be marginal for each tenor of JPY-USD and EUR-USD CIP arbitrage. To reconcile this tension between FX dealer bank balance sheet cost and the cross-section to arbitrage, I consider imperfect competition.

The second contribution of this paper is to estimate a model of imperfect competition in order to decompose arbitrage into components for balance sheet cost and markup. Models of imperfect competition in currency markets include [Farhi and Maggiori \(2017\)](#) for oligopolistic competition in the supply of reserve assets and [Azzimonti, De Francisco, and Quadrini \(2014\)](#) in the monopolistic supply of government debt. My model includes two types of FX dealer banks (US and non-US) that imperfectly compete in CIP arbitrage. The FX dealer banks strategically consider their price impact in allocating scarce balance sheet capacity to CIP arbitrage. Using the regulatory difference between US and non-US banks, I estimate balance sheet costs and customer demand elasticities from the term-structure of CIP arbitrage.

My model implies that US banks have dominant market share and earn large markups for short-term contracts that cross quarter-end. For 1-week quarter-crossing contracts, US banks earn an average spread of 108 bps. This markup is decreasing in tenor due to greater competition from non-US banks. For the 3-month CIP arbitrage, non-US banks and US banks compete resulting in small spreads of 4.5 bps for US banks and 18 bps for non-US banks. These findings highlight that markets are close to competitive when the four US and eight non-US banks compete. However, when the quarter-end capital regulation of non-US banks drives the number of low-cost providers down to four US banks, markups are large.

The third contribution is a counterfactual exercise, where I estimate CIP arbitrage in a market where non-US banks have quarter-average instead of quarter-end capital requirements. This counterfactual is relevant because bank regulators have become increasingly aware and critical of window-dressing incentives. The BIS issued a statement that quarter-end window-dressing undermines the efficacy of capital requirements and urged regulators to adopt quarter-average capital requirements ([Basel Committee on Banking Supervision \(2018\)](#)). In this counterfactual, the term-structure of CIP arbitrage is nearly flat. The quarter-crossing term-structure was driven by decreased competition due to the quarter-end balance sheet cost of non-US banks. The predominant effect of consistent quarter-average capital requirements is decreased supply from non-US banks. Without an intra-quarter regulatory constraint, non-US banks were low-cost providers for intra-quarter CIP arbitrage. In the counterfactual, non-US bank market share would have been 34% smaller and their average balance sheet cost 30 bps larger. On net, this decreased supply from non-US banks implies arbitrage returns would have been on average 25-32 bps larger. Non-US banks' CIP arbitrage profits would have been 49% smaller. In contrast, US bank CIP arbitrage profits would have been 173% larger.

My finding of imperfect competition among FX dealer banks informs models of financial intermediation. In frictionless models, a representative household is marginal in pricing assets and intermediaries are simply “veils” of household preferences. This frictionless benchmark cannot explain CIP arbitrage opportunities. We need a model with intermediary constraints, such as [Gabaix and Maggiori \(2015\)](#) in currency markets and more generally [Brunnermeier and Pedersen \(2008\)](#) and [He and Krishnamurthy \(2013\)](#). Within this class of intermediary asset pricing models, risk premia depend on the aggregate scarcity of intermediary risk bearing capacity. I empirically document that the concentration of capacity also matters in CIP arbitrage. FX dealer banks strategically withhold capacity in order to earn larger spreads. This evidence highlights another difference between marginal intermediaries and marginal households. Marginal intermediaries may have market power.

Understanding imperfect competition among financial intermediaries is important because intermediation is concentrated for a variety of markets. For example, [Siriwardane \(2018\)](#) documents that five dealers account for 65 percent of net selling in credit default swap (CDS) markets. In follow up work, [Eisfeldt, Herskovic, Rajan, and Siriwardane \(2018\)](#) estimate that removing the largest net supplier of CDS would increase CDS rates by 40%. In the US corporate bond market, 10-12 dealers account for 70% of the aggregate customer-dealer trading volume ([Bessembinder, Jacobsen, Maxwell, and Venkataraman \(2018\)](#)). However, for the average US corporate bond, the most active dealer accounts for 50% of the weekly trading volume ([Friewald and Nagler \(2016\)](#)). Depending on the degree to which customers

may substitute from one bond to another, financial intermediation in the US corporate bond market may be highly concentrated.

Following the introduction, I explain the empirical setting of CIP arbitrage in Section 2. Section 3 characterizes US bank and non-US bank marginal cost to CIP arbitrage. Section 4 provides motivating evidence of imperfect competition among FX dealers in CIP arbitrage. Within Section 5, I estimate the magnitude of markups using a model of imperfect competition. Using these estimates, I perform counterfactual analysis of bank capital requirements and their implications on CIP arbitrage returns. Section 6 concludes with a discussion of future research.

## 2 Empirical Setting and Data

### 2.1 FX Dealer Banks and CIP Arbitrage

I empirically study the FX arbitrages implied by CIP deviations. This market is an ideal setting to identify the effects of market power on asset prices. US and non-US banks are active financial intermediaries in the market. An established literature on CIP has documented the existence of large, persistent arbitrages in pricing of cross-currency forwards (Du et al. (2018)). These arbitrages exhibit substantial cross-sectional variation across currency pairs and tenors. Both of these elements are important for the identification strategy.

According to the EuroMoney FX survey, there are four major US banks and eight major non-US banks in the FX derivatives market. This survey captures a comprehensive representation of the wholesale FX trade. The 2018 survey covered 1,792 FX market customers, representing 46.87 trillion USD of demand in calendar year 2017. The four US banks include JP Morgan, Citigroup, Bank of America, and Goldman Sachs (in order of market share). In the 2017-2018 survey, these four US banks jointly had 32% of the market share in the spot and forward FX markets and 22% of the swap market.<sup>1</sup> The largest non-US banks include UBS, Deutsche Bank, HSBC, Standard Chartered, Barclays, BNP Paribas, Credit Agricole, and Société Générale (in order of market share). These eight non-US banks make up more than 28% of the spot and forward FX market and 46% of the swap market.<sup>2</sup> Over this period, rankings of the top banks are relatively stable.<sup>3</sup>

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<sup>1</sup>The next largest US FX dealer bank is Morgan Stanley, which has a market share of 2.25% in the spot and forward market 1.77% in the swap market.

<sup>2</sup>The next largest non-US FX dealer bank is Commerzbank, which has a market share of 2.16% in the spot and forward market and less than 1.28% in the swap market.

<sup>3</sup>Compared to the 2016-2017 survey, the sample of 12 banks is rather stable. The sample of US banks remain in the top 10 dealers and the sample of non-US banks remain in the top 15 dealers.

These US and non-US banks intermediate the market for forward contracts. A forward contract is an agreement today ( $t$ ) to exchange  $F_{t,\tau}$  units of foreign currency for US dollars at maturity ( $t + \tau$ ), where  $\tau$  is in units of quarters. The forward contract price implies a forward premium: the annualized interest rate implied by the difference between the forward and spot exchange rates:

$$\rho_{t,\tau}^f \equiv \frac{1}{4\tau}(f_{t,\tau} - s_{t,\tau}) \quad (1)$$

where  $f_{t,\tau}$  is the log forward exchange rate and  $s_{t,\tau}$  is the log spot exchange rate.

At the heart of forward pricing is CIP. The CIP condition follows from a no-arbitrage condition: the forward premium is equal to the cross-currency difference in risk-free rates. Denote the US dollar risk-free rate  $y^{\$}$  and the foreign risk-free rate  $y^f$ . The CIP condition is

$$\rho_{t,\tau}^f \equiv y_{t,\tau}^f - y_{t,\tau}^{\$}. \quad (2)$$

Prior to 2007, CIP approximately held. Since 2007, there have been persistent, large CIP violations for G10 currencies against the US dollar as documented in [Du et al. \(2018\)](#). Following their notation, define a CIP basis ( $x_{t,\tau}$ ) as the spread between the direct US dollar risk-free rate and the synthetic US dollar risk-free rate (foreign risk-free rate exchanged into US dollars):

$$x_{t,\tau}^f \equiv y_{t,\tau}^{\$} - (y_{t,\tau}^f - \rho_{t,\tau}^f). \quad (3)$$

This CIP basis implies an arbitrage opportunity. Suppose the CIP basis is negative: the direct USD risk-free rate is too low compared to the synthetic dollar rate. The arbitrage opportunity is to sell the forward and hedge the cash flows by borrowing USD, spot exchanging the USD to JPY and depositing the JPY until maturity. At maturity, exchange the JPY for USD at the forward exchange rate. Figure 1 illustrates how the arbitrage profit is  $-x_{t,\tau}^f > 0$ . Define an arbitrage return  $R_{t,\tau}^f$  to be the profit per unit notional:

$$R_{t,\tau}^f = |x_{t,\tau}^f|. \quad (4)$$

The absolute value of the CIP basis is equal to the CIP arbitrage return.

## 2.2 Data

The data for estimating the CIP basis is standard in the literature. From Bloomberg, I source spot currency exchange rates and forward premia at London closing rates. Following [Rime, Schrimpf, and Syrstad \(2017\)](#), I approximate the term-structure of currency risk-free borrowing rates using Overnight-Index-Swap (OIS) rates (also from Bloomberg at London

closing rates).

Empirically, I study the EUR-USD and JPY-USD currency pairs because of their liquidity<sup>4</sup> and tendency to be among the largest CIP arbitrage bases. Tenors include short-term maturities (1-week, 2-weeks, 3-weeks, 1-month, 2-month, and 3-month) such that the financial intermediation is empirically nearly risk-free. For longer maturities, counterparty risk may be of concern. For example, FX dealer banks have credit spreads of approximately 25 bps for maturities of 3-month or less. These credit spreads increase to 70 bps according to 5-year credit default swaps.<sup>5</sup>

For the EUR-USD and JPY-USD currency pairs, Figure 2 plots the 3-month CIP bases for a 10-day moving average from 2005 through 2018. From 2005 through 2006, the average EUR basis was -6 bps and the average JPY basis was -14 bps. During this period, bank balance sheet space was not scarce and CIP approximately held: the price for risk-free financial intermediation was nearly zero. During the financial crisis of 2008, CIP violations were large and volatile. A smaller increase in arbitrage returns occurred during the height of the European debt crisis in Fall 2011 and Spring 2012. Due to financial distress, no-arbitrage conditions systematically failed to hold. The literature on intermediary asset pricing explains the large returns to intermediation in periods of financial distress.<sup>6</sup>

The sample of interest focuses on the post-crisis period when CIP bases were especially large and persistent: 2014 Q3 through 2018 Q3. This sample covers the implementation of the SLR, a Basel III non-risk-weighted capital requirement. Note that all analyses treat fourth quarters separately in Appendix A due to year-end G-SIB evaluations. These year-end evaluations impact CIP bases because of heightened balance sheet constraints. For consistency, I focus on quarters 1-3, which are not subject to special year-end effects. Unlike the aforementioned periods of financial distress, this increase in arbitrage returns associated with capital regulation has persisted.

## 3 Marginal Cost of CIP Arbitrage

### 3.1 US and Non-US Balance Sheet Costs

Although CIP arbitrages are risk-free, they are balance sheet intensive. Compared to risky investment opportunities, arbitrage returns are smaller and use more balance sheet space per expected dollar of profit. Balance sheet space is scarce because of debt overhang. Basel

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<sup>4</sup>The EUR-USD and JPY-USD currency pairs have the top two largest FX derivatives volume according to BIS (2019).

<sup>5</sup>Data on short-term credit spreads are from Crane and data on 5-year CDS spreads are from Bloomberg.

<sup>6</sup>See He and Krishnamurthy (2018) for a survey of this literature.

III requires banks to meet a 3% non-risk-weighted capital ratio (BIS (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. The literature on CIP violations identifies these regulatory balance sheet constraints as the relevant limit to arbitrage (Du et al. (2018), Ivashina et al. (2015)). Admati et al. (2018) provides a theoretical explanation for why debt overhang incentivizes banks to sell assets rather than raise equity to meet capital requirements. Therefore, there exists a shadow price to bank balance sheet space, which constrains CIP arbitrage.

I formalize the implied balance sheet costs from bank capital requirements and assess their implications for CIP arbitrage. Basel III requires that national regulators minimally enforce quarter-end capital ratio compliance (BIS (2014)). US bank regulators enforce capital requirements based on quarter-average data. Regulators require US banks to be sufficiently well capitalized for the daily average balance sheet size of the quarter. A binding regulatory capital requirement for US banks implies a rate of return Lagrange multiplier to all balance sheet usage. For all CIP arbitrage, the US bank has a marginal balance sheet cost of

$$mc_{f,\tau}^{US} = mc^{US}, \quad (5)$$

where  $mc_{f,\tau}^{US}$  is the cost to a CIP arbitrage in currency  $f$  and tenor  $\tau$  and  $mc^{US}$  is the Lagrange multiplier to US bank balance sheet space. For a US bank, a one day position in the 1-week JPY-USD CIP arbitrage has the balance sheet effect as a on day position in a 3-month EUR-USD CIP arbitrage. This balance sheet cost equivalence across tenors depends on US banks optimally allocating balance sheet space within quarter. See Appendix B for a discussion of dynamic intra-quarter considerations.

In contrast, non-US banks have quarter-end capital requirements. Non-US regulators take a snapshot of the bank's balance sheet at quarter-end to assess capital adequacy (European Leverage Ratio Delegated Act). Effectively, regulators require non-US banks to be sufficiently well capitalized on 4 days of the year: March 31st, June 30th, September 30th, and December 31st. Therefore, non-US banks have a Lagrange multiplier to quarter-crossing balance sheet usage. This quarter-end balance sheet cost is amortized over the tenor of the contract. Define this quarter-crossing balance sheet cost for non-US banks to be  $mc_{QE}^F$  for a 3-month CIP arbitrage. For a 1-week CIP arbitrage that crosses quarter-end, this balance sheet cost is amortized over 1/13th of the time. Therefore the 1-week CIP arbitrage has a regulatory balance sheet cost that is 13 times as large as the 3-month CIP arbitrage. For intra-quarter CIP arbitrage, non-US banks do not have a regulatory constraint. However, there exist non-regulatory balance sheet costs such as funding value adjustment (Andersen et al. (2019)). These other balance sheet costs motivate the existence of a quarter-average balance sheet

cost, which I assume to be a constant rate of return across tenors. Therefore, non-US bank marginal cost for CIP arbitrage is

$$mc_{f,\tau}^F = mc^F + \frac{1}{\tau}mc_{QE}^F, \quad (6)$$

where  $mc_{QE}^F$  is the quarter-end component of non-US bank marginal cost (applies only for CIP arbitrages that cross quarter-end) and  $mc^F$  is the quarter-average component of non-US bank marginal cost (applies to all CIP arbitrage).

For each of the tenors in the data, Table 1 juxtaposes the balance sheet cost of US and non-US banks. US banks have constant marginal balance sheet costs across tenors. Non-US banks have two balance sheet cost components: a constant component across tenors  $mc^F$  and a quarter-end component  $MC_{QE}^F$  with term-structure  $1/\tau$ .

### 3.2 FX Dealer Bank Balance Sheet Window Dressing

I empirically test whether FX dealer banks behave in a manner consistent with their regulatory balance sheet costs. Since non-US banks have quarter-crossing balance sheet costs, I hypothesize that non-US banks window-dress. Window dressing is the shrinking of balance sheets near quarter-end to appear better capitalized to regulators. For US banks, I hypothesize no window dressing because US banks have no regulatory incentive to window-dress. I empirically test these hypotheses using data on short-term borrowing from US MMFs.<sup>7</sup>

At the end of each quarter, the 8 non-US banks decrease their short-term borrowing (less than 3-months) from US MMFs by about 80 billion USD. This decrease is economically large: 21% of their average short-term borrowing from US MMFs. This window-dressing behavior is evidence that non-US banks behave in a manner consistent with a quarter-end balance sheet constraint. On average, the 4 US banks borrowed 130 billion USD at maturities less than 3-months over the sample (see Figure 3). At quarter-end, borrowing decreased by approximately 5 billion USD (economically and statistically insignificant). I find no evidence of within-quarter trends to US banks managing their short-term borrowing. This lack of within-quarter trends to balance sheet size is consistent with a quarter-average balance sheet cost.

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<sup>7</sup>At a monthly frequency, US MMFs report portfolio holdings to the Securities and Exchange Commission (SEC). Crane Data aggregates and formats these reports into a dataset

## 4 Motivating Evidence of Imperfect Competition

In this section, I empirically test the joint hypothesis of price-taking and US or non-US banks active in CIP arbitrage across the term-structure. These two priors are prevalent in the literature. The FX cross-currency forward market is one of the largest, most liquid markets in the world. The BIS (2019) estimates that approximately \$1 trillion in net notional trades daily. By equating the CIP arbitrage return to a balance sheet cost, the literature implicitly assumes price-taking arbitrageurs. Furthermore, FX dealer banks are considered to be the marginal investors for CIP arbitrage (Rime et al. (2017)). Industry sources suggest that US and non-US banks are marginal for the JPY-USD CIP arbitrage. For example, in a Risk.net article, “FX swaps to avoid year-end basis blowout, banks say,” Thomas Pluta (global head of JP Morgan FX swaps) is quoted describing how Japanese clients of JP Morgan roll JPY-USD synthetic dollar positions.

Price-taking banks allocate the marginal unit of balance sheet space to the arbitrage with the largest spread (return minus marginal cost). Therefore, I may test whether the term-structure to CIP arbitrage is consistent with US or non-US bank balance sheet costs. I consider the following three hypotheses: marginal US banks, marginal non-US banks, and a mix of marginal US and non-US banks. By marginal, I mean that the bank is the low-cost arbitrageur and allocating balance sheet space across the term-structure to CIP arbitrage.

### 4.1 Marginal US Banks

The first hypothesis is that US banks are the lowest cost arbitrageurs. Suppose a US bank has 1 unit of balance sheet space to allocate. The US bank chooses an allocation  $q_{f,\tau}^{US}$  for CIP arbitrage currency  $f$  and tenor  $\tau$ . The profit of the US bank is

$$\pi^{US} = \sum_{f,\tau} q_{f,\tau}^{US} (R_{\tau}^f - mc^{US}) \quad (7)$$

subject to  $q_{f,\tau}^{US} \geq 0$  and  $\sum_{f,\tau} q_{f,\tau}^{US} = 1$ . Since US bank marginal cost is constant across currencies and tenors, the price-taking US bank maximizes profit by allocating all of its balance sheet space to the largest CIP arbitrage return. Therefore, for US banks to be marginal across the term-structure, CIP arbitrage returns need to be constant. Figure 4 Panel A illustrates a term-structure, where US banks are active and the low-cost arbitrageur.

Empirically, there is cross-sectional variation in CIP arbitrage across tenors and currencies. On average, the quarter-crossing JPY-USD arbitrages have the largest returns. These arbitrage returns are statistically significantly decreasing in tenor (Table 2 Panel A). The

arbitrage returns are on average 163 bps for the 1-week contract, 77 bps for the 1-month contract, and 56 bps for the 3-month contract. This variation is inconsistent with the hypothesized constant term-structure of a marginal US bank. The cross-sectional variation to CIP arbitrage rejects hypothesis 1. Price-taking US banks cannot be active in CIP arbitrage across the term-structure.

## 4.2 Marginal Non-US Banks

The second hypothesis is that non-US banks are the low-cost arbitrageurs. Suppose a non-US bank has one unit of quarter-crossing balance sheet capacity. The non-US bank chooses an allocation  $q_{f,\tau,QE}^F$  for quarter-crossing CIP arbitrage. The profit of the non-US bank is

$$\pi^F = \sum_{f,\tau} q_{f,\tau,QE}^F (R_{\tau,QE}^f - mc^F - \frac{1}{\tau} mc_{QE}^F) \quad (8)$$

subject to  $q_{f,\tau,QE}^F \geq 0$  and  $\sum_{f,\tau} q_{f,\tau,QE}^F = 1$ . The non-US bank maximizes profit by allocating all of its balance sheet space to the quarter-crossing arbitrages with the greatest spread (return minus marginal cost). Figure 4 Panel B illustrates a term-structure of quarter-crossing arbitrage returns, where non-US banks are marginal.

Empirically, at first glance, the term-structure to CIP arbitrage appears to be consistent with non-US bank marginal cost. The term-structure to quarter-crossing CIP arbitrage illustrated in Figure 5 for the JPY-USD and EUR-USD currency pairs appear similar to Figure 4 Panel B. However, upon closer inspection, the term-structure to quarter-crossing CIP arbitrage is too flat to be consistent with non-US bank marginal cost.

The intra-quarter CIP arbitrages are on average approximately 35-45 bps for the JPY-USD. Suppose a non-US bank is marginal across the intra-quarter CIP arbitrage opportunities. The upper bound to the non-US banks' quarter-average balance sheet cost is the smallest intra-quarter arbitrage ( $mc^F \leq \min_{\tau}(R_{\tau,NQE}^f)$ ). Define a quarter-crossing premium

$$\phi_{\tau}^f = R_{\tau,QE}^f - \min_{\tau}(R_{\tau,NQE}^f) \quad (9)$$

For a non-US bank to be marginal across the term-structure, then the quarter-crossing premium ( $\phi_{\tau}^f$ ) needs to be equivalent to the non-US bank's quarter-end balance sheet cost. I estimate  $\phi_{\tau}^f$  for the sample and empirically test whether the ratio  $\phi_{\tau}^f/\phi_{3M}^f$  is statistically significantly different from  $1/\tau$ .<sup>8</sup> Table 2 Panel A and B report that  $\phi_{\tau}^f/\phi_{3M}^f$  is statistically

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<sup>8</sup>For the 1-week prior to quarter-end, there is no arbitrage return that does not cross quarter-end. To address this problem, I use lagged data: the previous week's 1-week arbitrage return that does not cross quarter-end.

significantly flatter than  $1/\tau$  for all tenors and for both the JPY-USD and EUR-USD. The quarter-crossing premium for the 1-week JPY-USD CIP arbitrage is 5.36 times as large as the 3-month quarter-crossing premium. This difference is less than half of the 13 times difference implied by  $1/\tau$ . The term-structure to quarter-crossing CIP arbitrage is too flat for non-US banks. A price-taking non-US bank would maximize profit by allocating all of its quarter-crossing balance sheet space to the 3-month JPY-USD CIP arbitrage.

### 4.3 A Mix of Marginal US and Non-US Banks

The third hypothesis is a mix of marginal US and non-US banks. US banks are potentially the low-cost providers at short maturities, where non-US banks have high marginal costs. Non-US banks are potentially the low-cost providers at long maturities. Effectively, the mixed case is a capped version of the term-structure of non-US bank marginal cost. Figure 4 Panel C illustrates this term-structure of arbitrage returns.

The hypothesis of a mix of US and non-US banks implies a quarter-crossing term-structure that is flat for short maturities and decreasing for longer maturities. Suppose a split where US banks are the low-cost providers for the 1-week quarter-crossing arbitrage and non-US banks are low-cost providers for the 2-week to 3-month arbitrages. For price-taking non-US banks to be indifferent between the 2-week to 3-month arbitrages, quarter-crossing premia need to be decreasing by  $1/\tau$  with tenor. Table 2 Panel A shows that the term-structure to  $\phi_\tau^f$  is statistically significantly flatter than  $1/\tau$ . Therefore, non-US banks would prefer to allocate all of their balance sheet capacity to the 3-month CIP arbitrage. We may reject this split of marginal US and non-US banks. Suppose an alternative split where US banks are the low-cost provider for the 1-week and 2-week quarter-crossing arbitrage and non-US banks are low-cost providers for the 3-week to 3-month arbitrages. We may reject this split because the 1-week CIP arbitrage is statistically significantly larger than the 2-week arbitrage. Price-taking US banks would prefer to allocate all of their balance sheet capacity to the 1-week quarter-crossing CIP arbitrage. Since the 1-week JPY-USD CIP arbitrage is significantly larger than all other arbitrages, we may reject any mix of marginal, price-taking US and non-US banks.

### 4.4 Cross-Currency Evidence

Holding tenor constant, price-taking FX dealer banks maximize profit by allocating scarce balance sheet space to the largest CIP arbitrage return. The balance sheet cost to JPY-USD and EUR-USD CIP arbitrage is equivalent. Therefore, for FX dealer banks to be marginal in both JPY-USD and EUR-USD CIP arbitrage, returns need to be equal.

There is a significant level difference between the arbitrage returns for JPY-USD and EUR-USD currency pairs. On average JPY-USD arbitrage returns are statistically significantly greater than EUR-USD arbitrage returns across the term-structure. This implies that price-taking FX dealer banks are not marginal in EUR-USD arbitrage. Allocating scarce balance sheet space to an EUR-USD arbitrage is a misallocation, inconsistent with profit maximization. For example, the FX dealer bank could on average earn an additional 25 bps by switching from a 1-month quarter-crossing EUR-USD arbitrage to a JPY-USD arbitrage.<sup>9</sup>

## 4.5 The Need for a Model

The empirical CIP arbitrage term-structures are not consistent with price-taking US or non-US bank balance sheet costs. The slope of arbitrage returns with respect to tenor is too steep for US banks and too flat for non-US banks. This holds for the JPY-USD and EUR-USD arbitrages. Furthermore, there is a significant level difference, implying that price-taking banks would only engage in the JPY-USD arbitrage. For a discussion of the extraordinary conditions by which FX dealer banks could be price-takers and marginal in the cross-section of CIP arbitrage, see Appendix C.

Imperfect competition presents an alternative framework of thinking about CIP arbitrage and bank balance sheet costs. Depending on competition and customer demand elasticity, FX dealer banks may charge heterogeneous markups by currency and tenor. Markups due to imperfect competition is a possible explanation of the cross-sectional variation to CIP arbitrage. To understand the extent to which imperfect competition may explain this cross-sectional variation necessitates a model. In the following section, I develop a model to assess the extent to which imperfect competition may reconcile the differences between arbitrage returns and balance sheet costs.

# 5 Imperfect Competition in CIP Arbitrage

## 5.1 A Model of CIP Arbitrage

In this section, I calibrate a model of CIP arbitrage that recovers FX dealer bank balance sheet costs. I use my model to decompose arbitrage returns into cost and markup and to simulate the effects of counterfactual bank capital regulation.

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<sup>9</sup>On average, EUR-USD CIP arbitrages are dominated by JPY-USD CIP arbitrages. At the daily frequency, 87% of 1-week quarter crossing arbitrage returns are larger for the JPY-USD than the EUR-USD; 93% of 3-month arbitrage returns are larger for the JPY-USD than the EUR-USD.

FX dealer banks Cournot compete in supplying homogeneous cross-currency forwards in separate markets by tenor  $\tau$ . The demand for cross-currency forwards is given by  $R_\tau(q_\tau)$  where  $R_\tau$  is the price (arbitrage return) for tenor  $\tau$  and  $q_\tau = q_{\tau,1} + \dots + q_{\tau,N}$ , where  $q_i$  is bank  $i$ 's supply and there are  $N$  banks. FX dealer banks have constant marginal cost  $mc_{i,\tau}$  in quantity, but marginal cost may vary by tenor. For each tenor  $\tau$ , if bank  $i$  chooses quantity  $q_{i,\tau}$  and all other banks in total produce  $q_{-i,\tau}$ , then profits of bank  $i$  are

$$\pi_{i,\tau}(q_{i,\tau}, q_{-i,\tau}) = (R_\tau(q_\tau) - mc_{i,\tau})q_{i,\tau} \quad (10)$$

The Cournot competition equilibrium is a Nash equilibrium in quantities, which is determined by the first order conditions of all  $N$  banks. Maximizing profit  $\pi_{i,\tau}$  with respect to  $q_{i,\tau}$ , bank  $i$ 's first order condition is

$$q_{i,\tau}R'_\tau(q_\tau) + R_\tau(q_\tau) - mc_{i,\tau} = 0 \quad (11)$$

From this first order condition, I derive the two equations that I bring to the data. First is the basic Cournot oligopoly pricing formula (Shapiro (1989))

$$\frac{R_\tau(q_\tau) - mc_{i,\tau}}{R_\tau(q_\tau)} = \frac{s_{i,\tau}}{\epsilon_\tau} \quad (12)$$

where  $s_{i,\tau} \equiv q_{i,\tau}/q_\tau$  is bank  $i$ 's market share for tenor  $\tau$  and  $\epsilon_\tau = -R_\tau(q_\tau)/(q_\tau R'_\tau(q_\tau))$  is demand elasticity.

The second is a market share expression, derived from dividing the first order condition of bank  $i$  with the sum of all bank first order conditions:

$$s_{i,\tau} = \left(\frac{1}{N}\right) \left(\frac{R_\tau - mc_{i,\tau}}{R_\tau - \bar{m}c_\tau}\right) \quad (13)$$

where  $\bar{m}c_\tau \equiv (1/N) \sum_i mc_{i,\tau}$  is average marginal cost across all banks.

## 5.2 Estimation and Identification

I define a period in my model to be the arbitrage returns just prior and after each quarter-end of my sample. In each period, there are 11 arbitrage returns: six quarter-crossing CIP arbitrages for tenors 1-week to 3-months and five intra-quarter CIP arbitrages for tenors 1-week to 2-months. I estimate the six quarter crossing arbitrage returns using a three day average prior to quarter-end. Similarly, I estimate the five intra-quarter CIP arbitrages using a three day average just after each quarter-end. For each period, I estimate my model.

### 5.2.1 FX Dealer Bank Supply.

Although a term-structure of daily price data is available, quantity and market share data is not publicly available. European regulators have quantity data for FX dealer banks residing in the European Union. In future work, I hope to estimate a more sophisticated model of competition among FX dealer banks using quantity data. For now, due to data limitations, I use a Cournot model of FX dealer bank competition.

From survey data, I estimate the number of banks active in CIP arbitrage: 4 US banks and 8 non-US banks. Due to data limitations, I model these banks as symmetric within each group. Following the regulatory balance sheet cost micro-foundation in Section 3, I parameterize US and non-US bank marginal cost (Table 1). The assumption of constant marginal cost in quantity is plausible because CIP arbitrage is a small fraction of the banks' aggregate balance sheets.

US bank marginal cost  $mc^{US}$  is constant across tenors because of the quarter-average capital requirement constraint. The non-US bank's balance sheet cost has a quarter-average component  $mc^F$  and a quarter-end component. The quarter-end component has a term-structure of  $1/\tau$  corresponding to the amortization of the multiplier on the quarter-crossing constraint  $mc_{QE}^F$ . The quarter-end balance sheet cost is equal to zero if the arbitrage is intra-quarter.

### 5.2.2 Customer Demand.

Assuming that customers are segmented by tenor restricts them from substituting across tenors. At first glance, this assumption seems stark given the large differences between the quarter-crossing CIP arbitrage returns, but a simple computation shows that it is not so. Consider a customer that needs a 1-week JPY-USD forward for a period that crosses quarter-end. Suppose the customer could substitute between the 1-week forward and the 1-month forward. For the 1-week forward, the customer incurs a cost of 163 bps. For the 1-month forward, the customer holds the contract for 1-week and then sells the remaining 3-week contract. The 1-month quarter-crossing contract arbitrage return is 77 bps. The residual 3-week contract no longer crosses quarter-end and has an arbitrage return of 38 bps. The customer's cost to using a 1-month contract for 1-week over quarter-end is 156 bps ( $156 = 4(77 - 38)$ ). The customer could potentially save 7 bps by substituting into the 1-month forward, but this savings is small and the trading strategy involves risk. More generally, [Du, Hébert, and Huber \(2019\)](#) document a small risk premium to these calendar spread trades of approximately 5 bps. Thus, the tenor restriction is not a substantial restriction.

I assume that demand elasticity may differ by tenor, but not by whether the contract crosses quarter-end. This assumption is important because my model cannot distinguish

between the slope to quarter-crossing demand elasticity by tenor and non-US bank quarter-end balance sheet costs. In making this assumption, I am fully attributing the quarter-end increase in CIP arbitrage returns to a non-US bank cost shock. Insofar as demand for cross-currency forwards is more inelastic for quarter crossing contracts, I am overestimating the marginal cost of non-US banks. Note that this does not bias the marginal cost and markup estimates for US banks. Furthermore, US banks pricing the elasticity of demand is evidence of imperfect competition.

### 5.2.3 Identification.

With these assumptions, the model is overidentified with 11 arbitrage returns and 9 parameters to estimate for each quarter. The 11 arbitrage returns per quarter correspond to 5 tenors (1-week, 2-week, 3-week, 1-month, 2-month) that cross or do not cross quarter-end and a 3-month arbitrage return that always crosses quarter-end. The 9 parameters include marginal cost for US banks ( $mc_{US}$ ) and non-US banks ( $mc^F$  and  $mc_{QE}^F$ ) and a demand elasticity for each tenor ( $\epsilon_\tau$ ). I estimate parameters that minimize the root-mean-square error to the model's fit to arbitrage returns. Note that given balance sheet cost parameters, equation 13 identifies the market shares of US and non-US banks.

For the arbitrage returns that do not cross quarter-end, there is no variation in marginal cost by tenor. Denote CIP arbitrage returns that are intra-quarter with  $R_{\tau,NQE}(q_\tau)$ . The Cournot oligopoly pricing formula (equation 12) for intra-quarter arbitrage is

$$\frac{R_{\tau,NQE}(q_\tau) - mc_i}{R_{\tau,NQE}(q_\tau)} = \frac{s_{i,\tau}}{\epsilon_\tau} \quad (14)$$

for all  $i$  banks. Balance sheet costs are constant across tenors in intra-quarter CIP arbitrage. Therefore, the term-structure to intra-quarter CIP arbitrage identifies the term-structure variation to demand elasticity ( $\epsilon_\tau$ ).

The term-structure to arbitrage returns that cross quarter-end identify US and non-US bank marginal cost. Denote CIP arbitrage returns that are quarter-crossing with  $R_{\tau,QE}(q_\tau)$ . Consider a US bank  $i$  with constant balance sheet cost across quarter-crossing tenors. US bank  $i$ 's first order condition implies

$$\frac{R_{\tau,QE}(q_\tau) - mc_i}{R_{\tau,QE}(q_\tau)} = \frac{s_{i,\tau}}{\epsilon_\tau}. \quad (15)$$

Therefore, a steeper term-structure to quarter-crossing CIP arbitrage implies larger markups and market share for US banks. Since there are two symmetric types of banks, greater US bank market share implies smaller non-US bank market share. Through equation 13, non-US

bank market share identifies non-US bank marginal cost. Therefore, a steeper term-structure to quarter-crossing CIP arbitrage implies a larger quarter-end component to non-US bank marginal cost ( $mc_{QE}^F$ ).

## 5.3 Estimation Results

### 5.3.1 Marginal Cost Estimates.

Using my Cournot model, I recover estimates of marginal cost, markups, market shares, and demand elasticities. Figure 6 plots the average marginal cost estimates and the term-structure of JPY-USD CIP arbitrage. The average US bank marginal cost is 50.5 bps ( $MC^{US}$ , solid blue line). The US bank's marginal cost is well approximated by the 3-month JPY-USD CIP arbitrage return (average of 56 bps). The average non-US bank balance sheet cost has a quarter average component of 25.6 bps ( $MC^F$ , dashed red line) and a quarter-end component of 11.4 bps ( $MC_{QE}^F$ ). For contracts that cross quarter-end, the non-US has a steep upward sloping balance sheet cost ( $MC_{\tau}^F$ , red line). For detailed marginal cost estimates broken down for each quarter, see Table 3 Panel A.

For intra-quarter CIP arbitrages, US bank marginal cost tends to be higher than the arbitrage return. Therefore, US banks on average have approximately zero market share in intra-quarter CIP arbitrage (Table 3 Panel B). Non-US banks dominate and have nearly 100% market share in intra-quarter CIP arbitrage. Intra-quarter arbitrage returns average between 34-43 bps across tenors. I estimate non-US banks to have an average intra-quarter balance sheet cost of 25.6 bps, which implies a spread of between 8-17 bps.

For quarter-crossing CIP arbitrages, market share shifts from US banks to non-US banks as tenor increases. For 1-week CIP arbitrage, non-US banks tend to have balance sheet costs greater than the arbitrage return. US banks are the low-cost arbitrageurs for the 1-week contract and on average have 88% market share. Competition is low with 4 US banks dominating the market, resulting in an average spread of 108 bps. For the 3-month CIP arbitrage, non-US banks are the low-cost provider with an average 3-month balance sheet cost of 37 bps. The eight non-US banks have 90% of the 3-month market and earn an average spread of 18 bps. US banks are the high-cost arbitrageur for the 3-month CIP arbitrage with a balance sheet cost of 50.5 bps. US banks have 10% of the 3-month arbitrage market share and price nearly competitively: a small spread of 4.5 bps. In between the 1-week and the 3-month CIP arbitrages, competition increases as non-US bank marginal cost decreases. Markups on average decrease and market share becomes more disperse among the 12 competing US and non-US banks. Recall that the slope to quarter-crossing CIP arbitrage is too steep for US cost and too flat for non-US bank cost. Markups to CIP arbitrage due

to imperfect competition can explain this intermediate slope.

### 5.3.2 External Validity Tests of Marginal Cost Estimates.

To externally validate my model’s estimates of FX dealer bank marginal cost, I use short-term credit spreads. The non-US banks’ intra-quarter balance sheet costs are estimated to be on average 25.6 bps and closely track the intra-quarter 1-week CIP arbitrage return. [Andersen et al. \(2019\)](#) explain that due to debt overhang, FX dealer banks have balance sheet costs equal to at least their short-term credit spread. For non-US banks, this short-term credit spread may explain their non-regulatory balance sheet costs for intra-quarter CIP arbitrage. I define this credit spread:

$$CS_{t,F} = \frac{1}{v_{t,F}} \sum_{i,j} v_{t,\tau,i,j} (\gamma_{t,\tau,i,j} - y_{t,\tau}^{\$}) \quad (16)$$

where  $v_{t,F} = \sum_{i,j} v_{t,\tau,i,j}$  is the total dollars borrowed by all non-US banks for quarter  $t$ ,  $v_{t,\tau,i,j}$  is the dollars borrowed by bank  $i$  for unsecured issuance  $j$ ,  $\gamma_{t,\tau,i,j}$  is rate for that issuance, and  $y_{t,\tau}^{\$}$  is the dollar risk-free rate.

Empirically, I estimate the average credit spread for the 8 non-US FX dealer banks using borrowing rates from US MMFs. I use data on unsecured borrowing: interest rate on certificates of deposits and commercial paper. I estimate a dollar weighted average of credit spreads across maturities less than 3-months. The average credit spread for non-US banks over the sample is 26 bps. For a time-series comparison, I use an extended sample to span quarterly data from 2011 to 2018. Figure 7 illustrates how the short-term credit spread very closely tracks intra-quarter 1-week JPY-USD CIP arbitrage returns. There is a gap that opens up in 2016, which coincides with a regulatory reform in US MMFs. [Anderson, Du, and Schlusche \(2019\)](#) explain that this MMF regulatory shock decreased the supply of USD funding to foreign banks by 750 billion USD. Scarcity in USD funding implies that credit spreads estimated from US MMFs may underestimate the marginal cost to CIP arbitrage.

On average, US bank short-term credit spreads are 25 bps, similar to non-US banks. However, US bank balance sheet cost is on average 50 bps. For US banks, marginal cost is much larger than credit spreads because the quarter-average regulatory balance sheet constraint applies. For each quarter in the sample, my model estimates that US bank marginal cost is larger than that of US bank short-term credit spreads.

### 5.3.3 Demand Elasticity Estimates.

Demand elasticity estimates imply that customers are very inelastic in their demand for cross-currency forwards. On average, demand elasticity varies from 0.2 to 0.45 in the time series

and the term-structure is nearly flat. These very inelastic estimates of demand are consistent with customer using cross-currency forwards to fund long-term USD investments with short-term borrowing. [Ivashina et al. \(2015\)](#) theorize that credit quality shocks to foreign financial institutions may constrain their access to wholesale funding and generate inelastic demand for cross-currency forwards. This funding demand for cross-currency forwards explains why demand is very inelastic. An inability to roll over the funding position would require the customer to sell their potentially illiquid USD investment.

#### 5.3.4 Implications for EUR-USD CIP Arbitrage Returns.

Turning from the JPY-USD to the EUR-USD, I re-estimate my model of imperfect competition over the sample from Q3 2015 through Q3 2018.<sup>10</sup> This sample covers the quarters for which the EUR-CIP arbitrage exhibited quarter-end increases to arbitrage. Table 4 Panel A presents the estimates of marginal cost and demand elasticity by quarter. On average banks marginal in EUR-USD arbitrage have balance sheet costs that are smaller than that of banks marginal in JPY-USD arbitrage. US banks active in EUR-USD arbitrage have an average balance sheet cost that is about 10 bps smaller than that of US banks active in JPY-USD arbitrage. Non-US banks active in EUR-USD arbitrage have on average half as large of a quarter-end regulatory balance sheet cost as that of banks marginal in JPY-USD arbitrage. This evidence implies that banks are not homogeneous in their balance sheet costs. The FX dealer banks active in JPY-USD and EUR-USD arbitrage have lower balance sheet costs than those that are just active in JPY-USD arbitrage. Depending on the number of fewer banks active in EUR-USD arbitrage, my model estimates of demand elasticity varies. Figure 8 illustrates how the average demand elasticity estimates across quarters and tenors increases as the number of US and non-US banks active in EUR-USD arbitrage decreases. The EUR-USD arbitrage is smaller because customer demand is more inelastic and fewer, better capitalized banks with lower balance sheet costs are active in EUR-USD arbitrage.

### 5.4 Counterfactual Scenario

Using these Cournot model estimates, I consider the counterfactual where non-US banks only have quarter-average capital requirements. This counterfactual is empirically relevant because the BIS is urging national regulators to address the problem of window-dressing ([Basel Committee on Banking Supervision \(2018\)](#)). Window-dressing is the process by which non-US banks shrink intra-quarter balance sheets to meet quarter-end capital requirements. Section 3 on bank capital requirements explains how non-US banks have the incentive to

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<sup>10</sup>I exclude Q4 following the prior explanation of year-end G-SIB evaluations

window-dress due to quarter-end balance sheet constraints. Requiring non-US banks to instead meet quarter-average capital requirements would remove the incentive to window-dress.

In this counterfactual, I hold fixed the US bank marginal cost, demand elasticities, and the average split between US and non-US bank market share for quarter-crossing CIP arbitrage. I use the average split for quarter-crossing arbitrage because this is the market share that meets the non-US banks’ regulatory capital requirements. Effectively, I am assuming that level of the regulatory capital requirement does not change; only the enforcement changes. The non-US bank market share decreases in aggregate because they no longer dominate intra-quarter CIP arbitrage. On average across tenors, non-US banks have 54% of market share for CIP arbitrage that crosses quarter-end.<sup>11</sup> Using these model parameters (US market marginal cost, demand elasticities, and market share), I estimate the counterfactual arbitrage returns across tenors and non-US bank balance sheet cost.

The counterfactual CIP arbitrage returns are approximately constant across tenors and average 83 bps. Figure 9 plots the counterfactual JPY-USD CIP arbitrage term-structure against the data. The short-term quarter-crossing CIP arbitrages less than 1-month decrease, but all other arbitrage returns on average increase. For the 1-week quarter-crossing contract the arbitrage return decreased by 80 bps. Underlying this decrease is an increase in competition. For the 1-week contract, non-US bank market share increased from 22% to 54%. For the 3-month contract, the counterfactual arbitrage return increased by approximately 30 bps. This increase reflects the increase in cost to non-US banks. For the 3-month contract, non-US bank market share decreased from 90% to 54%. Note that since US and non-US bank marginal cost are constant across tenors, their market shares are also constant (see equation 13).

To assess the aggregate change in CIP arbitrage returns, I construct a 3-month weighted average of contracts that cross and do not cross quarter-end by tenor.

$$\bar{R}_\tau = \tau R_{\tau, QE} + (1 - \tau) R_{\tau, NQE} \quad (17)$$

For example, the quarter-average 1-week CIP arbitrage has 1/13 weight on the quarter

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<sup>11</sup>Averaging across tenors assumes that CIP arbitrage volumes are approximately equal across tenors. According to the BIS (2019), there is 269 billion in net daily average turnover in cross-currency forwards with maturities less than or equal to 1-week. For maturities over 1-week up to 1-month, there is 291 billion in volume. For maturities over 1-month up to 3-months, there is 322 billion in volume. Insofar volume is proportional to net CIP arbitrage, the 1-week CIP arbitrage is 30% of the total market rather than an equal weighted 17% implied by equal weighting. The quarter-end market share of non-US banks is smallest for 1-week CIP arbitrage. Correcting for greater weight on the 1-week contract implies that the counterfactual non-US bank market share is smaller. By simply averaging across tenors, I underestimate the decrease in non-US bank market share and underestimate the counterfactual increase in arbitrage returns.

crossing arbitrage return and 12/13th weight on the intra-quarter arbitrage return. This is equivalent to rolling the 1-week contract repeatedly to span 3-months. These quarter-average arbitrage returns increase by 25-32 bps across the term-structure.

On average across tenors, US banks have an estimated 12% of the 3-month averaged market share in the baseline model. Despite having 88% market share in the 1-week quarter-crossing arbitrage, this period is only 1/13th of the quarter. For the intra-quarter 1-week CIP arbitrage, US banks on average had 3% market share. In the counterfactual setting, non-US banks are much more constrained and US banks have an average market share of 46%. In the counterfactual, US banks have 34% more market share and arbitrage returns are 25-32 bps larger. On average, US bank CIP arbitrage profit is 173% larger in the counterfactual than the baseline.<sup>12</sup>

For non-US banks, the quarter-end capital requirement enabled window dressing: a large intra-quarter market share and small quarter-end market share. Disallowing this window dressing implies an average market share decrease from 88% to 54% and a quarter-average balance sheet cost increase of 30 bps. The counterfactual estimate of non-US bank balance sheet costs is 66 bps. In the counterfactual, non-US banks have 34% less market share and balance sheet costs are 30 bps larger. On average, non-US bank CIP arbitrage profits decrease by 49%. This decrease in non-US bank profit is primarily due to a decrease in market share; the increased balance sheet cost is approximately equivalent to the increase in arbitrage returns.

## 6 Concluding Discussion

Under post-crisis financial regulation, bank balance sheet space is scarce. Only a small set of global banks are sufficiently well capitalized to engage in balance-sheet intensive, risk-free financial intermediation. I empirically document that scarcity has generated markups to CIP arbitrage in the FX derivatives market. The identification strategy relies on a regulatory difference in bank capital requirements, which decreases competition near quarter-end. Using a Cournot model of imperfect competition, I decompose CIP arbitrage returns into cost and markup. Near quarter-end when competition is low, US banks are low-cost suppliers and earn large spreads of 108 bps for 1-week contracts. For intra-quarter CIP arbitrage, non-US banks are the low-cost suppliers and earn average spreads of 8-17 bps. These markups are economically significant in that they apply to the pricing of cross-currency forwards. This

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<sup>12</sup>CIP arbitrage profit is arbitrage return minus balance sheet cost multiplied by market share. The counterfactual arbitrage returns are on average 25-34 bps larger. Customer demand elasticities imply a decrease in average aggregate quantity of 19%. The estimated counterfactual profits are adjusted for this 19% decrease in total quantity

market is one of the most liquid in the world with net daily volume of approximately 1 trillion USD (BIS (2019)). These findings are theoretically important because they contribute to our understanding of intermediary asset pricing. The literature on intermediary asset pricing emphasizes aggregate constraints to intermediary risk bearing capacity as an important determinant to risk premia across many asset classes (He, Kelly, and Manela (2017)). My evidence of imperfect competition implies that the concentration of intermediary capital also matters.

The market distortions associated with quarter-end non-US bank capital requirements have drawn the attention of regulators.<sup>13</sup> Global financial regulators are pushing for the transition to quarter-average capital requirements. Using my model, I estimate CIP arbitrage and markups under the counterfactual market in which all FX dealer banks have quarter-average capital requirements. The term-structure flattens and there is no difference between quarter-crossing and intra-quarter CIP arbitrage. In the counterfactual, there is no quarter-end “market disruption.” US banks no longer earn large quarter-end spreads for short-term CIP arbitrage. However, the non-US banks are much more constrained in the counterfactual. Non-US banks need to meet quarter-end capital requirements throughout the quarter. The predominant effect is a decrease in the arbitrage activity of non-US banks. The counterfactual CIP arbitrages are on average approximately 30 bps larger. Consistent, quarter-average capital requirements would have decreased quarter-end arbitrage returns but on average increased CIP arbitrages.

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<sup>13</sup>The Bank of International Settlements issued a statement: “Window-dressing by banks is unacceptable, as it undermines the intended policy objectives of the leverage ratio requirement and risks disrupting the operations of financial markets.” (18 October 2018, available at [https://www.bis.org/publ/bcbs\\_n120.htm](https://www.bis.org/publ/bcbs_n120.htm))

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**Table 1. Term-Structure to US and non-US Marginal Balance Sheet Cost**

Non-US banks have a quarter-end regulatory capital requirement. Define the Lagrange multiplier for this constraint to be  $mc_{QE}^F$  for a 3-month CIP arbitrage. This quarter-crossing cost is amortized over contract tenor. This amortization results in a term-structure of  $1/\tau$  to the non-US bank's quarter-crossing balance sheet cost. For intra-quarter arbitrage, non-US banks may also have balance sheet costs, such as debt overhang. I parameterize this non-regulatory balance sheet costs for non-US banks to be  $mc^F$ . US banks have quarter-average regulatory capital requirements. This quarter-average constraint generates a rate of return Lagrange multiplier to all balance sheet exposures  $mc^{US}$ .

Tenor	$1/\tau$	$mc_{\tau}^F$	$mc_{\tau}^{US}$
3-Month	1	$mc^F + mc_{QE}^F$	$mc^{US}$
2-Month	1.5	$mc^F + 1.5mc_{QE}^F$	$mc^{US}$
1-Month	3	$mc^F + 3mc_{QE}^F$	$mc^{US}$
3-Week	4.3	$mc^F + 4.3mc_{QE}^F$	$mc^{US}$
2-Week	6.5	$mc^F + 6.5mc_{QE}^F$	$mc^{US}$
1-Week	13	$mc^F + 13mc_{QE}^F$	$mc^{US}$

**Table 2. Term-Structure of CIP Arbitrage Returns**

Table 2 presents the term-structure of JPY-USD and EUR-USD CIP arbitrage returns. Using daily data over the sample from 2014 Q3 through 2018 Q3, I report average arbitrage returns for JPY-USD in Panel A and EUR-USD in Panel B. I test the hypothesis that the term-structure to quarter-crossing CIP arbitrage is consistent with US bank marginal cost. The null hypothesis is that  $R_{\tau, QE}^f/R_{3M}^f - mc_{\tau}^{US}/mc_{3M}^{US}$  is equal to 0. I reject this null for all tenors in the JPY-USD and EUR-USD term structure. The term-structure is too steep for US bank marginal cost. I test the hypothesis that the term-structure to the quarter-crossing premium ( $\phi_{\tau}$ ) is consistent with non-US bank marginal cost. The null hypothesis is that  $\phi_{\tau}^f/\phi_{3M}^f - mc_{\tau}^F/mc_{3M}^F$  is equal to 0. I reject this null for all tenors in the JPY-USD and EUR-USD term structure. The quarter-crossing term-structure to CIP arbitrage is too flat for non-US bank marginal cost. Standard errors are in parentheses.

**Panel A. JPY-USD Term Structure**

QE	1-Week	2-Week	3-Week	1-Month	2-Month	3-Month
N	65	130	195	292	567	847
$R_{\tau, QE}^{JPY}$	163.13 (10.92)	109.91 (4.77)	88.16 (2.86)	76.96 (1.96)	60.03 (0.94)	55.67 (0.70)
$R_{\tau, QE}^{JPY}/R_{3M}^{JPY}$	2.81 (0.11)	1.91 (0.04)	1.54 (0.02)	1.32 (0.01)	1.07 (0.003)	N/A N/A
$mc_{\tau}^{US}/mc_{3M}^{US}$	1.00	1.00	1.00	1.00	1.00	N/A
$R_{\tau, QE}^{JPY}/R_{3M}^{JPY} - mc_{\tau}^{US}/mc_{3M}^{US}$	1.81 (0.11)	0.91 (0.04)	0.54 (0.02)	0.32 (0.01)	0.07 (0.003)	N/A N/A
$\phi_{\tau}^{JPY}$	135.61 (10.64)	83.37 (4.64)	62.12 (2.74)	52.04 (1.83)	32.43 (0.80)	25.98 (0.58)
$\phi_{\tau}^{JPY}/\phi_{3M}^{JPY}$	5.36 (0.27)	3.08 (0.10)	2.20 (0.06)	1.75 (0.03)	1.17 (0.01)	N/A N/A
$mc_{\tau}^F/mc_{3M}^F$	13.00	6.50	4.33	3.00	1.50	N/A
$\phi_{\tau}^{JPY}/\phi_{3M}^{JPY} - mc_{\tau}^F/mc_{3M}^F$	-7.64 (0.27)	-3.42 (0.10)	-2.13 (0.06)	-1.25 (0.03)	-0.33 (0.01)	N/A N/A
NQE	1-Week	2-Week	3-Week	1-Month	2-Month	3-Month
N	782	717	652	555	280	N/A
$R_{\tau, NQE}^{JPY}$	34.18 (0.93)	35.03 (0.67)	38.01 (0.70)	43.13 (0.82)	43.06 (1.01)	N/A N/A

Panel B. EUR-USD Term Structure

QE	1-Week	2-Week	3-Week	1-Month	2-Month	3-Month
N	65	130	195	292	567	847
$R_{\tau, QE}^{EUR}$	88.85 (8.20)	64.67 (4.03)	54.55 (2.47)	51.47 (1.72)	44.67 (0.87)	42.36 (0.65)
$R_{\tau, QE}^{EUR}/R_{3M}^{EUR}$	1.81 (0.10)	1.36 (0.04)	1.19 (0.02)	1.15 (0.01)	1.04 (0.004)	N/A N/A
$mc_{\tau}^{US}/mc_{3M}^{US}$	1.00	1.00	1.00	1.00	1.00	N/A
$R_{\tau, QE}^{EUR}/R_{3M}^{EUR} - mc_{\tau}^{US}/mc_{3M}^{US}$	0.81 (0.10)	0.36 (0.04)	0.19 (0.02)	0.15 (0.01)	0.04 (0.004)	N/A N/A
$\phi_{\tau}^{EUR}$	59.44 (6.78)	36.55 (3.27)	27.91 (1.97)	25.37 (1.34)	17.81 (0.57)	14.58 (0.39)
$\phi_{\tau}^{EUR}/\phi_{3M}^{EUR}$	4.03 (0.40)	2.16 (0.13)	1.52 (0.06)	1.40 (0.04)	1.13 (0.02)	N/A N/A
$mc_{\tau}^F/mc_{3M}^F$	13.00	6.50	4.33	3.00	1.50	N/A
$\phi_{\tau}^{EUR}/\phi_{3M}^{EUR} - mc_{\tau}^F/mc_{3M}^F$	-8.97 (0.40)	-4.34 (0.13)	-2.82 (0.06)	-1.60 (0.04)	-0.37 (0.02)	N/A N/A
NQE	1-Week	2-Week	3-Week	1-Month	2-Month	3-Month
N	782	717	652	555	280	N/A
$R_{\tau, NQE}^{EUR}$	29.43 (0.48)	30.89 (0.49)	32.67 (0.55)	37.75 (0.74)	37.18 (0.97)	N/A N/A

**Table 3. Model Estimates for the JPY-USD Arbitrage**

Table 3 details my model estimates of marginal cost, demand elasticity averaged over time  $\epsilon_t$  and averaged across tenors  $\epsilon_\tau$ , model fit as measured by RMSE (root mean square error) of arbitrage returns, and market share for US banks averaged over tenor for quarter-crossing CIP arbitrage (QE) and intra-quarter CIP arbitrage (NQE), using JPY-USD CIP arbitrage. Panel A presents model estimates by quarter and Panel B presents average model estimates for banks marginal in JPY-USD and EUR-USD arbitrage for the sample of Q3 2015 - Q3 2018, excluding Q4.

**Panel A. Model Estimates of Marginal Cost, Demand Elasticity, and Model Fit by Quarter**

Date	$mc^{US}$	$mc^F$	$mc_{QE}^F$	$\epsilon_t$	RMSE
9/30/14	25.29	8.83	6.87	0.21	0.36
3/31/15	39.43	20.35	3.17	0.33	1.04
6/30/15	37.00	25.34	5.31	0.40	0.75
9/30/15	39.30	21.16	28.54	0.29	0.40
3/31/16	60.17	40.54	9.16	0.40	1.26
6/30/16	66.00	32.79	23.92	0.30	3.64
9/30/16	103.91	53.64	20.02	0.34	4.99
3/31/17	36.55	8.43	9.19	0.21	1.89
6/30/17	37.33	17.38	9.01	0.34	1.89
9/30/17	46.01	26.37	6.02	0.45	1.71
3/31/18	69.92	34.43	12.02	0.38	3.08
6/30/18	50.70	22.75	9.51	0.35	3.01
9/30/18	44.73	20.41	5.59	0.45	2.64

**Panel B. Model Estimates of Demand Elasticity and Market Share by Tenor**

	1-Week	2-Week	3-Week	1-Month	2-Month	3-Month
Demand Elasticity ( $\epsilon_\tau$ )	0.35	0.36	0.35	0.32	0.31	0.37
US Market Share QE	0.88	0.68	0.51	0.39	0.21	0.10
US Market Share NQE	0.03	0.02	0.01	0.02	0.00	N/A

**Table 4. Model Estimates for the EUR-USD Arbitrage**

Table 4 details my model estimates of marginal cost, demand elasticity averaged over time  $\epsilon_t$  and averaged across tenors  $\epsilon_\tau$ , model fit as measured by RMSE (root mean square error) of arbitrage returns, using EUR-USD CIP arbitrage.

**Panel A. Model Estimates of Marginal Cost, Demand Elasticity, and Model Fit by Quarter**

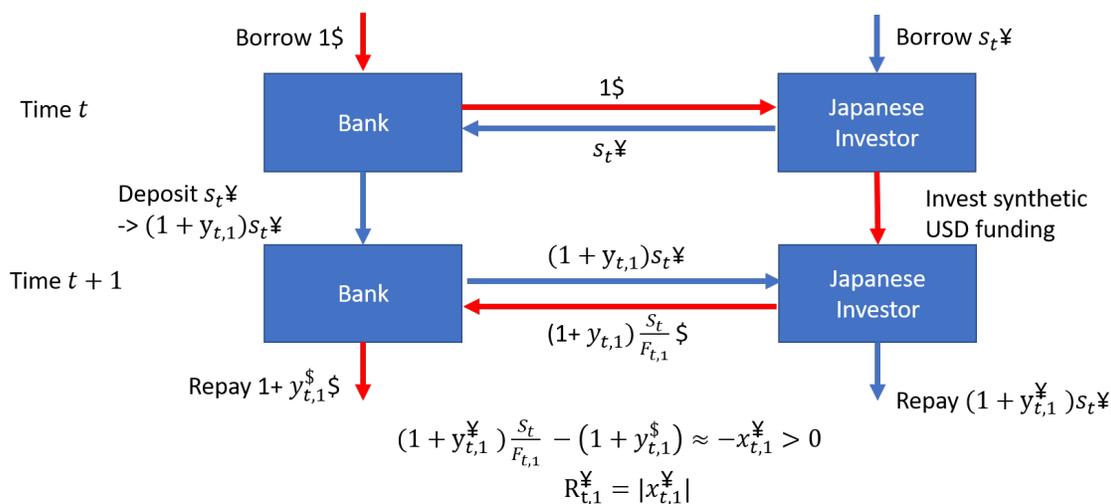
Date	$mc^{US}$	$mc^F$	$mc_{QE}^F$	$\epsilon_t$	RMSE
9/30/15	26.36	12.18	2.87	0.27	0.60
3/31/16	34.70	26.48	0.81	0.46	0.57
6/30/16	51.81	36.30	11.68	0.33	2.68
9/30/16	75.80	46.73	8.99	0.32	5.56
3/31/17	39.01	11.11	8.49	0.20	1.22
6/30/17	43.30	20.78	8.43	0.38	2.39
9/30/17	50.37	24.05	4.34	0.35	2.33
3/31/18	43.45	34.58	14.27	0.35	3.16
6/30/18	42.35	19.00	3.70	0.46	2.58
9/30/18	41.93	13.70	1.30	0.26	3.46

**Panel B. Comparison of Average Model Estimates for Banks Marginal in JPY-USD vs. EUR-USD Arbitrage**

Average	$mc^{US}$	$mc^F$	$mc_{QE}^F$	$\epsilon_t$	RMSE
JPY-USD Arbitrage	55.46	27.79	13.30	0.35	2.45
EUR-USD Arbitrage	44.91	24.49	6.49	0.34	2.45

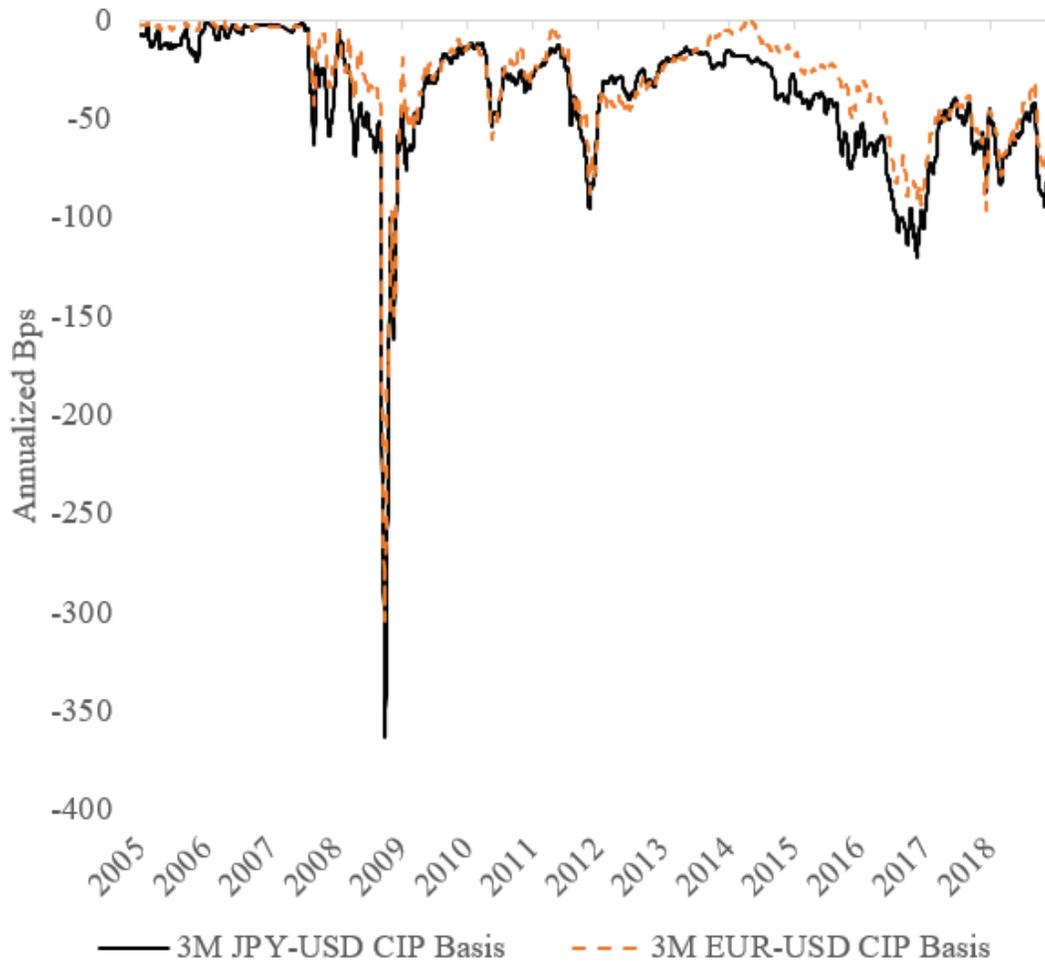
**Figure 1. The Equivalence of the CIP Basis Magnitude to an Arbitrage Return**

Figure 1 illustrates how the magnitude of a CIP basis is equivalent to an arbitrage return. The red lines trace the path of USD (\$) and the blue lines trace the path of JPY(¥). There are two agents: a bank and Japanese investor. The bank earns an arbitrage return by selling synthetic dollars funding. The Japanese investor pays the arbitrage return in order to buy synthetic dollar funding. The bank directly borrows \$1, spot exchanges the dollar to  $s_t ¥$ , deposits the  $s_t ¥$  to earn  $(1 + y_{t,1}^¥)s_t ¥$  in the next period, writes a forward contract to exchange  $(1 + y_{t,1}^¥)s_t ¥$  for  $(1 + y_{t,1}^\$) \frac{s_t}{F_{t,1}} \$$  in the next period, and then repays  $(1 + y_{t,1}^\$) \$$  in the next period. The net cash flow to this transaction is the arbitrage return ( $R_{t,1}^¥ = -x_{t,1}^¥$ ), where  $x_{t,1}^¥$  is the CIP basis.  $s_t$  is the spot JPY-USD exchange rate and  $F_{t,1}$  is the 1-period forward rate.  $y_{t,1}^¥$  is the 1-period JPY risk-free rate and  $y_{t,1}^\$$  is the 1-period USD risk-free rate. On the other side of this, the Japanese investor borrows JPY and repays JPY, but may invest in USD from period  $t$  to  $t + 1$ . The Japanese investor buys synthetic dollar funding.



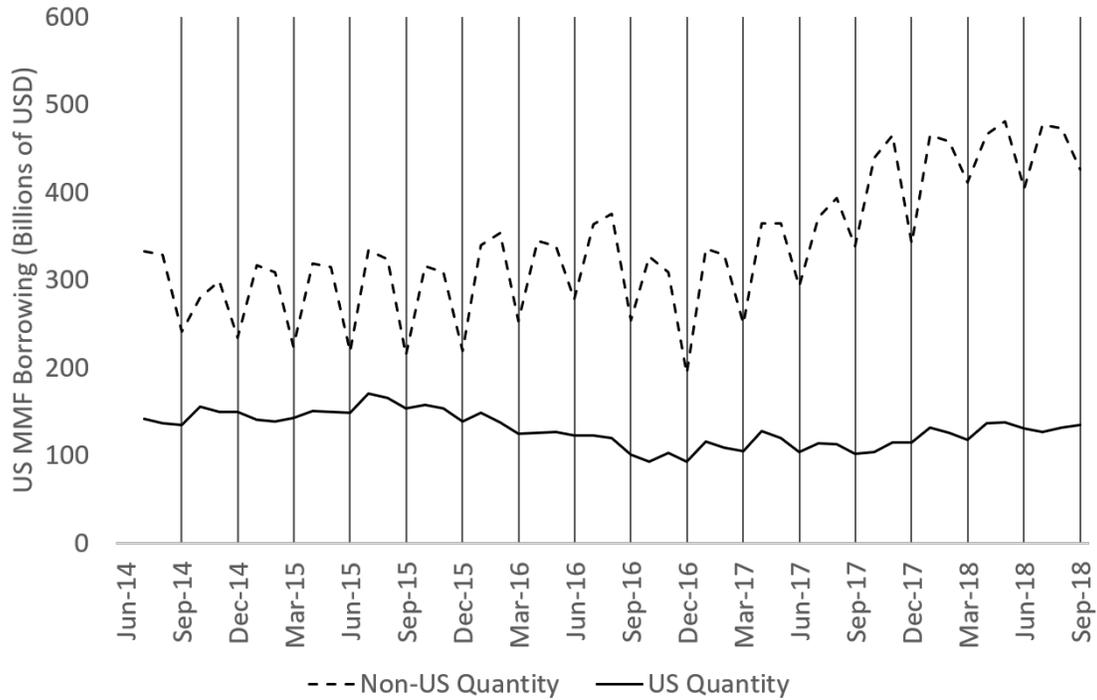
**Figure 2. 3-Month JPY-USD and EUR-USD CIP Arbitrage Bases**

In annualized basis points, Figure 2 plots the 3-month JPY-USD and EUR-USD CIP basis. The plotted time series is smoothed by a 10-trading day moving average. The sample is daily from Jan 2005 through Dec 2018.



**Figure 3. Non-US and US Bank Borrowing from US MMFs**

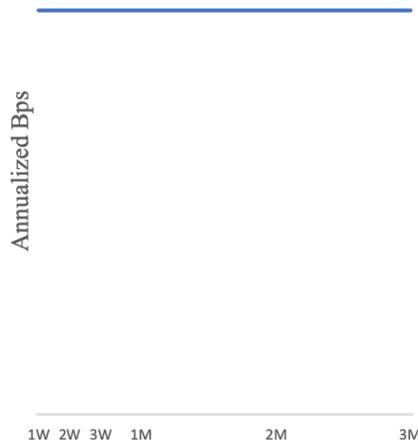
Figure 3 plots short-term US MMF borrowing by non-US and US banks from 2014 Q3 through 2018 Q3. Short-term borrowing is unsecured and secured borrowing with tenor less than 3-months. Non-US banks (dashed line) include UBS, Deutsche Bank, HSBC, Standard Chartered, Barclays, BNP Paribas, Credit Agricole, and Société Générale. US banks (solid line) include JP Morgan, Citigroup, Bank of America and Goldman Sachs.



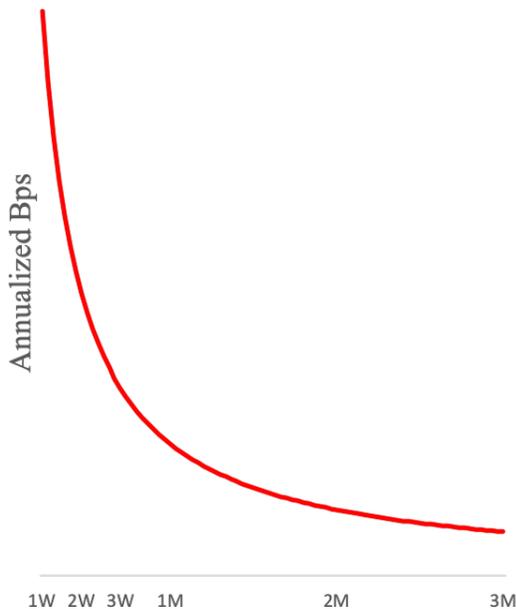
### Figure 4. Balance Sheet Cost Implied CIP Arbitrages

Figure 4 illustrates the 3 potential term-structures with price-taking US and non-US banks active in CIP arbitrage. Panel A shows how US banks are indifferent between arbitrages with the largest returns. Therefore, for arbitrages where US banks are marginal, the term-structure is constant. Panel B shows how non-US banks are indifferent between arbitrages that cross-quarter end when returns decrease with tenor at rate  $1/\tau$ . Panel C shows a mix of US banks marginal in short-term CIP arbitrage and non-US banks marginal for longer-term contracts.

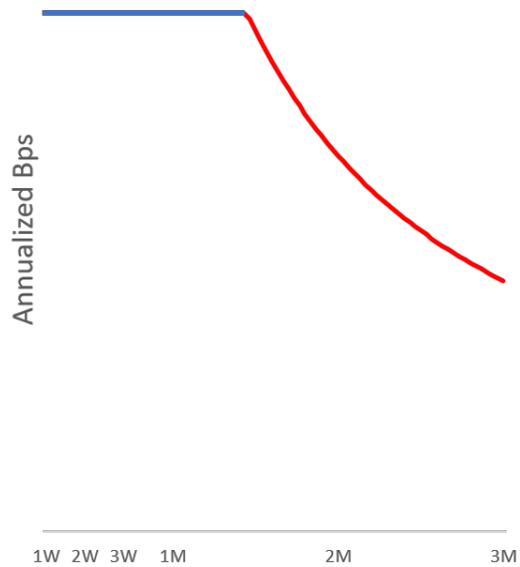
#### Panel A: Marginal US Banks



#### Panel B: Marginal Non-US Banks

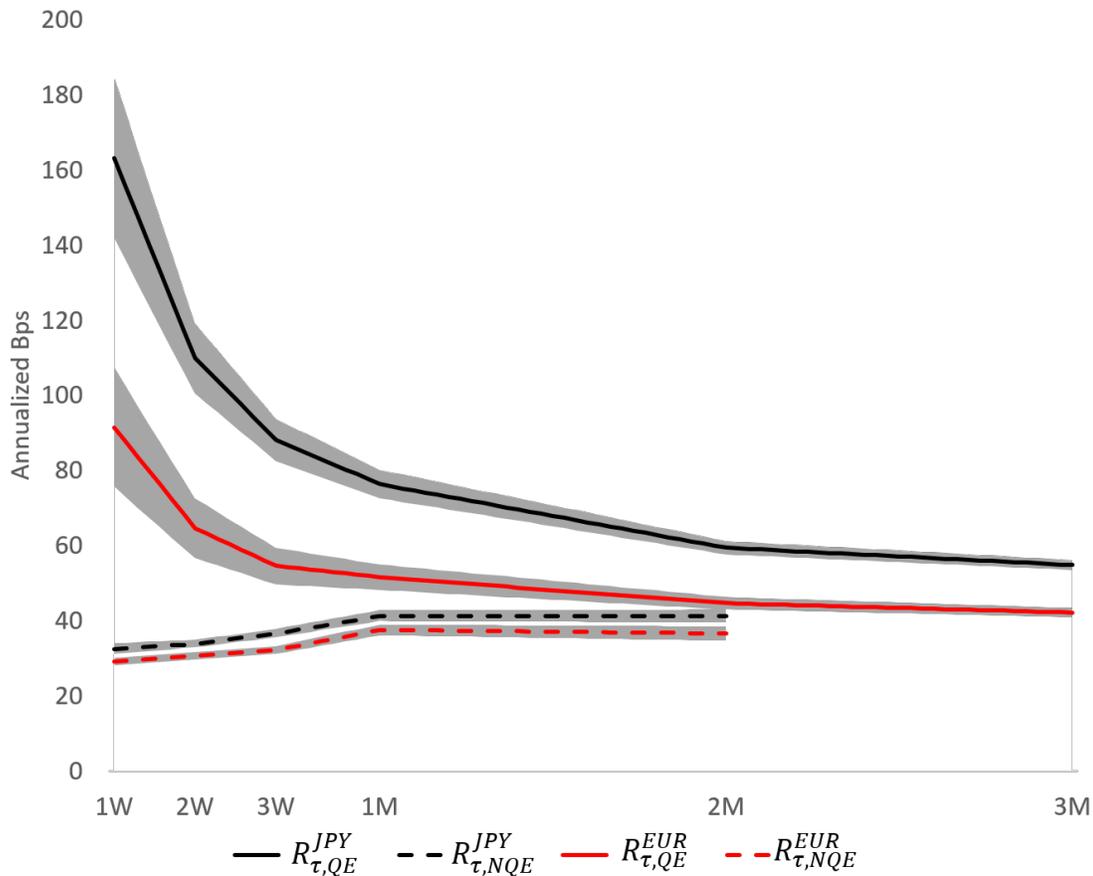


#### Panel C: Marginal US and Non-US Banks



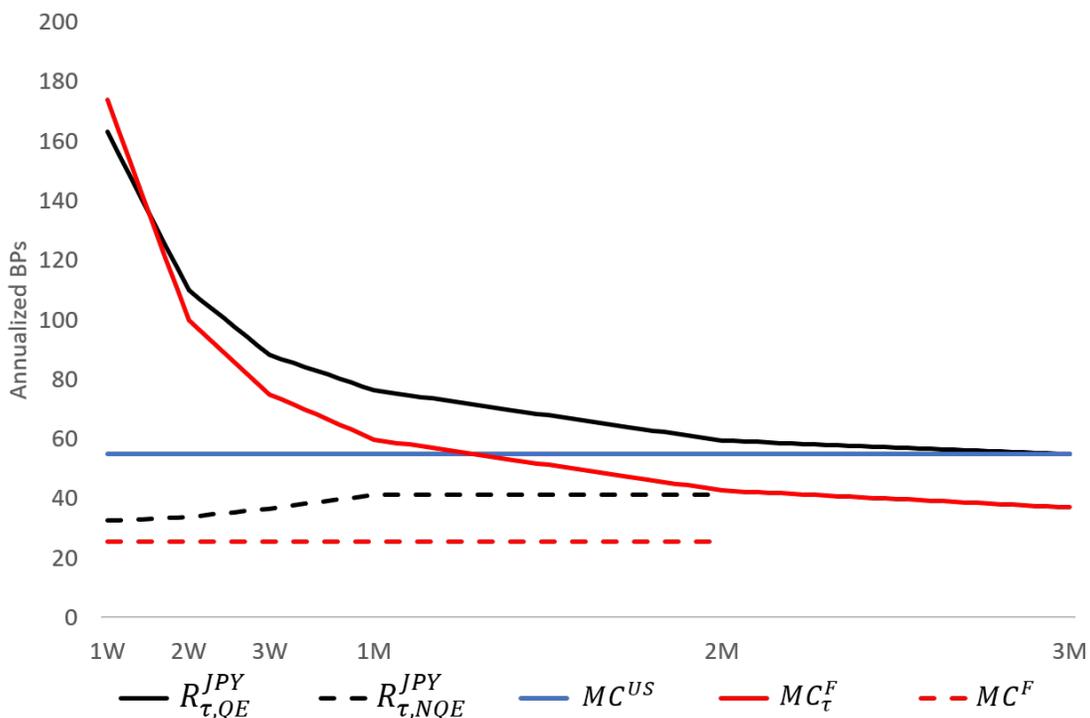
**Figure 5. Term-Structure of JPY CIP Arbitrage Returns**

Figure 5 plots the average term structure to JPY-USD and EUR-USD CIP arbitrage returns for contracts that cross quarter-end (QE, solid black line) and do not cross quarter-end (NQE, dashed black line). The sample is of daily data from 2014 Q3 to 2018 Q3, excluding Q4 due to G-SIB effects (see appendix A). The shaded regions are the 95% confidence interval bands. The term structure maturities include 1-week, 2-week, 3-week, 1-month, 2-month, and 3-month contracts.



**Figure 6. JPY-USD Arbitrage Returns and Marginal Cost Estimates**

Figure 6 plots the term-structure of JPY-USD CIP arbitrage and estimated marginal cost. The solid black line plots the CIP arbitrage return across tenors that cross quarter-end. The dashed black line plots the CIP arbitrage return across tenors that do not cross quarter-end. The marginal cost estimates are from the Cournot model (see Table 3). The solid blue line plots US bank marginal cost (constant). The solid red line plots non-US bank marginal cost for contracts that cross quarter-end (convex). The dashed red line plots non-US bank marginal cost for contracts that do not cross quarter-end (constant).

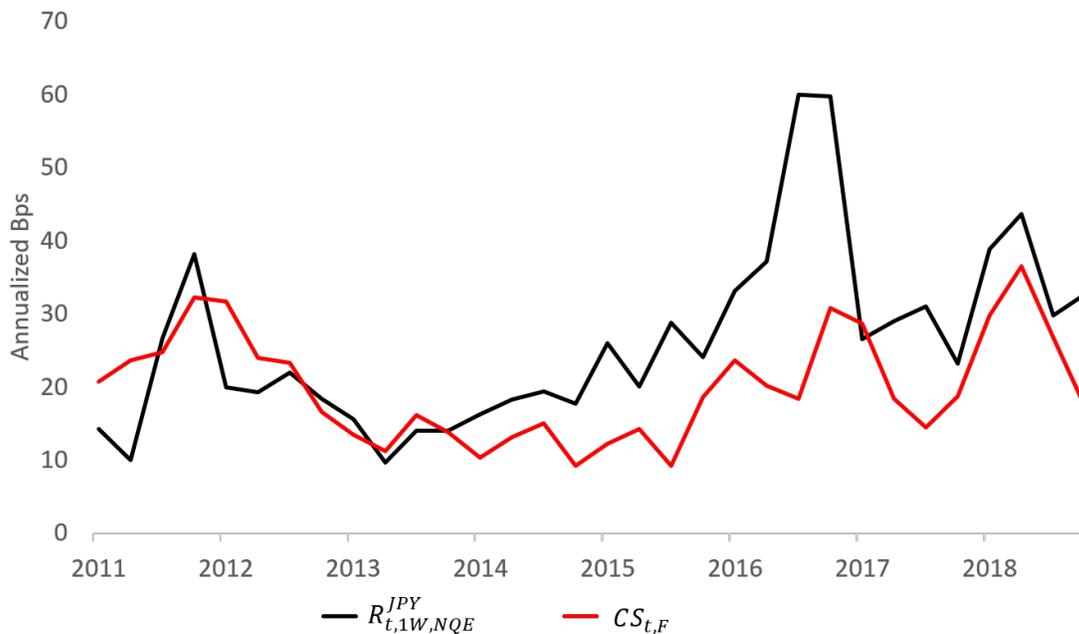


**Figure 7. Non-US Bank Credit Spread and the 1-Week JPY-USD Intra-Quarter CIP Arbitrage**

Figure 7 plots the time series to non-US bank credit spread and the 1-week intra-quarter JPY-USD CIP arbitrage return averaged at the quarterly frequency from Q1-2011 and Q4-2018. Non-US bank credit spreads are estimated using unsecured borrowing from US MMFs and averaged across tenors.

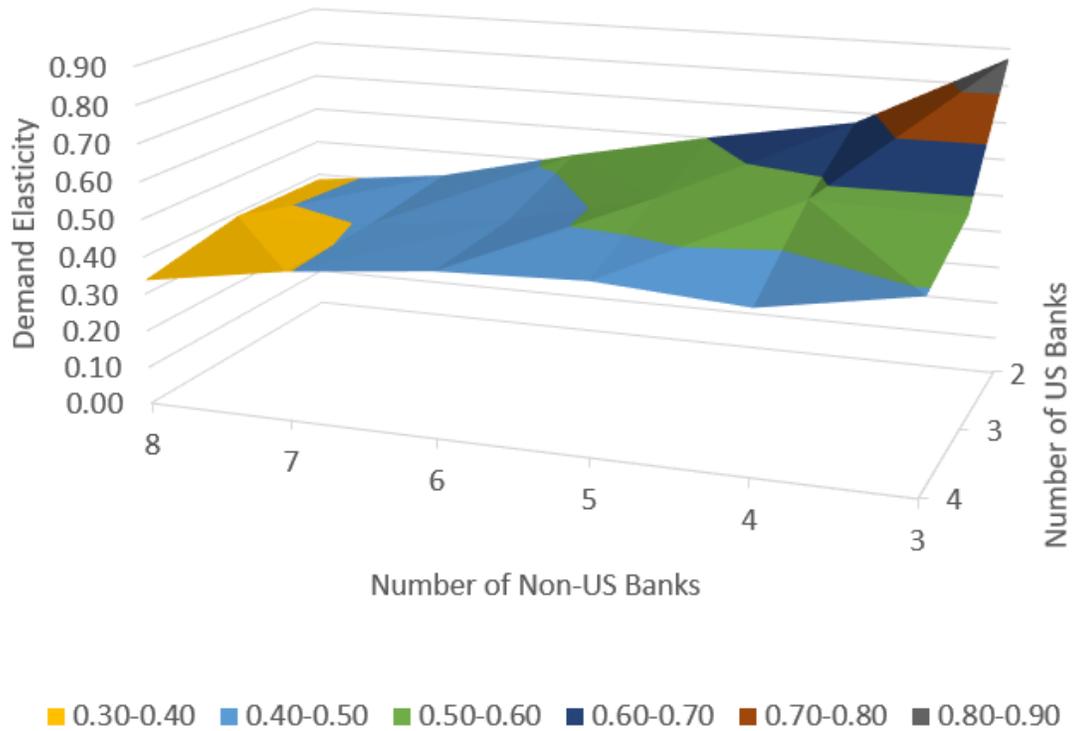
$$CS_{t,F} = \frac{1}{v_{t,F}} \sum_{i,j} v_{t,\tau,i,j} (\gamma_{t,\tau,i,j} - y_{t,\tau}^{\$})$$

where  $v_{t,F} = \sum_{i,j} v_{t,\tau,i,j}$  is the total dollars borrowed by all non-US banks for quarter  $t$ ,  $v_{t,\tau,i,j}$  is the dollars borrowed by bank  $i$  for unsecured issuance  $j$ ,  $\gamma_{t,\tau,i,j}$  is rate for that issuance, and  $y_{t,\tau}^{\$}$  is the dollar risk-free rate. These credit spreads are averaged by dollars borrowed  $v_{t,\tau,F}$  for all non-US banks across tenors.



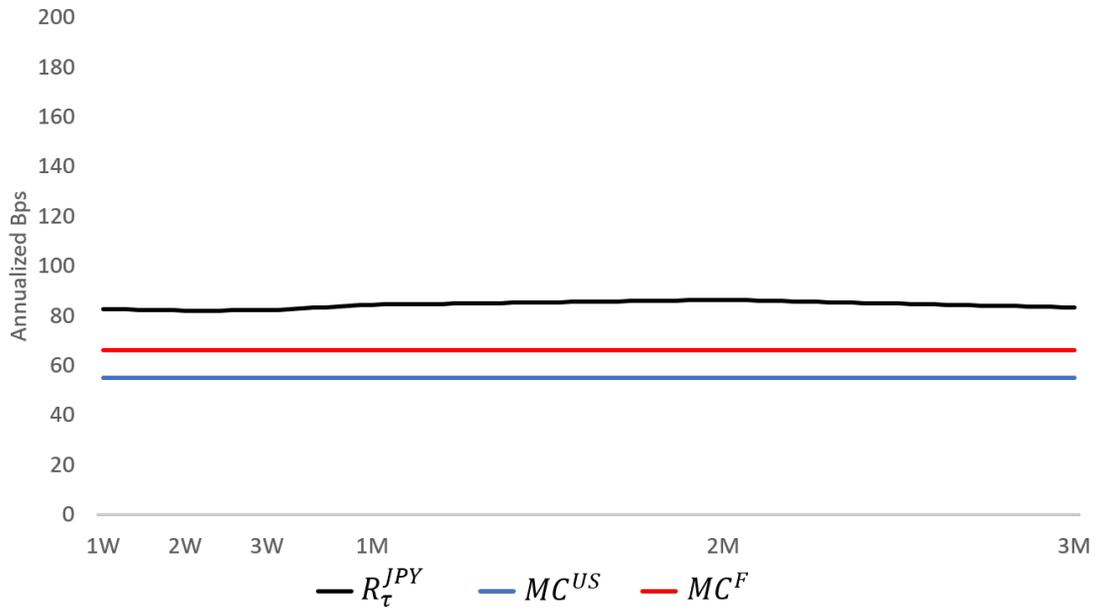
**Figure 8. Demand Elasticity Estimates for EUR-USD Arbitrage by Number of FX Dealer Banks**

Figure 8 plots a surface of model estimates of demand elasticity for EUR-USD CIP arbitrage, depending on various combinations of numbers of marginal US and non-US banks. Demand elasticity estimates tend to increase as the number of US and non-US banks marginal in EUR-USD CIP arbitrage decreases.



**Figure 9. Counterfactual CIP Arbitrage Return and Marginal Cost**

Figure 9 plots the counterfactual term-structure of JPY-USD arbitrage returns and marginal cost estimates in a world where non-US banks have quarter-average capital requirements. The solid black line plots the price across tenors: there is no difference between intra-quarter and quarter crossing CIP arbitrage returns. The solid blue line plots US bank marginal cost. The solid red line plots the counterfactual non-US bank quarter-average balance sheet cost.



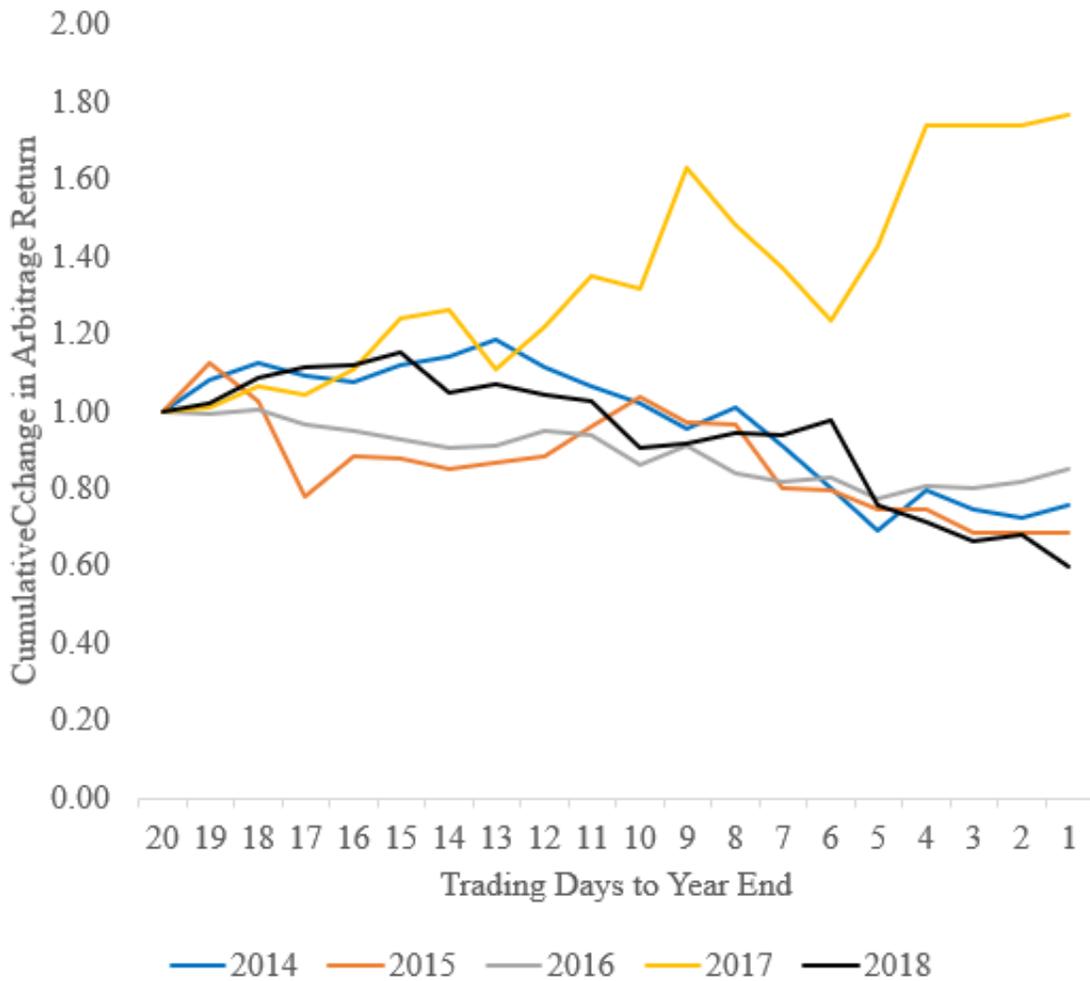
## Appendix A: Year-end Effects to CIP Arbitrage and G-SIB Capital Assessments

The term-structure of arbitrage steepens substantially in Q4 compared to Q1-Q3. This steepening coincides with the Financial Stability Board (FSB) G-SIB evaluations. Using a Dec 31st balance sheet snapshot, the FSB and national regulators categorizes banks into various tiers of additional capital buffers. As of Nov 2018, the tiers range from an additional 1% to 3.5% of buffer capital with discrete 0.5% jumps. This year-end balance sheet cost applies to all G-SIB banks. In Q4, USD, EUR, and JPY banks all have a quarter-end balance sheet cost. Figure A1 in appendix A (year-end arbitrage return dynamics) plots the JPY arbitrage return term-structure for each year end (2014-2018) and the average Q4 non-year end crossing contracts (NXYE). The year-end term-structure is much more volatile than the Q1-3 term-structure. For year-end 2017, the 1-week arbitrage return ratio was about 12.5 times that of the 3-month. However, for year-end 2015 and 2016, the ratio was about 3 times, which is similar to the Q1-Q3 term-structure. Industry sources attribute the cross-currency basis “blowout” of 2017 year-end to large US banks such as “JP Morgan and Citi shrinking their balance sheets to avoid being placed in a higher capital bucket and facing extra charges from regulators. This anecdotal evidence is corroborated in Appendix A Figure 1, which plots cumulative changes to the 3-month basis arbitrage return for the 20 trading days prior to year-end. Unlike all other year-ends, the 3-month arbitrage return trended upwards in 2017. The downward trend in the 3-month basis as year-end approaches is consistent with the incentive to save balance sheet space due to its future option value. As year-end approaches and option value decreases, banks do more CIP arbitrage and the return to arbitrage decreases. However, in 2017, US banks were surprised by their proximity to G-SIB bucket thresholds. US banks withdrew from CIP arbitrage, which substantially steepened the term-structure. For some year-ends, the G-SIB capital surcharges cause US banks to also have a quarter-end balance sheet cost.

Regulatory bank balance sheet costs exhibit a number of inconsistencies with characteristics of CIP arbitrage. CIP arbitrage returns vary by currency, but bank capital requirements are not currency-specific. CIP arbitrage returns have a steep quarter-end term-structure, but marginal US banks have quarter-average balance sheet costs. Furthermore, non-US bank balance sheet costs have a much steeper term-structure than that implied by the arbitrage return. These empirical inconsistencies imply that the CIP basis is not equal to a shadow balance sheet cost. Regulatory balance sheet costs only partially explain the characteristics of CIP arbitrage returns.

**Figure 1. Cumulative Change to the 3-Month CIP Arbitrage Return Near Year-End**

Appendix A Figure 1 plots the year-end trend to 3-month JPY-USD CIP arbitrage returns. The time span is 1-month prior to year-end (20 trading days) for years 2014 to 2018. Cumulative change is measured as the arbitrage return for day  $t$  divided by the arbitrage return at the beginning of December.



## Appendix B: Robustness Checks of Constant Marginal Cost across Tenors for US Banks

For robustness, I test two potential explanations for why quarter-average balance sheet constraints may not generate a constant balance sheet cost. First, banks may be optimistic about future balance sheet constraints. Optimistic banks may persistently expect balance sheet constraints to be less severe in the next quarter. Second, banks may misallocate balance sheet space. If banks regularly underestimate future intermediation demand, they will over-utilize balance sheet space in the beginning of each quarter. Toward the end of the quarter, balance sheet space will be scarce and more expensive.

First, bank optimism about future constraints implies that balance sheet space is more expensive this quarter than next quarter. Such optimism would yield a convex balance sheet cost, despite a quarter-average constraint. For example, in the last week of March, the 1-week contract is priced using the expensive balance sheet space and the 3-month contract is priced using 1/13ths of the expensive balance sheet space and 12/13ths of the cheap balance sheet space. In this example, US banks have higher balance sheet costs for the 1-week contract than the 3-month contract. An empirically testable implication of the bank optimism hypothesis is that 6-month balance sheet space is on average cheaper than 3-month balance sheet space. The optimistic bank believes balance sheet cost next quarter is cheaper than this quarter. Empirically, the 6-month price is on average 2.6 bps more expensive than that of the 3-month. Although statistically significant, this difference is economically small: about 5% of the 3-month CIP arbitrage. I find no evidence that US banks have quarter-average balance sheet constraints due to underestimating future balance sheet costs (see Appendix B Table 1).<sup>14</sup>

Second, bank underestimation of quarter-end demand for intermediation implies that balance sheet space is more expensive at the end of the quarter compared to the beginning. In this example, banks misallocate balance sheet space: they supply too much for too cheaply at the beginning of the quarter. Toward the end of the quarter, balance sheet space is scarce. This quarter-end scarcity generates a convex term-structure of intermediation prices, similar to the optimism example. I empirically test this hypothesis by looking at within-quarter trends to the 3-month CIP arbitrage. If banks are systematically misallocating balance sheet space, there should be predictable trends in prices for the 3-month arbitrage return. Empirically, there is no within-quarter trend to 3-month CIP arbitrage returns. The

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<sup>14</sup>In a similar exercise, Du et al. (2019) document that there is a very small risk premium in the forward implied arbitrage return. The future 3-month arbitrage return implied by the 6-month arbitrage return is on average approximately equal to the realized 3-month arbitrage return.

difference between average prices in the 1st and 3rd month of the quarter is 1 bps. I find no evidence of bank misallocation of balance sheet space and fail to reject that US banks have constant balance sheet costs across tenors (see Appendix B Table 2).

**Table 1. Test of Difference Between 6-Month and 3-Month JPY-USD CIP Arbitrage Returns**

I empirically test the bank optimism hypothesis that the 6-month JPY-USD CIP arbitrage returns is smaller than the 3-month arbitrage return. For column (1) the sample is daily observations from 2014 Q1-2 to 2018. I exclude Q3 and Q4 due to the 6-month contract spanning year-end in Q3 and Q4 (G-SIB effects). For column (2) the sample is without exclusions: daily observations for 2014 to 2018 spanning Q1-4

	1	2
3M	57.103 (0.700)	59.960 (0.662)
6M	61.315 (0.718)	62.777 (0.607)
Difference	-4.212 (0.139)	-2.817 (0.215)

**Table 2. Within Quarter Trends to 3-Month Arbitrage Returns**

The dependent variable is the 3-month JPY arbitrage return. For column (1), the independent variable is time to quarter-end (TTQE). For column (2) the independent variable is a dummy equal to 1 if it's the 3rd month of the quarter. Additionally, the column (2) sample is restricted to the 1st and 3rd months of each quarter. For both specifications, I include quarter-fixed effects and heteroskedasticity robust standard errors.

$$R_{t,3M}^{JPY} = \alpha_q + \beta X + \epsilon_t$$

$R_{t,3M}^{JPY}$	(1)	(2)
TTQE	-0.021 (0.013)	
3 <sup>rd</sup> Month		1.113 (0.719)
Quarter FE	Y	Y
Observations	818	561
R-Squared	0.863	0.832

## Appendix C: Conditions for Perfect Competition

In Appendix C, I explore the conditions for which perfect competition may generate a cross-section to arbitrage returns. Under perfect competition, price is equal to marginal cost for each market. The price of financial intermediation differs because marginal cost differs. Marginal cost may differ because of either segmentation or asset-specific costs. Under segmentation, the marginal bank differs by market resulting in disperse prices for financial intermediation. Under asset-specific costs, banks have balance sheet constraints specific to each asset.

The segmentation hypothesis is implausible because the price of financial intermediation differs for highly similar assets. Within the asset class of FX derivatives, the price of financial intermediation systematically varies by currency. From 2014-2018, the 3-month arbitrage return for the JPY-USD currency pair is on average 15 bps larger than that of the EUR-USD currency pair. The segmentation hypothesis implies that there does not exist a bank marginal in both 3-month JPY-USD and EUR-USD financial intermediation. This level of segmentation is implausible: JPY-USD and EUR-USD are the two most liquid FX derivative currency pairs and US banks actively intermediate both. Furthermore, within a currency, the convex term-structure of arbitrage returns implies that there is segmentation by tenor. The segmentation hypothesis implies that there does not exist a bank marginal in both the 1-week JPY-USD arbitrage (163 bps) and the 3-month JPY-USD arbitrage (56) at quarter-end. Segmentation by tenor within the same currency is implausible.

More generally, there is tension between the segmentation hypothesis and the strong factor structure to the price of financial intermediation. Across tenors of JPY-USD CIP arbitrage returns, the first factor explains 69% of total variation. Across currency (the 3-month JPY-USD and EUR-USD arbitrage returns), the first factor explains 95% of total variation. The segmentation hypothesis implies that although the marginal bank differs by market, the banks experience very similar cost shocks.

The asset-specific costs hypothesis is inconsistent with existing bank balance sheet regulations. First, the price of financial intermediation differs at a more granular level than capital requirements. To the best of my knowledge, there is no risk-free capital requirement that is specific by currency **and** tenor. However, the price-to financial intermediation varies by currency and tenor. A plausible currency-specific capital constraint may be due to bank stress tests. Under the US Federal Reserve stress tests, the adverse economic scenario involves “flight-to-safety capital flows.” The JPY is expected to appreciate and the EUR and GBP are expected to depreciate against the USD. The stress tests incentivize banks to hold larger JPY positions, which implies a smaller cost to JPY-USD intermediation. The

stress tests disincentivize EUR and GBP holdings, which implies a larger cost to intermediation. However, the CIP arbitrage is on average the largest for the JPY-USD currency pair. Hébert (2019) stresses this finding as an empirical failure of current regulatory policy. Although currency-specific balance sheet costs may exist, they are inconsistent with cross-currency differences in arbitrage returns.