Financial Stability Effects of Foreign-Exchange Risk Migration*

Puriya Abbassi
Deutsche Bundesbank

Falk Bräuning
Federal Reserve Bank of Boston

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Abstract

Firms trade derivatives with banks to mitigate the adverse impact of exchange-rate fluctuations. We study how the related migration of foreign exchange (FX) risk is managed by banks and affects both credit supply and real economic variables. For identification, we exploit the Brexit referendum in June 2016 as a quasi-natural experiment in combination with detailed micro-level FX derivatives data and the credit register in Germany. We show that, prior to the referendum, the corporate sector substantially increased the usage of derivatives, and banks on the other side of the trade did not fully intermediate that FX risk, but retained a large proportion of it in their own books. As a result, the depreciation of the British pound in the aftermath of the referendum poses a shock to the capital base of affected banks. We show that loss-facing banks in response cut back credit to firms, including to those without FX exposure to begin with. These results are stronger for less capitalized banks. Firms with ex-ante exposure to loss-facing banks experience a 32 percent larger reduction in credit than industry peers, and a stronger reduction in cash holdings and investment of about 8 and 2 percent, respectively. Our results show how a bank's uninsured derivatives book can take one corporation's FX risk and turn it into another corporation's financing risk.

Keywords: Foreign Exchange Risk, Financial Intermediation, Risk Migration, Financial Stability

JEL Classification: D53, D61, F31, G15, G21, G32

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1 Introduction

The primary objective of firms is to engage in profitable production of goods and services. While globalization and international trade has beneficial effects on firms' businesses and profit growth, it also brings about a challenge to manage the risk inherent to the management of cash flows denominated in foreign currency. As a result, firms typically use the foreign exchange forward (FX) market to manage their exposure to the associated FX risk (Ethier 1973). Banks, which are specialized in intermediation and risk management practices, provide these financial derivatives at a large scale to the corporate sector.[1] However, if (nonbank) firms trade FX financial derivatives with banks, the FX risk is essentially transferred to the banking sector, i.e., the FX risk migrates from the corporate sector to the banking sector.

A crucial question that arises in this context is whether banks retain some of the FX risk in their own books or fully intermediate it to other agents in the economy, including other firms and banks. This question is important not only for scholars but also for policy makers as migrated FX risk that is not fully intermediated by the banking sector bears crucial financial stability implications, i.e., if the risk materializes and banks will have to absorb the associated losses. In particular, unhedged financial derivatives exposure can induce an adverse shock to bank capital, thereby creating negative externalities for the corporate sector through a contraction in bank credit supply, including to firms that (i) have fully hedged their FX risk exposure and (ii) are not directly exposed to FX risk through their lines of business to begin with.

In this paper, we address this question along two dimensions. First, to guide our empirical analysis, we set up a simple model where the corporate sector increases its demand for FX forwards in response to elevated FX risk uncertainty. In equilibrium, we show that

[1] According to the BIS' Derivative Statistics (December 2014), financial institutions account for roughly 97% of all gross derivatives exposures. With an estimated average daily turnover of $653 billion (Bank for International Settlements 2016), the global FX forward market is a major derivative market of high importance to the globalized economy. In 2008:Q1, U.S. banks held a total notional amount of USD 18.4 trillion in FX derivatives, the second largest derivative class behind interest rate derivatives (Office of the Comptroller of the Currency).

the forward rate adjusts such that the banking sector supplies these additional derivative contracts and absorbs the implied FX risk. After an adverse FX shock, a banking equity loss from derivative exposure leads to a reduction in credit supply due to a binding capital constraint, which hampers firms' ability to borrow and invest. Second, we use these model predictions to assess their empirical relevance using a unique array of micro-data sources. More precisely, we combine transaction-level supervisory data on FX forward contracts with foreign external positions of banks in Germany, in addition to their credit registers for the period 2015–2016. Moreover, we utilize to firms' income statement and balance sheet data, which allows us to examine the real effects in response to an FX shock.

Empirically, we examine the different aspects of FX risk migration in the context of the U.K. referendum to leave the European Union in June 2016. The outcome of this so-called Brexit referendum came at a large surprise and provides an ideal setup to identify the financial stability effects of FX risk migration. First, we show that in the period between the referendum's announcement in February 2016 and its actual date in June 2016, firms increased the notional value of GBP forward contracts traded with German banks by about 23 percent, on average. We find that about one third of the firms that use the FX forward market to buy or sell pounds after the referendum was announced did not trade prior to the announcement. We argue that this surge in demand, which we observe both at the extensive and intensive margin of derivative usage, is a result of an increased uncertainty about the British pound's value after the Brexit vote, consistent with both survey and market-based measures of FX uncertainty.

Second, in light of the strong increase in GBP forward usage by the corporate sector, we find that individual banks increase their supply of GBP FX forwards but did maintain part of the FX risk in their books. That is, banks did not fully intermediate their clients' demand, i.e., they did not fully re-insure the resulting risk across their derivatives book, partly driven by offsetting on-balance-sheet exposure, higher spreads in the forward market, and skewed client demand for derivatives across different industries. For individual banks, we find that about 20 percent of the banks just prior to the Brexit referendum had accumulated a sizable derivative exposure to the post-referendum value of the pound to an extent of at least 25 percent of their equity value. After the UK's decision to leave the EU, the pound plummeted by about 8 percent against all major currencies and banks with a respective (net) long exposure incurred losses from their derivative positions (after controlling for potentially offsetting net GBP on-balance-sheet exposure). Our estimated losses indicate that, for 10 percent of banks, the loss associated with their GBP exposure (net of GBP on-balance-sheet gains/losses) was larger than 7.8 percent of equity.

Third, after the Brexit referendum and the depreciation of the pound, we find that exactly those banks with large losses from their GBP derivative exposure (and thus an adverse shock to their net worth) cut back credit to firms. We identify these supply effects using a difference-in-differences regression approach, exploiting within borrower variation in credit in the same quarter in combination with heterogeneous derivative losses across banks (similar to the Khwaja and Mian 2008 approach). Our estimates from these regressions indicate an average elasticity of 0.43 suggesting that for any percentage-point derivative loss, a bank cuts back credit by 43 basis points, on average. Consistent with the notion of capital-constraints being binding, this effect is substantially stronger for banks with a lower equity-to-assets ratio.

Fourth, our firm-level analysis shows that firms with a strong dependence on banks that suffered derivative losses also experience an overall cutback in credit after the referendum; that is, they were not able to substitute the funding loss by increasing borrowing from other banks. This overall credit contraction for affected firms is about 30 percent stronger than the average credit contraction after the Brexit referendum. Moreover, we also show that firms without any derivative usage—those that likely do not have any FX risk exposure—experienced a credit reduction from derivative-loss-facing banks. Finally, we show that affected firms reduce cash holdings and investment by about 8 and 2 percent, respectively, suggesting that the observed FX risk migration has real effects.

Related Literature. Our paper fits into the literature that studies risk management in multinational (globally active) entities to mitigate the impact of exchange-rate fluctuations. A subset of this research focuses on how non-financial firms handle this risk. For instance, Ethier (1973), Baron (1976), Lehrbass (1994), Allayannis and Ofek (2001), Allayannis and Weston (2015), and MacKay and Moeller (2007) discuss and highlight the important role of the FX forward markets for firms in dealing with FX risk and the effects on international trade, sales, and firm value. Our paper contributes to these studies along the following lines. First, we exploit evidence from supervisory transaction-level data, which is crucial for clean identification (see e.g., Brunnermeier, Gorton, and Krishnamurthy 2011). Second, we combine both risk management in corporates and in banks and thereby examine how FX risk is redistributed within the financial system and beyond. And third, we are able to assess the degree to which this risk is intermediated by those providing the insurances, i.e., banks; this is crucial for our understanding as to how risks are reshuffled in the economy.

Our paper also contributes to the large body of research that studies how shocks to banks' financing affect their lending behaviour and real activity (Bernanke and Gertler 1989; Holmstrom and Tirole 1997; Gertler and Kiyotaki 2010; Brunnermeier and Sannikov 2014, Chodorow-Reich 2013, and Ivashina, Scharfstein, and Stein 2015, among many others). In the context of international shock transmission, Peek and Rosengren (1997) and Peek and Rosengren (2000) document a credit-crunch channel by which a shock to the capital base affects international lending behaviour of multinational banks. Our empirical results are closely related to this work in the sense that we also document that, after a negative shock to net worth (originating in a foreign country), banks cut back credit supply across their entire credit book, irrespective of whether the (borrowing) firm had a FX risk exposure to begin with. That is, banks' imperfect intermediation of FX risk across their entire derivatives book creates negative externalities of systemic relevance. In this regard, our findings that the shock reduces cash holdings and investment at the firm level also relates to papers that highlight the role of the the banking system in transmitting shocks to the real economy.[2]

Our paper also relates closely to an emerging literature that studies the interrelation between banking activity and the foreign exchange markets. For example, Ivashina, Scharfstein, and Stein (2015) show that international banks reduce foreign dollar credit in response to higher funding cost of dollar positions in the FX swap market. Bruno and Shin (2015) study how monetary policy transmits across borders through adjustment in bank leverage and the dollar exchange rate. More generally, Braeuning and Ivashina (2016) show that global banks' lending portfolio adjusts because of changes in banks' FX hedging costs. In this paper, we show a distinct connection between bank credit supply and the FX markets: A bank's uninsured FX derivative book can take one corporation's FX risk and turn it into another corporation's financing risk once FX shocks materialize.

Finally, our paper relates to the growing literature that studies the financial stability effects of risk exposures of banks more generally, in particular through derivative exposures. For instance, Brunnermeier, Gorton, and Krishnamurthy (2011) and Begenau, Piazzesi, and Schneider (2015) conceptualize and design risk measures to guide data acquisition and outline dissemination process with the aim to inform policymakers, researchers and market participants about banks' risk exposures and systemic risk. One key insight that these studies convey is that systemic risk from banks' financial derivatives engagements cannot be detected based on balance sheet items and income statement items and is determined by market participants' response to shocks. We are able to address both of these challenges and examine the financial stability implications of the risk migration we document using supervisory transaction-level data on FX derivatives contracts.

The remainder of the paper is organized as follows. In Section 2, we describe our empirical setup. In Section 3, we discuss the data. Section 4 provides our empirical results. Section 5 concludes. All figures and tables are at the end of the paper. Appendix A contains a

[2]For example, Amiti and Weinstein (2011) and Amiti and Weinstein (2018) show the effect of bank health on firm exports growth and investments, respectively. Chodorow-Reich (2013) studies the impact of bank health on employment.

theoretical framework of FX risk migration.

2 Empirical Setup

To structure our empirical analysis, we build a stylized model of FX risk migration in the spirit of Froot, Scharfstein, and Stein (1993). The two-period model consists of a firm and a capital-constrained bank. In period 0, the firm enters a derivative contract with the bank to hedge the value of its period-1 wealth, which is subject to exchange rate risk (e.g., due to foreign currency income). In period 1, the exchange rate risk materializes and affects the firm's equity value. The firm produces output in period 1 using equity, subject to a concave production technology. Because the firm is financially constrained it needs to fund part of its investment by borrowing from the bank in period 1. Because of the concavity in the firm's profit function the firm wants to insulate its equity value from random fluctuation. The key parameter of the model is the uncertainty about the period-1 exchange rate. From this stylized model, we derive the following key prediction from the model, which we will guide our empirical analysis: *(i)* as the FX uncertainty increases, the firm's hedging demand increases; *(ii)* the bank provides the additional insurance at an increasing cost and absorbs the resulting risk on its books; and *(iii)* if the foreign currency appreciates, the bank's derivative position induces an equity loss, lowering the ability to provide credit to the firm in period 1 due to the capital constraint. We present the full model details and equilibrium in the derivative and credit market in the Appendix A.

We empirically test these effects of FX risk migration in the context of the U.K. referendum to leave the European Union on June 23, 2016. This Brexit referendum date was first announced by then-prime-minister David Cameron in a speech to the House of Commons on February 22, 2016. In response to the announced referendum, uncertainty about the future value of the British pound (after the Brexit referendum) increased substantially as the outcome of the referendum was not clear, but markets expected a substantial depreciation of the pound in response to a positive vote to leave the European Union. As such, the empirical setting closely mirrors the model setup.

Table 1 provides survey-based evidence of the increase in uncertainty due to the Brexit referendum announcement by showing the distribution of the Economic Consensus forecasts of the pound's value vis-á-vis the dollar in July 2016. Forecasts distributions are reported once for forecasts made before the announcement date in January 2016 (6-month forecasts) and once for forecasts made after the announcement in March 2016 (3-month forecasts). Economic Consensus forecast data provide both the mean and the range of the forecast distribution, which allows us to distinguish between the expected future exchange rate and the uncertainty about the future exchange rate. While the mean forecast for the USD/GBP rate in July 2017 somewhat shifted, indicating a depreciation by about 4 percent from January to March, most strikingly, the distribution of the forecasts widened substantially as indicated by an increase in the range of individual forecasts by more than 50 percent.

A similar picture of the pre-referendum uncertainty about the pound's value arises from market-based measures of future currency volatility. In particular, Figure 1 shows a strong increase in the Cboe/CME FX British Pound 30-Day Volatility Index, a forward looking measure of the market's expectation of USD/GBP volatility in 30 days. The volatility index strongly increases in May 2016 (when the 30-day window moves closer to the referendum date on June 23) and peaks just before the actual referendum. After the referendum, the index then quickly subsides to levels similar to those at the beginning of 2016. This drop in the volatility happens despite the fact that after the British voted to leave the European Union, the pound's value lost dramatically in value against all mayor currencies. For example, Figure 2 shows that the USD/GBP rate fell by about 10 percent in the days after the referendum and stayed at those levels thereafter. Thus, the resolution of the uncertainty about the outcome of the Brexit referendum led to a decrease in exchange rate uncertainty.

We exploit these dynamics around the Brexit referendum to link our theoretical predictions to our empirical analysis. First, we investigate firms' GBP forward usage in response to an increased FX uncertainty (the period after the announcement but before the referendum date), and how banks supply those derivatives and manage the resulting risk migration. Second, we look at the post-Brexit-referendum period when the exchange rate risk materialized, and banks with exposure to the pound incurred losses or gains from their derivative positions. In particular, we analyze changes in credit supply by loss-bearing banks and the potential real effects for the corporate sector.

3 Data

We use four key data sources for our analysis. First, and at the core of our empirical analysis, we use detailed supervisory data on FX derivatives that we obtained from the Deutsche Bundesbank, which, in conjunction with the European Central Bank and the German federal financial supervisory authority (BaFin), is the prudential bank supervisor in Germany. More precisely, the European Markets Infrastructure Regulation (EMIR)—the European analogue to the U.S. Dodd-Frank Act—grants the Deutsche Bundesbank access to all derivatives trades when at least one of the involved parties is based in Germany. The raw data that we observe include detailed information on all FX derivatives contracts, including information on the contracting parties, the initiation day, the contract maturity, the type of contract, the trading capacity (on own account or agent trades), the currency traded, the notional value (expressed in both currencies), the price (or rate), and the type of collateralization. For our analysis, we focus on the most liquid and economically most relevant FX derivatives market and restrict the data to forward contracts, which is by far the most frequently used FX derivatives contract (forwards account for 84.9% of all FX derivatives contracts in our sample).[3] Given the focus of our research question, we devote our attention to all forward transactions which involve the British pound; that is, we look at both forward sales and purchases of the pound.

[3] FX swaps account for about 8 percent. However, these contracts are funding instruments and not used by firms for hedging purposes.

Second, we use proprietary data on the external positions of banks (AUSTA - 'Auslandsstatus'). These reports are maintained by the Deutsche Bundesbank and provide, for each bank in Germany, comprehensive information on all non-euro denominated claims and liabilities (both held domestically and abroad) at the currency level in each month (stock at the end of each month). In addition, the reports include information on the maturity and on the sector (interbank, retail, and affiliated offices) that are related to the liability or asset position, respectively. This dataset is important for because it allows us to take stock of banks' foreign-currency-denominated assets and liabilities. Moreover, this information allows us to study whether banks are fully intermediating the FX risk that they engage in when meeting firms' FX risk management demand (which is the main question this paper explores). In particular, on-balance-sheet exposure in combination with derivative (off-balance-sheet) exposure allows us to comprehensively assess the overall currency exposure of each bank.

Third, we have access to the credit register from the Deutsche Bundesbank. Banks must report on a quarterly frequency all borrowers whose overall credit exposure exceeds EUR 1 million. Note that lending to small and medium-sized firms is not fully covered by this dataset. However, the credit register covers more than 70% of the total credit volume in Germany. The credit register provides information on the amount of loans outstanding at the borrower level for each bank in each quarter. Moreover, we have a comprehensive identification of borrower's industry code and country of residency.[4]

Fourth, we use Bureau van Dijk's Orbis data on firms' annual financial information. This dataset provides a number of variables, including the number of employees, sales, total debt, total assets, EBIT, among others.

[4]The credit register, however, does not record the maturity, collateral, and interest rate associated with the loans.

4 Results

4.1 Pre-Brexit FX Risk Migration

Based on our theoretical framework, we hypothesize that the increased uncertainty about the British pound's value after the Brexit referendum led to a surge in demand for GBP forward contracts by firms. Consistent with this conjecture, Figure 3 shows an increase in the total notional values of British pound sold and bought in the forward market by firms prior to the Brexit referendum in June 2016.[5] The weekly value of the notional contracts increased from an average of about GBP 30 billion in the pre-announcment period to a record high of about GBP 50 billion in the Brexit week. The figure also shows that the corporate sector was both increasing its short and long exposure on aggregate. Shortly after the Brexit referendum in June, the values dropped to a level similar to what had been witnessed before the referendum announcement. In fact, the movement of the total notional values contracted in the forward market comoves strongly with the GPB VIX uncertainty measure (Figure 1). Table 2 shows summary statistics of firms' GBP forward usage before and after the referendum was announced, confirming a larger hedging activity (larger notional values, more contracts) and a maturity extension.

In Table 3, we quantify firms' forward usage before the Brexit referendum in a regression setup at the firm level. In Panel A, we compare a firm's hedging behavior before the Brexit announcement with the post-announcement (and pre-referendum) period. In column (1), we estimate an extensive margin of forward usage by looking at new firm entry into the GBP forward market post-Brexit-announcement by collapsing, for a given firm, all contracts made in the pre-period and all contracts made in the post-period. We find that about one third of the firms that use GBP forwards contracts post-announcement are new firms that haven't been using those derivative contracts in the pre-announcement period. On the intensive

[5] In our model, firms' FX forward usage is tied to hedging purposes, i.e., risk management. In the data, we do not observe the underlying motive of firms' forward usage. Thus, although we believe this is rather unlikely, we cannot rule out that firms use forwards to speculate on FX rate movements.

margin, we find that the average total notional value (contract values sold + bought) per firm increased by about 23 percent in the post- relative to the pre-announcement period (column 2). While we find that a typical firm in our sample is about 8 percent of its total notional value short in British pounds, we do not find that, on average, a firm shifted more toward long or short positions after the announcement.

In Table 3, Panel B, we show similar results based on weekly data. Instead, of a post-announcement dummy, we use the lagged value of the logarithm of the GBP Volatility Index as an uncertainty measure of the pound's future value. The results confirm a positive association between the FX uncertainty and firms' forward usage. A one percent increase in the Volatility Index is related to a one percent increase in the number of firm's in the market, and a 9 percent increase in total notional value (sold+bought). As before, we do not find a systematic shift toward more long or short position, for the average firm.

Because firms buy and sell forward contracts with banks, a key question is whether banks that provide those derivative services to firms are retaining some of the FX risks in their books. For example, banks may face heterogeneous client demand for forwards such that their overall client trades cancel out, leaving banks unexposed to FX risk throught their derivative trading. Moreover, even if client trades do not cancel out at the bank-level, banks can engage in interdealer trade to hedge any nonzero net derivative demand from firms, thereby also passing on the FX risk instead of maintaining it on their books. Thus, the net exposure is a result of banks' net positions vis-á-vis firms and their interbank net positions. Figure 4 shows that the German banking system, on aggregate, has a nonzero net GBP forward position, which increases prior to the Brexit referendum date. Thus, the German banking system as a whole absorbs some of the FX risk, and is not fully "re-insured" in the international interbank market. Indeed, the negative net position indicates that the German banking system goes long prior to the Brexit vote.

While the net position of the entire German banking system shows the aggregate stand point, there could be important heterogeneity among German banks. This heterogeneity would be masked by only looking at aggregate exposures. In fact, our empirical identification of the effect of FX risk migration on credit supply and the real economy relies on cross-sectional exposure differences among banks and associated losses. To understand the exposure of German banks (for which we observe all contracts) in the context of the Brexit referendum, we are particularly interested in banks' risk taking in the run-up to the referendum date as measured by the exposure to the pound's value after the referendum. Therefore, we compute, for each bank i, the (cumulative) net (short) derivative exposure to the post-Brexit pound value as

$$\text{GBP Net Exposure}_{i,t} = \sum_{\substack{\tau \leq t \\ c \neq i \\ m > \text{Brexit}}} F^s_{i,c,\tau,m} - F^b_{i,c,\tau,m}. \tag{1}$$

where $F^s_{i,c,\tau,m}$ ($F^b_{i,c,\tau,m}$) indicates the notional value of forward contracts sold (bought) by a German bank i at time τ with counterparty c that matures at date m. Thus, a positive net exposure refers to an net short position, and a negative value refers to a net long exposure. Note that only contracts that mature after the Brexit referendum date on June 23, 2016, enter the exposure. Large absolute (nonzero) values indicate an exposure to the post-Brexit GBP value in the derivative market. It is important to highlight that an increase in the post-Brexit net exposure is not mechanically introduced by moving closer to the Brexit referendum date. While on the actual Brexit date *any* contract matures after the Brexit referendum, thereby adding to banks' gross post-Brexit exposure, it is not clear that the *net* position should change as time moves closer to the referendum date.

In Figure 5, we visualize the heterogeneity in banks' net exposure by plotting different percentiles of the cross-sectional distributions of net exposures (as a percentage of equity) in the run up to the Brexit referendum. The figure highlights important and growing heterogeneity in banks' net exposure to the post-Brexit value of the pound. Some banks increase their net short position (postive values), while others increase their net long position (negative values) as the Brexit referendum date moves closer. In fact, just before the Brexit referendum, about 20 percent of the banks (those below the 10th and above the 90th percentile) have a net exposure that is larger than about 25 percent of their equity value (in absolute values). On the other hand about 50 percent of the banks (those between the 25th and the 75th percentile) have a relatively small net exposure with less than 5 percent of equity (in absolute values). Summary statistics on the derivative net exposuere and other key variables for the banks in our core sample are reported in Table 5.

A natural question is why (some) banks increase their derivative exposure prior to the Brexit referendum.[6] We argue that this is likely linked to banks' on-balance-sheet exposure and their client demand in the derivative market (similar to our model). We first show evidence for skewed client demand—specifically due to industry specific factors. In Table 4, we report GBP forward usage (total notional as well as net sell) by industry during the period before the Brexit referendum was announced. To account for different number of firms in each industry, within each industry, we scale the total notional amount by the number of firms, and report net sell values as a percent of total notional. The table highlights important heterogeneity, with the financial sector (banks and nonbanks) being the most active users, both in terms of number of firms as well as total notionals per firm. We also find, that some sectors in aggregate are structurally short (e.g., Consumer Durables with 23 percent of total notional) or long (e.g., Transportation with 34 percent of the total notional). Importantly, we also report how these sectors responded deferentially to the announcement of the Brexit referendum. After the Brexit referendum was announced, we find that sectors adjust their net position heterogeneously. For example, Consumer Durables increase their net sell position (per firm) by about 23 percent relative to the total notional in the pre period. On the other hand, the Software and Services sector in relative terms built up more long positions.[7]

We do not analyze the factors why different sectors may have heterogeneous demand

[6]In principle, banks could re-insure potential risk from derivative trading in the interbank market, thereby maintaining an overall zero net derivative exposure. Similar to other markets, looking at the prices in the forward market may give us an indication whether increased risk premia made banks maintain part of the risks in their books. Indeed, this is an equilibrium outcome in our model. In Figures 7, we provide evidence for this channel. The figure shows that bid-ask spreads in the forward market widened substantially in the run up to the Brexit referendum.

[7]Within sectors we also find heterogeneity in hedging behavior.

for net short versus long positions in more detail (e.g., this could be due to differences in exports or foreign sales). However, given that the counterparty to all firms' derivatives trades is a bank, it could be that such skewed client demand for contracts maturing after the Brexit referendum is an important driver of banks' heterogeneous net derivative exposure. In particular, if banks have a derivative-client structure that is relatively concentrated toward firms from specific sectors which exhibit a skewed hedging demand. Figure 6 shows that, indeed, a given bank typically serves clients in the derivative market that are from relatively few industries. In fact, about one third of all banks only serve clients from one specific industry (HHI index of 1).[8] Thus, when the bank faces a skewed client demand for, say, long contracts, it may find itself in the position to meet this demand, for example, because of better forward rates or to maintain derivative client relationships.

In Table 6, we use a regression analysis to estimate the determinants of banks' net GBP exposure right before the Brexit referendum.[9] Column (1) shows that the on-balance sheet net GBP exposure (GBP assets minus GBP liabilities) is a significant determinant. explaining (together with size and capitalization) about 45 percent of the variation. The positive point estimate shows that banks that are net long on-balance-sheet built up a net short exposure in the GBP derivative market. In column (2), we add a bank's exposure to net-sell industries but find no evidence that this variable alone has no significant effect.[10] In column (3), however, we show that a bank's on-balance-sheet exposure interacts significantly with its derivative client structure (increasing the R-squared to 62 percent). First, banks with a net zero on-balance-sheet exposure (i.e., interaction term evaluated at zero) have significantly larger derivative short exposure if they a relatively higher share of clients from industries that

[8]We measure industry concentration in the derivative client portfolio based on total nationals in the pre-announcement period. That being said, concentration measures based on short and long positions are highly correlated.

[9]That is, in terms of Figure 4, we try to explain the dispersion at the second vertical dashed line. We restrict ourselves to those banks that we use in our credit regressions later on, and weight observations with the absolute value of banks' net exposure to focus on the observations in the tails.

[10]We compute bank j's exposure to net-sell industries as $\sum_i w_{i,j}$Net-Sell Industry$_i$, where i indexes industries, and the weights are computed during the pre-announcement period. The aggregate net-sell position of each industry i is computed based on all contracts in our sample that mature *after* the Brexit referendum. (This approach is similar to the construction of Bartik instruments.)

are, on aggregate, net long. Moreover, the positive sign on the interaction term means that banks, which are net long on-balance-sheet, have higher net short exposure off-balance-sheet if they have more clients from industries that are net long. These findings are consistent with banks' managing their overall exposure to the pound across their loan and derivative books, while being subject to potentially heterogeneous client demand in their derivative trading.

4.2 Post-Brexit FX Losses, Credit, and Real Effects

We next study the impact of the FX risk migration on credit markets. In particular, banks that increased their net exposure to the post-Brexit value of the pound through their FX forward book prior to the Brexit referendum, suffered losses or gains depending on whether they were net short or long in the pound. For a bank that is capital-constrained, an equity loss resulting from a net long position in the pound would then lead to a reduction in credit supply after the pound had depreciated.

To establish the link between losses from a bank's derivative trading and credit supply, we first construct a measure of the bank's GBP derivative losses from individual forward contracts. In particular, we compute the marked-to-market value at maturity for all contracts that a bank sold or bought between the Brexit referendum announcement and the referendum date and that matured after the Brexit referendum date. Formally, we calculate the bank's derivative losses as

$$\text{GBP Derivative Loss}_i = -\sum_{\substack{c \neq i \\ m > \text{Brexit} \\ t < \text{Brexit}}} (S_m - X^f_{i,c,t,m})F^s_{i,c,t,m} + (X^f_{i,c,t,m} - S_m)F^b_{i,c,t,m}, \qquad (2)$$

where $X^f_{i,c,t,m}$ is the agreed forward rate of a contract initiated at time t (between the Brexit announcement and referendum date) between bank i and counterparty c that matures at time m after the Brexit referendum. S_m is the spot rate prevailing at the maturity date. Both spot rates are in GBP per foreign notional currency (e.g., GBP/EUR). Thus, a marked-to-market loss from a contract where the bank buys pound forward happens if $X^f_{i,c,t,m} < S_m$, that is, if the pound has depreciated at maturity relative to the exchange rate agreed in the forward contract. The opposite holds for contracts where the bank agreed to sell pounds forward. Importantly, the way we construct these post-Brexit derivative losses, they are predetermined by the exposure entered before the Brexit referendum date and the spot exchange rate movement after the Brexit referendum date (which is exogenous to the bank).

Our second measure of GBP derivative losses takes into account marked-to-market gains (or losses) from on-balance-sheet positions denominated in British pounds. Controlling for on-balance-sheet gains/losses is important because banks with large net derivative exposures (either short of long) could enter those positions prior to the Brexit referendum to hedge their on-balance-sheet exposure (see our results from Table 6). Therefore, we compute

$$\text{GBP Net Derivative Loss}_i = \text{GBP Derivative Loss}_i - \Delta S \times \text{GBP Net Assets}_i, \qquad (3)$$

where "GBP Net Assets" is the difference between the bank's on-balance-sheet assets and liabilities in June 2016, and ΔS is the the percentage change in the GBP spot exchange rate of about 8 percent in the aftermath of the Brexit referendum. We impose this marked-to-market loss for the on-balance-sheet exposures for which do not observe the precise maturity date. However, because most on-balance-sheet net assets are of longer-term maturity (e.g., loans), the estimated on-balance-sheet loss/gain of net pound assets is likely to be unrealized. Thus, this variable builds in a forward looking component of losses that occur once the book value has to be written down.

We use these two FX derivative loss measures in a regression framework to establish a link between realized FX risk and credit. In a first set of results, we focus on the supply effect before moving to more aggregate measure of credit, which are an interplay between supply and demand shocks. To identify the supply effect, we use bank-firm-level credit exposure data, which allow us to control for concurrent demand effects. Our setup is similar to a standard difference-in-differences approach used in the banking literature (Khwaja and Mian 2008). In particular, we model credit growth (percentage change in exposure) at the bank-firm level from 2016:Q2 to 2016:Q3.[11] Our key explanatory variable is a bank's loss resulting from its derivative exposure to the post-referendum GBP value, and we control for borrower fixed effects in all regressions to account for demand heterogeneity. Thus, we compare credit growth by banks with different derivative losses to the *same* borrower firm. Formally, our baseline regression equation is given by

$$\Delta \text{Credit}_{i,j} = \beta \cdot \text{GBP Derivative (Net) Loss}_i + X_i\, \gamma + \alpha_j + \epsilon_{i,j}, \tag{4}$$

where α_j is borrower j's fixed effect, and X_i is a vector of bank-specific control variables. We us both the derivative loss and the net derivative loss (net of on-balance-sheet gains/losses). Note that there is only one time period in the regression, because we are looking at the change in credit from Q2 to Q3.

Table 7 presents the estimation results. Column (1) shows that a one-percentage-point increase in losses (relative to equity) from the FX derivative business translates into a significant reduction of credit by one-third of a percentage point. This effect holds after controlling for bank size, equity, and the on-balance-sheet net exposure to GBP assets. The latter control is important because banks with large derivative exposures could enter those positions prior to the Brexit referendum to hedge their on-balance-sheet exposure. In column (2), we use our second measure of a bank's losses from derivative trading, which directly adjusts for estimated losses/gains from a bank's on-balance-sheet positions, instead of including the on-balance-sheet net position as controls. Using this adjusted derivative loss measure, our coefficient estimate increases somewhat (in absolute value) and becomes highly significant at the one percent level. The point estimate indicates that an increase in

[11] The exposure in 2016:Q2 is only marginally affected by the outcome of the Brexit referendum on June 23, 2016, given that in Q2 there are only five business days after the referendum. While in principle there is still a chance that the 2016:Q2 credit exposure are affected by the referendum outcome, we find very similar results if we look at the change in credit from 2016:Q1 to 2016:Q3.

net derivative losses (relative to equity) by one percentage point leads to a cutback in credit by 0.43 percent.

Our baseline results from columns (1) and (2) establish a link between GBP forward losses and credit supply for the *average* bank in our sample. Our economic channel hypothesized in our model section builds on the bank's equity capital as the binding constraint, such that a loss from derivative trading, which decreases bank's equity capital, leads to a reduction in credit. Our previous coefficient estimates measure the effect of forward losses on credit for the average capitalized bank in the sample. (Table 5 shows that the average bank in our sample has an equity ratio of about 5.5 percent.) In that sense, our results are in line with our theoretical framework, where under an assumed capital constraint, a derivative loss leads to a contraction in credit.[12] It is noteworthy that our estimated effects of bank equity on credit is smaller than one; that is, we estimate an elasticity of smaller than one. This finding echoes that of several other studies (CITES) and is consistent with a smooth adjustment in credit in response to an equity shortfall relative to the bank's optimal level (which is based on both regulatory and internal risk management considerations).

In column (3), we provide further evidence on the concrete economic channel by looking at heterogeneous effects depending on the level of the capital ratio. In particular, we interact the derivative loss variable with bank equity to analyze if the contraction in credit in response to derivative losses is stronger for low-equity banks. (For completeness, we also interact the control variables with bank equity.) The positive coefficient on the interaction term shows that indeed low-equity banks cut back credit more strongly in response to derivative losses. In light of the previous discussion, low-equity banks are supposedly closer to the regulatory minimum capital ratio and, as a result, regulatory constraints become more important such that those banks have less room to adjust credit more smoothly.[13] In economic terms, we

[12]Unfortunately, measuring the tightness of a bank's capital constraint is not straightforward, as both regulatory and internal (risk management) consideration could affect a bank's optimal capital level. We follow the standard approach and use the cross-section of book equity as a proxy for the relative tightness of capital constraints.

[13]We obtain similar results if we use the regulatory leverage ratio instead of book-equity-to-assets. On the other hand, we do not find evidence that high-derivative-loss banks with low tier-1 (risk-weighted) capital

estimate that the cutback in credit is by a tenth of a percent stronger when a bank has a one-percentage-point lower equity ratio. This effect is significant at the 5 percent level and holds after controlling for borrower fixed effects. Thus, the coefficients are identified, as before, by comparing changes in credit by different banks to the *same* firm in the *same* quarter, depending on variation in derivative losses and equity ratios.

Next, we look at the more aggregate impact on credit markets. In particular, we now ask if the identified supply shock has an overall impact on firm-level credit. This is important because firms could potentially substitute the lack of credit availability from one bank by increasing borrowing from another bank. To estimate the credit effects at the firm level, we look at the total firm-level credit growth (percentage change in exposure by all creditors) from 2016:Q2 to 2016:Q3. We relate this firm-level credit growth to a dummy variable that indicates whether the firm had a substantial credit reliance on a bank with derivative losses prior to the Brexit referendum.[14] In particular, we compute for each firm j the variable

$$\text{Past Derivative-Loss-Bank Reliance}_j = \sum_i w_{i,j} \mathbb{1}(\text{Derivative Net Loss}_i < 0), \qquad (5)$$

where $w_{i,j} = \text{Credit}_{i,j} / \sum_i \text{Credit}_{i,j}$ is the weight based on 2016:Q2 exposures. We weight the loss dummy $\mathbb{1}(\text{Derivative Loss}_i < 0)$ from a firm's different creditors to account for the possibility that effects are less strong if a bank with large losses is not important to a given firm. However, our results do not depend on the weighting and are robust to a variety of other firm-level measures of exposure to loss banks.

At the firm level, we then run the following baseline regression:

$$\Delta\text{Credit}_j = \beta \text{Past Derivative-Loss-Bank Reliance}_j + \alpha_C + \alpha_I + \epsilon_j, \qquad (6)$$

where α_C and α_I are firm country and firm industry fixed effects, respectively. The industry

ratios adjust credit more after Brexit, consistent with the leverage ratio being the binding constraint.

[14] The notion of credit dependence is in line with the well-established presence of persistent banking relationships in credit markets.

classification is based on reported industries in the German credit register and is similar to a three-digit NACE Rev. 2 code.

Table 8 shows the results of the firm-level credit regressions. Column (1) shows that after the Brexit referendum total firm credit declined by about 2 percent, but the reduction was about one third larger for banks with a strong reliance on banks with derivative losses. In column (2), we find that this result holds after controlling for industry and country fixed effects. Thus, it is not the case that firms with a large reliance on high-derivative-loss banks are concentrated in certain industries or countries that in general had a decline in credit. In column (3) and (4), we show that the credit contraction happens for firms which are not directly affected by the Brexit referendum: German firms and firms for which we do not observe any FX derivative usage in the full derivative dataset (which we think of as a proxy for no FX risk). Those firms, in particular firms in the latter two groups, are likely not to be affected through direct FX exposure to the pound. Yet, also for these firms, we find a substantial reduction in credit if they have a strong reliance on banks with derivative losses.

Given the credit cutback for firms that rely on borrowing from banks with post-Brexit derivative losses, which firms could not substitute by increasing borrowing from other banks, we next ask whether the cutback in credit leads to real effects at the firm level. In Table 9, we use different basic firm-level statistics to investigate these real effects. These data are available at the annual frequency. Column (1) shows that firms with reliance on derivative-loss banks reduced their cash holdings from end of 2015 to end of 2016 by 8 percent more than otherwise similar firms. In particular, we control in column (1), as in all regressions, for industry fixed effects, country fixed effects, and lagged values of key firm data, including total assets and employment. In columns (2) and (3), we also find that investment in fixed assets and tangible assets decreases by about 2.2 and 2.5 percent, respectively, more for firms with reliance on derivative-loss banks. In column (4), we show that we do not find evidence on employment effects.

5 Conclusion

We show the financial stability effects of FX risk migration from the firm to the banking sector in the context of the Brexit referendum in 2016. In particular, our finding suggest that FX risk, if migrated to the banking sector and not fully intermediated, can transform into real effects to the broader economy through adjustments in bank credit supply.

Our results have important policy implications. First, and most directly, when designing regulatory FX risk charges for banks, policy makers should take into account the financial stability effects documented in this paper, in particular, spillovers to the bank's credit book. Second, and more broadly, while we do not address normative questions in this paper, our findings relate to the discussion about the optimal reallocation of FX risk in the economy (who should be holding the risks).

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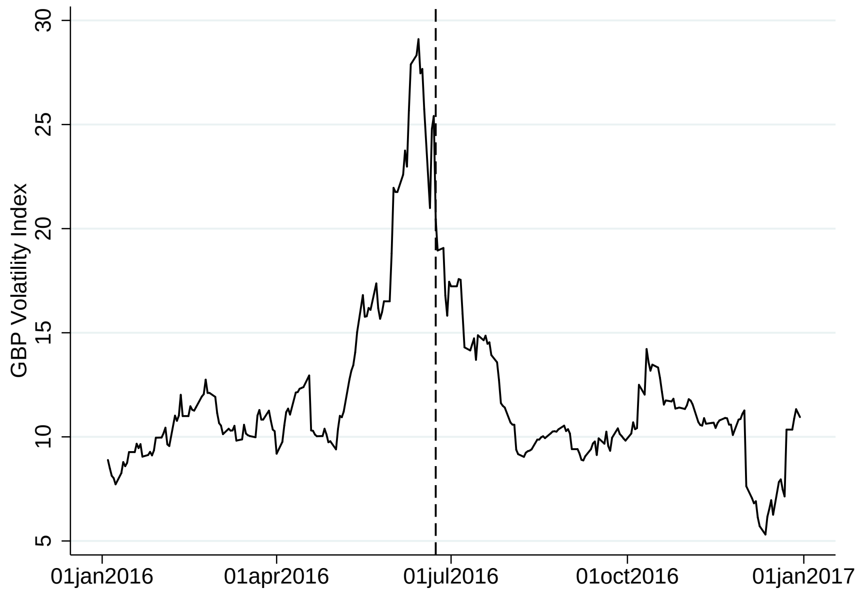
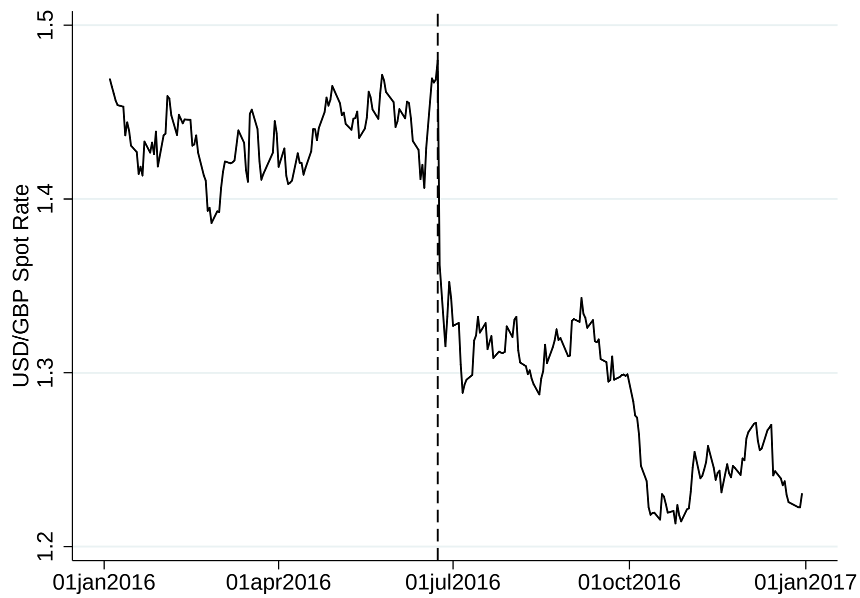
Figures

Figure 1: GBP 30-Day Forward-Looking Volatility Index



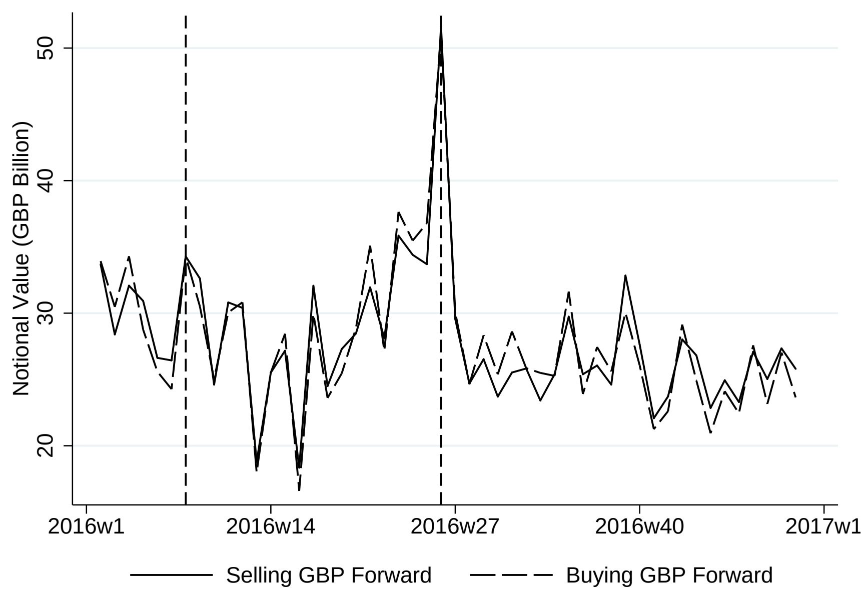
Notes: The figure shows the Cboe/CME FX British Pound 30-Day Volatility Index, which measures the market's expectation of 30-day currency-related volatility. The vertical line indicates the Brexit referendum date on June 23, 2016.

Figure 2: GBP Spot Exchange Rate



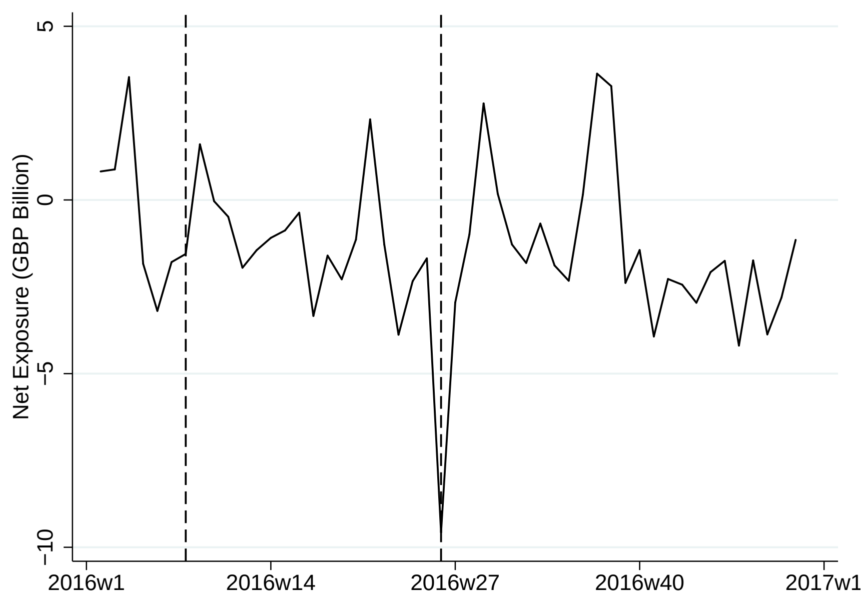
Notes: This figure shows the USD/GBP spot exchange rate. The vertical line indicates the Brexit referendum date on June 23, 2016.

Figure 3: Corporate Sector GBP Forward Contracts



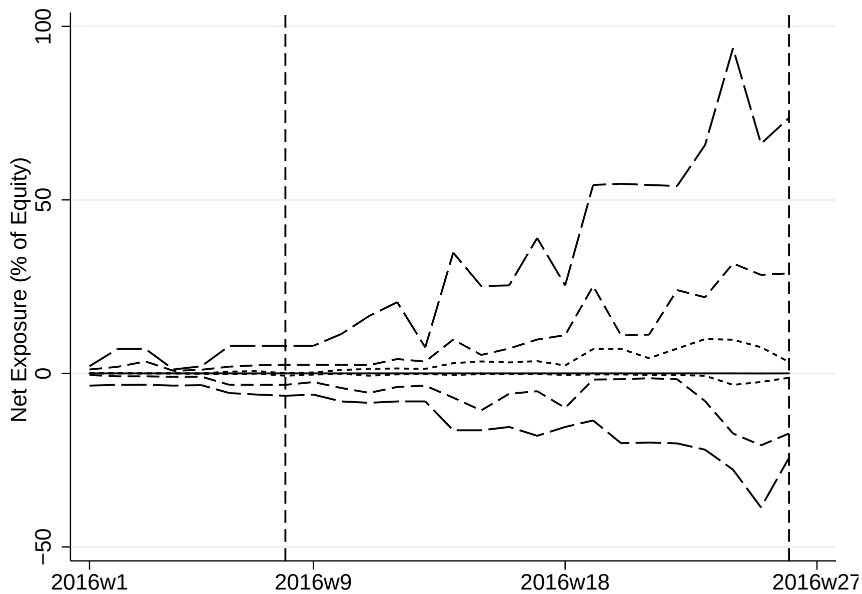
Note: This figure shows the weekly total notional value of GBP sold (solid line) and bought (dashed line) by firms. The sample includes all trades with German banks. The first vertical line indicates the announcement of the Brexit referendum on 2016w8. The second vertical line indicates the Brexit referendum on 2016w29.

Figure 4: German Banking System Net GBP Forwards Sold



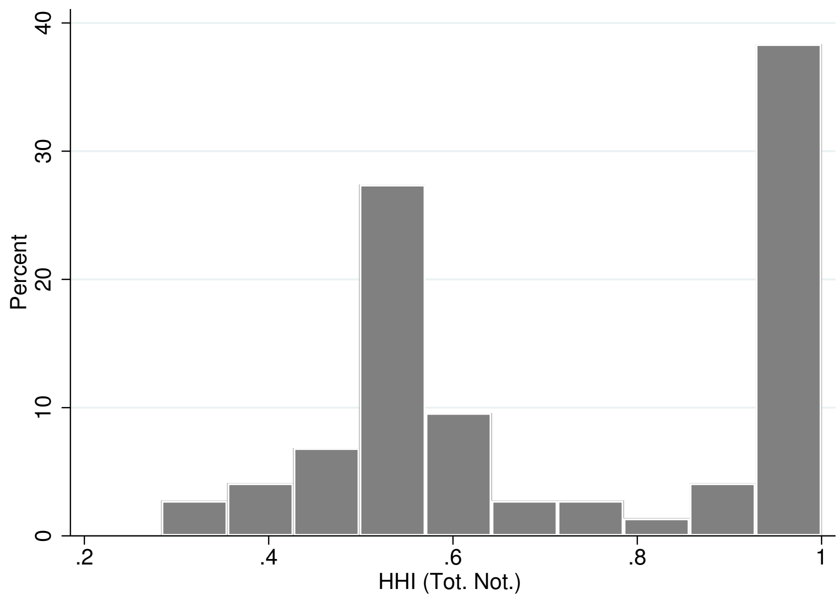
Note: This figure shows the net notional value of GBP sold forward by banks. "Net" refers to GBP sold forward minus GBP bought forward. The first vertical line indicates the announcement of the Brexit referendum on 2016w8. The second vertical line indicates the Brexit referendum on 2016w26.

Figure 5: Bank Heterogeneity in Net Exposure to Post-Brexit GBP Value



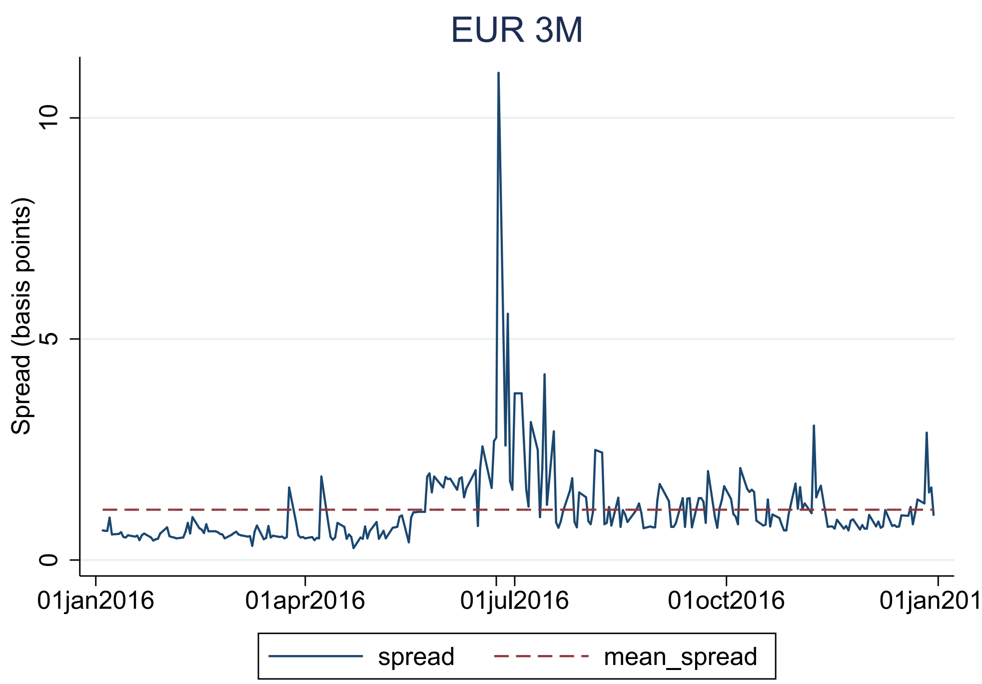
Note: This figure shows the cross-sectional distribution of the cumulative net notional value of GBP sold forward by banks with maturity date after the Brexit referendum on June 23, 2016. "Net" refers to the difference between exposure from GBP sold forward and GBP bought forward. The first vertical line indicates the announcement of the Brexit referendum on 2016w8. The second vertical line indicates the Brexit referendum on 2016w26. Long-dashed lines refer to the 5th and 95th percentile, dashed lines to the 10th and 90th percentile, and dotted lines to the 25th and 75th percentile, respectively.

Figure 6: Industry Concentration in Banks' Derivative Clients



Note: This figure shows the distribution of the industry concentration index (Herfindahl-Hirschman Index) of banks' clients in the derivative markets. Values closer to zero mean that a bank serves clients from all industries equally (in terms of total notional).

Figure 7: Bid-Ask Spread in Pound-Euro Forward Market



Bid-ask spread on three month EUR/GBP forward contracts (Bloomberg).

Tables

Table 1: Forecast Distribution for Post-Brexit-Referendum USD/GBP Rate

	Forecasts of July 2016 rate made before Announc. (January 2016)	after Announc. (April 2016)	% Change
Mean	1.50	1.44	–4.00
Range (Max–Min)	0.11	0.17	54.55
Relative Range (%)	7.33	11.81	60.98

Note: Data are taken from Consensus Economics. The range of the forecast distribution is a measure of FX rate uncertainty. Relative range is the range of the forecast distribution relative to its mean (in percent). The announcement of the Brexit referendum was on February 22, 2016.

Table 2: Firm-Level Summary Statistics on GBP Forward Usage

Panel A: Firm sells GBP forward

	Mean	St. Dev.	p10	p25	p75	p90	Obs.
Pre-Announcement Period							
Total Notional (GBP Mio)	103.12	702.19	0.08	0.50	24.61	125.67	5,773
Number of Contracts	15.25	71.38	1	1	6	20	5,773
Average Maturity (Days)	48.04	66.69	3	8.60	57	99.14	5,769
Post-Announcement Period							
Total Notional (GBP Mio)	106.52	748.71	0.11	0.63	27.33	142.10	5,112
Number of Contracts	16.00	75.23	1	1	8	23	5,112
Average Maturity (Days)	51.79	65.81	4	12	64	113	5,102

Panel B: Firm buys GBP forward

	Mean	St. Dev.	p10	p25	p75	p90	Obs.
Pre-Announcement Period							
Total Notional (GBP Mio)	101.81	667.06	0.10	0.53	26.46	126.61	5,337
Number of Contracts	15.04	68.50	1	1	7	21	5,337
Average Maturity (Days)	40.01	60.10	3	6.32	48	89	5,334
Post-Announcement Period							
Total Notional (GBP Mio)	114.02	778.68	0.13	0.70	30.91	155.69	4,746
Number of Contracts	16.63	74.83	1	1	8	23	4,746
Average Maturity (Days)	42.78	64.09	3	7	50.67	95.60	4,745

Note: The table shows summary statistics of firms GBP forward usages broken down by sell and buy, and by two periods. The period before the Brexit referendum was announced (from October 10, 2015, through February 22, 2016), and the period between the announcement date and the actual referendum date on June 23, 2016.

Table 3: FX Uncertainty and Firms' GBP Forward Usage

Panel A: Data Collapsed by Pre-/Post-Announcement

	Firm Entry (0/1) (1)	Log(Total Notional) (2)	Net Sell (% Tot. Not.) (3)
Post-Announcement	0.3498***	0.2262***	–0.0156
	(0.006)	(0.038)	(0.011)
Constant	0.6502***	1.4074***	0.0838***
	(0.006)	(0.036)	(0.008)
Observations	11,894	12,537	12,537

Panel B: Weekly Data with VIX Uncertainty Measure

	Derivative Usage (0/1) (1)	Log(Total Notional) (2)	Net Sell (% Tot. Not.) (3)
Log(GBP Volatility Index)	0.0066**	0.0892*	0.0155
	(0.003)	(0.046)	(0.013)
Constant	0.1440***	0.6086***	–0.0124
	(0.007)	(0.123)	(0.035)
Observations	216,750	34,823	34,823

Note: The table shows firms' forward usage in response to increased uncertainty. In Panel A, the data are collapsed into a pre-Brexit-announcement period (October 10, 2015, through February 22, 2016) and post-Brexit-announcement period (February 23, 2016 through 23 June 2016); thus, for each firm, there are two observations. Panel B, is at the weekly frequency (each observation is a firm-week) and uses the (lagged) GBP volatility index as an uncertainty measure. The dependent variable "Firm Entry" is a dummy variable equal one if a firm is a new derivative user after the announcement, and zero otherwise (sample conditioned on firms with derivatives usage in the post-announcement period). "Derivative Usage" is a dummy variable equal to one if the firm uses derivatives in a given week, and zero otherwise. "Total Notional" is the notional value (in GBP million) of total forward contracts sold and bought. "Net Sell" is the difference of the notional value of contracts sold and bought. Robust standard errors are clustered at the firm level and shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Industry-Level Usage of GBP Forwards and Change after Brexit Announcement

Industry Group	# Firms	Total Notional (GBP Mio./Firm)	Net Sell (% Tot. Not.)	Change Net Sell (GBP Mio./Firm)	Change Net Sell (% Tot. Not./per Firm)
Automobiles and Components	65	751.234	5.615	-25.398	-3.381
Consumer Durables and Apparel	57	78.107	23.830	17.876	22.887
Consumer Services	22	382.108	51.967	-115.087	-30.119
Media and Entertainment	31	167.095	-0.760	9.751	5.836
Retailing	49	28.985	-2.988	7.474	25.785
Food and Staples Retailing	32	66.785	18.626	-5.509	-8.249
Food, Beverage and Tobacco	95	28.342	3.265	3.477	12.269
Household and Personal Products	16	179.047	11.220	-14.822	-8.278
Energy	46	84.626	19.775	5.443	6.432
Banks	612	2008.133	2.231	-0.421	-0.021
Diversified Financials	2715	677.981	-3.476	11.547	1.703
Insurance	118	132.124	-0.786	-9.343	-7.071
Real Estate	12	39.190	24.607	3.299	8.419
Health Care Equipment and Services	47	325.654	-2.990	13.741	4.219
Pharma, Biotech and Life Sciences	56	329.641	11.089	9.504	2.883
Capital Goods	330	34.125	8.264	-3.115	-9.129
Commercial and Professional Services	50	31.824	2.713	0.646	2.030
Transportation	28	559.509	-34.119	154.846	27.675
Semiconductors and Semic. Equipment	17	14.679	1.108	-1.954	-13.315
Software and Services	58	160.887	18.000	-22.543	-14.012
Tech Hardware and Equipment	64	81.903	9.462	-5.726	-6.992
Materials	165	56.348	-20.846	6.757	11.991
Telecommunication Services	9	658.674	-35.639	127.638	19.378
Utilities	57	542.577	-1.475	51.874	9.561

Note: The table shows firms' forward usage (total notional and net notional) by industry in the pre-Brexit-announcement period (October 10, 2015, through February 22, 2016) as well as the change after the Brexit-announcement (period from February 23, 2016 through 23 June 2016) relative to the pre-Brexit announcement period. "Total Notional" is the notional value (in GBP million) of total forward contracts sold and bought. "Net Sell" is the difference of the notional value of contracts sold and bought. Firms are grouped into industries following S&P's Global Industry Classification Standard (GICS).

Table 5: Bank-Level Summary Statistics

	Mean	St. Dev.	p10	p25	p50	p75	p90	Obs.
Assets (EUR billion)	69.037	198.418	2.953	4.744	9.889	42.880	155.890	69
Log (Assets)	23.475	1.563	21.806	22.280	23.015	24.482	25.772	69
Equity (% of Assets)	5.520	2.343	3.075	4.250	5.327	6.091	8.288	69
GBP Net Exposure (% of Equity)	5.885	28.378	–11.526	–0.454	0.015	3.778	23.289	69
GBP Derivative Loss (% of Equity)	–0.277	3.476	–2.651	–0.333	–0.002	0.059	1.006	69
GBP Net Assets (% of Equity)	14.426	43.966	–4.181	–0.030	0.012	3.480	70.279	69
GBP Net Derivative Loss (% of Equity)	1.021	4.380	–1.510	–0.116	0.000	0.172	7.801	69

Note: This table shows summary statistics for the banks in the sample of Table 8. Each bank is one observation. Balance sheet positions are taken from supervisory data as reported on June 2016. Derivative exposures and losses are computed for contracts initiated during the period from the Brexit referendum announcement on February 22, 2016, through the actual referendum date on June 23, 2016. Moreover, only contracts that mature after the Brexit referendum date, i.e., those that are introducing exposure to the post-Brexit value of the GBP are considered. Derivative losses are value-weighted marked-to-market losses at forward contract maturity. "Net Derivative Loss" accounts for on-balance-sheet marked-to-market gains/losses. For details on the construction of the variables, see text.

Table 6: Determinants of Banks' GBP Net Sell Derivative Exposure

	Dep. Var.: GBP Net Exposure (% of Equity)		
	(1)	(2)	(3)
GBP Net Assets	0.7579**	0.7792**	1.1358***
	(0.2950)	(0.2959)	(0.2740)
Exposure to Net Sell Industries		–0.6039	–3.0014**
		(1.5951)	(1.2336)
GBP Net Assets * Exposure to Net Sell Industries			0.0633***
			(0.0192)
Equity (% Assets)	2.0209	3.3583	6.1114
	(3.6062)	(4.5402)	(3.9250)
Assets (in logs)	–2.9798	0.7064	9.4921
	(6.3126)	(8.3967)	(7.5246)
Observations	69	69	69
R-squared	0.451	0.453	0.617

Note: This table shows the determinants of banks' GBP net derivative exposure right before the Brexit referendum. Each observation corresponds to one bank. *Exposure to Net Sell Industries* is computed based on the pre-announcement period. Regressions are weighted by banks' (absolute value of) net GBP exposure. A constant is included in the regression but not shown. Robust standard errors are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Credit-Growth Regressions at the Bank-Firm Level

	Dep. Variable: Credit Growth (Percent)		
	(1)	(2)	(3)
GBP Derivative Loss (% of Equity)	–0.3289*		
	(0.1736)		
GBP Net Derivative Loss (% of Equity)		–0.4260***	–0.7719***
		(0.1503)	(0.2022)
GBP Net Derivative Loss * Equity			0.1040**
			(0.0455)
GBP Net Assets (% of Equity)	–0.0420***		
	(0.0156)		
Log (Assets)	–0.2533	–0.2950	–0.3628
	(0.2570)	(0.2550)	(0.5975)
Equity (% of Assets)	–0.4212	–0.4460	–0.6849
	(0.3117)	(0.3104)	(2.7295)
Log (Assets) * Equity			0.0085
			(0.1085)
Borrower Fixed Effects	Yes	Yes	Yes
Observations	60,000	60,000	60,000

Note: This table shows the post-Brexit referendum credit growth at the bank-firm level depending on a bank's GBP derivative losses and its equity ratio. The dependent variable ”Credit Growth” is a bank's percentage change in credit outstanding to a given borrower from 2016:Q2 to 2016:Q3. The independent variable ”GBP Derivative Loss” is the marked-to-market loss in the post-Brexit period from a bank's GBP derivative positions entered before the Brexit referendum (in percent of equity). The independent variable ”GBP Net Derivative Loss” adjusts the value of ”GBP Derivative Loss” by the estimated marked-to-market gain/loss from on-balance-sheet GBP exposure (in percent of equity). ”GBP Net Assets” is the difference between the bank's on-balance-sheet GBP asset and liabilities (percent of equity). All balance sheet variables are predetermined using June 2016 values. Robust standard errors are clustered at the bank level and reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Credit-Growth Regressions at the Firm Level

	Dependent Variable: Post-Brexit Change in Credit (Percent)			
	All Firms	All Firms	German Firms	No GBP Forwards Used
	(1)	(2)	(3)	(4)
Past Derivative-Loss-Bank Reliance	–0.8031***	–0.6259***	–0.8143***	–0.6534***
	(0.2229)	(0.2307)	(0.2316)	(0.2295)
Constant	–1.9391***			
	(0.0922)			
Industry FE	No	Yes	Yes	Yes
Country FE	No	Yes	Yes	Yes
Observations	371,576	351,245	310,426	349,212

Note: This table shows the post-Brexit referendum credit growth at the firm level depending on a firm's credit dependence on a bank with GBP derivative losses. The dependent variable ”Post-Brexit Change in Credit” is a firms percentage change in credit outstanding from 2016:Q2 through 2016:Q3. The independent variable ”Past Derivative-Loss-Bank Reliance” is the 2016:Q2-exposure-weighted sum of creditors of the firm that incurred GBP net derivative losses post-Brexit (see equation (5)). The sample in columns (3) and (4) restricts the sample to German firms and firms without GBP forward usage, respectively. Robust standard errors are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9: Real-Effects Regressions at the Firm Level

	Dependent Variable:			
	ΔCash Holdings (1)	Investment (2)	Investment (TA) (3)	ΔEmployment (4)
Past Derivative-Loss-Bank Reliance	–0.0803**	–0.0221**	–0.0252***	0.0043
	(0.0321)	(0.0087)	(0.0092)	(0.0048)
Firm Controls	Yes	Yes	Yes	Yes
Industry Fixed Effects	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	14,056	14,113	14,045	14,119

Note: This table shows real effects at the firm level depending on a firm's credit dependence on a bank with GBP derivative losses. The dependent variable "ΔCash Holdings" is the log difference in cash holdings. "Investment" is the log difference in fixed assets. "Investment (TA)" is the log difference in fixed tangible assets. "ΔEmployment" is the log difference in employment. All log differences refer to 2015 over 2016 changes using annual data. The independent variable "Past Derivative-Loss-Bank Reliance" is the 2016:Q2-exposure-weighted sum of creditors of the firm that incurred GBP net derivative losses post-Brexit (see equation (5)). "Firm Controls" include lagged values of cash holdings, employment, total assets, fixed assets, and fixed tangible assets. Robust standard errors are reported in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

A Theoretical Framework

We study the financial stability impact of FX risk migration in a two-period model. In period 0, a representative firm can hedge part of its foreign exchange exposure by trading forward contracts with a representative bank. In period 1, derivative contracts clear, the loan market opens, and investment takes place.

The fundamental source of uncertainty in the model is the value of the period-1 foreign exchange rate. To focus on the role of uncertainty in an as simple as possible setup, we assume the spot exchange rate in period 1 has a two-point distribution with equal probability:

$$S = \begin{cases} 1+\delta & \text{with prob. } p = 0.5 \\ 1-\delta & \text{with prob. } 1-p = 0.5, \end{cases} \tag{7}$$

where $0 < \delta < 1$. Thus, with probability one half the foreign currency depreciates or appreciates by 100δ percent. The mean future spot rate is normalized to $\mathbb{E}S = 1$, and our sole focus is on the standard deviation δ that characterized the exchange rate uncertainty.

Throughout the model exposition, all exchange rates are expressed in units of domestic currency per unit of foreign currency; that is, $S = 1.5$ means that a unit of foreign currency buys 1.5 units of domestic currency.

A.1 Firm

We consider a simple model in the spirit of Froot, Scharfstein, and Stein (1993). The key feature that generates hedging demand in response to an increase in uncertainty is the concavity of the firm's profit function. The firm has an initial endowment, the value of which is subject to exchange rate risk. In particular, the endowment $w_0 > 0$ is denominated in foreign currency and needs to be converted into domestic currency to be invested in the domestic production process. This endowment is, for example, a result of foreign revenues from existing production and sales. For simplicity, we abstract from wealth held already in domestic currency.

Production takes place in period 1 and is funded entirely through investment made in local currency. Thus, in order to invest, the firm wants to convert the initial endowment held in foreign currency into domestic currency. Exchange rate risk introduces uncertainty about the investment value funded with equity. In period 0, the firm therefore decides to hedge a share $h \in (0,1)$ of the initial wealth by buying domestic currency of value $X^f h w_0$ in the forward market, where X^f is the forward exchange rate (expressed in domestic per foreign currency), which the firm takes as given. The remaining, unhedged share $(1-h)$ of wealth is converted at the period 1 spot rate S. Thus, in period 1, the firm has a total equity value of

$$w = \left(hX^f + (1-h)S\right) w_0, \tag{8}$$

which is available for investment in production. From a period 0 perspective, if not all exposure is hedged, $h = 1$, then w is random. We focus on the case that the forward exchange rate trades at a discount ($X^f < 1$), i.e., in expectation, hedging reducing the period 1 wealth. Moreover, hedging is associated with a convex position cost, which we assume as a quadratic form $(hw_0)^2$. This cost is a short cut for modeling fees or margin requirements imposed by the dealer bank.

In addition to the amount of hedging, the firm decides on the value of debt L to hold, creating a total amount invested of $I = w + L$. Borrowing funds in the loan market is associated with an interest rate r, which the firm takes as given. The firm decides on the amount of leverage in period 1 after the exchange rate risk materialized; thus, external funding enables the firm to smooth out investment in light of exchange rate and related equity funding uncertainty. Finally, the firm uses a concave (decreasing returns-to-scale) production technology, which we assume for analytical tractability to be of a logarithmic form, $y = \theta \log(I)$, where y is total production output, sold at a unit price normalized to one, and $\theta > 0$ is a scale parameter.

We solve the model backwards by first determining the optimal amount amount of leverage in period 1 for a given value of w, and then deriving the optimal hedging decision in period 0 given the optimal leverage value.

The firm's optimal leverage decision in period 1 is given by

$$\max_{\{L\}} \theta \log (w + L) - (1 + r)L, \tag{9}$$

and the optimal amount of leverage is given by

$$L^d = \frac{\theta}{1 + r} - w, \tag{10}$$

where $\theta > (1+r)w$ is assumed to hold for all $w > 0$. Thus, the optimal leverage is a function of the firm's equity funds, which are random if $h < 1$. In particular, if w decreases due to unhedged currency exposure and a depreciation of the foreign currency, the firm wants to borrow more to maintain investment at the optimal level. Moreover, from equation (10) we find:

$$\frac{\partial L^d}{\partial r} < 0, \tag{11}$$

that is, the firm wants to reduce borrowing as the interest rate increases and obtaining external financing becomes more costly.

Moving to period 0, the loan interest rate r is a random variable that depends on the exchange rate movements in period 1 with values given by

$$r = \begin{cases} r^H & \text{if } S = 1 + \delta \\ r^L & \text{if } S = 1 - \delta, \end{cases} \tag{12}$$

where the superscript H (L) indicates the interest rate in the regime where S is high (low). In period 0, the firm thus maximizes expected profits by choosing the hedging ratio subject to the optimal leverage decision:

$$\max_{\{h\}} \mathbb{E}\left(\theta \log\left(w + L^d\right) - (1+r)L^d - (hw_0)^2\right) \tag{13}$$

$$s.t.\ L^d = \frac{\theta}{1+r} - w(h) \tag{14}$$

$$w = (hX^f + (1-h)S)w_0, \tag{15}$$

where the expectation is taken with respect to the period-1 exchange rate. The solution to the problem leads to the firm's demand function for FX forward contracts:

$$F^d = \frac{1}{4}(-r^H(\delta - X^f + 1) + r^L(\delta + X^f - 1) + 2X^f - 2, \tag{16}$$

which is upward sloping in X^f (i.e., downward sloping in the price of domestic currency $1/X^f$):

$$\frac{\partial F^d}{\partial X^f} = \frac{1}{2} + \frac{1}{4}(r^H + r^L) > 0. \tag{17}$$

Thus, the firm wants to sell more foreign currency forward contracts if the forward exchange rate is more favorable for the firm, that is, if the firm obtains more domestic currency per unit of foreign currency. Similarly, we can show that $\frac{\partial F^d}{\partial r^H} = \frac{\partial F^d}{\partial r^L} = -\frac{1}{4}(1 - \delta - X^f) > 0$ if $1 - X^f < \delta$; that is, provided that the FX uncertainty δ is high enough relative to the forward discount, the firm wants to hedge more as the interest rate increases to reduce fluctuations in domestic-currency wealth and the associated need to access the loan market for costly external funding.

Moreover, we can further derive the partial derivative with respect to the FX uncertainty parameter δ:

$$\frac{\partial F^d}{\partial \delta} = \frac{1}{4}(r^L - r^H) > 0, \tag{18}$$

if $r^L > r^H$. Thus, the firm's demand for forward contracts shifts up as the exchange rate uncertainty increases if the interest rate is higher in the regime where the domestic currency appreciates. The reason is that, due to the concavity of the firm's production function, large downward fluctuations in the exchange rate imply a disproportionate output and associated profit loss. The firm wants to avoid this risk, and hedge more as the uncertainty increases.

It is important to highlight that, for simplicity, we only focus on foreign exchange risk in the equity funded investment. More generally, we also could build in exchange rate risk in to the firm's profits through other channels, e.g., through foreign revenues (e.g., exporters), input cost more generally (e.g., importers), or the cost of foreign-currency debt. Also, note that we focus on firm's hedging demand in once direction (forward sale of foreign currency), which may be viewed as an (e.g., sectoral) net demand for short contracts.

A.2 Bank

The firm's counterparty in the loan and derivative market is a representative bank that provides credit and foreign exchange derivative services. In period 1, the loan market opens, and the bank chooses to issue loans of value L, funded through deposits D and fix equity capital K. Loans yield a gross return of $1 + r$, which the bank takes as given, while collecting deposits is associated with a convex cost $c(D)$. These costs can be interpreted as adjustment costs to the depository base or balance sheet costs.

The bank also provides FX forward contracts of total notional value F at a forward rate X^f. More precisely, F is the amount of foreign currency the bank agrees in period 0 to buy at period 1. Providing these derivative services may be associated with a convex cost $c(F)$. To meet its obligations in the forward market at period 1, the bank delivers domestic currency out of initial wealth, and converts the foreign currency received at the future spot rate S. We can think of the value F as the bank's *net* position in FX derivative trading. For example, while we do not mode this explicitly, the bank could engage in an interdealer market to hedge part of the FX risk resulting from firm (client) trades. Any nonzero net derivative position exposes the bank to FX risk, which materializes in period 1 and leads to either capital losses or gains.[15]

The bank's lending is subject to a capital constraint, which requires a share α of the loan portfolio to be funded with equity capital. A capital constraint is a standard assumption in the banking literature (e.g. Ivashina, Scharfstein, and Stein 2015) and has the most natural interpretation as a regulatory capital constraint, but it could also be due to internal risk management requirements. (In principle, we could add the requirement that net currency exposure needs to be funded partly with equity, but abstract from this channel for simplicity.) We assume that in equilibrium the capital constraint is binding, which means that the bank foregoes some positive NPV projects. In addition, a fixed equity capital means that raising equity is prohibitively (infinitely) costly in the short run. Given the binding capital constraint, in period 1, when capital gains or losses from FX derivative trading have realized, the loan supply is given by:

$$L^s = \frac{K - (X^f - S)F}{\alpha}, \tag{19}$$

where $K > (X^f - S)F$ is assumed to hold. Thus, because of the binding capital constraint, the loan supply in period 1 is inelastic as it does not directly depend on r.

In period 0, the bank chooses the amount of FX forward contracts it purchases to maximize expected profits taking the prices in the loan and derivative market as given:

$$\max_{\{L\}} \mathbb{E}\left((1+r)L^s - c(D) - (X^f - S)F\right) \tag{20}$$

$$s.t. \quad L^s = D + K \tag{21}$$

$$K = \alpha L^s - (X^f - S)F \tag{22}$$

To obtain an analytically tractable solution of the optimal FX forward provision, we assume a quadratic cost functions for lending and forwards of the form $c_1(L)^2$ and $c_2(F)^2$, respectively, with scaling parameters $c_1, c_2 > 0$. Substituting out D and L, we can then derive the bank's

[15]For simplicity, we also assume the bank has no on-balance sheet exposure to the foreign currency.

derivative supply function:

$$F^s = \frac{\alpha(2\alpha + (1+\delta)r^H + (1-\delta)r^L + 2) - 4c_1K}{4\left(\alpha^2 c_2 + c_1\left(\delta^2 + (X^f-1)^2\right)\right)} - \frac{\alpha(2\alpha + r^H + r^L + 2) + 4c_1K}{4\left(\alpha^2 c_2 + c_1\left(\delta^2 + (X^f-1)^2\right)\right)} X^f. \quad (23)$$

While the expression is lengthy, it is easy to show that the bank's derivative supply is decreasing in X^f:

$$\frac{\partial F^s}{\partial X^f} = -\frac{\alpha(2\alpha + r^H + r^L + 2) + 4c_1K}{4\left(\alpha^2 c_2 + c_1\left(\delta^2 + (X^f-1)^2\right)\right)} < 0. \quad (24)$$

In other words, when the forward rate increases, that is, becomes more unfavorable for the bank, the bank wants to reduce its derivative exposure.

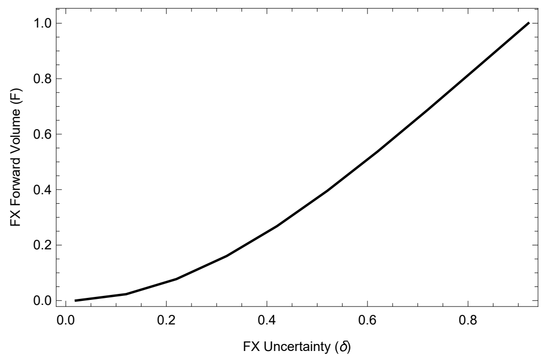
A.3 Equilibrium

We can derive the equilibrium prices in the FX derivative and loan market by equating demand and supply in the forward and loan market. Equilibrium in the loan market is state dependent on the exchange rate realization in period 1. Overall, equilibrium is characterized by a vector $(X^f, r(S))$ such that $F^s = F^d$ and $L^s(S) = L^d(S)$ for all S. Figure A1 illustrates the qualitative impact of an increase in the FX uncertainty δ on credit and derivative market outcomes. The figure illustrates the qualitative features of the equilibrium for the following parameterization: $\theta = 1.12, \alpha = 0.1, K = 1, w_0 = 0.05, c_1 = 0.48, c_2 = 0$.

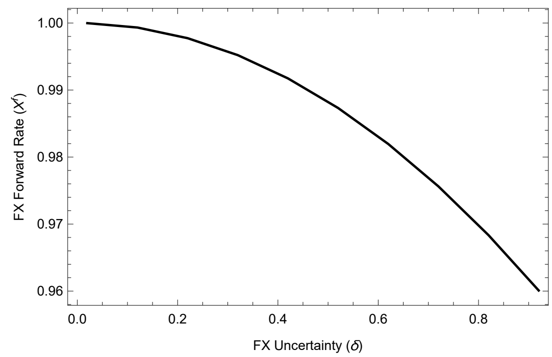
Panel A shows that the total hedging activity increases as uncertainty rises. The increased derivative usage leads to price pressure that increases the forward discount, as Panel B shows. This forward discount makes the bank willing to expose itself to FX risk to receive higher expected return from derivatives trades with a potential loss in its credit business in the state of the world where the foreign currency depreciates. The second and third row of Figure A1 show the credit market outcomes for the high and low realization of the spot rate. With a high S, i.e., an appreciation of the foreign currency, the interest rates falls and loan volume increases. This is a result of the capital gains by the bank from its derivative market that leads to an increased loan supply. On the other hand, if S falls, the bank incurs losses on its derivative exposure to the foreign currency, credit contracts and loan rates increase.

Figure A1: FX Uncertainty and Derivative and Credit Market Equilibrium

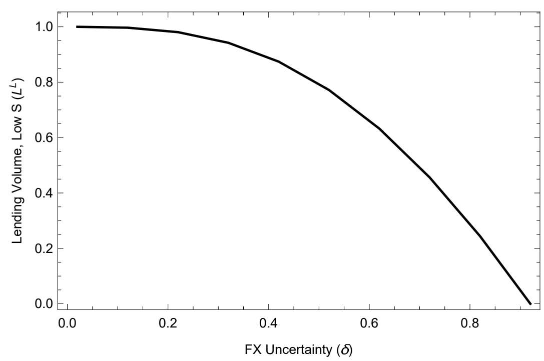
(a) FX Forward Volume



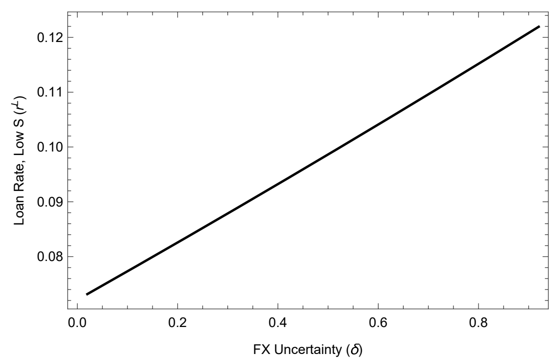
(b) FX Forward Rate



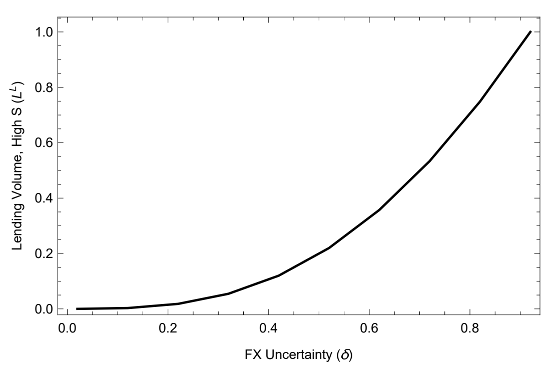
(c) Loan Volume, Low S



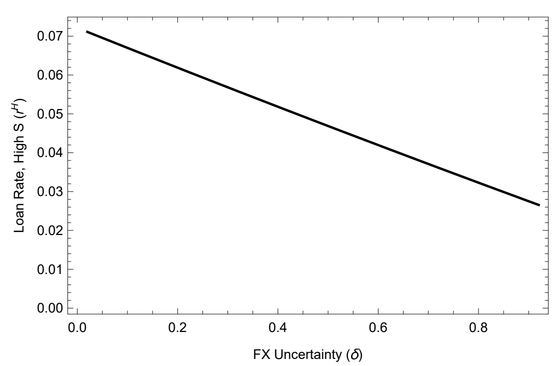
(d) Loan Rate, Low S



(e) Loan Volume, High S



(f) Loan Rate, High S



Notes: The figure shows the qualitative impact of changes in FX uncertainty ($\delta \in (0,1)$) on derivative and credit market outcomes. Panel (a) and (b) show the forward market equilibrium, panels (c) and (d) show the credit market equilibrium if the foreign currency depreciates (low S), and panels (e) and (f) show the credit market equilibrium if the foreign currency appreciates (high S). The figure shows normalized equilibrium quantities that take values between zero and one.