Essays on International Finance and Financial Stability

by

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Abstract

This dissertation consists of three essays on topics in international finance and financial stability. The first essay examines the real effects of macroprudential foreign exchange (FX) regulations designed to reduce risk-taking by financial intermediaries. I exploit a natural experiment in South Korea at the bank-level that can be traced through firms. The regulation limits the banks' ratio of FX derivatives positions to capital. By using cross-bank variation in the tightness of the regulation, I show that the regulation causes a reduction in the supply of FX derivatives. Controlling for hedging demand, I find that exporting firms reduce hedging with constrained banks by 47% relative to unconstrained banks. Further, I show that the reduction in the banks' supply of hedging instruments results in a substantial decline in firm exports. For a one-standard-deviation increase in a firm's exposure to the regulation shock transmitted by banks, exports fall by 17.1% for high-hedge firms and rise by 5.7% for low-hedge firms, resulting in a differential effect of 22.8%. Collectively, my results provide causal evidence that regulations aiming to curtail risk-taking behaviors of financial intermediaries can affect the real side of the economy.

The second essay studies the pricing implications of macroprudential FX regulations. FX position limit is a leverage-based cap on net open FX position and widely used by emerging market economies as a part of their macroprudential FX regulations. I develop an intermediary-based asset pricing model where intermediaries face both margin constraint and position limit constraint and show how and when the position limit leads to a gap between onshore and offshore forward rates. The model predicts that (1) the basis increases with the shadow costs of the two constraints across time and increases with the country-specific position limit across countries, (2) the shadow cost of each constraint non-linearly increases as the intermediary sector's relative performance declines below a threshold, and (3) higher

shadow cost of the position limit predicts lower future excess return on local-currency denominated assets, as buying local assets relaxes the position limit constraint imposed on the intermediaries. I test the model predictions and find consistent evidence in the countries with tight position limits.

The third essay develops a stress testing procedure to test the resilience of financial institutions to climate-related risks. Climate change can impose systemic risks upon the financial sector, either through disruptions of economic activity resulting from the physical impacts of climate change or through changes in policies as the economy transitions to a less carbon-intensive environment. We introduce a measure called CRISK, systemic climate risk, which is the expected capital shortfall of a financial institution in a climate stress scenario. We use the measure to study the climate-related risk exposure of large global banks in the collapse in fossil-fuel prices in 2020.

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Chapter 1

The Real Consequences of Macroprudential FX Regulations

Abstract

I examine the real effects of macroprudential foreign exchange (FX) regulations designed to reduce risk-taking by financial intermediaries. I exploit a natural experiment in South Korea at the bank-level that can be traced through firms. The regulation limits the banks' ratio of FX derivatives positions to capital. By using cross-bank variation in the tightness of the regulation, I show that the regulation causes a reduction in the supply of FX derivatives. Controlling for hedging demand, I find that exporting firms reduce hedging with constrained banks by 47% relative to unconstrained banks. Further, I show that the reduction in the banks' supply of hedging instruments results in a substantial decline in firm exports. For a one-standard-deviation increase in a firm's exposure to the regulation shock transmitted by banks, exports fall by 17.1% for high-hedge firms and rise by 5.7% for low-hedge firms, resulting in a differential effect of 22.8%. Collectively, my results provide causal evidence that regulations aiming to curtail risk-taking behaviors of financial intermediaries can affect the real side of the economy.

1.1 Introduction

Global financial shocks can severely destabilize the financial and macroeconomic states of emerging markets (EM) through volatile capital flows. A surge in capital inflow can contribute to excessive credit expansions and a buildup of systemic risk, and a sudden reversal of capital inflow can lead to an increased vulnerability to crises. Therefore, managing the volatility of capital flows is a significant concern to many EM economies. EM economies have commonly adopted two types of measures to address vulnerability to external shocks: capital controls that are designed to limit capital flows directly and macroprudential foreign exchange (FX) regulations that are designed to mitigate financial-stability risks associated with capital flows.

Although previous studies have largely focused on the role of capital controls, a growing number of countries have adopted a macroprudential approach in the form of FX-related measures that limit net or gross open FX positions, FX exposures, FX funding, or currency mismatches. Figure 1.1 plots the number of EM economies that use macroprudential FX regulations, based on the International Monetary Fund's (IMF) integrated Macroprudential Policy database compiled by Alam et al. (2020). As of 2018, 74 out of 98 EM economies are using macroprudential FX regulations. Figure 1.2 shows that macroprudential FX regulations have substantially tightened, especially since the global financial crisis (GFC). A growing body of literature has documented the effectiveness of using macroprudential FX regulations.[1] However, little consideration has been given to analyzing their real implications.

In this paper, I examine whether macroprudential FX regulations imposed on financial intermediaries have real effects on non-financial sectors. Specifically, I study how a regulation that limits banks' ratios of FX derivatives positions to equity capital affects the supply of FX derivatives and firms' exports. By exploiting a natural experiment in South Korea at the bank-level, which can be traced through firms, I show that the regulation caused a reduction in the supply of FX derivatives, and it in turn induced firms to reduce their exports. To the best of my knowledge, this is the first paper to show that macroprudential FX regulations can affect the real side of the economy, especially exports, due to a shortage of FX hedging instruments. Importantly, this implies that macroprudential regulations can have a negative effect on real economic outcomes for non-financial firms, even if they mitigate vulnerabilities to the financial sector.

How do macroprudential FX regulations affect firms' exports? I answer this question in two steps. First, how do the macroprudential FX regulations cause a reduction in the supply of FX derivatives?

[1] Bergant et al. (2020) show that tighter regulation reduces the sensitivity of gross domestic product growth to VIX movements and capital flow shocks. Ostry et al. (2012) find that countries with stronger regulation were more resilient during the GFC.

Second, how does a reduction in the supply of FX derivatives lead to a decline in exports?

The first question relates to the imbalance between the hedging demand of exporters versus importers and costly equity financing by banks. If the exporters' and importers' hedging demands were balanced, banks could simply match the two sides of offsetting demand, and the leverage-based FX regulatory constraint would not bind. Similarly, if it were costless for banks to raise equity capital, banks could raise equity to meet the requirement, and there would be no reduction in the supply of FX derivatives. However, I show that banks chose to reduce their FX derivatives position instead of raising capital to meet the requirement. This is an optimal choice for banks if it is costly to raise equity. In fact, the two factors—the imbalance in the hedging demands and the intermediary constraint—are not confined to the emerging market context. Du et al. (2018) finds that the interaction between the two factors, global imbalance in investment demand versus funding supply and intermediaries' balance sheet constraints, has resulted in covered interest rate parity (CIP) deviations in the currencies of developed markets. This has occurred in the context of tightened capital requirements in the post-GFC period.

The second question relates to export decline and can be answered by considering the inability of firms to find alternative sources of hedging to ease the regulation shock transmitted by the banks. Even if a fraction of banks reduced the supply of FX derivatives following the regulation, firms could substitute part of their hedging toward banks that are less constrained by the regulation. However, I show that this is not the case. The firms' hedging with constrained banks fell compared to their hedging with unconstrained banks, and total firm-level hedging also fell. These results suggest that the firms' inability to offset the liquidity shock transmitted by banks by borrowing from alternative sources is not limited to the credit market and can be extended to the derivatives market. The unavailability of FX hedging instruments, resulting in a decline in exports, implies that FX derivatives are crucial risk management tools for firms with exposure to FX risk.

A natural experiment in Korea provides a suitable setting to study the real effects of macroprudential regulation for several reasons. First, it offers a setting in which the exposure to the regulation shock varies across banks. When the regulation was imposed in Korea, only a subset of banks was constrained, and this allows me to estimate a bank-specific tightness of the regulation. This cross-bank heterogeneity in the strictness of regulation provides an identification strategy for my empirical analysis. Second, data on the details of FX derivatives contracts at the firm-bank pair level are available for analysis. This allows me to isolate banks' hedging supply from firms' hedging demand by comparing contracts with constrained banks and contracts with unconstrained banks. Comparisons are made between firms with similar characteristics, and within the same industries, to control for the change in hedging demand. Third, firm-level FX derivatives holdings and export sales are observable. Therefore, I can evaluate the real outcomes at the firm level by comparing the firms that traded with constrained banks and those that did not.

To understand how the regulation shock to the banks propagates to firms, I proceed in three steps. First, I conduct a bank-level analysis to evaluate the banks' responses following the regulatory imposition. The regulation requires all banks located in Korea to maintain their ratio of FX derivatives to capital below a certain level. When this regulation was first announced, the constraint was binding only for a fraction of banks. I define the treatment group as the banks whose ratio of FX derivatives to capital exceeded the regulatory cap when the regulation was introduced. I compare their responses with those from the banks whose regulatory constraint was not binding. Using the difference-in-differences specification, I find that the constrained banks' FX derivatives position is reduced more than that of the unconstrained banks. I find that the gap between the two groups' FX derivatives positions decreases as the regulations are tightened. This result suggests that it is costly for banks to raise equity capital, and therefore banks cut down their FX derivatives position.

For the second step, I use contract-level data for FX derivatives, observed during the six months before and after the regulation was imposed. With these data I estimate the transmission of regulation shock from banks to firms. I control for changes in hedging demand by examining the hedging with constrained banks and the hedging with unconstrained banks for *similar* firms. For this purpose, I define similar firms as those in the same industry with similar characteristics. I find that the net FX derivatives position of contracts with constrained banks increased by 45% relative to that with unconstrained banks. The increase in the net FX derivatives position implies a contraction in hedging for the exporters and an expansion in hedging for the non-exporters, including the importers and the firms hedging their exposure to FX risk from the foreign currency debt. Both cases help loosen the banks' regulatory constraint, as their long foreign currency position in FX derivatives would decrease. I find that the effect on hedging is much stronger for exporters than for non-exporters. The exporters' hedging with constrained banks declined by 47% more than their hedging with unconstrained banks. These results suggest that regulation causes a reduction in the supply of FX derivatives.

In the third step, I conduct a firm-level analysis to understand how the regulatory shock transmitted from banks to firms affects real outcomes for firms. I define exposed firms as those whose counterparty bank for FX derivatives was constrained and compare their change in FX derivatives position with non-exposed firms. I find that the exposed exporters' hedging fell by 40–45% compared to the non-exposed exporters. This firm-level reduction in hedging implies that firms were not able to offset the shock, because switching counterparty bank relationships is costly to firms. Further, I examine whether the reduction in the supply of FX derivatives affects firms' exports, which are the primary source of exposure to FX risks. I find that firms that used to hedge at least 10% of their export sales with FX derivatives, which I refer to as high-hedge firms, substantially reduced their exports. For a one-standard-deviation increase in the firm's exposure to the regulation shock transmitted by banks, export sales fall by 17.1% for high-hedge firms and rise by 5.7% for low-hedge firms, resulting in the differential effect of 22.8%.

Based on my analyses, I argue that macroprudential FX regulation can cause a reduction in FX derivatives, which can lead to a reduction in exports by affected firms. My findings imply that the regulation achieves its goal of reducing the aggregate-level FX maturity mismatch, but only at the expense of reducing exports. This finding is important, especially for the firms that have been actively using FX derivatives to mitigate their exposure to FX risk. Further, the muted effect on the importers combined with the negative effect on the exporters has an important macroeconomic implication: the regulation could adversely affect the trade balance. It is concerning that a macroprudential regulation could destabilize what it intended to stabilize. Although my analysis does not involve an overall welfare assessment, the findings here demonstrate that macroprudential policies can have adverse effects. These effects should be carefully considered in future policy development.

I perform several robustness tests throughout the analyses to confirm the validity of the results. First, I find that the results are robust to including bank fixed effects in the bank-level analysis and including bank, firm, and contract characteristics as control variables in the contract-level and firm-level analyses. Second, I analyze changes in FX derivatives separately for foreign banks and confirm that the relative reduction in FX derivatives of the constrained banks was large and significant even within foreign banks. This suggests that the result is not driven by the difference in business models between foreign and domestic banks. Third, I estimate the impact of regulation on banks' foreign currency lending to test a potentially confounding effect of credit shock. I find no significant change in the share of foreign currency lending of the constrained banks compared to unconstrained banks. Fourth, I estimate the impact on firms' domestic sales as a placebo test and find that the effect is small and insignificant. This result implies that the decrease in export sales is indeed caused by a regulatory shock as opposed to a systemic relationship between troubled firms and constrained banks.

The conclusions of this paper apply to other emerging market economies as well as developed economies. The leverage-based cap on banks' net position of FX spot or (and) derivatives position is common. Globally, approximately three out of four countries, including developed economies, have limits on their financial sector's open FX positions as of 2018.[2] Therefore, the implications of my results may extend to countries with similar regulations.

Related Literature

This paper relates to various strands of literature. The main contribution of this paper is to an actively growing body of literature concerning the effects of macroprudential regulations in the context of international finance. Studies including Bruno et al. (2017), Ostry et al. (2012), and Acharya and Vij (2020) show the effectiveness of the regulations in achieving their goals. Bruno and Shin (2014) studied the same Korean macroprudential FX policies that are analyzed in this paper and found that the sensitivity of incoming capital flows to global conditions decreased in Korea following the introduction of

[2]Based on the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions, 147 out of 192 countries have imposed limits on the financial sector's open FX positions as of 2018. (AREAER) Of these, 27 are advanced economies.

the regulations.[3] However, Aiyar et al. (2014), Cerutti et al. (2015), Reinhardt and Sowerbutts (2015), and Keller (2019) document leakages and unintended consequences of macroprudential regulations or capital controls. I extend this literature by providing new evidence for an unintended consequence of macroprudential regulation: a substantial decline in exports due to a shortage of hedging instruments. This paper is closely related to that of Keller (2019), who analyzes a similar setting in Peru to identify the capital control shock transmitted through loans, which resulted in risk-shifting from banks to firms. In my paper, the transmission channel is through FX derivatives rather than loans, and I focus on the real effects that arise from the shortage of firms' hedging instruments. Another closely related paper is that of Ahnert et al. (2020), who evaluate the effectiveness and unintended consequences of macroprudential FX regulations using cross-country panel data. Unlike their work, I use bank-level data that can be traced through firms, and I control for firm-level changes in export opportunities by using contract-level data.

There is a large body of literature on the effect of financial shocks on the real economy. Theoretical work from Bernanke and Blinder (1988), Bernanke and Gertler (1989), Holmstrom and Tirole (1997), and Stein (1998) shows that financial shocks only affect the real economy if there are credit market imperfections at both the bank- and firm-levels. Empirical studies by Khwaja and Mian (2008) and Schnabl (2012) identify the transmission of liquidity shocks using a within-firm estimator. Paravisini et al. (2014) study the effect of credit on exporting firms and find that credit shortages reduce exports by raising the variable cost of production. Here, I add to this body of literature by documenting evidence that is similar to the bank lending channel and the firm borrowing channel in the derivatives market. In my setting, banks face a regulatory shock rather than a liquidity shock related to financial crises. The macroprudential FX regulation, combined with costly external financing, leads to a market imperfection for the banks. The market imperfection for the firms is that they are not able to offset the shock by switching across banks, which suggests that switching across banks is costly for firms in derivatives markets, as it is in credit markets. Moreover, like the findings in credit markets (Khwaja and Mian (2008)), larger firms appear to cope better with the unfavorable effects of bank shocks in the derivatives market

[3] See Choi (2014) as well.

than do smaller firms.

My paper also relates to the effects of frictions in financial intermediation on asset prices and real outcomes. In an FX market context, Gabaix and Maggiori (2015) and Du et al. (2019) apply intermediary-based asset pricing models to the exchange rate literature. On the empirical side, Du et al. (2018), Avdjiev et al. (2019) and Fleckenstein and Longstaff (2018) document the link between large, persistent CIP deviations and the intermediary constraints imposed after the GFC.[4] Ivashina et al. (2015) explain how regulatory capital constraints may lead to the violation of CIP. I contribute to the field by documenting that FX macroprudential regulation can cause financial intermediation to be costly and that the regulation can have real consequences.

My work here builds on the literature concerning the real implications of derivatives hedging. Empirical studies from Allayannis and Weston (2015), Carter et al. (2006), Jin and Jorion (2006), Campello et al. (2011), and Gilje and Taillard (2017) find that hedging is associated with an increase in firm values. Here, I highlight the importance of FX derivatives as a corporate hedging tool for managing exposure to FX risk by showing that firms' exports fall as they face a reduction in the supply of FX derivatives.

My empirical results add to the growing body of literature studying the implications of bank capital regulations on banks' behaviors. Greenwood et al. (2017) show that both the aggregate level of activity and the distribution of activity across banks will be distorted by having multiple competing capital requirements. Duffie (2018) finds that bank capital regulations have been increasingly successful in improving financial stability, but have been accompanied by some reduction in secondary-market liquidity. Studies including Allahrakha et al. (2018), Anbil and Senyuz (2018), Bicu et al. (2017) and Van Horen and Kotidis (2018) examine the effect of leverage ratio constraints on the repo markets. Haynes et al. (2019) study the impact of the leverage ratio on the derivatives market. Although the macroprudential FX regulation I study limits banks' FX derivative positions as opposed to leverage, it takes the form of imposing a leverage-based cap. I find that banks choose to shrink their balance sheet exposure rather than raising equity to meet the FX derivative capital requirement, which is consistent

[4] CIP had been close to zero before the GFC (Frenkel and Levich (1975) and Frenkel and Levich (1977)).

with the model of Admati et al. (2018).

Outline of the Paper

The remainder of the paper proceeds as follows: Section 1.2 discusses the regulatory background of the FX derivatives position limit. Section 3.2 describes the sample and data. Section 1.4 develops empirical methodology and reports the results. Section 3.7 concludes.

1.2 The Setting

1.2.1 Background

Reducing the volatility of capital flows is a challenge for many emerging market economies. In the case of Korea, a large part of the volatile capital flows was attributable to the banking sector's cross-border foreign currency (FC) liabilities.

From 2000 to 2007, prior to the GFC, Korea had twin surpluses in the balance of payments and a surge in capital inflows (Figure 1.3). The surge in capital inflows was primarily driven by the banking sector's borrowings, which subsequently had a dramatic reversal during the GFC (Figure 1.4). The outflow during the fourth quarter of 2008 was close to $40 billion, or 4% of the country's annual GDP.

In terms of external debt, Figure 1.5 shows that Korea's external debt had increased throughout the 2000s prior to the GFC, and Figure 1.6 shows that the short-term component of external debt rose substantially. Even after taking the huge accumulation of foreign exchange (FX) reserves (Figure 1.7) into account, liquidity—defined as FX reserves less short-term debt, scaled by GDP—had been deteriorating since 2005 (Figure 1.8).[5]

The surge in the banking sector's short-term borrowings was closely related to the increase in exporters' hedging demand (relative to importers' hedging demand) and banks' position covering practices. During 2006–2007, the high global demand lead exporters to have long-term US Dollar (USD) receivables, and exporters sold a large amount of USD forwards to banks in order to hedge FX exposure

[5] A measure of liquidity by Acharya and Krishnamurthy (2019)

from the USD receivables.[6] The left panel of Figure 1.9 presents the structure of firms' FX position. Because banks purchased USD forwards from exporters, they were long USD forwards. Had there been importer's hedging demand matching that of exporters', banks could have covered the long position by selling USD forwards to the importers. However, importers' hedging demand fell far short of exporters' hedging demand for several reasons. First, importers' FX liabilities are typically short-term and easier to predict. Second, it could be optimal for importers to not hedge when central bank aggressively accumulates FX reserves, in anticipation that the reserves would be used to reduce currency depreciation (Acharya and Krishnamurthy (2019)). Third, the main importing sector in Korea is the energy sector, within which firms have sufficiently large market power, allowing them to pass the FX risk to their customers through pricing. (Kim (2010))

In the shortage of natural USD forward buyers, banks needed to cover the long position in USD forwards by constructing a short position in synthetic forwards. A short position in synthetic forwards is constructed by borrowing USD, converting USD to Korean Won (KRW) in FX spot market, and investing in risk-free KRW-denominated bonds. In this process, foreign bank branches typically used short-term external USD borrowing from their parent banks.[7] The structure of banks' FX position is illustrated in the right panel of Figure 1.9.

As a result, although its firms and banks hedged their FX mismatches, Korea was left with a substantial *maturity* mismatch which made the financial system vulnerable. Korea suffered severely from USD funding liquidity crisis during the GFC, as its banks were not able to roll over the short-term external debt. As shown in Figure 1.10, the average KRW CIP basis—a measure of FX funding liquidity—was -300bps between 2007 and 2009.[8]. KRW also depreciated rapidly and Korea was close to suffering a currency crisis.[9] Figure 1.11 shows that USD appreciated by 34% during 2008.

[6] McCauley and Zukunft (2008), Ree et al. (2012) and others

[7] The domestic banks' maturity mismatch was not as severe as the foreign bank branches. (Ree et al. (2012))

[8] The average for G10 currencies during the same period was -20.8bps with maximum deviation of -63.1bps for Danish Krone. (Du et al. (2018))

[9] International Monetary Fund (2012)

1.2.2 Policy Measures

To address the vulnerabilities, Korea introduced two main macroprudential measures to improve resilience against capital flow volatility through the banking sector.[10]

FX Derivatives Position Limit

The first measure, announced in June 2010, was to limit banks' FX derivatives (FXD) position relative to their capital:

$$\frac{\text{FXD Position}}{\text{Capital}} < \text{Regulatory Cap} \tag{1.1}$$

The FXD position is defined as monthly average of daily net aggregate delta-adjusted notional value of all FXD contracts including FX forwards, swaps, and options that the bank holds.[11] Since the net FXD position is aggregated across all currencies, banks' FXD position in a currency pair that does not involve KRW (e.g. EUR-USD pair) has no effect on the constraint. The equity capital base is defined as the sum of Tier 1 capital (paid-in capital) and Tier 2 capital (including long-term, longer than a year, borrowing from its parent bank) in all currencies. The exchange rate to convert KRW-denominated capital base to USD is the average of the exchange rate used for the previous year's calculation and previous year's average exchange rate.

The limit (1.1) is placed on each bank, namely: the FXD position of a bank must be within a certain specified level relative to its equity capital at the end of the previous month. The current regulatory cap is 50% for domestic banks and 250% for foreign banks. Table 1.1 shows the historical change in the regulatory caps imposed on foreign banks and domestic banks. The regulation was tightened in the first three changes and loosened in the last two. For my empirical analysis, the last change in 2020 is not included due to lack of data availability. According to the regulator's statements, the main underlying factors that led the regulator to adjust the limit is the banking sector's aggregate short-term external debt and the USD funding liquidity condition.

The policy seeks to limit the short-term FC borrowings of banks by requiring them to put up more

[10] International Monetary Fund (2012), Bruno and Shin (2014)

[11] For non-USD FXDs, the notional values are converted to USD based on the day's exchange rate.

equity capital as they increase their FXD position. The link between banks' FXD position and short-term borrowing lies on the exporters' hedging demand in excess of the hedging demand of the opposite side, such as that of importers. Due to the imbalance in the hedging demand, banks hedged their forwards positions with offsetting positions in synthetic forwards by using cash instruments. In addition, foreign bank branches' accessibility to USD funding from their parent banks facilitated the hedging of derivatives by using cash. Figure 1.12 shows the comovement between the aggregate net FXD position and the aggregate external short-term FC borrowings of the banking sector.

Macroprudential Stability Levy

The second measure, effective since August 2011, was to impose a levy on the non-core FC denominated liabilities of the banking sector. This measure is designed to induce banks to cut down their FC borrowings by increasing their funding costs. The proceeds of the levy flow into the Foreign Exchange Stabilization Fund, which is separate from government revenue and can be used as a buffer in financial crises.

The levy is 20 basis points per year for non-deposit FC liabilities of up to 1 year maturity, and it is lower for longer maturities: 10 bps for up to 3 year maturity, 5 bps for up to 5 year maturity, and 2 bps for longer than 5 year maturity.

1.3 Data and Summary Statistics

1.3.1 Data Sources

I use three data sets for analysis: bank data, FXD contract data, and firm data. All data are publicly available. Banks' FXD position data is hand-collected from the banks' financial statements and the rest of banks' financial data is downloaded from the Korean Financial Statistics Information System[12] managed by Korea's financial regulator, the Financial Supervisory Service. FXD contract data of all listed non-financial firms is hand-collected from firms' financial statements published on the Korean Data

[12] http://efisis.fss.or.kr/fss/fsiview/indexw.html

Analysis, Retrieval and Transfer (DART) System[13]. DART is the repository of Korea's corporate filings where the disclosure filings of all Korean firms subject to external audit (including listed and non-listed) can be downloaded. The data source for firm-level financial data is TS2000, a commercial data aggregator managed by Korea Listed Companies Association. The market data such as spot and forward exchange rates, as well as interest rates, are obtained from Bloomberg and Datastream.

1.3.2 Bank Data

I focus on 46 banks that were operating as of December 2009, the last reporting period before the imposition of FXD position limit. Among them, 29 are foreign banks and 17 are domestic banks. The list of banks' full names are included in Appendix (Table A.1). Banks' on-balance sheet FX position (defined as FC assets less FC liabilities), FXD position, and the FX derivatives-position-to-capital (DPTC) ratio are observed on a monthly basis. Other financial variables of banks are observed on a quarterly basis. The sample period is from 2008 to 2018.

Aggregate Data

The mean DPTC ratio peaked at 16.9 in 2007 for foreign banks and at 0.4 in 2008 for domestic banks.[14] As of December 2009, the last reporting period before the regulation, the average DPTC ratio of foreign banks was 2.9, which exceeded the regulatory cap of 2.5. Figure 1.13 shows that 14 foreign banks had a DPTC ratio exceeding the regulatory cap, and all of them except one reduced their DPTC ratio below the regulatory cap six months after the first announcement. On the other hand, the average DPTC ratio of domestic banks was 0.17 as of December 2009, which was below the regulatory cap of 0.5. Figure 1.14 shows that the two domestic banks with a DPTC ratio above the regulatory cap reduced their DPTC ratio below the cap six months after the first announcement.

The top panel of Figure 1.15 plots the gross aggregate FXD position of banks with the announcement dates of changes in the minimum FXD capital requirement. The bottom panel plots the minimum FXD capital requirement (inverse of regulatory cap) for foreign banks and domestic banks. The

[13] https://englishdart.fss.or.kr/

[14] Figure A.1 in the Appendix plots the time series of the mean, 10-percentile, 90-percentile DPTC ratios for foreign banks and those of domestic banks, overlaid with the regulatory cap.

gross aggregate FXD position decreased after the imposition of the regulation, and it fell further following subsequent tightening adjustments.

Bank-specific Data

To study the effect of the FXD position limit on banks, I exploit the heterogeneity in the tightness of the regulation across banks. Table 1.2 reports banks' asset, derivatives position (*DerivPosition*), capital, DPTC ratio, size of derivatives positions in excess of the limit (*DerivExceeded*), and size of shock (defined as *DerivExceeded*/*DerivPosition*) if the constraint was binding. The heterogeneity in DPTC ratio comes from both its numerator and denominator, but it is driven more strongly by its numerator.[15] Among the 46 sample banks, the regulatory constraint was binding for 16 banks as of December 2009, prior to the first announcement of the regulation. The constrained foreign banks had to reduce their DPTC ratios to below 2.5 and the constrained domestic banks had to reduce their DPTC ratios to below 0.5.

The constrained banks in aggregate needed to reduce about 15 billion USD of their FXD position. Table 1.3 reports bank summary statistics by whether the bank was constrained (treated) or not (control). The constrained banks consist mostly of foreign banks. They are, on average, smaller, more leveraged, and have lower loans to assets ratios. The differences in these characteristics are statistically significant; therefore, I control for such differences in my empirical analysis. I also run separate analyses for foreign banks and domestic banks.

Figure 1.16 compares the average FXD position of constrained banks with that of unconstrained banks. It shows that the constrained banks reduced their FXD positions after the imposition of regulation, relative to unconstrained banks. In terms of FXD market share, Figure 1.17 shows that the constrained banks' share fell while foreign banks' share remained relatively stable. This is because unconstrained foreign banks took over a part of the constrained foreign banks' share.

[15]The standard deviation of DPTA is 0.19 and that of CTA is 0.12

1.3.3 FXD Contract Data

All non-financial firms in Korea have been required to disclose the details of their existing financial derivatives contracts since 1999.[16] I hand-collected the details of FXD contracts for the years 2009 and 2010. Among approximately 300 firms that had been using FXD as of 2009, I focus on 148 firms that continued to use FXD in 2010. Of these, 132 firms fully disclosed their counterparty information, while 16 firms disclosed only that of their main counterparty.[17] Although I am not able to include the 16 firms (with large FXD market shares) in the contract-level analysis, I include them in the firm-level analysis.

A FXD contract is defined as a firm-bank pair. I aggregate all contracts for a single firm-bank pair in case a bank had multiple contracts with the same bank in the same year. The net FXD position is computed by aggregating the delta-adjusted notional of individual FXD contracts for the firm-bank pair. A positive net FXD position indicates a long position in USD, or in a USD equivalent amount for a non-USD foreign currency such as Euro. While the delta of forwards, futures and swaps is 1, the delta of each option needs to be calculated. The regulatory enforcement authorities use the Black-Scholes model to calculate the delta of options. I take a simplified assumption that the delta of every option contract is 0.5. With this assumption, a long position in a call and a short position in a put would result in delta of 1, which is consistent with delta of forwards. This assumption is conservative; using the Black-Scholes delta would only make the results stronger.[18] To illustrate the calculation of net FXD position, suppose that an exporting firm A sold a USD forward with notional of \$100 and wrote a USD call option with notional of \$100 to bank B in year 2009. In this case, the net FXD position of the firm-bank pair (A,B) is $\$ -150$. The negative sign indicates that the firm would make a loss from its FXD trades with bank B in the case that USD appreciates.

[16] Ban and Kim (2004)

[17] The top 10 firms' market share of FXD usage (sum of FXD assets and FXD liabilities) is 88%, yet none of them reports the full list of counterparties. This is because the regulator does allow firms to disclose at the aggregate level, as opposed to the contract level, if: (1) the number of contracts is excessively large, and (2) the payoff structure is simple enough such that profit and losses from the contracts would be predictable, given future movements in the exchange rate. When firms report at the aggregate level, they typically do not disclose the full list of counterparties.

[18] Most of the options are exotic options with a Black-Scholes delta between 0.7 and 0.9.

The sample contains 251 contracts between 132 firms and 33 banks[19]. Table 1.4 reports the contract-level summary statistics by exposure. The contracts that do not involve KRW and the contracts without directional (buy or sell) information are excluded.[20] Roughly half of the contracts are firms taking a long position in foreign-currency. In terms of pairs, the USD-KRW pair is most common (86%). All contracts that involve KRW, but not USD, JPY, or EUR are categorized as one group. Forwards are most common type of contract, composing 53% of all contracts in the sample.

A contract is "Exposed" if the firm dealt with a constrained bank, that is, a bank that was required to reduce its DPTC ratio at the end of the 2009 calendar year. 40% of the contracts are exposed and 60% are non-exposed. The contract characteristics (size, side, pair and type) of exposed firms are statistically significantly different from those of non-exposed firms; therefore, I control for contract characteristics in my analysis.

1.3.4 Firm Data

The contract-level data are aggregated at the firm -level. Table 1.5 provides summary statistics on firm-level data by exposure. A firm is classified as "Exposed" if its main FXD counterparty bank (in terms of notional) is constrained. The exposed and non-exposed firms are similar in terms of all characteristics except FC liability share. The full-sample average net FXD position of firms is -8% of assets (similar in terms of sales), which means that firms on average make losses equal to 8% of assets in the case USD appreciates by 1 Won. This translates into approximately 20% in terms of export hedge ratio; in other words, firms hedge one-fifth of their export sales using FXD. To offer a concrete example, suppose that an exporter's total sales are worth $100 and the share of export sales is 50%. Suppose that the export sales are all account receivables, so that the firm has $50 to receive in the future. If the firm hedges $10 worth of USD forwards, 20% of the export sales is hedged. For completeness, in the Appendix (Table A.3), I show summary statistics of the subsample excluding the 16 firms that disclosed only their main counterparty.

[19] Thirteen banks in the bank data set do not have any FXD contracts with sample firms.

[20] Non-KRW FXD contracts, such as those in a EUR-USD pair, do not affect banks' FXD position limit, and they compose only 4% of total contract notional.

I categorize firms into net FXD buyers and net FXD sellers.[21] The net FXD buyers are the firms with a positive net FXD position. These firms profit from their FXD trades in the case that foreign currency appreciates, and they are typically importers or firms with FC borrowings. They mostly use swaps that match the exact cash flows of their FC loans or FC bonds they issued. Their median FC liability hedge ratio, defined as the amount of FXD bought divided by FC liabilities, is 0.56. The correlation between FC liabilities and net FXD position is 0.78.

The FXD sellers are the firms with negative net FXD position, and they are typically exporters. They primarily use forwards to hedge their export sales. Their median export hedge ratio, defined as FXD sold amount divided by export sales is 0.68. The hedge ratio of FXD sellers does not provide much information about whether firms used FXDs for the purpose of hedging or speculating, because unearned revenues are not captured in sales. To be specific, a manufacturing firm "JinSungTEC" had an export hedge ratio of 9.95, which may look like its FXD position serves a speculating purpose. However, the firm received export orders for the next ten years and its FXD was for hedging the future USD cash inflows. Since the orders flow into the unearned revenue account until the products are delivered, they do not affect sales. This kind of case makes it difficult to identify whether firms were hedging or speculating by simply looking at the hedge ratio. Nevertheless, a strong correlation (-0.93) between export sales and net FXD position suggests that the primary purpose of holding FXD was to hedge rather than to speculate.

1.4 Empirical Methodology and Results

The facts that the regulation is in terms of DPTC ratio and that not all banks exceeded the regulatory cap when it was implemented provide an identification strategy. By exploiting the cross-bank heterogeneity in DPTC ratio, I first estimate the impact of regulation on banks' FXD positions, capital, FC liabilities, and FC loans for period from 2008 to 2018 with difference-in-differences (DiD) estimator. Second, in order to disentangle banks' hedging supply from firms' hedging demand, I use FXD contract-level data for years 2009 and 2010 and estimate the transmission of the regulation shock from

[21] Tables A.12 – A.14 in the Appendix provide the list of firms with information on their hedging practices.

banks to firms. Third, I study the impact of changes in FXD position of firms on their real outcomes.

1.4.1 Impact of Regulations on Banks

This section studies the impact of the regulations on banks' FXD positions, capital, FC liabilities and FC loans.

Banks' Adjustments of FX Derivatives Positions and Capital

Since the regulation is enforced in terms of DPTC ratio, banks may manage their ratio by adjusting their derivatives position or their capital bases (or both). I show that the banks primarily adjusted the former, using the following baseline specification:

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it} \tag{1.2}$$

The outcome variable is either log of derivatives holdings (*LogDeriv*), log of capital (*LogCapital*), or DPTC ratio (*FXD*/*Capital*). $Constrained_i$ is a dummy variable that indicates whether the constraint was binding for bank i. $Regulation_t$ captures the time-variation in the overall tightness of the regulation. $Regulation_t$ is defined as the minimum FXD capital requirement (an inverse of the regulatory cap on DPTC ratio); it is 0 before the regulation's imposition, and higher values indicate a tighter regulatory constraint. The bottom panel of Figure 1.16 plots $Regulation_t$. Because the minimum FXD capital requirement is different for foreign banks and domestic banks, I construct $Regulation_t$ by taking either a simple average or a weighted average. $Regulation_t^{Avg}$ denotes the simple average and $Regulation_t^{WAvg}$ denotes the weighted average, where the weight is the derivatives positions. I use the official announcement dates rather than the effective dates (presented in Table 1.1) whenever the minimum FXD capital requirement is adjusted, as banks may preemptively react to the regulation upon the announcements before the effective dates.[22] I include monthly time fixed effects γ_t to control for

[22] The first news article mentioning that the regulators are considering introducing a regulation related to banks' FX derivatives positions was published about two weeks before the official announcement date (on 27 May 2010). My results are robust to changing the imposition date from the official announcement date (13 June 2010) to the first news date (27 May 2010).

any potential trends. I also estimate the above specification (1.2) by weighted least squares, where the weights are the size of derivatives position as of December 2009. For some specifications, I add bank fixed effects δ_i to control for differences in time-invariant factors among banks:

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t + \delta_i + \gamma_t + \varepsilon_{it} \tag{1.3}$$

I cluster standard errors by bank.

The DiD specification requires the parallel-trends assumption. The Figure 1.16 which plots the aggregate FXD position (top panel) and the normalized average FXD position by treatment (middle panel) shows that the trends were indeed parallel. It would be concerning if banks in the control group are indirectly affected by the regulation as firms substitute the banks in the treated group with the banks in the control group. However, in subsection 1.4.2 and subsection 1.4.3, I document that firms are typically unable to switch banks.

Table 1.6 reports the results. The top panel results are based on the simple average minimum FXD capital requirement, $Regulation_t^{Avg}$. The main coefficient of interest is β_1; it is expected to have a negative sign for *LogFXD*, because the constrained banks' FXD position relative to unconstrained banks' is expected to decrease as the regulation gets tighter (reflected in a higher $Regulation_t$). The estimated β_1 coefficients in columns (1) and (2) imply that the constrained banks' FXD position is reduced by 60–62%[23] more than that of unconstrained banks per unit increase in $Regulation_t$. Further, β_1 remains negative and significant when bank fixed effects are added (column (2)) and when estimated under the weighted least squares models where the weight is the pre-shock FXD position (Table A.5 in the Appendix). Columns (3) and (4) are the results when the outcome variable is *LogCapital*. I find that the estimated β_1 coefficients are small and insignificant. Columns (5) and (6) confirm that the regulation was indeed binding for the constrained banks, and therefore they reduced their DPTC ratios after the regulation.

In sum, the results suggest that the constrained banks chose to reduce their FXD position instead of increasing their capital. These results are robust to using the weighted average minimum FXD capital

[23] $1 - \exp(-0.913)$

requirement, $Regulation_t^{WAvg}$, as reported in the bottom panel of Table 1.6. While it is not surprising to find that DPTC ratio of constrained banks decreased after the regulation, the result that banks reduced the DPTC ratio by adjusting their FXD position rather than their equity capital is not obvious. If equity financing is costly, banks would choose to reduce DPTC ratio by cutting down the FXD position along with the short-term external borrowing from the parent banks, rather than to increase their equity capital.

To ensure that the results are not driven by differences in characteristics or differential exposure to the GFC across foreign banks and domestic banks, I run the same analyses separately for foreign banks and domestic banks. Tables 1.7 and 1.8 are the results for foreign banks and domestic banks, respectively. They suggest that the full-sample results are driven by the foreign banks. In other words, even among foreign banks, constrained banks reduced more of their FXD positions. This could not have been driven by the GFC, which cannot explain the variation within foreign banks.

Impact on FX Derivatives Pricing

If the reduction in FXD position was driven by a shift in supply as opposed to a shift demand, one would expect to see an increase in the mark-up on FXD contracts. An increase in mark-up corresponds to a decrease in USD forwards prices as exporters are sellers of USD forwards. Put differently, constrained banks would lower forward prices to reduce their long positions.

Since I do not observe firm-specific pricing (mark-up) on derivatives, I am not able to directly show that the constrained banks lowered USD forward prices relative to the unconstrained banks. Yet, I show suggestive evidence that the mark-up of USD forwards increased after the regulation by comparing short-term and long-term covered interest rate parity (CIP) deviations.

Define CIP deviation for maturity n at time t, ($x_{t,t+n}$), as the difference between the USD rate ($y^{\$}_{t,t+n}$) and the USD rate implied by forward price ($f_{t,t+n}$), spot exchange rate (s_t)[24], and KRW rate ($y^{₩}_{t,t+n}$):

$$x_{t,t+n} = y^{\$}_{t,t+n} - \left(y^{₩}_{t,t+n} - \frac{1}{n}(f_{t,t+n} - s_t) \right) = \frac{1}{n}(f_{t,t+n} - s_t) - (y^{₩}_{t,t+n} - y^{\$}_{t,t+n})$$

[24] Value of 1 USD in terms of KRW; higher s_t means USD appreciation.

. CIP deviation would likely fall (or, equivalently, increase in terms of magnitude) as firms raise mark-up by lowering forward prices. Because banks' long positions in USD forwards are concentrated in longer tenors, regulation would likely affect the long-term CIP deviation more than the short-term one. Figure 1.18 plots 3-month and 3-year CIP deviations. It shows that the 3-year CIP deviation fell relative to 3-month CIP deviation, particularly after the first two announcements. (The last vertical line indicates a loosening of the regulation as opposed to a tightening.)

Impact on Banks' Foreign Currency (FC) Liabilities and FC Loans[25]

Figure 1.19 shows that banks' FX positions are reasonably hedged; their on-balance sheet FC positions offset off-balance sheet FX derivatives positions. As banks need to match their FC assets and FC liabilities, a reduction in the net long FXD positions would lead to either a decrease in FC liabilities or an increase in FC assets (or both). To understand how the regulations affect banks' FX balance sheets, I estimate the same specification (1.2) with two outcome variables: FC loans share and FC liabilities share.

Table 1.9 shows that the impacts on FC loan share and FC liability share are insignificant. This suggests that the transmission of the regulatory shock on banks to firms is through the hedging channel (i.e., FXD contract relationship), rather than through the credit channel (i.e., loan relationship). Furthermore, my findings imply that similar regulations could have very different consequences, depending on whether the banking sector's FC liability is primarily used for funding domestic loans or FXD positions. For instance, Keller (2019) finds that a similar regulation by Peru that limits local banks' holdings of forward contracts results in inducing banks to increase FC loan share. On the other hand, in the case of an export-driven economy, it is FXD hedging that is paramount for exporters. Therefore, before the regulation, banks' FC borrowing had been predominantly used for banks to fund their FXD positions dealt with exporters.

In the Appendix (Table A.8), I show the results under the weighted models. When the observations are weighted by the pre-shock FXD position, the constrained banks reduced both FC loan share and FC liability share relative to unconstrained banks. The decrease in FC loan share could be due to the

[25] For this analysis, the closed banks are excluded due to data availability.

other macroprudential measure, the levy on the non-core FC liabilities, which raises the effective cost of FC funding.

Impact on Banks' Security Holdings

Although it is not the main focus of this paper, banks' adjustments of security holdings following the regulations suggest that the government bonds used in constructing the synthetic short USD forward positions were short-term government bonds rather than long-term ones. Table 1.12 shows this result. Korea Treasury Bonds (KTBs) are long-term (3-year to 30-year) government bonds, and Monetary Stabilization Bonds (MSBs) are short-term (91-day to 2-year) bonds issued by Bank of Korea. Columns (3) and (4) in Table 1.12 show that the constrained banks reduced their short-term government bond holdings as they reduced their long USD position in forwards.

All of the main results on banks' adjustments of FX derivatives positions, capital, FC liabilities, FC loans and security holdings are robust to excluding three banks that were unconstrained but became constrained at a point in time after the regulation.[26] (Appendix Table A.15–A.17)

1.4.2 Transmission of Shock to Firms

This section uses contract-level data to estimate the transmission of the regulation shock from banks to firms. An identification challenge is to disentangle the hedging demand and the hedging supply; the observed relative reduction in hedging by firms that traded with constrained banks could be due to an increase in hedging demand of firms that traded with unconstrained banks, as opposed to a decrease in supply from constrained banks. To illustrate the identification challenge, suppose that exporters predominantly trade FXD with constrained banks while non-exporters predominantly trade with unconstrained banks. If exporting opportunities were impaired during the GFC, the exporting firms that traded with constrained banks may demand less hedging than the firms that traded with unconstrained banks.

To address this problem, I examine the change in FXD hedging across contract relationships *within*

[26] Deutsche Bank, Goldman Sachs, and Mizuho

the same industry and within groups of firms with similar characteristics. Since half of the sample firms have a single contract relationship, the firm fixed effects approach (in Khwaja and Mian (2008) and Schnabl (2012), for example) would excessively reduce the sample size. Therefore, I estimate an OLS specification with controls for firm characteristics:

$$\Delta FXD_{i,j} = \alpha + \beta\ Constrained_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j} \quad (1.4)$$

The identification assumption is that the change in hedging demand is uncorrelated with the regulation shock, conditional on observed characteristics.

The outcome variable is change in net FXD position of firm j with bank i (scaled by firm j's asset) between the years 2009 and 2010. I winsorize the top 2% and bottom 2% of the scaled net FXD position to ensure that the results are not driven by outliers. $Constrained_i$ is a dummy variable that takes the value of 1 if the contract is dealt with a constrained bank and is 0 otherwise. Firm controls include log size, scaled net FXD position before the shock, FC liability share, and seven industry dummies. I also include contract and bank characteristics ensure that the results are not confounded by pre-shock differences in these characteristics. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank i's share of firm j's total FXD position, derivative type, and currency pair. The derivative type for contract (i, j) is the percentage of FXDs dealt between firm j and bank i that are classified as forwards, swaps, options, and futures. Similarly, currency pair is the percentage of FXDs that are categorized as USD-KRW pair, JPY-KRW pair, EUR-KRW pair and other pairs involving KRW. I cluster standard errors at the bank level.

I estimate the transmission separately by the direction of FXD contract. I define the exporter's FXD contract as the contract in which the firm takes a short position in foreign currency. I define the non-exporter's FXD contract as the contract in which the firm takes a long position in foreign currency. Non-exporters include importers as well as the firms with FC liabilities. I classify the sample contracts by their direction rather than by the exporting status of the firm, because direction is what matters for the constrained banks. From the perspective of constrained banks, either a reduction in exporters' contracts or an increase in non-exporters' contracts (or both) will reduce banks' long positions in FXD, and therefore will make them less constrained. Since a decrease in banks' long position in FXD corresponds to an upward adjustment in firms' net FXD position, the expected sign of β is positive for both exporters' contracts and non-exporters' contracts.

Table 1.13 show the results. Column (1) reports the result for the exporters' contracts. The scaled net FXD position of the contracts dealt with constrained banks increased by 5.3% after the shock, compared to the contracts with unconstrained banks. Given that the pre-shock average scaled net FXD position of the exporters' contracts was -8%, the change translates into a 67%[27] reduction in hedging. Column (2) adds firm controls, bank controls, and contract controls, and it shows that the relative reduction in hedging is by 47%, which is economically significant. I further find that the net option positions increase by 8.6% relative to forwards. As the pre-shock net option position was negative, an increase in net position means a reduction in hedging via options. This result is related to the fact that firms' exotic option positions incurred huge losses during the global financial crisis, which I explain in further detail in the next subsection.

Columns (3) and (4) show that the regulatory shock did not affect the non-exporters' hedging. This is likely related to the reasons why importers' hedging demand had been weak; potential reasons include central bank puts, the market power of Korea's importing sector, and importers' cash flows being relatively easier to predict (than exporters' cash flows). I report the full sample results in columns (5) and (6) for completeness.

Since the bank-specific tightness of regulation (*Shock*) is observed, I also use the following specification by replacing binary variable $Constrained_i$ in (1.4) with $Shock_i$:

$$\Delta FXD_{i,j} = \beta + \beta_{Shock} Shock_i + FirmControls + BankControls + ContractControls + \varepsilon_{i,j} \qquad (1.5)$$

$Shock_i$ is the percentage of bank i's FXD position that banks were required to reduce at the imposition of the regulation, presented in Table 1.2.

Table 1.14 presents the results. Columns (1) and (2) show that the impact on exporters' contracts

[27] (-8+5.3)/(-8)-1

remain large and significant. Column (2) shows that a one-standard-deviation increase[28] in *Shock* leads to a 2% increase in scaled net FXD position (corresponding to a 28% reduction in hedging[29]) for exporters' contracts. Columns (3) and (4) show that the non-exporters' contracts were not affected. The full sample results, columns (5) and (6), are weaker than those under the specification (1.4).

All results are robust to replacing the dependent variable, assets-scaled FXD position, with sales-scaled FXD position. The results with sales-scaled FXD position are reported in the Appendix.

Relation to Exotic Options Crisis

Most of the options in the sample are Knock-In/Knock-Out (KIKO) exotic options that many small and medium-sized enterprises entered before the financial crisis.[30] Typical payoff structure of exotic options is presented in the Appendix (Figure A.3). The continued appreciation trend of KRW with low volatility triggered the popularity of the exotic options and many firms presumably entered into the contracts without having a good understanding of the risks. After making large losses during the financial crisis, some firms sued banks for not fully informing them of the potential risks. The case of non-financial firms suffering from exotic FX derivatives positions is not unique to Korea; many EM countries have had similar experiences.[31]

To test whether the option contracts are driving the main results, I use the same specification without the option contracts. These results are independent of the simplified assumption that the delta of options is 0.5. Table 1.15 presents the results for specification (1.4), and Table 1.16 shows the results for specification (1.5). The results of exporters' contracts are still significant after excluding the options. Column (1) of Table 1.15 shows that the scaled net FXD position of sell contracts with constrained banks increased by 2.6% (corresponding to a 33% reduction in hedging). Column (1) of Table 1.16 shows that a one-standard-deviation increase in *Shock* leads to 1.7% increase in the scaled net FXD position (or, a 22% reduction in hedging).

[28] Standard deviation of *Shock* is 11.8%.

[29] (-8+2.2)/(-8)-1

[30] About 500 SMEs were holding KIKO exotic options contracts in June 2008; this number decreased to about 300 SMEs at the end of 2008.

[31] Korea, Sri Lanka, Japan, Indonesia, China, Brazil, Mexico and Poland (See Dodd (2009))

In summary, the results from the contract-level analysis suggest that the regulation caused a reduction in the supply of hedging, and the effect was particularly large for the exporters' contracts. Exporters' hedging with constrained banks decreased considerably, by 47%, compared to their hedging with unconstrained banks.

1.4.3 Impact on Real Outcomes of Firms

This section uses firm-level data to estimate the impact of changes in FXD position of banks on real outcomes of firms.

Firm-level Reduction in Hedging

To estimate the impact of the regulation shock on firm-level FX derivatives hedging, I use the following OLS specification:

$$\Delta Y_j = \beta_E \, Exposed_j + FirmControls + \varepsilon_j \tag{1.6}$$

for the full sample of 148 firms, including the 16 firms that do not fully disclose the list of their counterparties. ΔY_j denotes the change in firm-level FXD position (scaled by assets) between 2009 and 2010. The dummy variable $Exposed_j$ is 1 if the firm j's main bank is constrained and is 0 otherwise. The main bank is defined as the firm's counterparty bank with the largest FXD position. The firm control variables are same as those in the contract-level regressions. The identification assumption is that the change in hedging demand is uncorrelated with the bank exposure, conditional on observables.

For the subsample of 132 firms that disclosed complete list of their counterparties and notional amounts for each counterparty, I use the following specification:

$$\Delta Y_j = \beta_{\overline{E}} \, Exposure_j + FirmControls + \varepsilon_j \tag{1.7}$$

where $Exposure_j$ is the notional-weighted average shock of firm j's counterparty banks.

First, I report the effects on firm-level FXD position by firm size. Table 1.17 presents the result for the full sample. Columns (1) and (2) show that the net FXD position of exposed firms shifted up by 43–47% relative to non-exposed firms, given that the pre-shock average scaled FXD position was −8.2%. Columns (3)–(6) show that the effects are large for small firms, but small and insignificant for large firms. The results for the subsample with complete disclosure of counterparties in Table 1.18 corroborates that firms were not able to offset the regulation shock transmitted by banks, and small firms in particular had difficulty finding an alternative source of FXD hedging. These results are analogous to the evidence in the credit market (Khwaja and Mian (2008), for example).

Second, I report the effects on firm-level FXD position by the sign of net FXD position of firms. I define firms with negative net FXD position as exporters and those with positive FXD position as non-exporters.[32] Table 1.19 reports the full sample results. Columns (1) and (2) show that the exporters moved up their net short FXD position by 40–45% relative to non-exposed firms, given that the pre-shock average scaled FXD position for exporters was 16%. In contrast, there was almost no effect on non-exporters. Results for the fully disclosed firms in Table 1.20 are similar.

Overall, the results suggest that switching bank relationship in the FX derivatives market is costly for firms. Some plausible reasons are related to the facts that the FX derivatives are customized products and that banks typically bundle their services. In my sample, contracts are often customized to meet firm-specific hedging demand in terms of maturity and payoff structure. In addition, for a given firm, its main bank in terms of FX derivatives contracts typically coincides with its main bank in terms of loans.

Main Result: Impact on Firms' Exports

Provided that the reduction in banks' hedging supply primarily affected exporters (net FXD sellers), I confine the sample to exporters and examine the effect of the shock on their exports. I hypothesize that the impact would be larger for the firms with a larger export hedge ratio, and use the following specification to estimate the impact on exports:

$$\Delta Y_j = \beta_E \, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls + \varepsilon_j \qquad (1.8)$$

[32] Based on this classification, a firm with non-zero export sales may be classified as "non-exporter" if, for instance, the firm holds a large amount of FC debt and its main purpose of hedging is to address the FC debt exposure.

$Exposure_j$ is the weighted average shock of firm j's counterparty banks. $HighHedge_j$ is an indicator variable that takes the value 1 if firm j sold FXD more than 10% of its export sales and is 0 otherwise. With this definition, about 75% of FXD selling firms are classified as high-hedge firm ($HighHedge = 1$). The results are robust to the choice of threshold (0.1); I show that the results get even stronger if I use a continuous variable: the hedge ratio itself. Still, I use the dummy variable to ensure that the results are not driven by outliers.[33]

Table 1.21 presents the results for the change in log exports. The impact of the regulatory shock on exports is substantial; column (1) shows that for a one-standard-deviation increase in *Exposure*, firm exports fall by 17.1% for high-hedge firms and rise by 5.7% for low-hedge firms, and therefore the differential effect is 22.8%. Column (2) adds firm controls and the differential result is largely unchanged. Table 1.22 shows that the results are robust to replacing *HighHedge* variable with export hedge ratio, *HedgeRatio*, which is defined as amount of FXD sold divided by export sales.

Additionally, I test whether the firms with high export hedge ratio reduce their firm-level FXD hedging as they are more exposed to the regulatory shock. Table 1.23 shows that the change in net FXD position for high hedge firms was indeed large. The net FXD position moved up by 50–56%[34] more for high-hedge firms than for low-hedge firms, for a one-standard-deviation increase in *Exposure*.

Further, as a placebo test to confirm that my results reflect the impact of the regulatory shock, I estimate the impact on firms' domestic sales. If the result on exports is driven by a systemic relationship between troubled firms and constrained banks, one expects those troubled firms to experience declines in both domestic and export sales. However, in Table 1.24, I show that the change in domestic sales is small and insignificant, unlike that in export sales. This result confirms that the decline in export is caused by the reduction in the supply of hedging instruments, rather than by a systemic firm-bank relationship.

[33] If a firm receives export orders for the next few years and enters FXD to hedge the exposure, its export hedge ratio may exceed 1, as unearned revenues are not captured in sales. It is valid to classify such a firm as *HighHedge* firm, as it relies heavily on FXD hedging; however, the hedge ratio itself may not be a perfect measure of the ratio of hedging to the full underlying exposure.

[34] 0.06/0.12, 0.067/0.12

1.5 Robustness Results

To ensure that my results indeed reflect the impact of the regulatory shock of focus and not other shocks, I conduct several robustness checks.

First, one potential concern is a confounding effect of the non-random sorting of firm-bank relationships. Although firm-bank sorting is non-random, Table 1.5 shows that the key firm characteristics are not significantly different across exposed firms and non-exposed firms. This holds for the subset of firms that fully disclose their counterparty information (Appendix Table A.3) as well as the subset of firms with net negative FXD positions (Appendix Table A.2). Figure A.4 in the Appendix shows low correlations between firm characteristics (export share, profitability, FC liability share, and firm size) and firm exposure to the regulatory shock. Nevertheless, I control for a large number of bank, firm, and contract characteristics to ensure that the results are not confounded by the differences in these characteristics throughout my analyses.

To corroborate that the results are not confounded by potentially systemic firm-bank relationships, I conduct an analysis using coarsened exact matching (CEM) (See Blackwell et al. (2009)) based on FC liability share, the dimension along which the exposed and non-exposed firms statistically significantly differ. I coarsen the sample into five bins, considering the trade-off between keeping observations and the post-match similarity of FC liability share for the treatment and control groups. Table A.22 in the Appendix shows that the results remain similar; the interaction term is negative and significant for change in log exports, positive and significant for change in net FXD position (scaled by assets), and small and insignificant for change in log domestic sales. Table A.23 in the Appendix shows that the results are robust even after matching firms on export share, profitability, and FC liability share.[35] I include export share as a matching variable to address an alternative hypothesis that exporters predominantly traded with foreign banks, which are the majority of constrained banks. I also include profitability as a matching variable to address an alternative hypothesis that troubled firms predominantly traded with constrained banks.

Second, one may be concerned about the difference in business models between foreign banks and

[35] I coarsen the sample into three bins per matching variable.

domestic banks. Almost by construction, it is likely that foreign banks would suffer more from the regulation, because they are more active in FXD business than domestic banks. In fact, a few foreign banks closed in 2017, after the regulation.[36] However, it is noteworthy that only half (14 out of 29) of foreign banks in my sample were constrained at the imposition of the regulation, and in fact I find stronger results in the bank-level analysis when I constrain my sample to foreign banks (Table 1.7). This suggests that my results are not driven by the differences in bank characteristics across foreign banks and domestic banks.

Third, one could be worried that the result is confounded by a credit supply shock. Specifically, an alternative hypothesis is that the constrained banks were in trouble during the GFC, and therefore they were more likely to suffer from the credit supply shock. However, the results that constrained banks' share of FC lending was not significant for the full sample (Table 1.9), for foreign banks (Table 1.10), and for domestic banks (Table 1.11) corroborate that the mechanism at work is through the hedging channel, rather than the credit channel.

1.6 Conclusion

In this paper, I exploit a natural experiment in South Korea to examine the real effects of macroprudential FX regulations that were designed to reduce risk-taking by financial intermediaries. First, by using the cross-bank variation in the tightness of regulation, I find that the regulation limiting the banks' ratio of FX derivatives to equity caused a reduction in the supply of FX derivatives. Second, I find that exporters' hedging with the constrained banks was reduced by 47% relative to that with the unconstrained banks. Third, I find that the reduction subsequently caused firms relying on FX derivatives as a hedging tool to substantially reduce exports. I offer a mechanism in which the imbalances in hedging demand, banks' costly equity financing, and firms' costly switching of banking relationship play a central role in explaining the empirical findings. In sum, my results suggest that macroprudential regulations could affect the real side of the economy.

[36] Royal Bank of Scotland, Barclays, Goldman Sachs International Bank, and UBS

Figures

Figure 1.1: Number of Countries using Macroprudential FX Regulations

The number of emerging market (and developing economies) countries using macroprudential FX regulations, based on IMF integrated Macroprudential Policy Database.

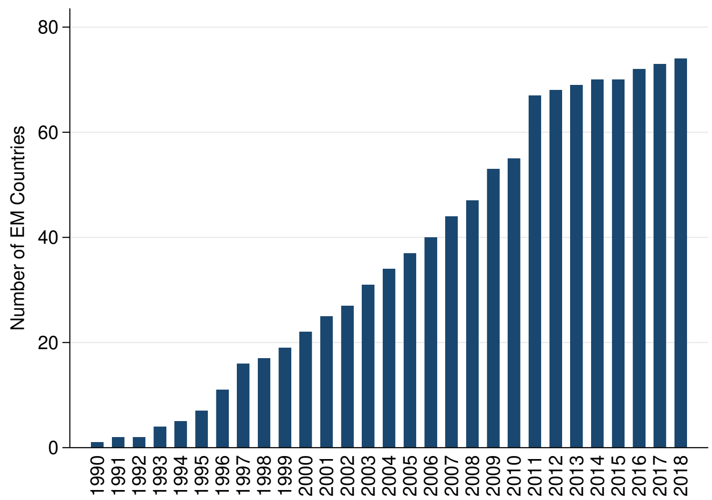


Figure 1.2: Tightness Macroprudential FX Regulations

The cross-country average of the number of the tightening measures (net of loosening ones), based on IMF integrated Macroprudential Policy Database.

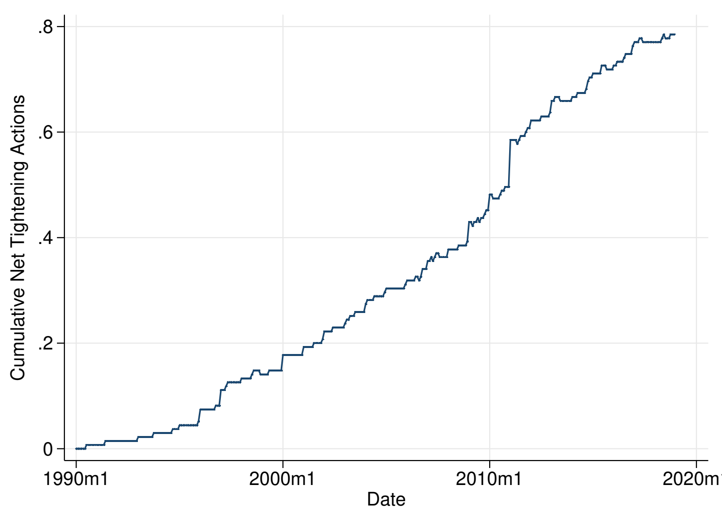


Figure 1.3: Balance of Payments

Korea's balance of payments. The vertical line indicates the imposition of the regulation.

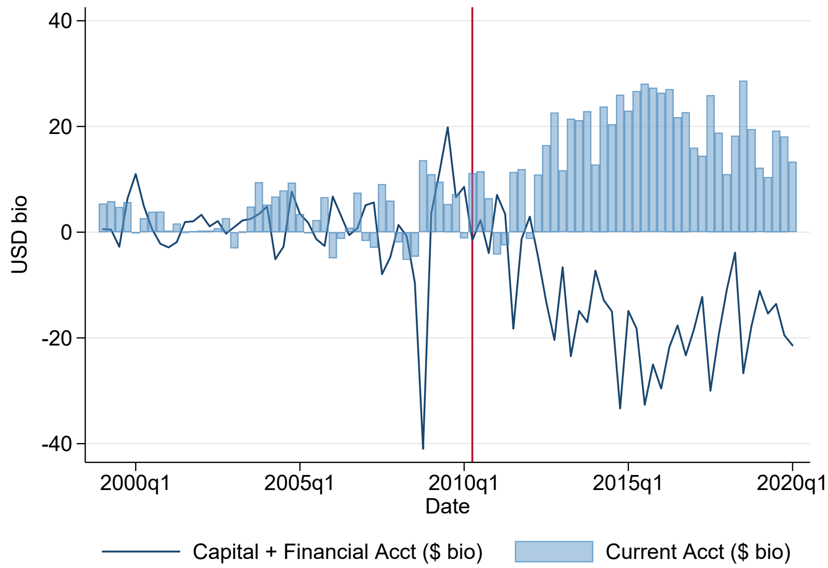


Figure 1.4: Gross Foreign Capital Inflows

Korea's gross foreign capital inflows. The vertical line indicates the imposition of the regulation.

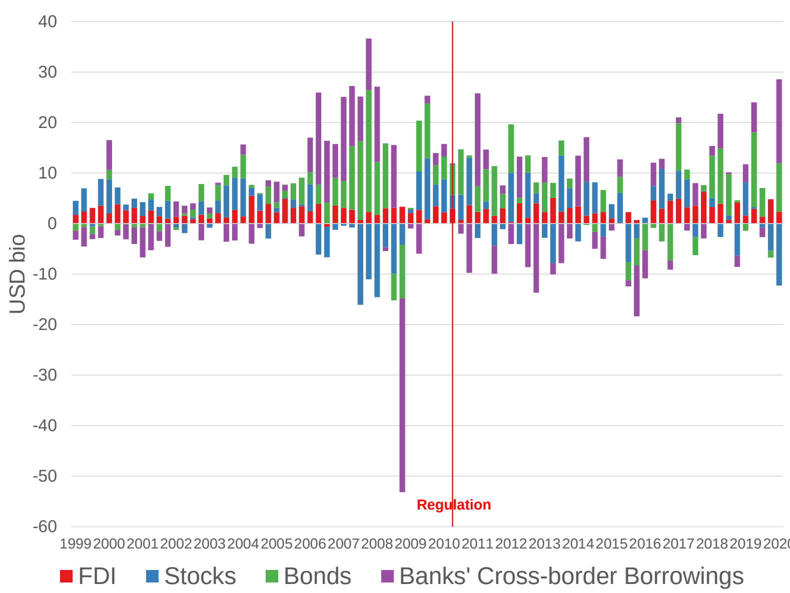


Figure 1.5: Total External Debt

Korea's total external debt in USD billion (bar) and external debt as a percentage of GDP (line).

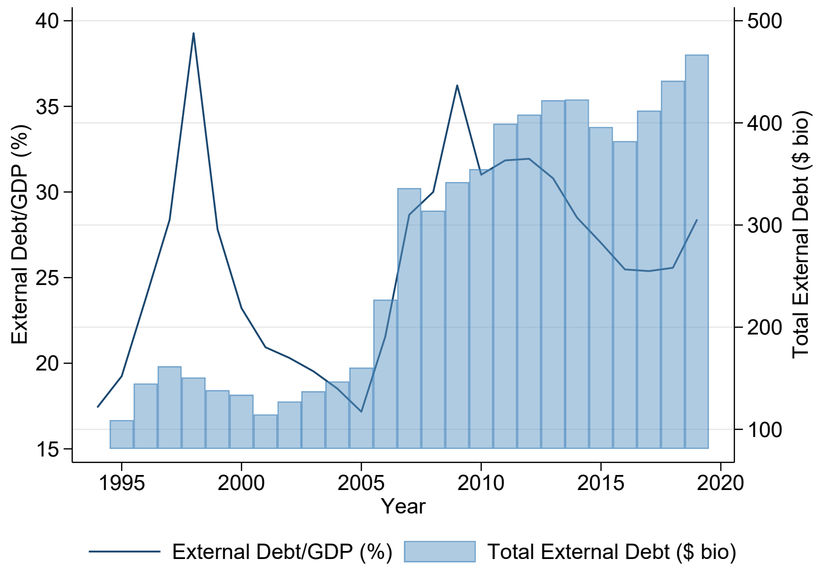


Figure 1.6: Short-term External Debt

Korea's total short-term external debt in USD billion (bar) and share of short-term external debt in percentage (line).

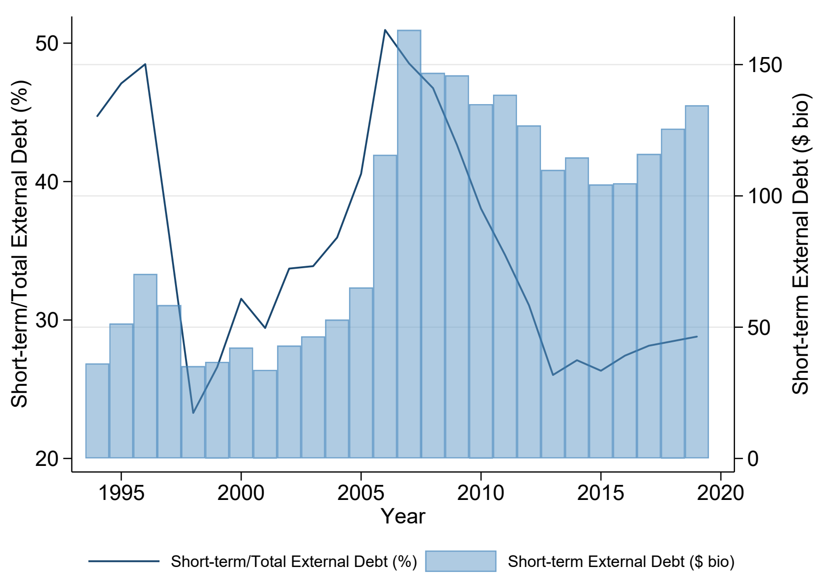


Figure 1.7: FX Reserves

Bank of Korea's FX reserves in USD billion.

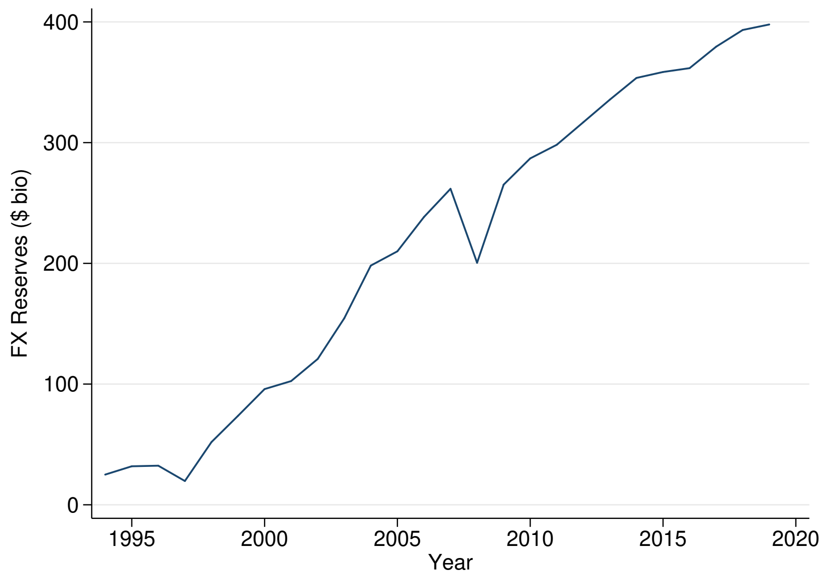


Figure 1.8: Liquidity

Korea's FX reserves less short-term external debt in USD billion (bar), and liquidity (line), defined as: (FX Reserves - Short-term External Debt)/GDP.

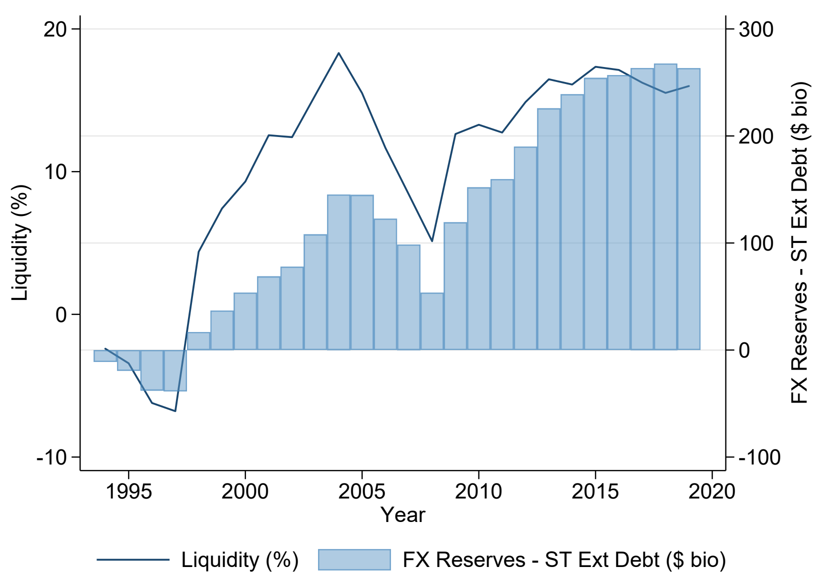


Figure 1.9: FX Position of Exporters and Banks before the Regulation

The left panel illustrates the structure of exporters' FX position and the right panel illustrates the structure of banks' FX position, prior to the regulation. Exporters had long position in foreign currency (due to export sales), and hedged the long exposure by taking short position in FX derivatives. As banks are the firms' FX derivatives counterparties, banks had long position in foreign currency due to the FX derivatives. Banks hedged the long exposure by foreign currency borrowing.

Firms (Exporters)			Banks		
Long FC:	*Short FC:*		*Long FC:*	*Short FC:*	
FC Receivables	**FX Derivatives**	→	**FX Derivatives**	**FC Borrowing**	<- Cross-
(Long-term)	(Long-term)		(Long-term)	(Short-term)	border
	FC Loans		FC Loans	FC Deposits	

Figure 1.10: CIP Bases

10-day moving average of daily CIP bases for different maturities. CIP basis at time t for maturity n is defined as:

$$x_{t,t+n} = y^{\$}_{t,t+n} - \left(y^{₩}_{t,t+n} - \frac{1}{n}(f_{t,t+n} - s_t) \right) = \frac{1}{n}(f_{t,t+n} - s_t) - (y^{₩}_{t,t+n} - y^{\$}_{t,t+n})$$

where $f_{t,t+n}$ is forward exchange rate, and s_t is spot exchange rate defined as value of 1 USD in terms of KRW. Higher s_t means USD appreciation. I use U.S. treasury yield for USD interest rate ($y^{\$}$) and Korean government bond yield for KRW interest rate ($y^{₩}$).

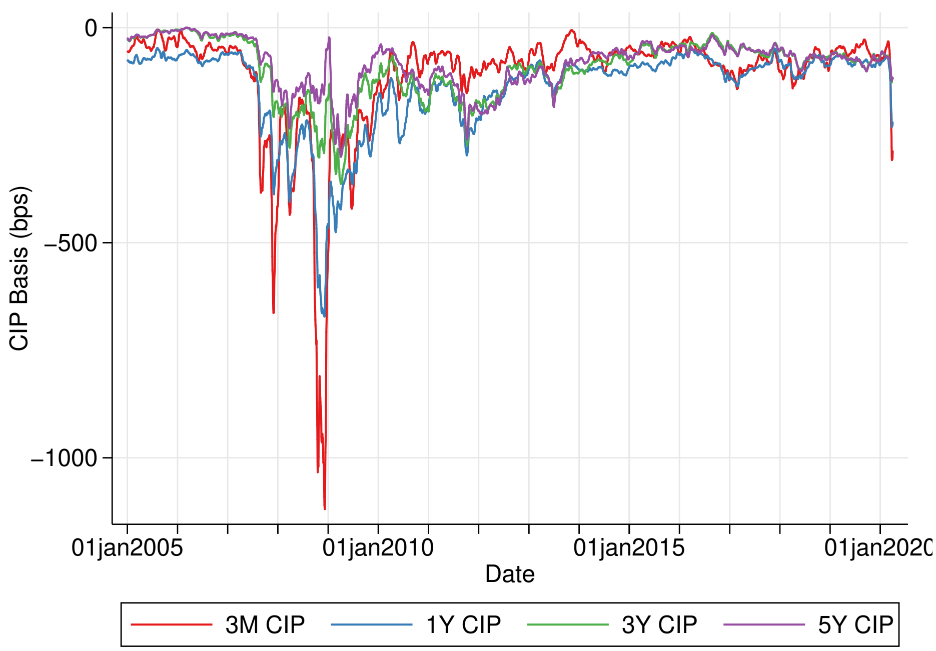


Figure 1.11: Korean Won Exchange Rate

Exchange rate is defined as value of 1 USD in terms of Korean Won (KRW). A higher exchange rate means depreciation of KRW.

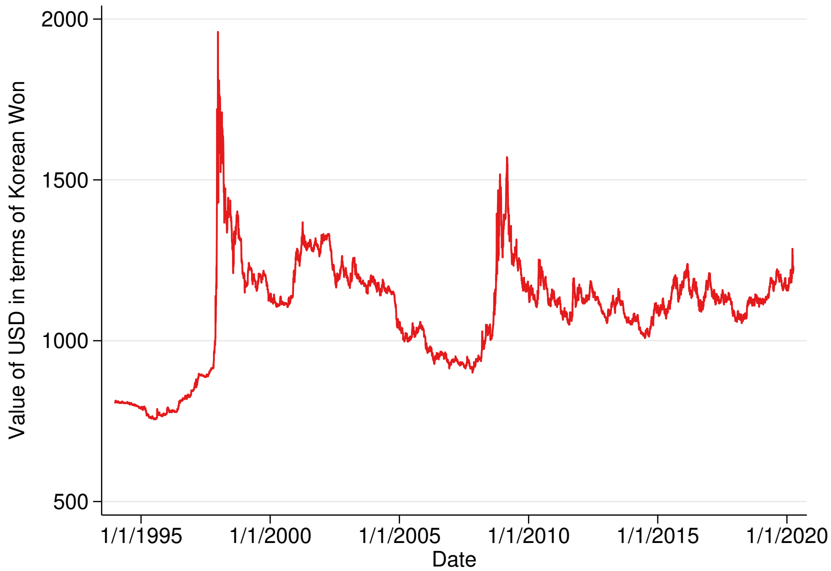


Figure 1.12: FX Derivatives Position and External Short-term Borrowings

The dotted line is the aggregate external short-term debt and the solid line is the aggregate net FXD position of the banking sector.

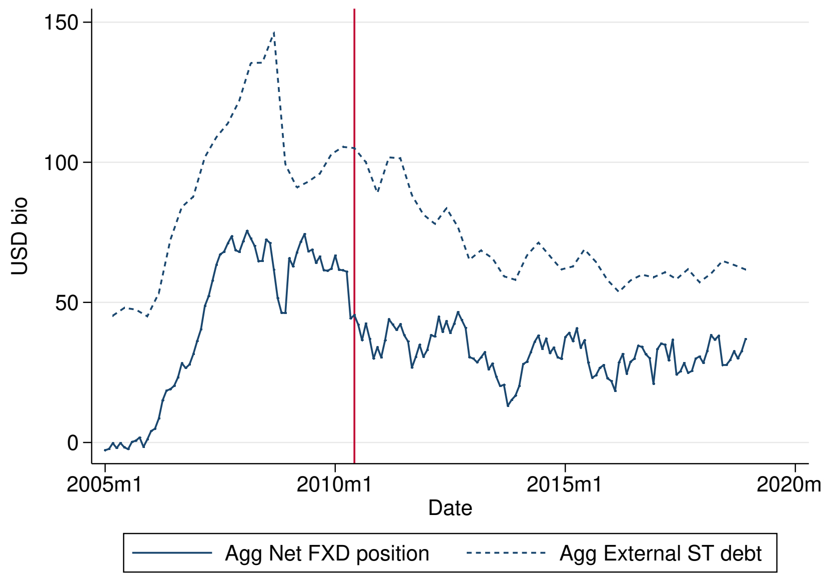
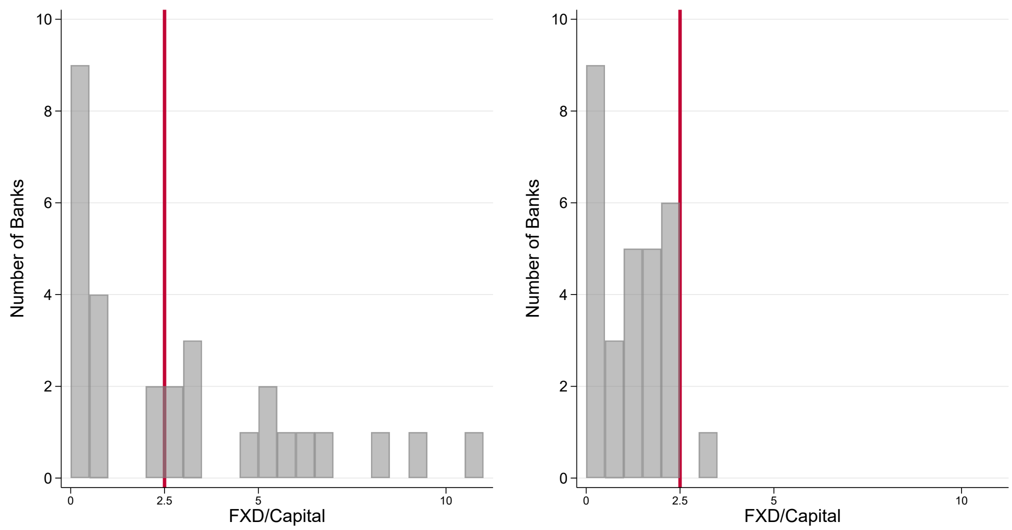


Figure 1.13: FX Derivatives Position to Capital Ratio, before and after the Regulation (Foreign Banks)

The histogram of FX derivatives position to capital (DPTC) ratio of foreign banks, six months before and six months after the first announcement of regulation.



Foreign Banks

Figure 1.14: FX Derivatives Position to Capital Ratio, before and after the Regulation (Domestic Banks)

The histogram of FX derivatives position to capital (DPTC) ratio of domestic banks, six months before and six months after the first announcement of regulation.

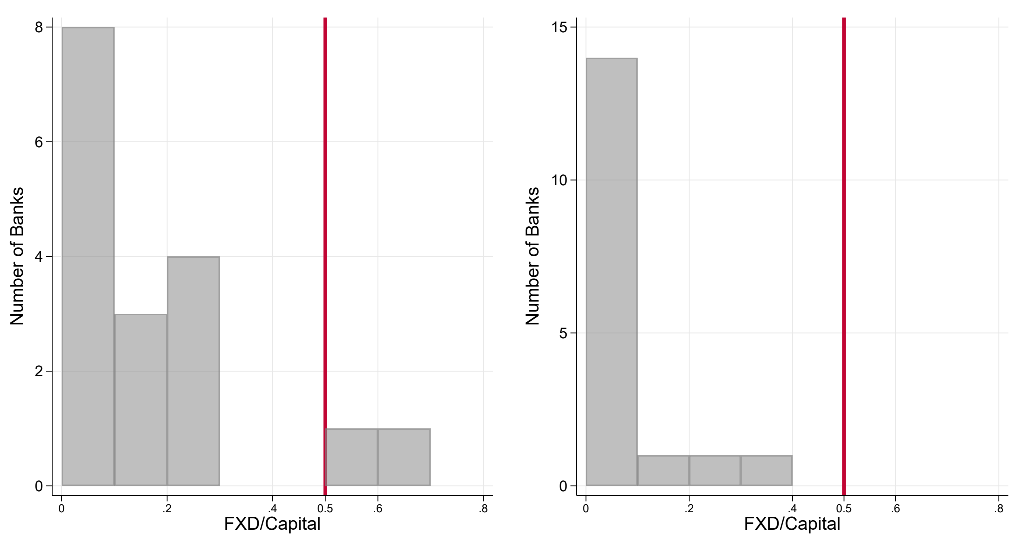


Figure 1.15: Aggregate FX Derivatives Position of Banks

The top panel shows the aggregate gross FXD position of banks, including both foreign banks and domestic banks, with the announcement dates (vertical lines) of changes in the minimum FXD capital requirement. The bottom panel shows the historical change in the minimum FXD capital requirement that banks are required to hold. The higher regulation indicates *tighter* regulation.

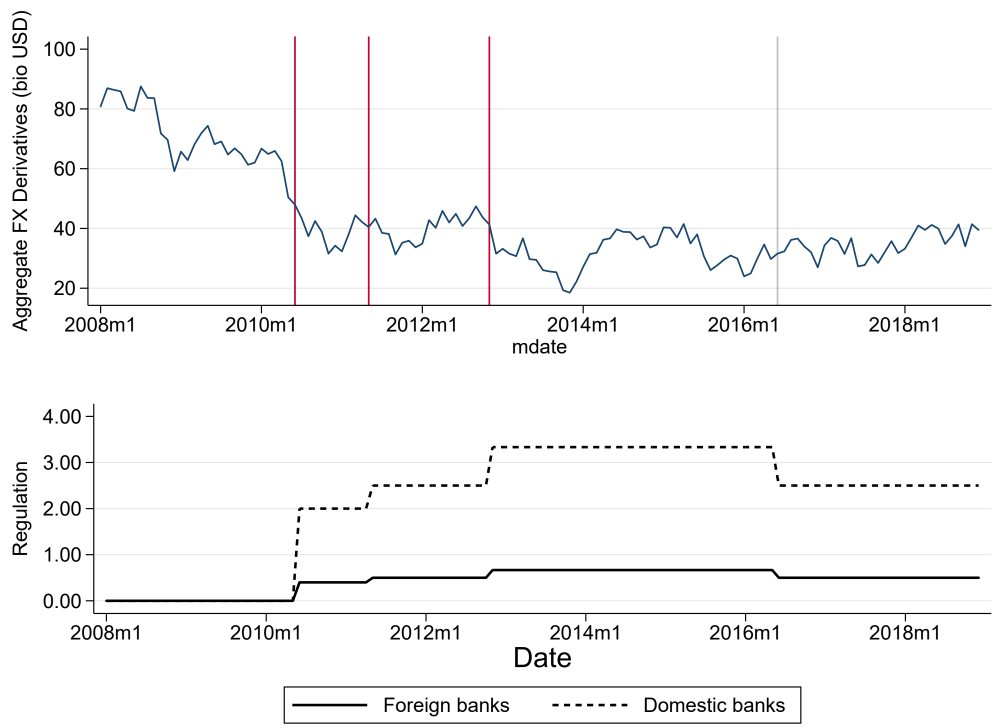


Figure 1.16: FX Derivatives Position by Treatment

The top panel plots the aggregate FXD position in billion USD of constrained (solid) and unconstrained (dotted) banks. The middle panel plots the average FXD position of constrained (solid) and unconstrained (dotted) banks. The vertical lines indicate the announcement dates of the changes in the minimum FXD capital requirement. The bottom panel plots the minimum FXD capital requirement. The higher value indicates *tighter* regulation. The blue line is the simple average of foreign banks' and domestic banks' minimum FXD capital requirements. The red solid line is weighted average where the weight is FXD position.

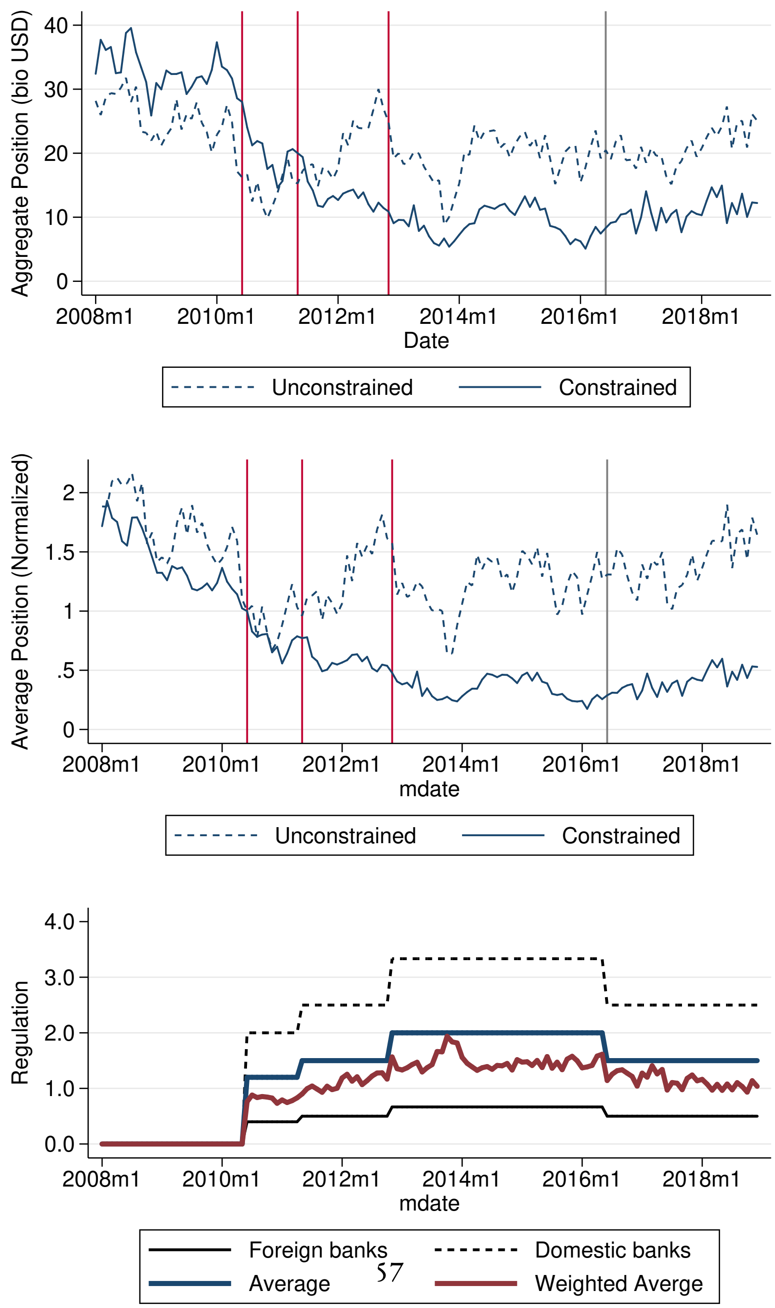


Figure 1.17: FX Derivatives Position Share

The top panel is FXD position share by constrained banks. The middle panel is FXD position share by foreign banks. The bottom panel shows FXD position share by foreign vs. domestic banks as well as constrained vs. unconstrained banks.

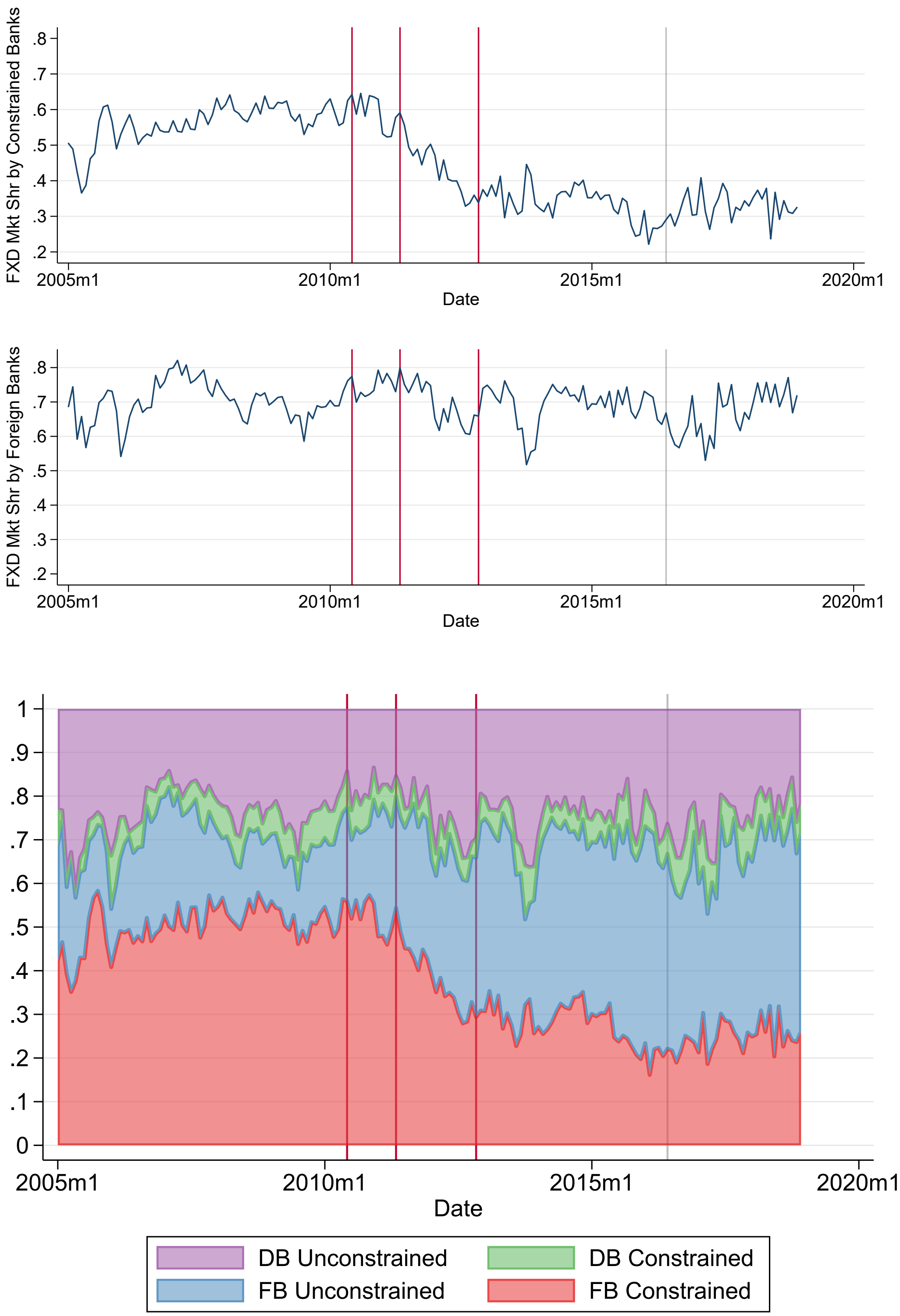


Figure 1.18: CIP Deviations: Short-term and long-term

10-day moving average of 3-year (solid) and 3-month (dotted) USD-KRW CIP deviations where CIP deviation is defined as:

$$x_{t,t+n} = y^{\$}_{t,t+n} - \left(y^{₩}_{t,t+n} - \frac{1}{n}(f_{t,t+n} - s_t)\right) = \frac{1}{n}(f_{t,t+n} - s_t) - (y^{₩}_{t,t+n} - y^{\$}_{t,t+n})$$

$f_{t,t+n}$ is forward exchange rate, and s_t is spot exchange rate defined as value of 1 USD in terms of KRW. Higher s_t means USD appreciation. I use U.S. treasury yield for USD interest rate ($y^{\$}$) and Korean government bond yield for KRW interest rate ($y^{₩}$).

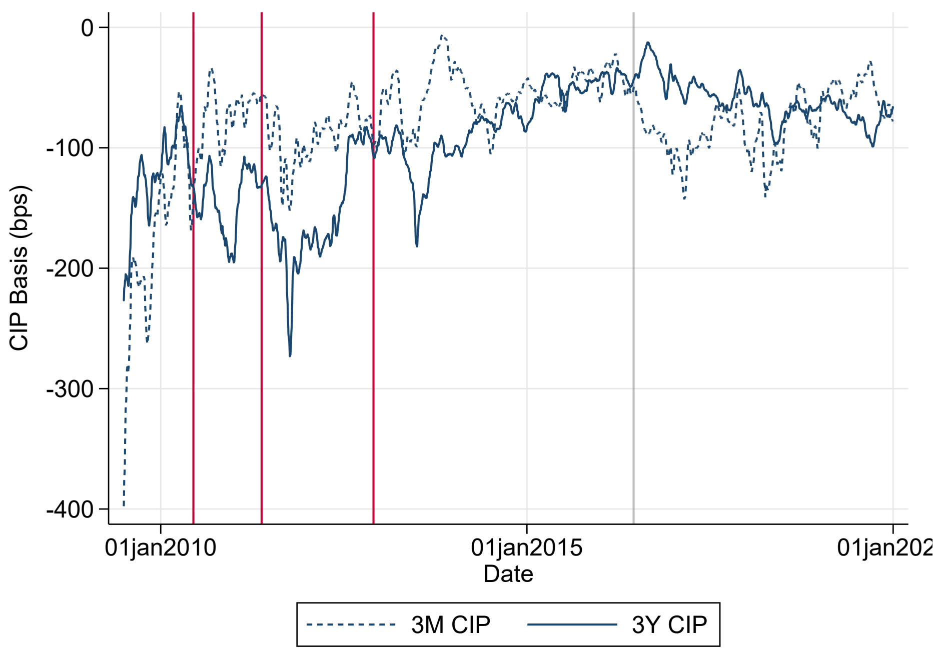
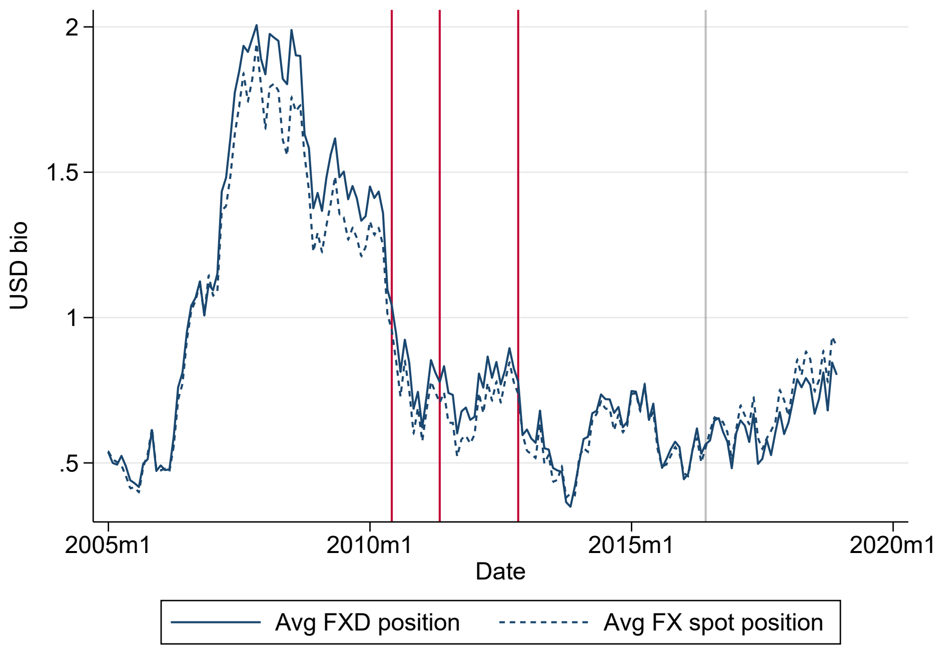


Figure 1.19: Banks' FX Positions: On-balance sheet position vs. FXD position

The average on-balance sheet FX position of banks (dotted) offsets their average FXD position (solid).



Tables

Table 1.1: FX Derivatives Position Limits

The top two rows show the historical changes in the regulatory cap on the ratio of FX derivatives to capital. 250% means that a bank's FX derivatives position is required to be lower than 2.5 times its capital. The bottom two rows show the announcement dates and the effective dates. The regulation was first announced on 13 June 2010.

Foreign Banks	250%	200%	150%	200%	250%
Domestic Banks	50%	40%	30%	40%	50%
Announced on	6/13/2010	5/19/2011	11/27/2012	6/16/2016	3/18/2020
Effective from	10/31/2010	7/31/2011	1/31/2013	7/31/2016	3/19/2020

Table 1.2: Banks' FXD Positions (As of Dec 2009)

Foreign is 1 if the bank is foreign bank branch and 0 if otherwise. *Assets*, *DerivPosition* and *Capital* are in 1,000 USD. *DPTCRatio* is Derivatives Position to Capital ratio. *DerivExceeded* is *DerivPosition* less the size (in 1,000 USD) of derivatives position that the bank is allowed to take. *Constrained* is 1 if the bank needs to reduce its DPTC ratio and 0 if otherwise. *Shock* is *DerivExceeded*/*DerivPosition*. *DPTARatio* is Derivatives Position to Assets ratio. *CTARatio* is Capital to Assets ratio. *DerivPosShare* is market share.

Bank	Foreign	Assets	DerivPosition	Capital	DPTCRatio	DerivExceeded	Constrained	Shock	DPTARatio	CTARatio	DerivPosShare
UOB	1	1,601,133	1,292,500	122,000	11	987,500	1	0.76	0.81	0.08	0.02
Barclays*	1	11,670,373	2,525,772	277,580	9	1,831,821	1	0.73	0.22	0.02	0.04
StateStreet	1	2,077,924	823,084	102,148	8	567,715	1	0.69	0.4	0.05	0.01
CS	1	5,860,097	4,252,749	610,104	7	2,727,490	1	0.64	0.73	0.1	0.07
BNP	1	12,355,659	4,450,664	709,914	6	2,675,879	1	0.6	0.36	0.06	0.07
DBS	1	3,917,999	1,810,170	304,008	6	1,050,151	1	0.58	0.46	0.08	0.03
ANZ	1	4,190,502	1,185,243	220,920	5	632,943	1	0.53	0.28	0.05	0.02
BOA	1	7,201,784	1,796,047	358,225	5	900,485	1	0.5	0.25	0.05	0.03
MorganStanley	1	5,489,824	1,413,215	309,701	5	638,963	1	0.45	0.26	0.06	0.02
CIG	1	13,270,216	2,485,735	715,450	3	697,110	1	0.28	0.19	0.05	0.04
HSBC	1	20,617,534	5,994,277	1,972,932	3	1,061,948	1	0.18	0.29	0.1	0.1
ABNRBS*	1	7,155,556	1,470,707	489,208	3	247,686	1	0.17	0.21	0.07	0.02
ING	1	13,996,040	2,311,018	836,297	3	220,275	1	0.1	0.17	0.06	0.04
UBS*	1	5,095,065	1,141,340	443,393	3	32,857	1	0.03	0.22	0.09	0.02
Citi	0	44,900,564	2,982,505	4,264,960	1	850,025	1	0.29	0.07	0.09	0.05
StandChar	0	58,232,404	2,220,717	3,792,562	1	324,436	1	0.15	0.04	0.07	0.04
DB	1	9,893,187	1,942,116	821,928	2	−112,705	0	0	0.2	0.08	0.03
SocGen	1	6,284,281	1,211,031	563,549	2	−197,842	0	0	0.19	0.09	0.02
CCBC	1	1,276,478	160,987	168,333	1	−259,846	0	0	0.13	0.13	0
MUFG	1	8,464,476	912,865	986,416	1	−1,553,176	0	0	0.11	0.12	0.01
BNYMellon	1	1,124,330	103,472	142,688	1	−253,248	0	0	0.09	0.13	0
Scotia	1	1,008,951	61,785	113,939	1	−223,063	0	0	0.06	0.11	0
JPM	1	14,655,266	5,150,490	10,387,546	0	−20,818,374	0	0	0.35	0.71	0.08
Yamaguchi	1	117,378	20,306	54,831	0	−116,770	0	0	0.17	0.47	0
KEBHana	0	116,057,552	2,086,478	7,703,450	0	−1,765,247	0	0	0.02	0.07	0.03
KEB*	0	82,483,816	1,651,937	6,241,667	0	−1,468,896	0	0	0.02	0.08	0.03
Busan	0	26,102,380	403,293	1,804,721	0	−499,067	0	0	0.02	0.07	0.01
Woori	0	186,484,800	2,348,102	11,717,465	0	−3,510,631	0	0	0.01	0.06	0.04
KDB	0	104,773,424	2,529,950	12,961,896	0	−3,950,998	0	0	0.02	0.12	0.04
KB	0	219,698,320	2,071,910	15,240,589	0	−5,548,385	0	0	0.01	0.07	0.03
IBK	0	129,253,992	1,125,675	10,421,005	0	−4,084,828	0	0	0.01	0.08	0.02
Shinhan	0	168,008,736	1,098,607	11,709,110	0	−4,755,948	0	0	0.01	0.07	0.02
MitsuiSumitomo	1	4,826,040	79,700	1,045,047	0	−2,532,917	0	0	0.02	0.22	0
NH	0	156,517,472	832,138	11,855,901	0	−5,095,813	0	0	0.01	0.08	0.01
Daegu	0	23,864,670	40,901	645,505	0	−281,852	0	0	0	0.03	0
GS*	1	2,304,765	−5,726	187,500	0	−463,024	0	0	0	0.08	0
Kyongnam	0	17,481,136	32,240	1,238,000	0	−586,760	0	0	0	0.07	0
Kwangjoo	0	13,614,953	9,186	940,000	0	−460,814	0	0	0	0.07	0
SH	0	16,038,712	2,793	704,286	0	−349,350	0	0	0	0.04	0
Mizuho	1	5,995,878	−240	634,977	0	−1,587,202	0	0	0	0.11	0
Jeonbuk	0	6,192,970	0	229,462	0	−114,731	0	0	0	0.04	0
Jeju	0	2,526,683	0	180,000	0	−90,000	0	0	0	0.07	0
Mellat	1	2,615,603	0	82,812	0	−207,030	0	0	0	0.03	0
ICBC	1	2,110,354	0	582,500	0	−1,456,250	0	0	0	0.28	0
BankComm	1	1,763,835	0	253,333	0	−633,333	0	0	0	0.14	0
BOC	1	1,406,988	0	230,390	0	−575,974	0	0	0	0.16	0

* indicates closed banks. Full names and parent bank's country are listed in Appendix Table A.1.

Table 1.3: Bank Summary Statistics (As of Dec 2009)

	Full Sample		Constrained		Unconstrained		Difference	
	mean	sd	mean	sd	mean	sd	b	t
FXD (mio USD)	1,348	1,467	2,385	1,421	796	1,178	-1,589***	(-3.8)
Capital (mio USD)	2,726	4,317	971	1,275	3,662	5,046	2,691**	(2.8)
Asset (mio USD)	33,708	55,924	13,602	15,845	44,432	66,190	30,830*	(2.4)
FXD/Assets (%)	14	19	31	21	5	8	-26***	(-4.8)
Loans/Assets (%)	40	29	18	19	52	27	34***	(5.1)
Deposits/Assets (%)	20	28	10	20	26	30	16*	(2.1)
Equity/Assets(%)	7	4	5	2	7	4	2*	(2.3)
FC Loan Share (%)	44	41	67	40	34	38	-33*	(-2.2)
FC Liab Share (%)	18	23	13	16	20	26	8	(1.2)
Observations	46		16		30		46	

Table 1.4: FX Derivatives Contracts Summary Statistics

	Full Sample		Constrained		Unconstrained		Difference	
	mean	sd	mean	sd	mean	sd	b	t
Notional Net (USD mio)	18.0	77	30.1	92	10.2	64	-20	(-1.9)
FXDNet/Assets (%)	-2.9	9	-3.0	9	-2.9	8	0	(0.1)
Direction: Firm sells FC (%)	51.4	49	41.4	48	57.7	49	16*	(2.6)
Pair: USD-KRW (%)	86.2	32	95.5	17	80.2	37	-15***	(-4.4)
Pair: JPY-KRW (%)	11.4	30	1.5	11	17.8	36	16***	(5.3)
Pair: EUR-KRW (%)	1.8	10	1.6	8	2.0	11	0	(0.3)
Type: Forwards (%)	52.8	49	38.2	47	62.1	48	24***	(3.9)
Type: Swaps (%)	39.0	48	48.4	49	32.9	47	-16*	(-2.5)
Type: Options (%)	7.9	26	13.4	33	4.3	20	-9*	(-2.4)
Type: Futures (%)	0.4	6	0.0	0	0.7	8	1	(1.0)
Observations	251		98		153		251	

Table 1.5: Firm Summary Statistics (Full Sample)

	Full Sample		Exposed		Non-Exposed		Difference	
	mean	sd	mean	sd	mean	sd	b	t
Assets (USD mio)	2,371.130	6422.07	2,673.585	8728.05	2,202.391	4719.67	-471.19	(-0.36)
FXDNet/Assets	-0.082	0.19	-0.065	0.18	-0.091	0.20	-0.03	(-0.79)
Sales (USD mio)	1,936.725	4648.93	1,801.008	4534.04	2,012.440	4733.92	211.43	(0.27)
FXDNet/Sales	-0.097	0.28	-0.061	0.26	-0.118	0.30	-0.06	(-1.23)
Number of Banks	2.385	2.41	2.472	2.08	2.337	2.58	-0.13	(-0.35)
Log Size	26.804	1.83	26.836	1.76	26.786	1.87	-0.05	(-0.16)
Leverage	0.487	0.18	0.511	0.16	0.474	0.19	-0.04	(-1.26)
Gross Profit Margin	0.211	0.17	0.210	0.19	0.211	0.15	0.00	(0.02)
FC Asset Share	0.096	0.11	0.088	0.11	0.101	0.11	0.01	(0.66)
FC Liab Share	0.197	0.19	0.240	0.19	0.173	0.20	-0.07*	(-2.05)
Export Share	0.473	0.31	0.425	0.32	0.502	0.30	0.08	(1.38)
Export HedgeRatio	0.409	0.71	0.435	0.72	0.393	0.71	-0.04	(-0.31)
FCL HedgeRatio	0.485	2.11	0.803	3.41	0.300	0.50	-0.50	(-1.07)
Observations	148		53		95		148	

Table 1.6: Impact on banks' FX Derivatives Position and Capital (Full Sample)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{Avg} + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it}$$

Y_{it} is either log(FX Derivatives position), log(Capital) or FXD/Capital. $Constrained_i$ is dummy variable that takes 1 if bank i is constrained and 0 if otherwise. $Regulation_t^{Avg}$ is 0 before the regulation and takes **simple average** of foreign banks' and domestic banks' minimum FXD capital requirements. Higher $Regulation_t^{Avg}$ indicates tighter constraint. Columns (2), (4), and (6) add bank fixed effects:

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{Avg} + \delta_i + \gamma_t + \varepsilon_{it}$$

The sample period is 2008–2019 on a monthly basis. Standard errors are clustered by bank.

	(1)	(2)	(3)	(4)	(5)	(6)
	LogFXD	LogFXD	LogCapital	LogCapital	FXD/Capital	FXD/Capital
Constrained=1 x Regulation	-0.913***	-0.967***	0.0294	0.0276	-3.383***	-3.377***
	(-3.18)	(-3.28)	(0.36)	(0.36)	(-5.13)	(-5.17)
Constrained=1	5.341***		-0.648		6.505***	
	(3.92)		(-1.52)		(5.40)	
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	5906	5906	5886	5886	5886	5886
Adj RSqr	0.109	0.802	0.0548	0.914	0.409	0.497

t statistics in parentheses

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \delta_i + \gamma_t + \varepsilon_{it}$$

$Regulation_t^{WAvg}$ is the **weighted average** of the minimum FXD capital requirements, where the weight is the FXD position in each month.

	(1)	(2)	(3)	(4)	(5)	(6)
	LogFXD	LogFXD	LogCapital	LogCapital	FXD/Capital	FXD/Capital
Constrained=1 x Regulation	-1.207***	-1.292***	0.0230	0.0166	-4.398***	-4.388***
	(-3.05)	(-3.17)	(0.21)	(0.16)	(-5.16)	(-5.21)
Constrained=1	5.312***		-0.631		6.326***	
	(3.91)		(-1.49)		(5.44)	
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	5906	5906	5886	5886	5886	5886
Adj RSqr	0.109	0.803	0.0548	0.914	0.404	0.492

t statistics in parentheses

$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 1.7: Impact on banks' Derivatives Position and Capital (**Foreign banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{FB} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1) LogFXD	(2) LogFXD	(3) LogCapital	(4) LogCapital	(5) FXD/Capital	(6) FXD/Capital
Constrained=1 x Regulation	-4.318***	-4.551***	-0.0418	-0.0156	-11.23***	-11.23***
	(-2.88)	(-2.99)	(-0.14)	(-0.05)	(-5.66)	(-5.73)
Constrained=1	6.341***		0.123		6.959***	
	(3.08)		(0.30)		(5.87)	
Constant	16.11***	21.04***	26.22***	25.81***	5.936***	12.27***
	(8.07)	(50.75)	(66.20)	(179.85)	(3.65)	(5.38)
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	3698	3698	3694	3694	3694	3694
Adj RSqr	0.155	0.760	0.0528	0.835	0.474	0.532

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.8: Impact on banks' Derivatives Position and Capital (**Domestic banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{DB} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1) LogFXD	(2) LogFXD	(3) LogCapital	(4) LogCapital	(5) FXD/Capital	(6) FXD/Capital
Constrained=1 x Regulation	-0.105	-0.126	-0.0588*	-0.0596*	-0.107***	-0.107***
	(-0.61)	(-0.72)	(-2.05)	(-1.98)	(-9.28)	(-9.34)
Constrained=1	4.401**		0.351		0.471***	
	(2.38)		(0.85)		(10.39)	
Constant	17.24***	19.02***	28.60***	28.25***	0.224***	0.252***
	(9.07)	(30.50)	(69.52)	(371.30)	(3.85)	(4.82)
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	2208	2208	2192	2192	2192	2192
Adj RSqr	0.0528	0.875	0.0246	0.933	0.535	0.647

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.9: Impact on Banks' FC Loans and FC Liabilities (**All banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it}$$

Columns (2) and (4) add bank fixed effects:

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \delta_i + \gamma_t + \varepsilon_{it}$$

The outcome variables are share of foreign currency loans (*FCLoanShr*) and share of foreign currency liabilities (*FCLiabShr*). The sample period is 2008–2019 on a quarterly basis. Standard errors are clustered by bank.

	(1) FCLoanShr	(2) FCLoanShr	(3) FCLiabShr	(4) FCLiabShr
Constrained=1 x Regulation	-0.0509	-0.0495	-0.0150	-0.00923
	(-1.50)	(-1.52)	(-0.45)	(-0.29)
Constrained=1	0.299**		-0.0253	
	(2.22)		(-0.36)	
Constant	0.344***	0.980***	0.292***	0.408***
	(4.69)	(23.57)	(5.11)	(12.94)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	1523	1523	1680	1680
Adj RSqr	0.132	0.884	0.0886	0.787

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.10: Impact on Banks' FC Loans and FC Liabilities (**Foreign banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{FB} + \delta_i + \gamma_t + \varepsilon_{it}$$

The outcome variables are share of foreign currency loans (*FCLoanShr*) and share of foreign currency liabilities (*FCLiabShr*).

	(1)	(2)	(3)	(4)
	FCLoanShr	FCLoanShr	FCLiabShr	FCLiabShr
Constrained=1 x Regulation	-0.165	-0.117	0.0304	0.0565
	(-1.45)	(-1.03)	(0.28)	(0.53)
Constrained=1	0.211*		-0.130	
	(1.72)		(-1.31)	
Constant	0.582***	1.007***	0.456***	0.456***
	(6.72)	(15.87)	(5.24)	(11.36)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	914	914	1071	1071
Adj RSqr	0.154	0.785	0.173	0.782

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.11: Impact on Banks' FC Loans and FC Liabilities (**Domestic banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{DB} + \delta_i + \gamma_t + \varepsilon_{it}$$

The outcome variables are share of foreign currency loans (*FCLoanShr*) and share of foreign currency liabilities (*FCLiabShr*).

	(1) FCLoanShr	(2) FCLoanShr	(3) FCLiabShr	(4) FCLiabShr
Constrained=1 x Regulation	-0.00821	-0.00859	-0.00877*	-0.00906*
	(-0.82)	(-0.86)	(-1.89)	(-1.99)
Constrained=1	0.0243		0.0272	
	(0.58)		(1.06)	
Constant	0.0666**	0.0598***	0.0746***	0.0700***
	(2.58)	(5.59)	(3.69)	(12.30)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	609	609	609	609
Adj RSqr	0.160	0.895	0.143	0.940

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.12: Impact on Banks' Security Holdings

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \delta_i + \gamma_t + \varepsilon_{it}$$

The outcome variables are KTB holdings and MSB holdings scaled by assets. KTB is long-term Korean government bond with maturities: 3, 5, 10, 20, 30 yr.
MSB is issued by Bank of Korea and the maturities are: 91day, 1yr, 2yr.

	(1) KTB/Asset	(2) KTB/Asset	(3) MSB/Asset	(4) MSB/Asset
Constrained=1 x Regulation	0.00950	0.0105	-0.0626***	-0.0595***
	(0.62)	(0.70)	(-2.90)	(-3.02)
Constrained=1	0.0361		0.145***	
	(0.97)		(2.96)	
BankFE	N	Y	N	Y
TimeFE				
N	1692	1692	1692	1692
Adj RSqr	0.114	0.737	0.241	0.756

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 1.13: Transmission of Regulatory Shock to FXD Hedging (FXD Contract-level)

$$\Delta FXD_{i,j} = \alpha + \beta\ Constrained_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

The dependent variable is change in net FXD position dealt between firm j and bank i, scaled by assets. $Constrained_i$ is 1 if the contract is dealt with a constrained bank and 0 if otherwise. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank i's share of firm j's total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Constrained	0.0529***	0.0374**	0.00189	0.00317**	0.0228**	0.0129*
	(3.66)	(2.52)	(1.00)	(2.09)	(2.28)	(1.70)
Type Swaps		0.0114		-0.00114		0.00511
		(0.59)		(-0.15)		(1.13)
Type Options		0.0862***		0		0.0992***
		(4.48)		(.)		(6.38)
Type Futures		0.0111		0		0.00293
		(0.54)		(.)		(0.34)
Pair EURKRW		0.0661		0		0.0469
		(1.20)		(.)		(1.45)
Pair JPYKRW		-0.0188		0.00658**		0.00104
		(-1.29)		(2.17)		(0.15)
Pair XXXKRW		-0.00541		-0.00207		-0.000744
		(-0.43)		(-0.18)		(-0.13)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	129	129	122	122	251	251
RSqr	0.0964	0.353	0.00419	0.125	0.0371	0.315

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.14: Transmission of Regulatory Shock to FXD Hedging (FXD Contract-level)

$$\Delta FXD_{i,j} = \alpha + \beta_{Shock} Shock_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

The dependent variable is change in net FXD position dealt between firm j and bank i, scaled by assets. $Shock_i$ is the percentage of bank i's FXD position that needed to be reduced at the imposition of the regulation. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank i's share of firm j's total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1) Exporters	(2) Exporters	(3) Non-exporters	(4) Non-exporters	(5) Full Sample	(6) Full Sample
Shock	0.0306***	0.0220***	0.00100*	0.00161*	0.00765	0.00482
	(2.95)	(3.00)	(1.73)	(2.03)	(1.46)	(1.51)
Type Swaps		0.0159		-0.000985		0.00598
		(0.85)		(-0.13)		(1.36)
Type Options		0.0865***		0		0.100***
		(4.49)		(.)		(6.63)
Type Futures		0.00914		0		0.00298
		(0.45)		(.)		(0.34)
Pair EURKRW		0.0562		0		0.0460
		(1.06)		(.)		(1.43)
Pair JPYKRW		-0.0200		0.00680*		-0.000960
		(-1.31)		(1.93)		(-0.13)
Pair XXXKRW		-0.00860		0.00465		0.00317
		(-0.76)		(0.45)		(0.44)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	129	129	122	122	251	251
RSqr	0.0820	0.350	0.00650	0.127	0.0174	0.313

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.15: Transmission of Regulatory Shock to FXD Hedging (Subsample without option contracts)

$$\Delta FXD_{i,j} = \alpha + \beta Constrained_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{j,b}$$

FX option contracts are excluded. The dependent variable is change in net FXD position dealt between firm *j* and bank *i*, scaled by assets. $Constrained_i$ is 1 if the contract is dealt with a constrained bank and 0 if otherwise. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank *i*'s share of firm *j*'s total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Constrained	0.0259*	0.0296*	0.00192	0.00326*	0.0121**	0.00927
	(1.96)	(2.06)	(0.99)	(2.00)	(2.12)	(1.28)
Type Swaps		-0.000369		-0.00110		0.00325
		(-0.02)		(-0.14)		(0.65)
Type Options		0		0		0
		(.)		(.)		(.)
Type Futures		0.0193		0		0.00604
		(0.85)		(.)		(0.72)
Pair EURKRW		0.0218		0		0.0218*
		(0.70)		(.)		(1.91)
Pair JPYKRW		-0.0182		0.00662**		-0.000000735
		(-1.08)		(2.17)		(-0.00)
Pair XXXKRW		0.000695		-0.00265		0.00137
		(0.05)		(-0.23)		(0.25)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	111	111	122	122	233	233
RSqr	0.0270	0.125	0.00415	0.125	0.0144	0.0566

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.16: Transmission of Regulatory Shock to FXD Hedging (Subsample without option contracts)

$$\Delta FXD_{i,j} = \alpha + \beta_{Shock} Shock_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

FX option contracts are excluded. The dependent variable is change in net FXD position dealt between firm j and bank i, scaled by assets. $Shock_i$ is the percentage of bank i's FXD position that needed to be reduced at the imposition of the regulation. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank i's share of firm j's total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Shock	0.0168**	0.0183**	0.00103*	0.00169*	0.00509**	0.00363
	(2.34)	(2.88)	(1.71)	(2.03)	(2.11)	(1.25)
Type Swaps		0.00435		-0.000947		0.00391
		(0.21)		(-0.12)		(0.78)
Type Options		0		0		0
		(.)		(.)		(.)
Type Futures		0.0171		0		0.00602
		(0.75)		(.)		(0.71)
Pair EURKRW		0.0141		0		0.0210*
		(0.48)		(.)		(1.96)
Pair JPYKRW		-0.0187		0.00687*		-0.00135
		(-1.07)		(1.91)		(-0.17)
Pair XXXKRW		-0.00287		0.00427		0.00421
		(-0.20)		(0.41)		(0.58)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	111	111	122	122	233	233
RSqr	0.0287	0.124	0.00638	0.127	0.0109	0.0551

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.17: Impact on Firm-level FXD Position (Full Sample by Size)

$$\Delta Y_j = \beta_E \, Exposed_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm *j*'s net FXD position scaled by assets. Independent variable *Exposed* is 1 if the firm's main FXD counterparty bank is constrained. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1) Full Sample	(2) Full Sample	(3) Small	(4) Small	(5) Large	(6) Large
Exposed	0.0352**	0.0385**	0.0608**	0.0716**	0.00838	0.00910
	(2.13)	(2.43)	(2.50)	(2.49)	(0.40)	(0.52)
Constant	-0.00329	0.0265	-0.00167	-0.180	-0.00487	-0.260
	(-0.28)	(0.17)	(-0.10)	(-0.24)	(-0.28)	(-0.98)
FirmControls	N	Y	N	Y	N	Y
N	148	148	74	74	74	74
RSqr	0.0253	0.0771	0.0743	0.186	0.00151	0.0237

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.18: Impact on Firm-level FXD Position (Fully Disclosed Firms by Size)

$$\Delta Y_j = \beta_E \, Exposure_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm *j*'s net FXD position scaled by assets. Independent variable *Exposure* is the weighted average shock of the firm's FXD counterparty banks. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1) Full Sample	(2) Full Sample	(3) Small	(4) Small	(5) Large	(6) Large
Exposure	0.0270***	0.0304***	0.0367***	0.0379***	0.0174**	0.0195***
	(3.45)	(3.86)	(2.83)	(3.13)	(2.27)	(2.73)
Constant	0.0105	0.146	0.0190	-0.153	0.00289	0.222
	(1.39)	(1.26)	(1.45)	(-0.23)	(0.37)	(1.12)
FirmControls	N	Y	N	Y	N	Y
N	132	132	66	66	66	66
RSqr	0.0687	0.164	0.0888	0.465	0.0537	0.154

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.19: Impact on Firm-level FXD Position (Full Sample by Net FXD Position)

$$\Delta Y_j = \beta_E \, Exposed_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm *j*'s net FXD position scaled by assets. Independent variable *Exposed* is 1 if the firm's main FXD counterparty bank is constrained. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1)	(2)	(3)	(4)
	Exporter	Exporter	Non-exporter	Non-exporter
Exposed	0.0640**	0.0728***	-0.00226	-0.00229
	(2.48)	(2.72)	(-0.39)	(-0.41)
Constant	-0.00302	-0.0811	-0.00380	0.0451
	(-0.17)	(-0.27)	(-1.24)	(0.84)
FirmControls	N	Y	N	Y
N	92	92	56	56
RSqr	0.0510	0.113	0.00307	0.0798

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.20: Impact on Firm-level FXD Position (Fully Disclosed Firms by Net FXD Position)

$$\Delta Y_j = \beta_E \, Exposure_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm *j*'s net FXD position scaled by assets. Independent variable *Exposure* is the weighted average shock of the firm's FXD counterparty banks. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1)	(2)	(3)	(4)
	Exporter	Exporter	Non-exporter	Non-exporter
Exposure	0.0513***	0.0582***	0.00151	0.000738
	(3.95)	(4.22)	(0.45)	(0.19)
Constant	0.0246**	0.0183	-0.00564**	0.0591
	(2.10)	(0.08)	(-2.05)	(0.88)
FirmControls	N	Y	N	Y
N	82	82	50	50
RSqr	0.140	0.245	0.00502	0.0851

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.21: Impact on Export Sales

$$\Delta Y_j = \beta_E \, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in log export sales. Independent variable $Exposure_j$ is the weighted average shock of the firm j's FXD counterparty banks. $HighHedge_j$ takes 1 if firm j sold amount of FXD is more than 10% of its export sales, and 0 if otherwise. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1)	(2)
	LogExport	LogExport
Firm_highHR=1 × Exposure	-0.228*	-0.189*
	(-1.94)	(-1.81)
Exposure	0.0571	0.0956
	(0.77)	(1.55)
Firm_highHR=1	0.136	0.0217
	(1.30)	(0.24)
Constant	0.212***	-1.615
	(2.66)	(-1.22)
FirmControls	N	Y
N	74	74
RSqr	0.0817	0.324

t statistics in parentheses

$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 1.22: Impact on Export Sales

$$\Delta Y_j = \beta_E \, Exposure_j + \beta_h HedgeRatio_j + \beta_{Eh} Exposure_j \times HedgeRatio_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in log export sales. Independent variable $Exposure_j$ is the weighted average shock of the firm j's FXD counterparty banks. $HedgeRatio_j$ is firm j's sold amount of FXD divided by export sales. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1) LogExport	(2) LogExport
Exposure × Export Hedge Ratio	-0.196***	-0.237**
	(-3.96)	(-2.24)
Exposure	-0.0557	-0.0530
	(-0.99)	(-0.83)
Export Hedge Ratio	0.0808	0.153**
	(1.29)	(2.12)
Constant	0.299***	-1.663
	(6.14)	(-1.31)
FirmControls	N	Y
N	74	74
RSqr	0.228	0.464

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.23: Impact on Firm-level FXD Position

$$\Delta Y_j = \beta_E\, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm j's net FXD notional scaled by assets. Independent variable $Exposure_j$ is the weighted average shock of the firm j's FXD counterparty banks. $HighHedge_j$ takes 1 if firm j sold amount of FXD is more than 10% of its export sales, and 0 if otherwise. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1)	(2)
	FXD/Asset	FXD/Asset
Firm_highHR=1 × Exposure	0.0594***	0.0667***
	(2.70)	(2.84)
Exposure	0.0124	0.0124
	(1.22)	(1.16)
Firm_highHR=1	0.0418**	0.0433**
	(2.13)	(2.15)
Constant	-0.00820	-0.124
	(-1.01)	(-0.56)
FirmControls	N	Y
N	74	74
RSqr	0.215	0.319

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1.24: Impact on Domestic Sales as a Placebo Test

$$\Delta Y_j = \beta_E\, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls_j + \varepsilon_j$$

Outcome variable is change in firm j's log domestic sales. Independent variable $Exposure_j$ is the weighted average shock of the firm j's FXD counterparty banks. $HighHedge_j$ takes 1 if firm j sold amount of FXD is more than 10% of its export sales, and 0 if otherwise. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies.

	(1)	(2)
	LogDomesticSales	LogDomesticSales
Firm_highHR=1 × Exposure	-0.0372	-0.00911
	(-0.37)	(-0.09)
Exposure	-0.00754	0.000967
	(-0.09)	(0.01)
Firm_highHR=1	0.127	0.0932
	(1.44)	(0.95)
Constant	0.0885	0.315
	(1.24)	(0.35)
FirmControls	N	Y
N	74	74
RSqr	0.0353	0.118

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Chapter 2

Understanding the Onshore versus Offshore Forward Rate Basis: The Role of FX Position Limits and Margin Constraints

Abstract

During the global financial crisis of 2007–2009, the difference between the exchange rate for locally traded (onshore) forward contracts and contracts with the same maturity traded outside the jurisdiction of countries (offshore) increased significantly, though the magnitudes varied across currencies. This deviation from the law of one price can be explained by two constraints imposed on financial intermediaries: margin constraint and position limit constraint (a leverage-based cap on net open foreign exchange position). In an intermediary-based asset pricing model where intermediaries face both margin constraint and position limit constraint, I show how and when the position limit leads to a gap between onshore and offshore forward rates. The model predicts that (1) the basis increases with the shadow costs of the two constraints across time and increases with the country-specific position limit across countries; (2) the shadow cost of each constraint non-linearly increases as the intermediary sector's relative performance declines below a threshold; and (3) higher shadow cost of the position limit predicts lower future excess return on local-currency denominated assets, as buying local assets relaxes the position limit constraint imposed on the intermediaries. I test the model predictions and find consistent evidence in the countries with tight position limits.

2.1 Introduction

In the aftermath of the global financial crisis, many new regulations were imposed on financial intermediaries to improve the resilience of the financial system. Given that financial intermediaries are active in trading financial assets across asset classes globally, it is important to understand how regulations imposed on the financial intermediaries affect asset prices. This paper studies the effect of a macroprudential foreign exchange (FX) regulation, which limits financial intermediaries' net open FX positions, on the risk and return of assets.

Limits on a bank's net open FX position, the difference between its assets and liabilities denominated in foreign currency, are imposed by regulators to prevent banks from taking unmatched currency positions, thereby discouraging them from speculating on exchange rate movements. Such limits are imposed on all banks operating within the jurisdiction of countries and are commonly specified as leverage caps. For instance, banks in Indonesia are not allowed to take net open FX positions of more than 20% of their capital. These regulations are becoming increasingly prevalent. Based on the Annual Report on Exchange Arrangements and Exchange Restrictions by International Monetary Fund (IMF), approximately 77% of countries had limits on the financial sector's open FX positions as of 2018.

The main challenges in identifying the effect of the regulations on asset prices are the lack of a valid counterfactual for the outcome in the absence of regulations and the short time-series of the post-crisis period. This paper addresses these challenges by examining a unique setting in the currency markets of emerging market (EM) economies where (1) the markets are segmented by regulation and (2) only the local market participants face the FX position limit. This setting provides a useful laboratory because the market segmentation was enforced prior to the global financial crisis, and the offshore market prices can be considered a counterfactual for the outcomes in the treatment group without the treatment.

The segmentation in EM currency markets is enforced by the regulators to limit the delivery of their home currencies offshore, outside the jurisdiction of countries.[1] The authorities of these countries have been concerned that large offshore markets in their currencies could induce greater volatility in capital flows and exchange rates. Consequently, onshore market participants have limited access to offshore forwards traded outside the jurisdiction of countries with restrictions on currency conversion, and offshore market participants have limited access to the onshore forwards. An offshore forward contract is similar to a regular FX forward contract except that it does not require physical delivery of currencies at maturity. Therefore, whenever a price discrepancy between onshore and offshore forward contracts arises, global banks with access to both markets can arbitrage the price gap (basis) away.[2] For convenience in this paper, offshore non-deliverable forwards are referred to as US forward contracts and onshore forwards as EM forward contracts.

During the financial crisis, the prices of EM forward contracts and US forward contracts with the same maturity diverged significantly. This is clearly a failure of the law of one price, as contracts with identical cash flows were traded at different prices. In this paper, with an intermediary-based asset pricing model where the intermediary sector faces FX position limit in addition to margin constraint, I explain the time-series and cross-sectional variation in the basis. Although there have been a number of studies on the determinants of onshore-offshore forward rate bases of a single currency, to the best of my knowledge, this paper is the first to link the time-series and cross-sectional variations in the basis to

[1] Appendix B.5 lists relevant regulations for each country in the sample.

[2] Appendix B.6 shows the list of major dealers in the market and the local presence of global banks.

FX position limit.

I extend the margin-based asset pricing model of Garleanu and Pedersen (2011). My model includes three types of agents: EM risk-averse, US risk-averse, and global bank agents. The local risk-averse agents have limited access to non-local assets, while global bank agents have access to all assets. All agents are subject to margin constraints. In addition to the margin constraint, each EM risk-averse agent and global bank faces the EM country-specific FX position limit.

With the model, I first link the shadow cost of the position limit to the interest rate spread. The spread between two EM-currency denominated uncollateralized rates, one traded in the EM ($r^{e₩u}$) and the other traded outside the EM ($r^{0₩u}$), represents the shadow cost of the position limit λ:

$$\lambda = r^{0₩u} - r^{e₩u} \tag{2.1}$$

Intuitively, because investment in EM currency-denominated uncollateralized rate $r^{e₩u}$ in the EM relaxes the position limit by increasing the bank's capital base while the same instrument traded outside of EM $r^{e\$u}$ does not, the spread captures the marginal utility of relaxing the position limit constraint.

Next, I show how the FX position limit affects the excess returns on different types of assets: USD-denominated and EM currency-denominated assets traded in onshore and offshore locations. Since the assets traded outside of EM, such as US forwards, are not subject to the position limit, their required excess return μ^{0i} when a global bank holds long positions in equilibrium is the same as in the Garleanu and Pedersen (2011) economy:

$$\mu^{0i} - r = \beta^{0i} \times \text{covariance risk premium} + m^{0i} \times \text{margin premium} \tag{2.2}$$

In contrast, the assets traded in the EM are affected by the position limit, and therefore the position limit premium shows up in the expression for the excess required returns. For instance, suppose that a global bank holds a net long USD position in the EM. Purchase of an EM forward contract, an agreement to receive USD in exchange of EM currency, will further increase its USD exposure and therefore make the position limit more binding. Hence, for EM forward contracts in which the global bank holds long positions, the required excess return includes the position limit premium:

$$\mu^{ef} - r = \beta^{ef} \times \text{covariance risk premium} + m^{ef} \times \text{margin premium} + \pi^{e} \times \text{position limit premium} \tag{2.3}$$

where π^e denotes country-specific position limit.

It follows that the basis is linearly related to the two terms: the product of the margin and the shadow cost of the margin requirement and the product of the position limit and the shadow cost of position limit. The basis widens when the position limit is tighter, required margin is higher, or shadow prices of the two constraints increase.

The model offers additional predictions that can be tested. First, when global banks' aggregate consumption share is sufficiently low, the shadow cost of margin constraint increases non-linearly as the consumption share of global banks falls. Second, the shadow cost of position limit constraint has non-linear relation with global banks' consumption relative to EM's consumption. The relation depends on (1) whether USD-denominated assets are riskier than local currency-denominated assets in the EM, and (2) the global banks' aggregate net USD position in each EM. Third, higher basis predicts lower future excess return on EM assets because buying local currency-denominated assets relaxes position limit constraint by increasing the global banks' capital base in the EM.

I empirically test these predictions for five EM countries with similar settings in which markets are segmented, and position limits are imposed only on the local market participants. The data on daily exchange rates and interest rates are obtained from Bloomberg, and historical position limits data are obtained from central banks. Based on the empirical tests, I find evidence consistent with model implications in the countries with tight position limits.

Related Literature

This paper relates to three strands of literature. First, this paper fits into the literature that studies the impact of frictions in financial intermediation on asset prices. Previous studies including He and Krishnamurthy (2012), He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), and Moreira and Savov (2017) provide models of intermediary-based asset pricing. On the empirical side, Adrian et al. (2014) and He et al. (2017) show that the shocks to the equity capital ratio of financial intermediaries explain the cross-sectional variation in expected returns. Gabaix et al. (2007) study the pricing of prepayment risks in mortgage-backed security (MBS) markets and find evidence that the marginal investor in the MBS market is a specialized arbitrageur that trades exclusively in the MBS market. Koijen and Yogo (2015) study life insurers and the pricing of insurance policies, and show that insurers sold policies at prices below actuarial fair value because sales of such policies increase regulatory capital in the short-run. Siriwardane (2018) shows that capital shocks at protection sellers impact pricing in the credit default swap market. I add to this literature by showing how foreign exchange position limit constraint imposed on global banks affects asset prices. Since onshore and offshore markets are segmented by regulation and the foreign exchange position limits are imposed only on the onshore market participants, it is an excellent setting to test whether a constraint on intermediaries affects asset prices without making assumptions on which class of agents are constrained.

Second, the onshore-offshore forward rate basis is related to the empirical literature studying frictions in the interest rate market and FX swap market. Klinger and Sundaresan (2018) and Jermann (2018) examine the disparity between the interest rate swap rate and the yield of a Treasury bond with dealer banks' balance sheet constraints combined with the demand of underfunded pension plans and with the regulation-induced cost of holding Treasuries, respectively. Coffey et al. (2009), Mancini-

Griffoli and Ranaldo (2011), Ivashina et al. (2015), and Du et al. (2018) study the covered interest rate parity (CIP) violations during the financial crisis. This paper shows that the onshore-offshore forward rate basis is driven not only by funding distress but also by position limit, which has not yet been carefully studied as a friction in the FX derivative markets.

Third, there is a literature that studies the relation between onshore and offshore foreign exchange forward markets. Ma et al. (2004) and Santaella (2015) provide overviews of NDF markets in Asia and Latin America. McCauley et al. (2014) document that the basis widens sharply in stressed market conditions, including the global financial crises. Wang (2015) finds that the CIP deviations observed in the onshore forward market were primarily caused by conversion restriction in the spot market, while offshore forwards reflect the market's expectation of the future spot rate. Some papers analyze the two-way influence between onshore and offshore forwards of a single currency. (Misra and Behera (2006), Kim and Song (2010), Behera (2011), Cadarajat and Lubis (2012) and Goyal et al. (2013)). However, none of these papers presents a model that links the basis to position limits.

This paper is organized as follows: section 2.2 provides motivating evidence, section 2.3 presents a model linking the basis to the margin requirement and position limits, section 2.4 contains model predictions and section 2.5 includes empirical results of testing the predictions. Section 3.7 concludes.

2.2 Motivating Evidence

I motivate my model by presenting some stylized facts based on daily EM forward and US forward rates for five currencies, Indonesian Rupiah (IDR), Indian Rupee (INR), Korean Won (KRW), New Taiwan Dollar (TWD) and Thailand Baht (THB), from 2000 January to 2018 July. The exact starting date is different for each country based on data availability. The data source is Bloomberg.

1. Basis, defined as log EM forward less log US forward, deviated significantly from zero during the financial crisis for all currencies except Korean Won. Figure 2.1 shows this graphically, and the first row of Table 2.1 reports the difference in mean basis during the crisis (2007-2009) and the rest of the period.

2. The magnitude of the deviation during the crisis roughly aligns with the tightness of capital-based position caps. The second row in Table 2.1 shows position limit in 2018 (as a percentage of bank capital) imposed by each local central bank. The position limit is relatively tight in Thailand, India, and Indonesia, compared to Korea. In Taiwan, each bank is allowed to determine its own positions; however, they are subject to the approval of central bank. Figure 2.2 presents time-series of position limits for the sample currencies. Overall, the position limits do not vary over time for each country.

3. Since EM forwards are deliverable contracts while US forwards are non-deliverable, it is natural to ask whether this difference affects the basis. Although I do not test this formally, I provide a suggestive evidence that the delivery requirement has insignificant effect on the basis. The evidence is from the time-series variation in Thailand Baht basis. The EM forward and US forward are both deliverable contracts for THB. Had the basis been mainly driven by the cost of funding deliverable contracts, THB would not have shown any significant spike during the financial crisis. However, the basis surged by 1%[3] during the crisis. Figure 2.3 also shows that there was a significantly negative basis during the crisis.

4. The bases for longer-term contracts tend to be less volatile than the bases for shorter-term contracts. For instance, 6-month contracts are less volatile than 1-month contracts. (Figure B.2-B.6)

5. The volatility of basis is higher during the financial crisis (2007-2009) for all currencies, and Indonesia had the most volatile basis among the sample countries. (Table 2.2)

2.3 Model

2.3.1 Model Illustration

For illustration, I show a simplified version of the model to demonstrate the roles of position limit and the margin constraint. Consider two countries– an EM onshore market and an offshore "US" market – and a global bank operating in the two countries with the following balance sheets:

EM Branch (e)		US Branch (0)	
Assets:	Liabilities:	Assets:	Liabilities:
$\theta^{e\$}$	$\eta^{e\$u}(<0)$	$\theta^{0\$}$	$\eta^{0\$u}(<0)$
$\theta^{e₩}$			$\eta^{0\$c}(<0)$
	Capital in EM		Capital in US
EM forward (θ^{ef})		US forward (θ^{0f})	

θ and η are portfolio weights in risky assets and risk-less assets respectively, and the portfolio weights sum to 1:

$$\theta^{e\$} + \theta^{e₩} + \eta^{e\$u} + \theta^{0\$} + \eta^{0\$u} + \eta^{0\$c} = 1$$

[3] compared to non-crisis excluding the time period when unremunerated reserve requirement (URR) was imposed. BoT enacted an URR regime effective 12/18/2006- 03/02-2008 to slow speculative capital inflows. BoT applied 30% reserve requirement on investments into Thailand and restricted the movements of THB from onshore to offshore.

A long position in an asset makes it "asset" and a short position in an asset makes it "liability". In the model, the sign of the position is not restricted for any asset. Assets are characterized by trading location, denominated currency, and collateralization in case of risk-less assets. Trading locations 0 denotes US and e denotes EM. \$ denotes USD-denominated assets and ₩[4] denotes EM currency-denominated assets. u denotes uncollateralized loans and c denotes collateralized loans.

Suppose that each country has risk-averse agents who have access to only the assets that are traded in his country; global bank has access to all of the assets traded in both locations, and has log utility. Then, the global bank's portfolio allocation problem is:

$$\max_{\theta^i, \eta^i} \; r^{0\$c} + \eta^{0\$u}(r^{0\$u} - r) + \eta^{e\$u}(r^{e\$u} - r) + \sum_{i \in \{e\$,\, e₩,\, e0\$\}} \theta^i(\mu^i - r) - \frac{1}{2}\sum_{i,j} \theta^i \theta^j \sigma^i (\sigma^j)^T$$

subject to (1) FX position limit constraint and (2) margin constraint.

1. The FX position limit is modeled as:

$$\frac{|\theta^{e\$} + \theta^{ef} + \eta^{e\$u}|}{\theta^{e\$} + \theta^{e₩} + \eta^{e\$u}} \leq \frac{1}{\pi} \quad (e.g. = 20\%)$$

The ratio of net USD position to capital **in EM** should not exceed $1/\pi$.

(a) How does this constraint affect asset prices? Suppose that the global bank has long USD position: $\theta^{e\$} + \theta^{ef} + \eta^{e\$u} > 0$. There are three ways for global bank to relax the constraint.

i. First, global bank can buy more EM-currency denominated asset e₩ to increase its capital in the EM (denominator effect). Because investment in EM-currency denominated asset in EM (e₩) relaxes the constraint while the same asset traded in the US (0₩) does not, the expected return on e₩ is lower than 0₩ in equilibrium.

ii. Second, global bank can sell EM forwards ef, contracts to receive USD in the future, to reduce the USD exposure (numerator effect). Since the *sale* of the EM forward relaxes the constraint while the sale of US forward does not, the expected return on ef is higher than $0f$.

iii. Third, global bank can sell USD-denominated assets in EM e\$. Whether the expected return on e\$ earns premium or discount compared to 0\$ depends on π.

The size of premium due to position limit depends on how tight the position limit (π) is and the marginal utility of relaxing the position limit constraint.

(b) When does this constraint bind more for global bank? Suppose for a moment that USD-denominated asset (e\$) is riskier than EM currency- denominated asset (e₩) in EM. Since

[4] Korean Won

global bank is more risk tolerant, he is more heavily invested in the riskier $e\$$. Therefore, following a series of bad shocks in EM, global bank loses more and risk-averse agent becomes a larger part of the market. As a result, premium on $e\$$ rises by more than $e₩$ to induce risk-averse agents to hold more $e\$$ for markets to clear. This is when the position limit constraint binds more (less) if global bank holds net long (short) USD position in EM.

2. Following Garleanu and Pedersen (2011), the margin constraint is modeled as:

$$\underbrace{\sum_{i\in\{e\$,e₩,0\$\}} m^i|\theta^i|}_{\text{Margin for risky assets positions}} + \underbrace{\eta^{0\$u} + \eta^{e\$u}}_{\text{uncollateralized USD loans}} \leq \overbrace{1}^{100\%\text{ of wealth}}$$

The capital uses in margin for positions in risky assets and riskless uncollateralized USD loans must be less than 100% of his wealth.

2.3.2 Full Model

I extend continuous-time model of Garleanu and Pedersen (2011) with multiple EM economies and the US. Trading locations are again denoted by L: $L = 0$ for US and $L > 0$ for EM. I denote USD-denominated assets with \$ and EM currency-denominated assets with ₩[5].

Risky Assets

Each country has a continuum of assets and each asset i pays a dividend δ_t^i at time t and is available in a net supply of 1. The dividend of each security i follows:

$$d\delta_t^i = \delta_t^i \left(\mu_t^{\delta^i} dt + \sigma_t^{\delta^i} dw_t\right)$$

There are two types of assets in each EM country: USD-denominated assets and EM currency-denominated assets. In each EM e, there are two consumption goods, \$-denominated and ₩-denominated :

$$dC_t^{e\$} = \mu^{C^{e\$}} C_t^{e\$} dt + \sigma^{C^{e\$}} C_t^{e\$} dw_t$$

$$dC_t^{e₩} = \mu^{C^{e₩}} C_t^{e₩} dt + \sigma^{C^{e₩}} C_t^{e₩} dw_t$$

[5] Korean Won

There is a single consumption good in the US:

$$dC_t^0 = \mu^{C^0} C_t^0 dt + \sigma^{C^0} C_t^0 dw_t$$

Appealing informally to the Law of Large Numbers, $E[\delta_t^{e\$} | C_t^{e\$}] = C_t^{e\$}$, $E[\delta_t^{e\text{₩}} | C_t^{e\text{₩}}] = C_t^{e\text{₩}}$ for each EM e and $E[\delta_t^0 | C_t^0] = C_t^0$.
Each asset requires asset-specific margin $m^i \in [0, 1]$, a fraction of the investment that must be financed by an agent's own capital.

Money-Market Assets

There are two riskless money-market assets in the US, collateralized loans (r) and uncollateralized loans ($r^{0\$u}$). There is only one riskless money-market asset in each EM country, uncollateralized USD-denominated loans ($r^{e\$u}$). This assumption is based on the fact that collateralized loan markets are not well developed in many emerging market economies. In addition, there are uncollateralized loans denominated in EM currencies, traded in the EM and in the US. These assets are riskless in each denominating EM currency, but are *risky* in USD.

Derivatives

In addition to these underlying assets, there are derivatives in net zero supply. A type of derivatives in particular interest is FX forwards, contracts to receive USD in exchange of pre-specified amount of other currencies in a pre-specified future date. US forwards are denoted $0f$ and EM forwards are ef. I assume that margins required for derivatives are lower than those for underlying assets.

Agents

There are three types of agents: EM risk-averse ea, global bank b, and US risk-averse $0a$. The local risk-averse agents can trade only the local assets. Global bank has access to all markets by having branches in the EM countries and in the US. Each agent $g \in \{ea, b, 0a\}$ maximizes his utility for consumption

$$E_t \int_0^\infty e^{-\rho s} u^g(C_s) ds$$

where $u^a(C) = \frac{1}{1-\gamma^a} C^{1-\gamma^a}$ with $\gamma^a > 1$, and $u^b(C) = \log(C)$ with $\gamma^b = 1$.

Each agent chooses his consumption C_t^g, portfolio weight θ_t^i for each asset i, and the proportion $\eta_t^{L\$u}$ invested in each riskless USD-denominated uncollateralized loan in each location L. The rest of his wealth is invested in riskless collateralized loans. The wealth W_t evolves as the following:

$$dW_t = \left(W_t \left(r_t + \sum_L \eta_t^{L\$u} (r_t^{L\$u} - r_t) \right) \right) dt + W_t \sum_i \theta_t^i \sigma_t^i dw_t$$

where the last term is summation over all risky assets and derivatives. Without loss of generality, returns on assets that are denominated in non-USD are converted back to USD.

Margin Constraint

Each agent can tie up his capital in margin for positions in risky assets and riskless uncollateralized USD loans ($\eta^{L\$u}$). These capital uses must be less than 100% of the wealth:

$$\underbrace{\sum_i m^i |\theta^i|}_{\text{Capital in Margin}} + \underbrace{\sum_L \eta^{L\$u}}_{\text{Investment in riskless uncollateralized loans}} \leq \underbrace{1}_{\text{Wealth}} \tag{2.4}$$

Again, the first term is summation over all risky assets and derivatives.

The relevant state variable for margin constraint is b's consumption as a fraction of the sum of the total global consumption:

$$\frac{C^b}{C^0 + \sum_{L \geq 1} (C^{L\$} + C^{L₩})}$$

This is direct extension of Garleanu and Pedersen (2011). Since global bank b is less risk averse, he invests more in the risky assets and therefore loses more following a series of bad shocks in $C^{e\$}$, $C^{e₩}$ for some EM e or C^0. As the risk-averse agent (ea and $0a$) becomes a larger part of the market, the market price of risk increases to induce them to hold enough of the risky assets for market to clear. This is when global bank's leverage rises and its margin constraint becomes more binding. The relation between the shadow cost of funding ψ and the state variable is non-linear as plotted in Figure 2.4.

FX Position Limit Constraint

In addition to the margin constraint, each EM risk-averse agent and global bank faces EM country-specific position limit. EM branch's foreign exchange net exposure, the difference between assets and liabilities in foreign currencies, cannot exceed $1/\pi$ (e.g. 1/5=20% for Indonesia) of the branch's capital:

$$\underbrace{\left| \sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} \right|}_{\text{Net USD Exposure in EM}} \leq \overbrace{\frac{1}{\pi}}^{\substack{\text{higher } \pi = \\ \text{tighter constraint}}} \underbrace{\left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u} \right)}_{\text{Capital in EM}} \tag{2.5}$$

As π increases position limit becomes more stringent.

The relevant state variable for position limit constraint of EM e is the b's consumption as a fraction of the EM's total consumption plus b's consumption:

$$\frac{C^b}{C^{e\$} + C^{e₩} + C^b}$$

Suppose that asset $e\$$ have higher volatility than $e₩$. When global bank's consumption C^b declines more than the EM's total consumption, $C^{e\$} + C^{e₩}$, risk-averse agents become a larger part of $e\$$ market and $e₩$ market, and risk premium for $e\$$ rises by more than the risk premium for $e₩$ assets to induce ea to hold more $e\$$ assets and more $e₩$ assets for markets to clear. In this case, if b is net long (short) USD in the EM: $\sum_j \theta^{e\$j} + \theta^{ef} + \eta^e > (<) 0$, his position limit is more (less) binding. A series of bad shocks in C^0 will make $0a$ become a larger part of $0\$$ market and therefore the risk premium on $0\$$ would increase. However, since positions in $0\$$ are not subject to the position limit, bad shocks in C^0 will not affect the position limit constraint, assuming that C^0 and $C^{e\$}$ or $C^{e₩}$ are independent.

Equilibrium

An equilibrium for the economy is a set of prices, agent decisions for consumptions and asset positions such that (1) given prices, each agent maximizes his utility subject to constraints and (2) markets clear.

2.3.3 Asset Prices

Consider the optimization problem of global bank. The logarithmic utility for consumption implies that the problem can be reduced to mean-variance optimization:

$$\max_{\Theta, \{\eta^{L\$u}\}} \; r + \sum_L \left(\eta^{L\$u}(r^{L\$u} - r)\right) + \Theta'(\mu - r) - \frac{1}{2}\Theta'\Sigma\Theta$$

subject to the margin constraint (2.4) and position limit constraint (2.5). Θ denotes positions in risky assets, and Σ denotes variance-covariance matrix of risky assets.

Interest Rates

Attaching Lagrange multiplier ψ to the margin constraint, the first-order condition with respect to the weight in the US uncollateralized loan, $\eta^{0\$u}$ is:

$$\psi_t = r_t^{0\$u} - r_t \tag{2.6}$$

This is the result of Garleanu and Pedersen (2011). Intuitively, global bank is willing to borrow at higher rate on uncollateralized loan because uncollateralized loan relaxes the margin constraint while collateralized loan requires capital. Therefore, the interest-rate differential between uncollateralized and collateralized loan captures the global bank's shadow cost of funding.

The expression for shadow cost of position limit constraint depends on global bank's net USD exposure in EM branch. First, suppose that EM branch is net USD long: $\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} > 0$. Attaching Lagrange multiplier λ to the position limit constraint, the shadow cost of position limit constraint is:

$$\lambda_t = \frac{r_t^{0\$u} - r_t^{e\$u}}{1 - \pi_t} \geq 0 \tag{2.7}$$

Since the position limit constraint becomes:

$$\begin{aligned} \sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} &\leq \frac{1}{\pi} \left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u} \right) \\ \sum_i \theta^{e\$i} + \theta^{ef} &\leq \frac{1}{\pi} \left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} \right) + \eta^{e\$u} \left(\frac{1}{\pi} - 1 \right) \end{aligned}$$

if $\pi > 1$, then constraint becomes looser as $\eta^{e\$u}$ decreases. As EM \$ denominated collateralized loans loosen the position limit, while USD-denominated uncollateralized loans do not, $r_t^{0\$u} \leq r_t^{e\$u}$. On the other hand, if $\pi < 1$, constraint becomes tighter as η^c decreases. Because USD-denominated collateralized loans in the EM tighten the position limit, whereas USD denominated uncollateralized loans do not, $r_t^{0\$u} \geq r_t^{e\$u}$.

Now suppose that global banks are net short USD in EM. The shadow cost of position limit constraint is:

$$\lambda_t = \frac{r_t^{0\$u} - r_t^{e\$u}}{1 + \pi_t} \geq 0 \tag{2.8}$$

Constraint becomes tighter as $\eta^{e\$u}$ decreases:

$$\begin{aligned} -\left(\sum_i \theta^{e\$i} + \theta^{ef} + \eta^{e\$u} \right) &\leq \frac{1}{\pi} \left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} + \eta^{e\$u} \right) \\ -\left(\sum_i \theta^{e\$i} + \theta^{ef} \right) &\leq \frac{1}{\pi} \left(\sum_i \theta^{e\$i} + \sum_i \theta^{e₩i} \right) + \eta^{e\$u} \left(\frac{1}{\pi} + 1 \right) \end{aligned}$$

The USD-denominated collateralized loans in the EM tighten the position limit, while uncollateralized loans in the US do not; therefore, $r_t^{0\$u} \geq r_t^{e\$u}$.

Risky Assets

Global bank's first-order conditions with respect to the risky asset positions Θ depends on the net USD exposure of global bank in the EM. First, suppose that global bank is net USD **long** in the EM. Then the expected excess returns on the risky assets are as following.

$$\mu^{0\$i} - r = \begin{cases} \beta^{0\$i} + \psi m^{0\$i} & \text{if } \theta^{0\$i} > 0 \\ \beta^{0\$i} - \psi m^{0\$i} & \text{if } \theta^{0\$i} < 0 \end{cases} \tag{2.9}$$

$$\mu^{0₩i} - r = \begin{cases} \beta^{0₩i} + \psi m^{0₩i} & \text{if } \theta^{0₩i} > 0 \\ \beta^{0₩i} - \psi m^{0₩i} & \text{if } \theta^{0₩i} < 0 \end{cases} \tag{2.10}$$

$$\mu^{0f} = \begin{cases} \beta^{0f} + \psi m^{0f} & \text{if } \theta^{0f} > 0 \\ \beta^{0f} - \psi m^{0f} & \text{if } \theta^{0f} < 0 \end{cases} \tag{2.11}$$

where $\beta_t^{C^b,i} = \mathrm{Cov}_t\left(\frac{dC^b}{C^b}, \frac{dP^i}{P^i}\right)$ denotes the conditional covariance between global bank's consumption growth and the return on security i. The expected excess returns on the assets that are traded in the US depends on $\beta^{C^b,i}$, the asset-specific margin and the shadow cost of funding ψ, as in Garleanu and Pedersen (2011) economy. The sign of the margin premium depends on whether global bank is long or short the security because both long and short positions require margin.

In contrast, the assets traded in the EM are affected by position limits, and therefore the shadow cost of the position limit constraint λ shows up in the first-order conditions:

$$\mu^{e\$i} - r = \begin{cases} \beta^{e\$i} + \psi m^{e\$i} - \lambda(1-\pi) & \text{if } \theta^{e\$i} > 0 \\ \beta^{e\$i} - \psi m^{e\$i} - \lambda(1-\pi) & \text{if } \theta^{e\$i} < 0 \end{cases} \tag{2.12}$$

$$\mu^{e₩i} - r = \begin{cases} \beta^{e₩i} + \psi m^{e₩i} - \lambda & \text{if } \theta^{e₩i} > 0 \\ \beta^{e₩i} - \psi m^{e₩i} - \lambda & \text{if } \theta^{e₩i} < 0 \end{cases} \tag{2.13}$$

$$\mu^{ef} = \begin{cases} \beta^{ef} + \psi m^{ef} + \lambda\pi & \text{if } \theta^{ef} > 0 \\ \beta^{ef} - \psi m^{ef} + \lambda\pi & \text{if } \theta^{ef} < 0 \end{cases} \tag{2.14}$$

Intuitively, purchase of EM asset relaxes the position limit constraint and therefore its expected excess return is lower by λ compared to the expected excess return when position limit is not imposed. The last term in equation (2.13) represents this. Because global bank is already net long USD in the EM, purchase of forward contracts to receive USD makes the constraint even tighter. Hence, EM forwards earn premium of $\lambda\pi$, the last term of equation (2.14). The purchase of USD-denominated asset has two effects. On the one hand, it increases its capital in the EM, which relaxes the constraint. On the other hand, it increases its USD exposure, which makes the constraint more stringent. The expected excess return on USD-denominated assets traded in EM is discounted by λ due to the former effect and it earns premium of $\lambda\pi$ due to the latter effect. In sum, if $\pi > 1$, the last term in equation (2.12) is positive; the expected excess return on USD denominated asset earns premium of $\lambda(\pi - 1)$.

Suppose now that EM branch is net USD **short**. The global bank's first-order conditions with respect to the positions of risky assets traded in the US are the same as the case when the global bank is net USD long in the EM and the equations (2.9)-(2.11) remain the same. This is simply because they are not subject to the position limit. The expected excess returns on the EM currency-denominated assets also do not depend on the net USD position of global bank in the EM, because EM currency-denominated assets always relaxes the position limit constraint by increasing the bank's capital base in the EM. Therefore, equation (2.13) also remains the same. However, when global bank is net short USD, the purchase of EM forward relaxes the position limit constraint and therefore its expected excess return is discounted by $\lambda\pi$:

$$\mu^{ef} = \begin{cases} \beta^{ef} + \psi m^{ef} - \lambda\pi & \text{if } \theta^{ef} > 0 \\ \beta^{ef} - \psi m^{ef} - \lambda\pi & \text{if } \theta^{ef} < 0 \end{cases} \tag{2.15}$$

By similar argument, the purchase of USD denominated asset unambiguously relaxes the position limit, and thus its expected excess return is discounted by $\lambda(1+\pi)$:

$$\mu^{e\$i} - r = \begin{cases} \beta^{e\$i} + \psi m^{e\$i} - \lambda(1+\pi) & \text{if long} \\ \beta^{e\$i} - \psi m^{e\$i} - \lambda(1+\pi) & \text{if short} \end{cases} \tag{2.16}$$

EM Currency-denominated Money Market Assets

Since global bank is interested in USD returns, the EM currency-denominated money market assets are risky. Because uncollateralized loans can be thought of as risky assets with margin of

$$m = \begin{cases} 1 & \text{if long} \\ -1 & \text{if short} \end{cases}$$

first-order conditions on the positions in EM currency-denominated uncollateralized loans give:

$$\begin{aligned} \mu^{0₩u} - r &= \beta^{0₩u} + \psi \\ \mu^{e₩u} - r &= \beta^{e₩u} + \psi - \lambda \\ \Rightarrow \mu^{0₩u} - \mu^{e₩u} &= (r^{0₩u\ in₩} - s) - (r^{e₩u\ in₩} - s) \\ &= r^{0₩u\ in₩} - r^{e₩u\ in₩} \approx \lambda \end{aligned} \tag{2.17}$$

where s is expected instantaneous return on spot exchange rate (defined as the value of 1 USD in terms of EM currencies). The equation (2.17) expresses the shadow cost of position limit in terms of observable quantities. In words, because investment in EM currency denominated rates $e₩u$ relaxes the position limit by increasing the bank's capital base, $e₩u$ earns premium of λ compared to $0₩u$ traded in the US. This equation is used for empirical test of the model predictions.

2.4 Predictions

1. **Basis**. Define basis as: $basis = \mu^{0f} - \mu^{ef}$. A basis arises when all agents are constrained by one or more constraints: margin constraint and position limit constraint for all agents, and access constraint for risk-averse agents. Such a situation arises when b is constrained by both position limit constraint and margin constraint, ea is constrained by his limited ability to hold $0f$ and $0a$ is constrained by his limited ability to hold ef. The basis depends on global bank's net USD position in the EM as well as its positions in US forward and EM forward. First, suppose that b is net long USD in its EM branch.

   (A) If global bank is long both US forward and EM forward, the basis is:

   $$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(m^{0f} - m^{ef}\right) - \lambda\pi \tag{2.18}$$

   (B) If global bank is short US forward and long EM forward, the basis is:

   $$basis = \left(\beta^{0f} - \beta^{ef}\right) - \psi(m^{0f} + m^{ef}) - \lambda\pi \tag{2.19}$$

   (C) If global bank is short both US forward and EM forward, the basis is:

   $$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(-m^{0f} + m^{ef}\right) - \lambda\pi \tag{2.20}$$

   (D) If global bank is long US forward and short EM forward, the basis is:

   $$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi(m^{0f} + m^{ef}) - \lambda\pi \tag{2.21}$$

   Analogously, there are four expressions for basis depending on b's positions in the forwards when b is net short USD in its EM branch. The margin effects remain the same as the case when b is net long USD. However, sign on $\lambda\pi$ is positive in this case because long position in EM forward relaxes the position limit constraint if b is net short USD in its EM branch.

(A) If global bank is long both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(m^{0f} - m^{ef}\right) + \lambda\pi \tag{2.22}$$

(B) If global bank is short US forward and long EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) - \psi(m^{0f} + m^{ef}) + \lambda\pi \tag{2.23}$$

(C) If global bank is short both US forward and EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi\left(-m^{0f} + m^{ef}\right) + \lambda\pi \tag{2.24}$$

(D) If global bank is long US forward and short EM forward, the basis is:

$$basis = \left(\beta^{0f} - \beta^{ef}\right) + \psi(m^{0f} + m^{ef}) + \lambda\pi \tag{2.25}$$

In any case, the $|basis|$ increases in $|\lambda\pi|$, after controlling for the margin effect.

Due to limited data availability, this prediction is hard to test. Specifically, there is no active market for EM-currency denominated uncollateralized loan outside of the EM. Therefore, $r^{e₩u}$ is unobservable and λ from equation (2.17) is not obtainable. In addition, data on net USD positions[6] of global banks, net forward positions (θ^{ef}, θ^{0f}) and margins (m^{ef}, m^{0f}) are extremely hard to obtain.

On the other hand, the following predictions are testable.

2. **Shadow Cost of Margin Constraint (ψ)**: When global bank's consumption share is low enough, the shadow cost of margin constraint ψ increases non-linearly as the consumption share of global bank falls. See Figure 2.4 based on Garleanu and Pedersen (2011)'s calibration.

3. **Shadow Cost of Position Limit (λ)**: The shadow cost of position limit constraint has non-linear relation with global bank's consumption relative to EM's ($\frac{C^b}{(C^b+C^{EM})}$). The relation depends on (1) whether $e\$$ are riskier than $e₩$, and (2) global bank's net USD position in each EM. See Figure 2.5 and 2.6.

[6] I considered BIS international banking statistics as a potential data source. However, they include only on-balance sheet items while net USD position subject to position limit includes off-balance sheet derivatives positions as well. In addition, aggregate statistics only for foreign bank branches are not available. For selected countries, Korea and Taiwan, data on global banks' net forward positions in each country are available. See Appendix for the detailed data availability.

4. **Return predictability**: Regardless of global bank's net USD position in EM, buying EM denominated EM asset relaxes position limit constraint by increasing the bank's capital base:

$$\mu^{e₩i} - r = \begin{cases} \beta^{e₩i} + \psi m^{e₩i} - \lambda & \text{if long} \\ \beta^{e₩i} - \psi m^{e₩i} - \lambda & \text{if short} \end{cases}$$

2.5 Empirical Tests

2.5.1 Data

I focus on six countries with similar market settings where markets are segmented and position limits are imposed only on the local market participants. I use the following data sources:

Spot, Forward Exchange Rates, TED Spread. I obtain daily spot exchange rate, forward exchange rate with different tenors (1-month, 3-month, 6-month and 1-year), and TED spread, 3-month Libor rate less 3-month T-bill interest rate, from Bloomberg. The sample period is 2003 - 2018 June, which is the longest overlapping period. For Thailand, I exclude the period when URR was implemented, as the basis was significantly wider during this period.

Position Limits. Historical position limits are obtained from each central bank.[7]

US Firm Data. Market equity and dividend data are obtained from CRSP.

EM Market Data. Each EM's stock and bond data are from Bloomberg.

2.5.2 Shadow Cost of Margin Constraint and Performance of Global Banks Relative to the World

Performance of Global Banks

As discussed in the full model section, the relevant state variable for margin constraint is *b*'s consumption as a fraction of the sum of the total global consumption. I use market equity of firms as a proxy for consumption. To construct the global bank's consumption share, I use Fama French's 49 industry definition and MSCI ACWI index[8]. Figure 2.7 plots the proxy for consumption share of global bank with varying definition of global banks.

Proxy for Shadow Cost of Margin Constraint

Following Garleanu and Pedersen (2011), I use TED spread, 3-month LIBOR − 3-month US Treasury yield, as a proxy for shadow cost of margin constraint.

[7] Bank Indonesia, Reserve Bank of India, Bank of Korea, Central Bank of the Republic of China, Bank of Thailand

[8] Market capitalization weighted index; it is comprised of stocks from 23 developed countries and 24 emerging markets.

Non-linear Relation: Regression Kink Model

Figure 2.8 is the scatter plot of TED spread and the proxy for global bank's consumption share; it suggests that the shadow cost of margin constraint indeed non-linearly increases as the global bank's consumption share falls. To formally test the non-linear relation, I estimate parameters in the following specification on monthly basis:

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

Table 2.3 shows that both slopes b_1 and b_2 are significant and negative, which is not entirely in line with the model prediction of $b_1 < 0$ and $b_2 = 0$. However, b_1 is steeper than b_2, and testing for a threshold effect, the two slopes are significantly different with p-value of 8% (Table 2.4). Figure 2.9 shows the fitted line with kink.

2.5.3 Shadow Cost of Position Limit Constraint and Performance of Global Banks Relative to the EM

Performance of Global Banks

The relevant state variable for position limit constraint of EM e is the b's consumption as a fraction of the EM's total consumption plus b's consumption. Again, I use global bank's market equity as a proxy for global banks' consumption, and each EM's market capitalization of equity index as a proxy for EM's consumption.

Proxy for Shadow Cost of Position Limit Constraint

To obtain a proxy for the shadow cost of position limit constraint ($\hat{\lambda}$), I first assume that the margins required for both EM forwards and US forwards are negligible. This assumption considerably simplifies the expression for basis; the basis expression is reduced to the following two cases:

$$Basis = \begin{cases} -\lambda\pi & \text{if net USD long} \\ \lambda\pi & \text{if net USD short} \end{cases}$$

from equations (2.18) - (2.25). In practice, the required margins are small (however non-zero) compared to equities, and I proceed with the simplifying assumption to test the model predictions.[9] Figure 2.10 plots the constructed proxy for the position limit constraint for each country. Specifically, daily

[9] It is extremely difficult to obtain micro-data on margins particularly because they are traded over-the-counter market.

shadow cost of position limit is calculated as:

$$\hat{\lambda}_t = |Basis_t|/\pi_t \tag{2.26}$$

where $Basis_t = -\frac{1}{n}\ln(USFwd_{t,t+n}) + \frac{1}{n}\ln(EMFwd_{t,t+n})$. I use 6-month tenor ($n = 0.5$ year), because contracts with shorter tenor such as 1-week or 1-month are noisy and contracts with longer tenor such as 1-year and longer are not actively traded. To obtain monthly basis, I average daily basis for each calendar month. Since Taiwan implicitly regulates the positions by requiring banks to get approval of their internal position limit, I do not observe π for Taiwan.

Non-linear Relation

Figure 2.11 include scatter plots of the constructed proxy for λ and the global bank's consumption relative to each EM's consumption on monthly basis. Unreported analysis shows that linear regression coefficient is significantly negative only for Indonesia. This could be consistent with the model, if the true threshold lies outside of observed range. Overall, none of the rest of the three countries shows strong result consistent with the model.

2.5.4 Return Predictability

To test[10] whether high λ predicts lower future return on EM assets, I regress quarterly excess return (including the change in exchange rate) on each EM's stock index and government bond. The latter is same as currency risk premium if government bond is risk-free.

EM Stock Returns (in USD)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

where $xr_{t,t+1}$ is return on a 1$ worth of investment in the EM's stock market (EM currency-denominated) converted back to USD for each quarter, in excess of US risk-free rate for the same period. The explanatory variable is lagged $\hat{\lambda}$ (average of daily $|Basis_t|/\pi_t$ for the previous month). Table 2.5 reports regression results for each country. The reported standard errors are Newey-West corrected. As the model predicts, the coefficients are negative and significant for Indonesia, India, and Thailand, where the position limits are relatively tight. This result remains similar for Indonesia and India when lagged TED spread is included as regressor (Table 2.6). Korea's result is inconsistent with the model, potentially due to lower degree of segmentation[11], other regulations and structural factors that are not modeled.

[10] Sample period is short, 61 quarters, for return predictability analysis.

[11] In Korea's case, local market participants are allowed to trade US forwards to some extent (subject to a certain limit).

EM Currency Risk Premium

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

where $xr_{t,t+1}$ is return on a 1\$ worth of investment in the EM's 3-month government bond (EM currency-denominated) converted back to USD for each quarter, in excess of US risk-free rate for the same period. This return is EM currency risk premium if EM government bond is risk-free. Table 2.7 reports regression results for each country. For Indonesia, the coefficient is significantly negative, consistent with the model. The results are overall weaker when TED spread is included in the regression, and the result for Korea is inconsistent with the model (Table 2.8). Again, this could be due to high degree of segmentation and other factors that are not modeled.

2.6 Conclusion

This paper explores the mispricing of FX forward contracts traded locally and the contracts traded outside of a country's jurisdiction for countries with FX position limits. With an intermediary asset pricing model, I show how the onshore and offshore FX forward contracts can be mispriced when the position limits bind for global banks. The main model prediction is that the basis is the sum of $|\text{position limit} \times \text{its shadow cost}|$ and $|\text{required margin} \times \text{its shadow cost}|$. Furthermore, the model implicates return predictability that high basis would predict the lower future excess returns on EM assets. The rationale behind this hypothesis is that when global banks allocate more capital to an EM economy and invest in the local-currency denominated assets, global banks' position limit constraint is relaxed. The model predictions are tested empirically, and I find evidence consistent with model implications, particularly in the countries with tight position limits.

Tables

Table 2.1: Size of bases and Position Limits in 2018

The first row is the difference in basis during the crisis and basis outside of the crisis. The second row is position limit expressed as % of bank capital.

	KRW	TWD	INR	THB	IDR
Basis during crisis - Basis during the rest	0%	-0.59%	0.52%	0.67%	0.74%
Position limit[12] as % of bank capital	50%	*	25%	15%	20%

*each authorized bank is allowed to determine its own positions subject to the approval of the central bank.

Table 2.2: Difference in Mean Basis for Each Country

Mean and standard deviation of daily basis (6-month tenor) during the crisis (2007-2009) and non-crisis (2001-2006 and 2010-2018) are reported for each country. For Thailand, URR period is excluded.

IDR

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.011	0.051	-0.003	0.026	0.0074***	(3.790)
Observations	715		3455		4170	

THB

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.014	0.014	-0.007	0.012	0.0067***	(9.700)
Observations	422		3790		4212	

INR

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.007	0.029	-0.002	0.014	0.0052***	(4.764)
Observations	737		3981		4718	

TWD

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	0.008	0.021	0.002	0.014	-0.0059***	(-7.428)
Observations	739		3931		4670	

KRW

	Crisis		Non-Crisis		Diff	
	mean	sd	mean	sd	b	t
basis_6m	-0.001	0.009	-0.001	0.005	0.0002	(0.668)
Observations	747		3802		4549	

Table 2.3: Regression Kink Model Estimates

The dependent variable is TED spread, difference between 3-month LIBOR and 3-month US Treasury yield. w^b is the proxy for global bank's consumption share.

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

	Est	SE	Pval	CI_L	CI_R
b1	-0.21	0.06	0.03	-0.35	-0.08
b2	-0.04	0.02	0.06	-0.07	-0.01
a1	0.01	0.00	0.00	0.00	0.01
k	0.17	0.01	0.00	0.15	0.18

Table 2.4: Testing for Threshold Effect

Testing whether the two slopes b_1 and b_2 are significantly different.

$$TED_t = b_1(w_t^b - k)_- + b_2(w_t^b - k)_+ + a_1 + \varepsilon_t$$

	FStat	Pval	CritVal	Level
1	5.25	0.08	4.89	0.90

Table 2.5: Stock Index Return Predictability with the Shadow Cost of Position Limit (λ)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly excess stock market index return and $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 2.26.

	IDR	INR	THB	KRW
Lambda Lag	-10.00***	-20.59**	-36.78***	4.695***
	(-5.55)	(-2.68)	(-4.27)	(5.91)
Constant	0.0702**	0.0646**	0.0606**	0.00729
	(3.39)	(2.91)	(3.18)	(0.65)
Observations	61	61	54	61
Adjusted R^2	0.14	0.06	0.07	0.03

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.6: Stock Index Return Predictability with the Shadow Cost of Position Limit (λ) and the Shadow Cost of Margin Constraint (ψ)

$$xr_{t,t+1} = \alpha + \beta^{\lambda}\hat{\lambda}_t + \beta^{\psi}\hat{\psi}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly excess stock market index return, $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 2.26, and $\hat{\psi}_t$ is TED spread, a measure of the shadow cost of margin constraint.

	IDR	INR	THB	KRW
Lambda Lag	-8.349**	-17.08*	-12.93	5.147***
	(-3.00)	(-2.57)	(-0.48)	(3.61)
Ted3M Lag	-5.617	-4.174	-14.70	-10.94***
	(-1.38)	(-1.57)	(-1.95)	(-3.64)
Constant	0.0891**	0.0775**	0.0927***	0.0540**
	(3.30)	(3.41)	(4.73)	(3.00)
Observations	61	61	54	61
Adjusted R^2	0.15	0.05	0.13	0.17

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.7: Carry Trade Return Predictability with the Shadow Cost of Position Limit (λ)

$$xr_{t,t+1} = \alpha + \beta\hat{\lambda}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly currency risk premium and $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 2.26.

	IDR	INR	THB	KRW
Lambda Lag	-3.654***	-1.016	-6.797*	1.098
	(-4.07)	(-0.94)	(-2.44)	(1.67)
Constant	0.0121	0.00118	0.00604	-0.00445
	(1.72)	(0.22)	(1.07)	(-0.52)
Observations	61	61	54	61
Adjusted R^2	0.17	-0.01	0.04	-0.00

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.8: Carry Trade Return Predictability with the Shadow Cost of Position Limit (λ) and the Shadow Cost of Margin Constraint (ψ)

$$xr_{t,t+1} = \alpha + \beta^{\lambda}\hat{\lambda}_t + \beta^{\psi}\hat{\psi}_t + \varepsilon_{t+1}$$

$xr_{t,t+1}$ is quarterly currency risk premium, $\hat{\lambda}_t$ is the measure of the shadow cost of position limit from Equation 2.26, and $\hat{\psi}_t$ is TED spread, a measure of the shadow cost of margin constraint.

	IDR	INR	THB	KRW
Lambda Lag	-2.972*	1.320	-4.900	1.300**
	(-2.06)	(1.24)	(-0.88)	(3.22)
Ted3M Lag	-2.316*	-2.776***	-1.170	-4.891***
	(-2.03)	(-4.39)	(-0.90)	(-7.77)
Constant	0.0198*	0.00977	0.00859*	0.0164**
	(2.45)	(2.00)	(2.18)	(2.78)
Observations	61	61	54	61
Adjusted R^2	0.19	0.05	0.03	0.16

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figures

Figure 2.1: Time Series of 6M Basis

Time series of basis, difference between log of EM 6M forward rate and log of US 6M forward rate, for each country.

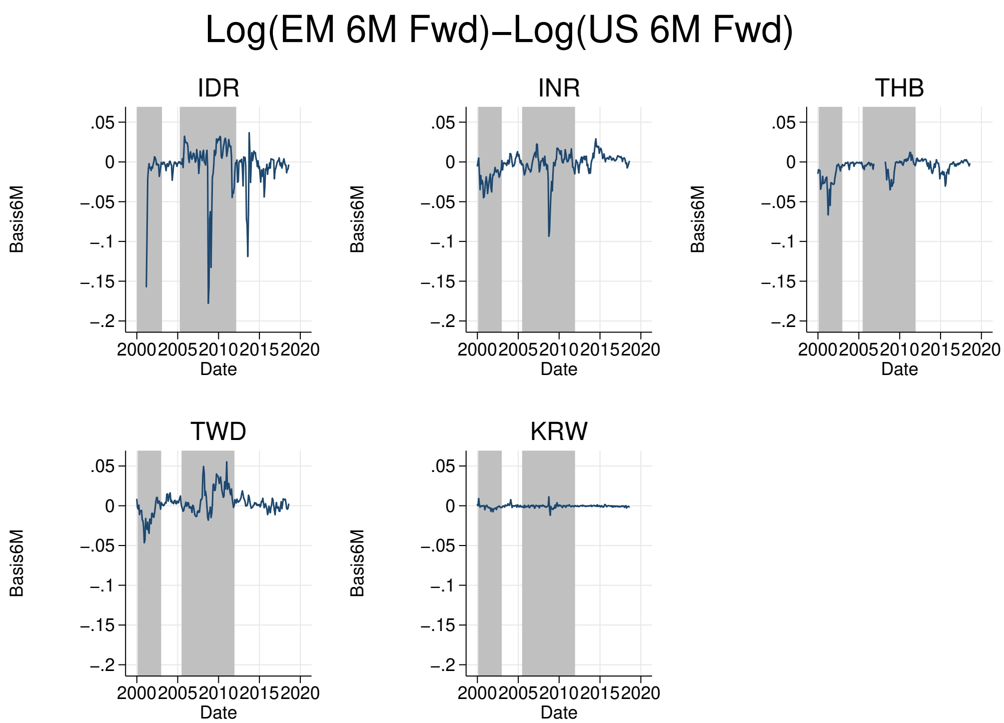


Figure 2.2: Position Limits

Historical position limits ($1/\pi$) for each country. Higher PL indicates tighter position limit. In Taiwan, each authorized bank is allowed to determine its own positions subject to the approval of the central bank. Therefore, explicit position limits are not observed for Taiwan.

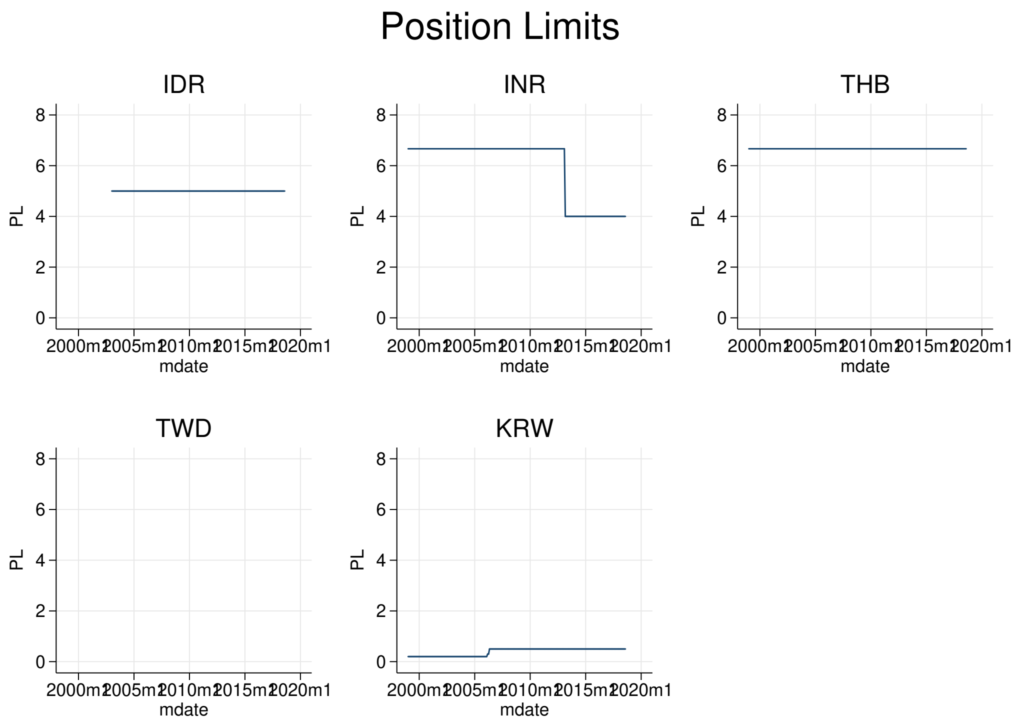


Figure 2.3: Thailand Baht Basis

Time series of basis for Thailand Baht. Blue area indicates the period when unremunerated reserve requirement was applied.

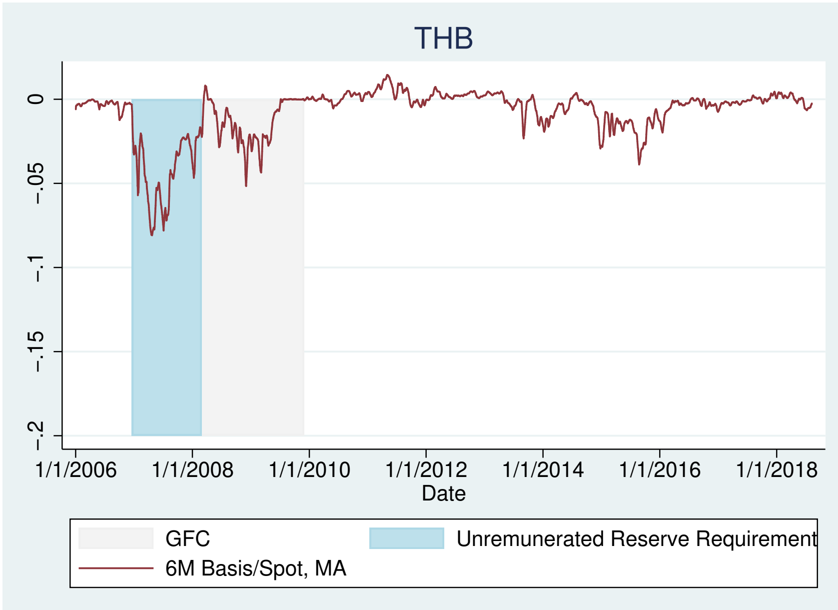


Figure 2.4: Model Prediction about Margin Constraint

Model prediction of non-linear relation between the shadow dost of margin constraint (ψ) and the performance of global banks relative to the world (c^b). This plot is generated based on Garleanu and Pedersen (2011)'s calibrated model. When global banks are poor enough, their margin constraint binds more and the shadow cost of margin constraint (ψ) rises.

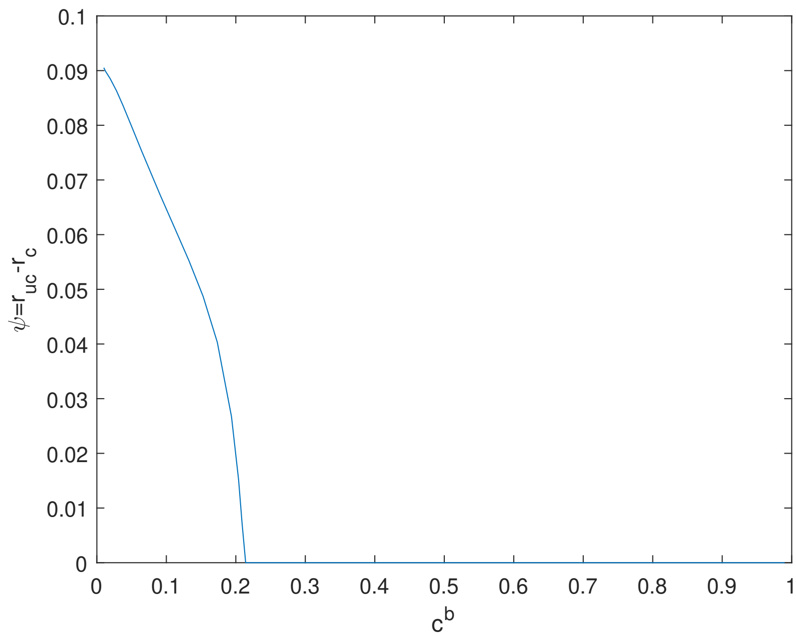
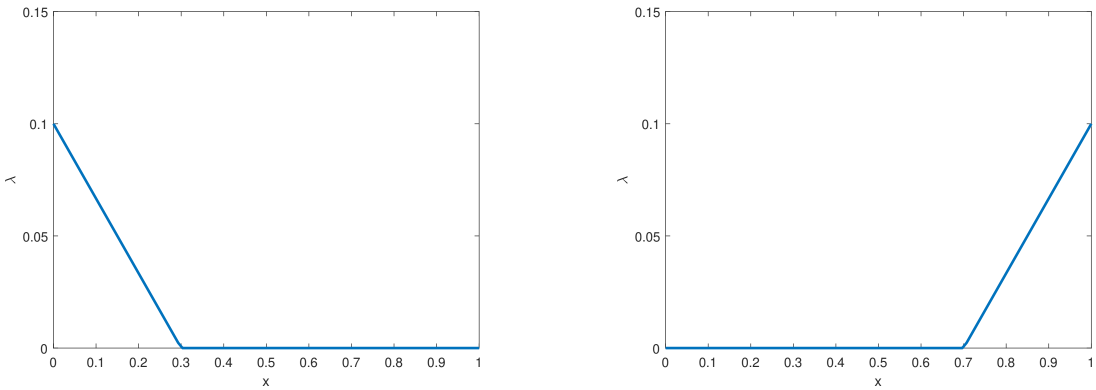


Figure 2.5: Model Prediction about FX Position Limit Constraint when \$ assets are *more* volatile than ₩ assets in EM.

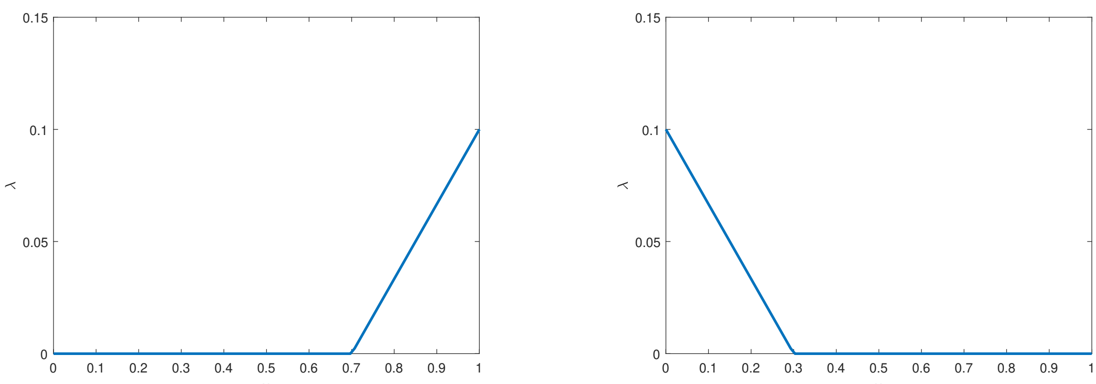
Since global bank is more risk tolerant, he is more heavily invested in the riskier asset $e\$$ than $e₩$. Following a series of bad shocks, global bank loses more and risk-averse agent becomes a larger part of the market. As a result, premium on $e\$$ rises by more than $e₩$ to induce risk-averse agents to hold more $e\$$ for markets to clear. This is when position limit constraint binds more (higher λ) if global bank holds net long USD position in the EM. Therefore, as global bank's relative performance (x) decreases, shadow cost of position limit (λ) increases non-linearly. (Panel a).



(a) Net Long USD in EM

(b) Net Short USD in EM

Figure 2.6: Model Prediction about FX Position Limit Constraint when \$ assets are *less* volatile than ₩ assets in EM.



(a) Net Long USD in EM

(b) Net Short USD in EM

Figure 2.7: Proxy for Global Banks' Performance

Time series of global banks' performance measure: $c^b = \frac{ME^b}{ME^a + ME^b}$. For the numerator, Fama French's 49 industry definition is used to classify firms. For the denominator, MSCI's global equity (ACWI) index is used.

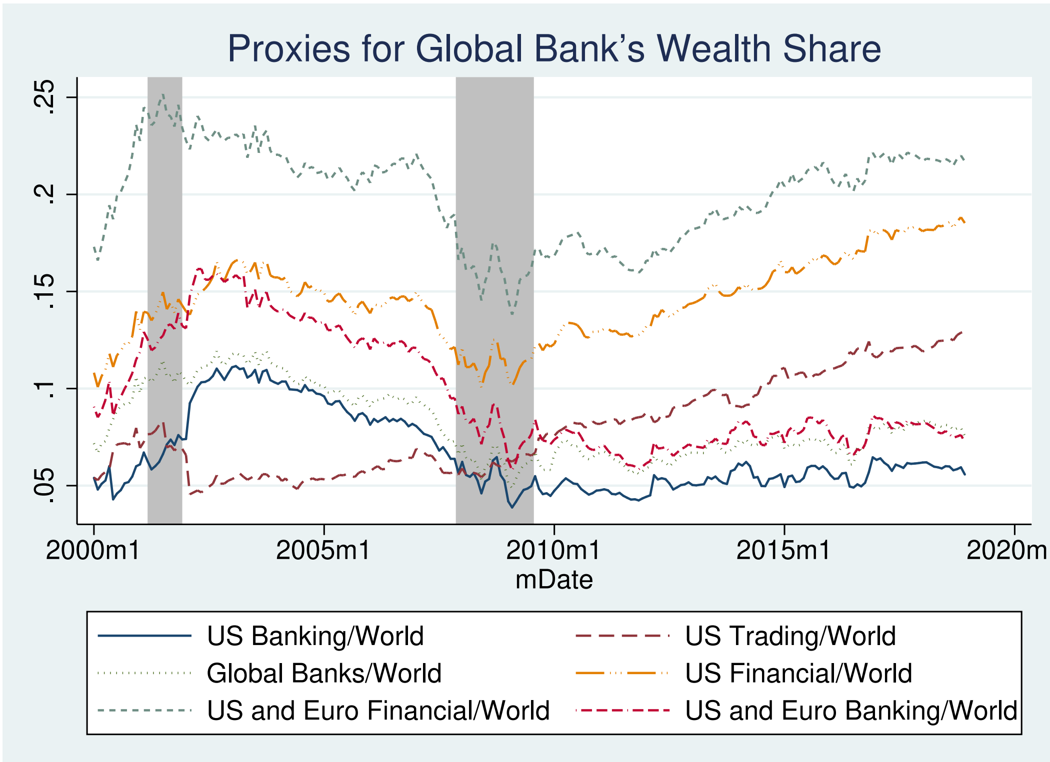
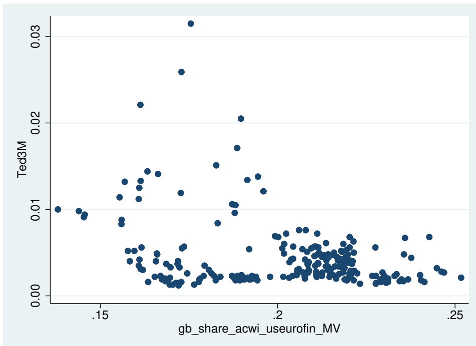
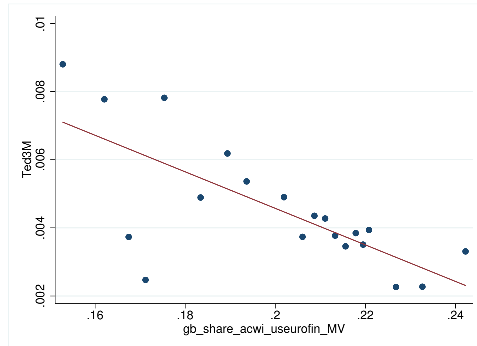


Figure 2.8: TED Spread vs. Global Bank's Consumption Share



(a) Scatter Plot



(b) Binned Scatter

Figure 2.9: TED Spread vs. Global Bank's Consumption Share (Fitted)

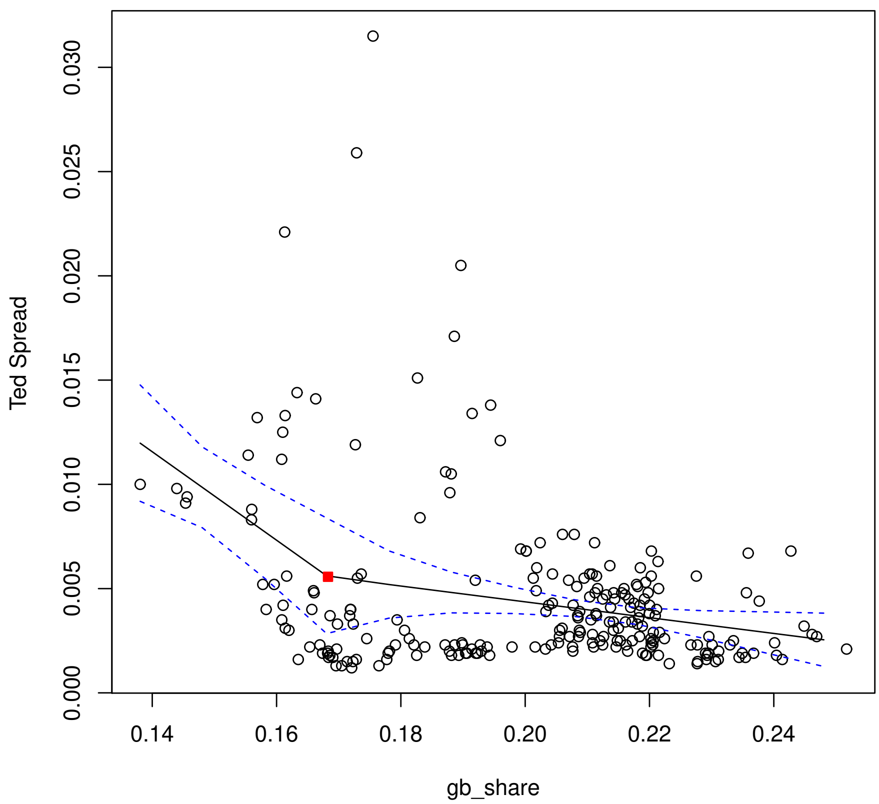


Figure 2.10: Proxy for the Shadow Cost of Position Limit ($\hat{\lambda}$)

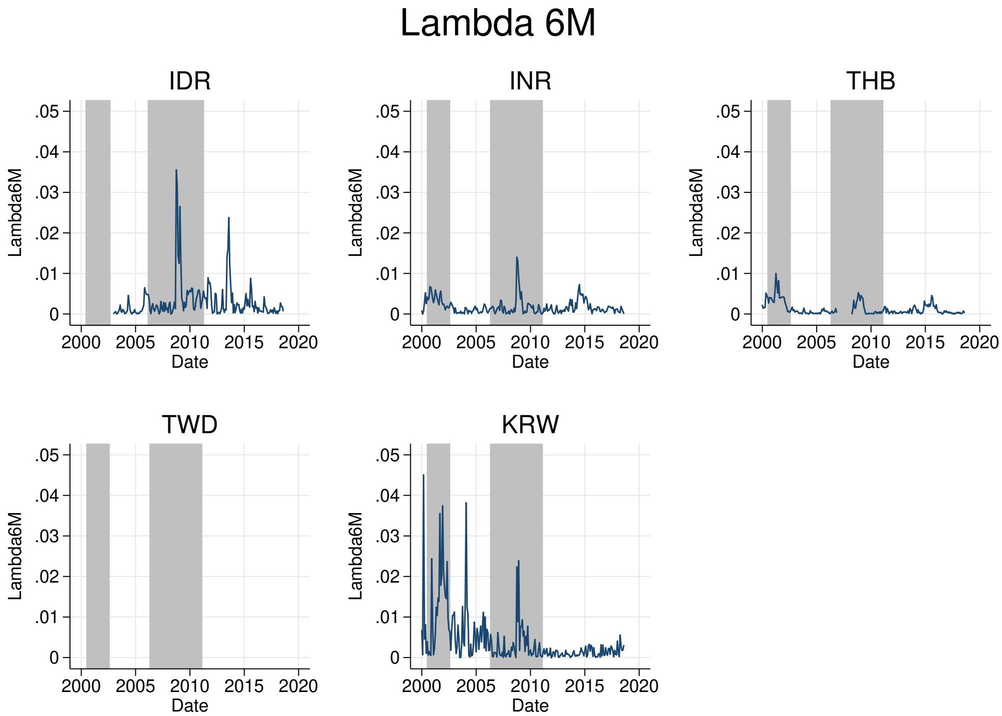
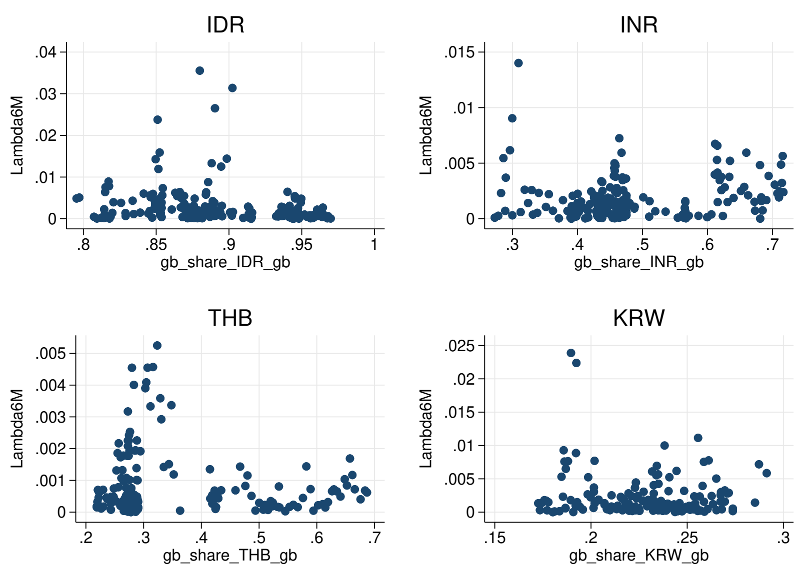


Figure 2.11: Proxy for Shadow Cost of Position Limit ($\hat{\lambda}$) vs. Global Banks' Performance Relative to EM



Chapter 3

Climate Stress Testing (with Robert Engle)

Abstract

Climate change could impose systemic risks upon the financial sector, either via disruptions of economic activity resulting from the physical impacts of climate change or changes in policies as the economy transitions to a less carbon-intensive environment. We develop a stress testing procedure to test the resilience of financial institutions to climate-related risks. Specifically, we introduce a measure called CRISK, systemic climate risk, which is the expected capital shortfall of a financial institution in a climate stress scenario. We use the measure to study the climate-related risk exposure of large global banks in the collapse in fossil-fuel prices in 2020.

3.1 Introduction

Understanding the impact of climate change on financial systems is an important question for researchers, central banks, and financial regulators across the world. Krueger et al. (2020) find that institutional investors believe climate risks have financial implications for their portfolio firms and that these risks already have begun to materialize. Many central banks have recently started including climate stress scenarios in their own stress testing frameworks.[1] The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), which consists of 89 member countries as of March 2021, analyzes the impact of climate change on macroeconomic and financial stability.[2]

How does climate change impose systemic risk on the financial sector? Two main channels are: first, through disruptions of economic activity resulting from the physical impacts of climate change; second, through the changes in policies as economies transition to a less carbon-intensive environment. The former are referred to as physical risks and the latter are referred to as transition risks.[3] Physical

[1] For example, the central banks and the regulators of Australia, Canada, England, France, and the Netherlands have already begun performing climate stress tests, or have announced their intention to conduct such tests.

[2] See `https://www.ngfs.net/en` for further details on NGFS.

[3] NGFS defines physical risks as financial risks which can be categorized as either acute—if they arise from climate and weather-related events and acute destruction of the environment—or chronic—if they arise from progressive shifts in cli-

risks can affect financial institutions through their exposures to firms and households that experience extreme weather shocks. On the other hand, transition risks can affect financial institutions through their exposures to firms with business models not aligned with a low-carbon economy. Fossil fuel firms are a prominent example: banks that provide financing to fossil fuel firms are expected to suffer when the default risk of their loan portfolios increases, as economies transition into a lower-carbon environment. If banks systemically suffer substantial losses following an abrupt rise in the physical risks or transition risks, climate change poses a considerable risk to financial system.

How much systemic risks does climate change impose on the financial system? This question is at the heart of understanding the impact of climate change on financial systems. We contribute to answering the question by developing a climate stress testing methodology to test the resilience of financial institutions to climate-related risks. Specifically, we develop a measure called CRISK, which is the expected capital shortfall of a financial institution in a climate stress scenario. The stress testing procedure involves three steps. The first step is to measure the climate risk factor. While there are many ways to measure the climate risk factor, we use stranded asset portfolio return as a proxy measure for transition risk. The second step is to estimate a time-varying climate beta of financial institutions using the Dynamic Conditional Beta (DCB) model. The third step is to compute CRISK, which is a function of a given financial firm's size, leverage, and expected equity loss conditional on climate stress. This step is based on the same methodology as SRISK of Acharya et al. (2011), Acharya et al. (2012), and Brownlees and Engle (2017), with the climate factor is added as the second factor.

We apply the methodology to measure the climate risk of 27 large global banks, whose aggregate oil and gas loan market share exceeds 80%. The stress scenario that we consider is a 50% drop in the return on stranded asset portfolio over six months. This corresponds to the first percentile of historic return on stranded asset portfolio. We find that, first, the climate beta varies over time, highlighting the importance of dynamic estimation. Second, climate betas of banks move together over time, and there was a common spike in climate beta as well as in CRISK when energy prices collapsed in 2020. The measured CRISKs for some of the banks were economically substantial. For instance, Citigroup's CRISK increased by 73 billion US dollars during the year 2020. In other words, the expected amount of capital that Citigroup would need to raise under the climate stress scenario to restore a prudential capital ratio[4] increased by 73 billion US dollars in 2020. In a decomposition analysis, we find that the increase in CRISK during 2020 is primarily due to decreases in equity values of banks, as opposed to decreases in debt values or increases in climate betas. Third, we find evidence that banks with higher loan exposure to the oil and gas industry tend to have higher climate betas, corroborating the economic validity of our climate beta estimates.

mate and weather patterns or from gradual loss of ecosystem services. NGFS defines transition risks as financial risks which can result from the process of adjustment towards a lower-carbon and more circular economy, prompted, for example, by changes in climate and environmental policy, technology, or market sentiment (NGFS (2020)).

[4]We set prudential capital ratio as 8%.

Related Literature

This paper contributes to several strands of literature. First, it adds to the growing body of literature on climate finance. Giglio et al. (2020) provide a review on the literature regarding the pricing of climate risks across different asset classes. Studies including Bolton and Kacperczyk (2020), Engle et al. (2020), and Ilhan et al. (2020) suggest that climate risks are priced in equity market. A few papers also have examined the effects of climate change on banks' loan pricing. Chava (2014) finds that banks charge a significantly higher interest rate on the loans provided to firms with environmental issues. Ginglinger and Quentin (2019) find consistent evidence that greater climate risk leads to lower leverage after the Paris Agreement, partly because lenders increase the spreads when lending to firms with the greatest climate risk. We add to the literature by quantifying climate-related risk exposure of financial institutions. Despite the evidence that banks do price the climate risks, our CRISK measures suggest that climate change could lead to a substantial increase in systemic risk when transition risks rise sharply.

This paper also contributes to the literature on stress testing and systemic risk measurement. In the context of climate-related stress testing, Reinders et al. (2020) use Merton's contingent claims model to assess the impact of a carbon tax shock on the value of corporate debt and residential mortgages in the Dutch banking sector. Compared to other stress testing methodologies, CRISK methodology inherits the benefits of the SRISK methodology. First, CRISK does not require any proprietary information and can be readily computed using publicly available data on balance sheet information and market information of each financial institution, and return on the stranded asset portfolio. Moreover, it can be estimated on a high-frequency basis. Therefore, it is very easy to estimate and promptly reflects current market conditions. It is thus a useful monitor that enables regulators to respond in a timely manner in the case intervention is necessary. Second, CRISK measures the expected capital shortfall conditional on *aggregate* stress. That is, we are not measuring how much capital a bank would need when the bank is under stress in isolation. Third, firm-level CRISK can be aggregated to country-level CRISK, which provides early warning signals of macroeconomic distress due to climate change. Fourth, by applying a consistent methodology to different firms in different countries, the CRISK measure allows comparison across firms and across countries. Lastly, implementing the CRISK measure offers value incremental to other stress testing methodologies that are already in place. Previous studies including Acharya et al. (2014) and Brownlees and Engle (2017) show that regulatory capital shortfalls measured relative to total assets give similar rankings to SRISK. However, rankings are different when the regulatory capital shortfalls are measured relative to risk-weighted assets, and they are also different from those observed in the European stress tests.

Outline of the Paper

The remainder of the paper proceeds as follows: Section 3.2 describes the data. Section 3.3 develops our empirical methodology and reports the stress testing results. Section 3.4 analyzes CRISK of large global banks during 2020. Section 3.5 tests the economic validity of our estimates. Section 3.6 discusses future directions for research, and section 3.7 concludes.

3.2 Data

We estimate the climate betas and CRISK of large global banks in the U.S., the U.K., Canada, Japan, and France for the sample period from 2000 to 2020. We focus on the large global banks as they hold more than 80% of syndicated loans made to oil and gas industry. The list of top 50 global banks by oil and gas loan exposure is presented in Table C.18 in Appendix. We use return on an S&P 500 ETF for the market return. The stock return and accounting data of banks are from Datastream, and syndicated loan data is from LPC DealScan and Bloomberg League Table. We use DealScan-Compustat link from Schwert (2018).

3.3 Methodology and Empirical Results

The climate stress testing procedure involves three steps. The first step is to measure the climate risk factor by using stranded asset portfolio return as a proxy measure for transition risk. The second step is to estimate time-varying climate beta of financial institutions using the DCB model. The third step is to compute CRISK, which is a function of a given firm's size, leverage, and expected equity loss conditional on climate stress. This step extends SRISK methodology of Acharya et al. (2011), Acharya et al. (2012), and Brownlees and Engle (2017) by adding the climate factor as the second factor.

3.3.1 Climate Factor Measurement

There are several ways to measure the climate risk factor, including the climate news index constructed by Engle et al. (2020). We use Litterman's "stranded asset" portfolio return as a measure of transition risks.[5] The stranded asset portfolio consists of a long position in the stranded asset index comprised of 30% in Energy Select Sector SPDR ETF (*XLE*) and 70% in VanEck Vectors Coal ETF (*KOL*), and a short position in SPDR S&P 500 ETF Trust (*SPY*). We directly use the return on stranded asset portfolio as climate factor:

$$CF^{Str} = 0.3XLE + 0.7KOL - SPY$$

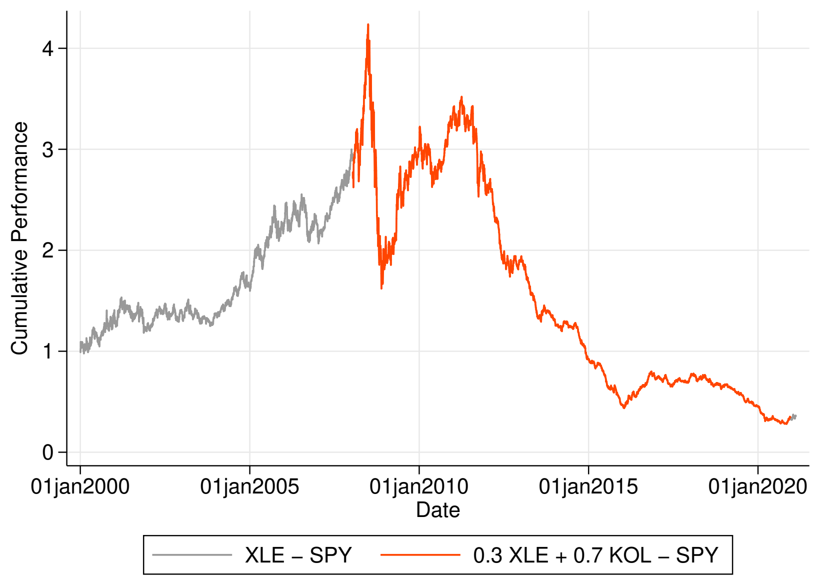
[5] This acts as a proxy for the World Wildlife Fund stranded assets total return swap. See http://www.intentionalendowments.org/selling_stranded_assets_profit_protection_and_prosperity for further details.

because it can be easily computed on a daily basis, and the portfolio is expected to underperform as economies transition to lower-carbon economy. A short position in the stranded asset portfolio is a bet on the underperformance of coal and other fossil fuel firms; therefore, a *lower* value of CF^{Str} indicates underperformance of fossil fuel firms and therefore *higher* transition risk. Since the VanEck Vectors Coal ETF started in 2008 and was liquidated in 2020, the climate factor is computed as:

$$CF^{Str} = XLE - SPY$$

for the period outside of 2008–2020. Figure 3.1 shows that cumulative return on the stranded asset portfolio has been falling since 2011.

Figure 3.1: Stranded Asset Portfolio Cumulative Return



3.3.2 Climate Beta Estimation

We use the DCB model to estimate the time-varying climate betas. The GARCH-DCC model of Engle (2002), Engle (2009), Engle (2016) allows volatility and correlation to be time-varying. Following the standard factor model approach, we model bank i's stock return as:

$$r_{it} = \beta_{it}^{Mkt} MKT_t + \beta_{it}^{Climate} CF_t + \varepsilon_{it},$$

where r_{it} is the stock return of bank i, MKT is the market return, and CF is the climate factor, measured as return on the stranded asset portfolio. The market beta and the climate beta in this regression measure the sensitivity of bank i to market risk and to transition-related climate risk, respectively. One would expect that banks with large amounts of loans to the fossil fuel industry will be more sensitive to climate risk on average and will have positive climate beta. However, in the case that a bank holds a large amount of loans to the renewable energy sector, the bank's climate beta could be negative.

For stock markets with a closing time different from that of the New York market, we take asynchronous trading into consideration by including the lags of the independent variables:

$$r_{it} = \beta_{1it}^{Mkt} MKT_t + \beta_{2it}^{Mkt} MKT_{t-1} + \beta_{1it}^{Climate} CF_t + \beta_{2it}^{Climate} CF_{t-1} + \varepsilon_{it}$$

Assuming that returns are serially independent, we estimate the following two specifications separately and sum the coefficients.

$$\begin{aligned} r_{it} &= \beta_{1it}^{Mkt} MKT_t + \beta_{1it}^{Climate} CF_t + \varepsilon_{it} \\ r_{it} &= \beta_{2it}^{Mkt} MKT_{t-1} + \beta_{2it}^{Climate} CF_{t-1} + \varepsilon_{it} \end{aligned}$$

The sum, $\beta_{1it}^{Mkt} + \beta_{2it}^{Mkt}$, is the estimate of market beta and the sum, $\beta_{1it}^{Climate} + \beta_{2it}^{Climate}$, is the estimate of climate beta.

We present the estimated climate beta of large global banks in the U.S., U.K., Canada, Japan, and France in Figures 3.2–3.6. For illustration, we plot six-month moving averages of the estimates. We report the non-smoothed climate beta estimates and market beta estimates in the Appendix.

Figure 3.2: Climate Beta of U.S. Banks

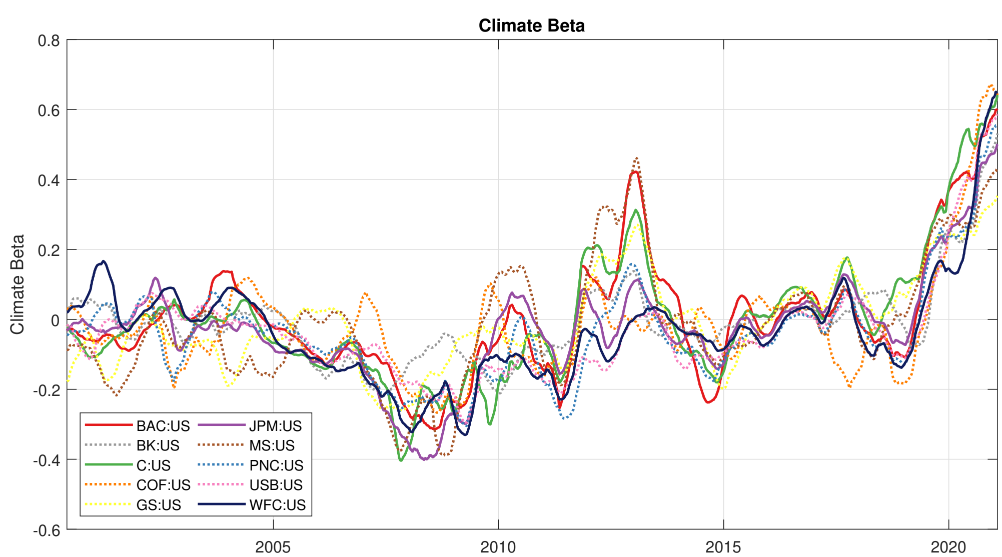


Figure 3.3: Climate Beta of U.K. Banks

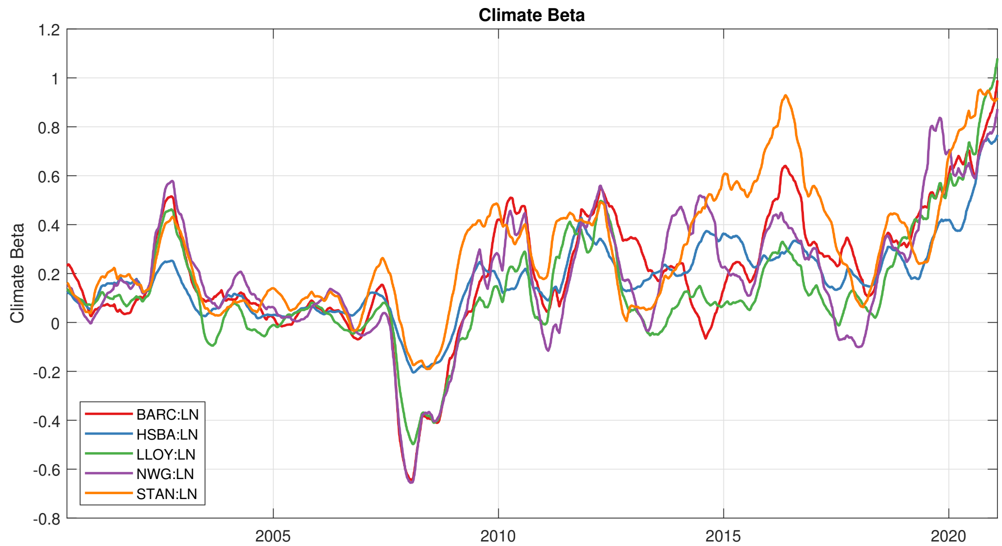


Figure 3.4: Climate Beta of Canadian Banks

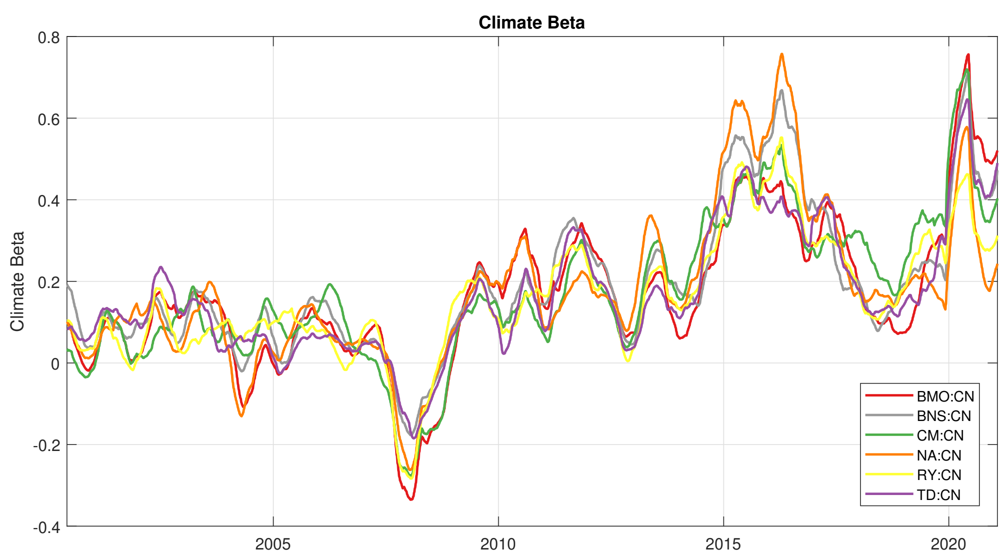


Figure 3.5: Climate Beta of Japanese Banks

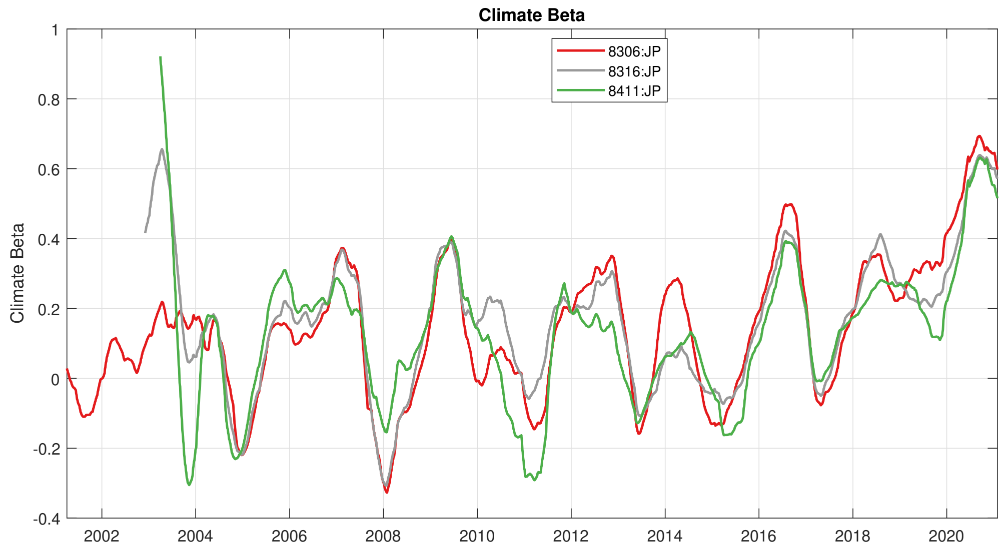
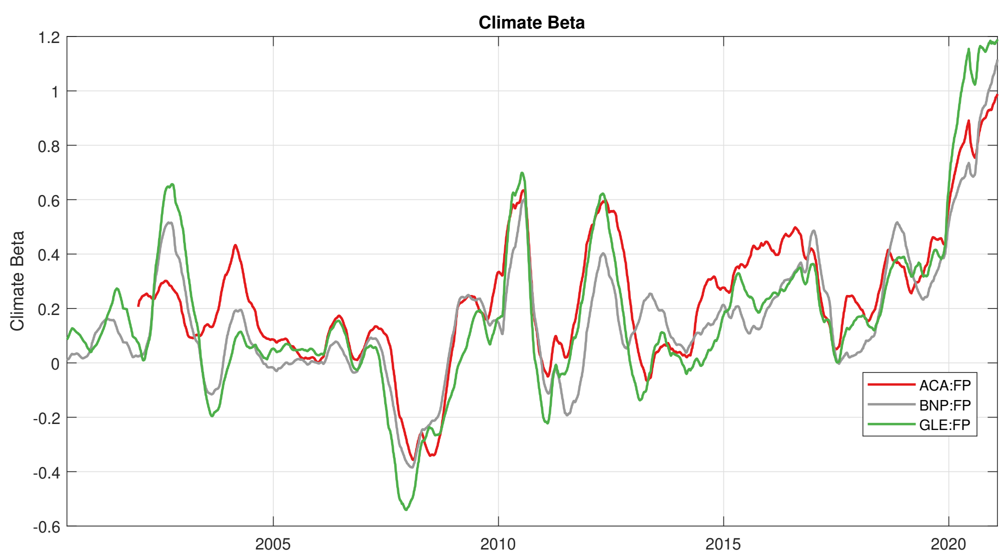


Figure 3.6: Climate Beta of French Banks



Based on the estimation results, we summarize the main findings as follows. First, it is worth noting that the climate beta varies over time, and therefore it is important to estimate the betas dynamically. Second, we observe a common spike in the year 2020 as banks' exposure to the transition risk rose substantially due to a collapse in energy prices. Third, the average level of climate beta is different across countries, and this could be due to differences in country-specific climate-related regulations, or differences in climate-conscious investing patterns across countries. In the U.S., the climate beta estimates range from -0.4 to 0.7, and were often not significantly different from zero before 2015. In terms of magnitude, a climate beta of 0.5 means that a 1% fall in stranded asset portfolio return is associated with a 0.5% fall in the bank's stock return. The climate beta estimates' proximity to zero could be related to the non-linearity in the climate beta as a function of the return on stranded asset portfolio. That is, we expect that the values of bank stocks are relatively insensitive to fluctuations in the stock prices of oil and gas firms as long as they are sufficiently far from default. On the other hand, the estimates for UK banks were higher on average.

3.3.3 CRISK Estimation

Following SRISK methodology in Acharya et al. (2011), Acharya et al. (2012), Brownlees and Engle (2017), CRISK for each financial institution is computed as:

$$
\begin{aligned}
CRISK_{it} &= k \cdot DEBT_{it} - (1-k) \cdot EQUITY_{it} \cdot (1 - LRMES_{it}) && (3.1)\\
&= k \cdot DEBT_{it} - (1-k) \cdot EQUITY_{it} \cdot \exp\left(\beta_{it}^{Climate} \log(1-\theta)\right) && (3.2)
\end{aligned}
$$

where $\beta_{it}^{Climate}$ is the climate beta of bank i, $DEBT$ is book value of debt (book value of assets less book value of equity), and $EQUITY$ is market capitalization. $LRMES$ is long-run marginal expected shortfall, the expected stock return conditional on the systemic climate event. We set the prudential capital fraction k to 8% and the climate stress level θ to 50%. This corresponds to the first percentile of six-month return (fractional) on the stranded assets. The summary statistics are included in the Appendix. Figures 3.7–3.11 present the estimated CRISK of large global banks in the U.S., U.K., Canada, Japan, and France.

The estimated CRISKs are often negative until 2019. As CRISK is the expected capital *shortfall*, a negative CRISK indicates that the bank holds a capital surplus. This is likely related to the non-linear relationship between the climate beta and the performance of fossil-fuel firms. A bank will not have a capital shortfall if its climate beta is small and therefore have a negative CRISK. In contrast, the CRISKs increased substantially across countries in 2020.

Since CRISK is a function of climate beta, as well as a function of the size and leverage of a bank, the ranking of CRISKs can differ from that of the climate beta estimates. For instance, while the climate beta estimates of the U.S. banks were relatively low, their CRISKs were substantial, as high as 95 billion USD for Citibank in June 2020. To put this into context, Citibank's SRISK, the expected capital shortage in a potential future financial crisis, was 125 billion USD in June 2020.[6] In contrast, CRISKs of Canadian banks in June 2020 range from 6 billion to 33 billion USD, despite their high climate betas.

[6]NYU's V-lab (`https://vlab.stern.nyu.edu/`) provides systemic risk analysis.

Figure 3.7: CRISK of U.S. Banks

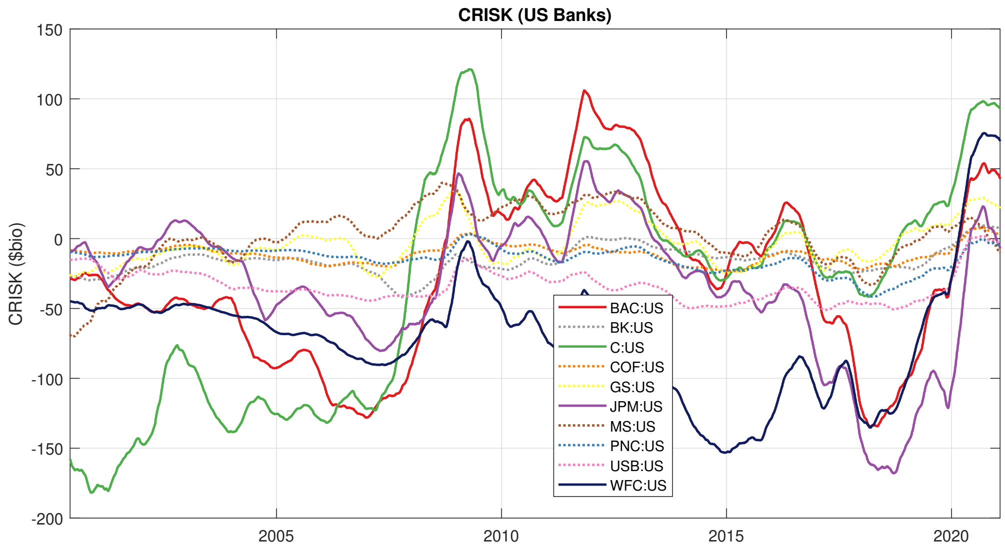


Figure 3.8: CRISK of U.K. Banks

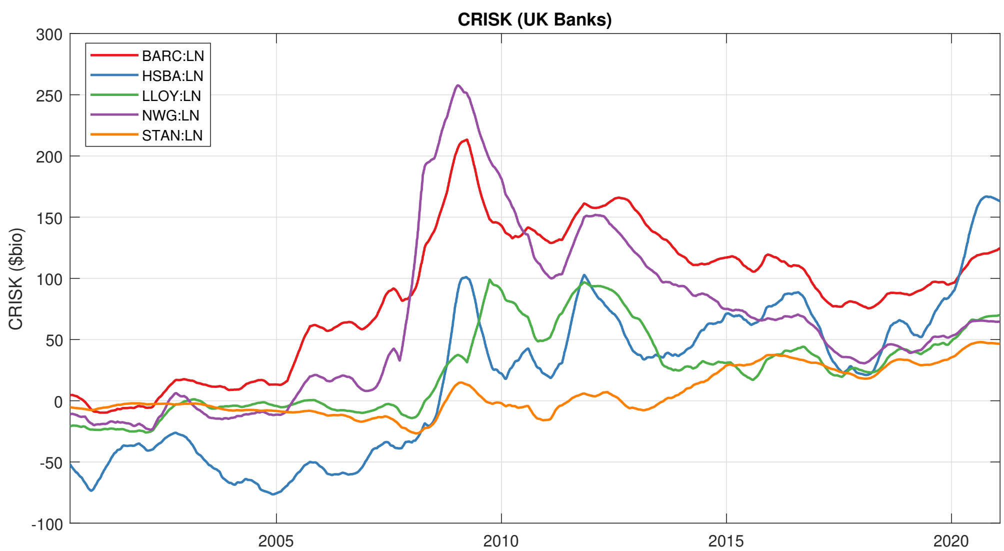


Figure 3.9: CRISK Beta of Canadian Banks

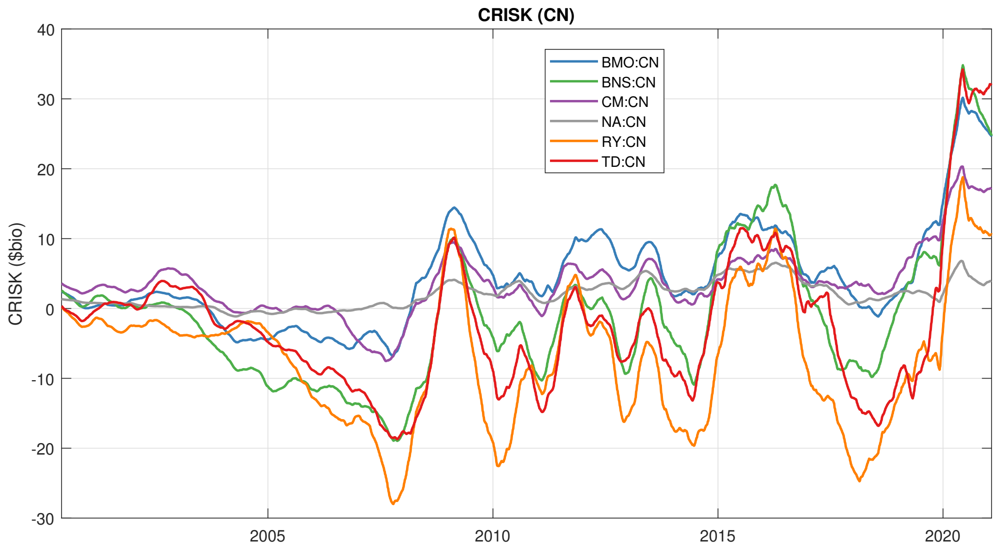


Figure 3.10: CRISK Beta of Japanese Banks

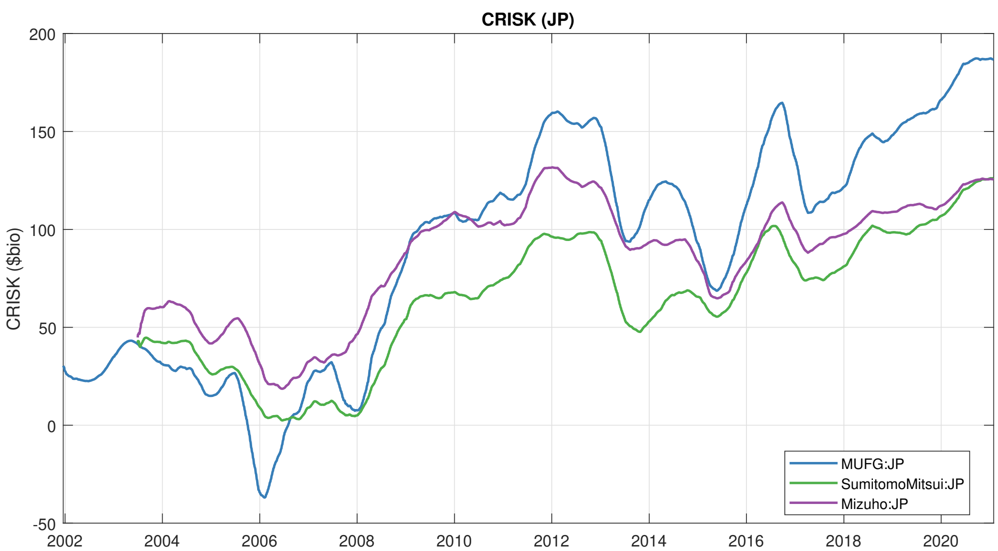
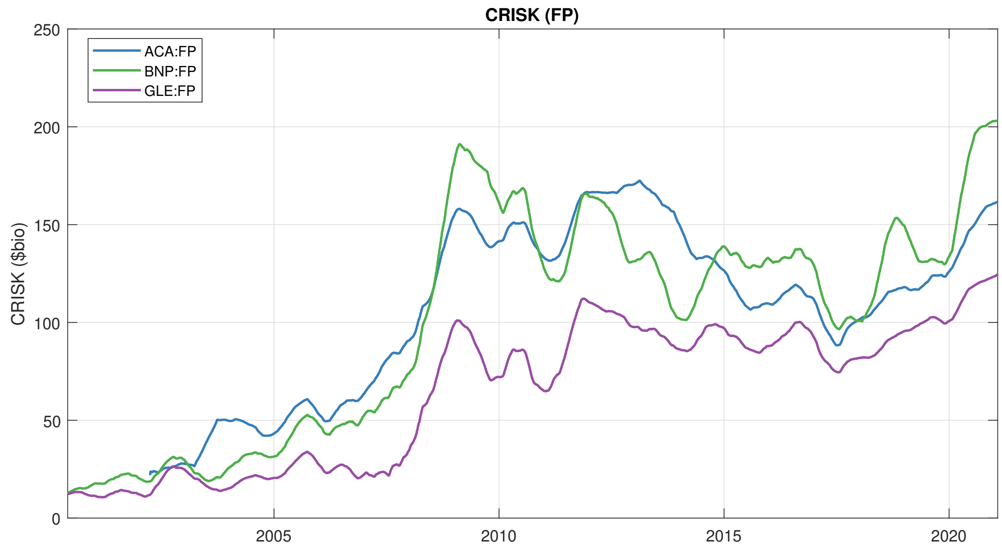


Figure 3.11: CRISK of French Banks



3.4 Discussion

Given that CRISK increased substantially in 2020, we focus on the first half of 2020 and analyze CRISK in relation to banks' loan exposure to the oil and gas industry. In this section, we first provide suggestive evidence that our CRISK measure during 2020 roughly aligns with the size of currently active loans made to the U.S. firms in the oil and gas industry. Then, we decompose the CRISK estimates into the components due to debt, equity, and risk, respectively. We find that decline in the equity component contributes the most to the overall increase in CRISK.

U.S. Banks

Figure 3.12 overlays the CRISK measures of the U.S. banks, and Table 3.1 tabulates the banks' exposure to the oil and gas industry. LenderAmt is the sum of all active loans from the bank to U.S. firms in the oil and gas industry as of April 2020.[7]

[7] We appreciate Sascha Steffen for sharing this measure.

Figure 3.12: Climate SRISK, US Large Banks, SPY

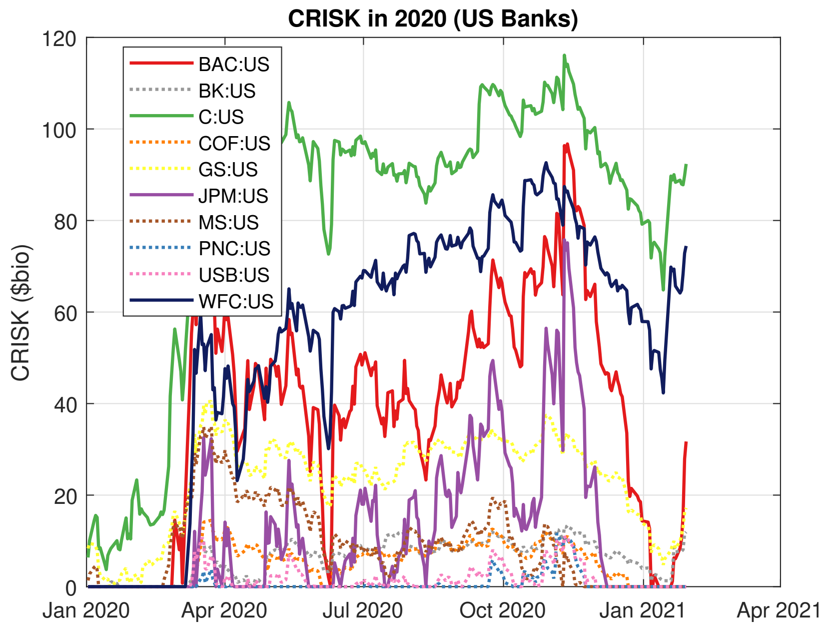


Table 3.1: US Bank Exposure to the Oil & Gas Industry

No	Name	Ticker	LenderAmt
1	Wells Fargo	WFC	46,939
2	JP Morgan	JPM	38,792
3	BofA	BAC	29,720
4	Citi	C	28,072
5	US Bancorp	USB	12,091
6	PNC Bank	PNC	11,818
7	Goldman Sachs	GS	11,597
8	Morgan Stanley	MS	10,024
9	Capital One Financial Corp	COF	9,621
10	Bank of New York Mellon	BK	1,289

To better understand what drives variation in CRISK, we decompose climate SRISK into three components based on Equation 3.1:

$$dCRISK = \underbrace{k \cdot \Delta DEBT}_{dDEBT} \underbrace{-(1-k)(1-LRMES) \cdot \Delta EQUITY}_{dEQUITY} + \underbrace{(1-k) \cdot EQUITY \cdot \Delta LRMES}_{dRISK},$$

where $LRMES$ is the long-run marginal expected shortfall, $EQUITY$ is market capitalization, and $DEBT$ is book value of debt. The first component, $dDEBT = k \cdot \Delta DEBT$ is the contribution of the firm's debt to CRISK. CRISK increases as the firm takes on more debt. The second component, $dEQUITY = -(1-k)(1-LRMES_t) \cdot \Delta EQUITY$ is the effect of the firm's equity position on CRISK. CRISK increases as the firm's market capitalization deteriorates. The third component, $dRISK = (1-k) \cdot EQUITY_{t-1} \cdot \Delta LRMES$ is the contribution of increase in volatility or correlation to CRISK.

Table 3.2: CRISK Decomposition

CRISK(t) is the bank's CRISK at the end of 2020, and CRISK($t-1$) is CRISK at the beginning of year 2020. dCRISK= CRISK(t)-CRISK($t-1$) is the change in CRISK during 2020. dDEBT is the contribution of the firm's debt to CRISK. dEQUITY is the contribution of the firm's equity position on CRISK. dRISK is the contribution of increase in volatility or correlation to CRISK. All amounts are in billion USD.

Bank	CRISK(t-1)	CRISK(t)	dCRISK	dDEBT	dEQUITY	dRISK
BAC:US	-64.8965	14.3707	79.2673	24.6334	44.8699	6.8189
BK:US	-9.6406	3.9441	13.5847	4.1082	8.3751	0.66718
C:US	6.3751	79.1793	72.8042	17.4887	35.4314	17.4808
COF:US	-12.1534	-2.5786	9.5748	3.2452	3.6666	2.4092
GS:US	8.3554	13.9449	5.5895	9.8983	-4.0906	-1.4365
JPM:US	-152.8409	-47.2889	105.5521	38.4204	54.2831	8.526
MS:US	1.3604	-20.9967	-22.3571	3.65	-27.0428	-0.078239
PNC:US	-27.777	-13.9468	13.8303	3.8029	8.9501	0.87967
USB:US	-41.2873	-11.7315	29.5558	4.131	20.581	4.8556
WFC:US	-47.169	57.9275	105.0966	-0.84144	97.4332	8.358

Table 3.2 decomposes the change in CRISK during the year 2020 into the three components. The decomposition suggests that the decline in equity contributes the most to the increase in CRISK. Put differently, banks were already stressed without the climate stress scenario. Nevertheless, the difference between CRISK and non-stressed CRISK is sizable for the largest banks including Bank of America, Citi, and JP Morgan. Figure 3.13 plots the CRISK and non-stressed CRISK, which is the CRISK when the climate stress level θ is set to be zero. It shows that the gap between the CRISK and non-stressed CRISKs opens up in 2019 and reaches 70 –90 billion US dollars at the end of 2020. This gap corresponds to 20 – 30% of banks' equity.[8]

[8] See Appendix for reference.

Figure 3.13: Stressed vs. Non-stressed CRISK

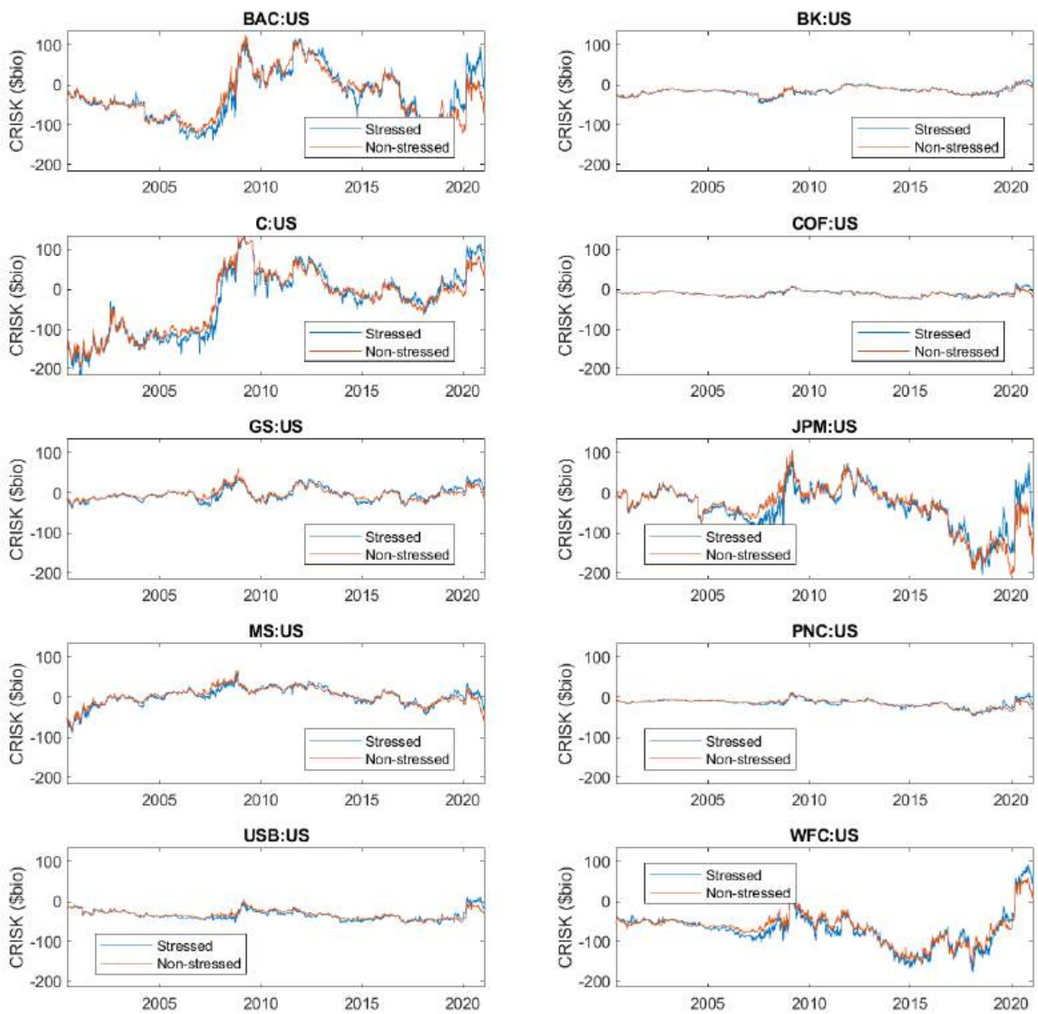
Stressed CRISK is computed as:

$$kD - (1-k)\exp\left(\beta^{Climate}\log(1-\theta)\right)\,W$$

Non-stressed CRISK is computed as:

$$kD - (1-k)W$$

where k is prudential capital ratio, D is debt, and W is market equity of each bank.



U.K. Banks

We document similar findings for the U.K. banks. Figure 3.14, Table 3.3 and Table 3.4 present the results for the U.K. banks.

Figure 3.14: Climate SRISK, US Large Banks, SPY

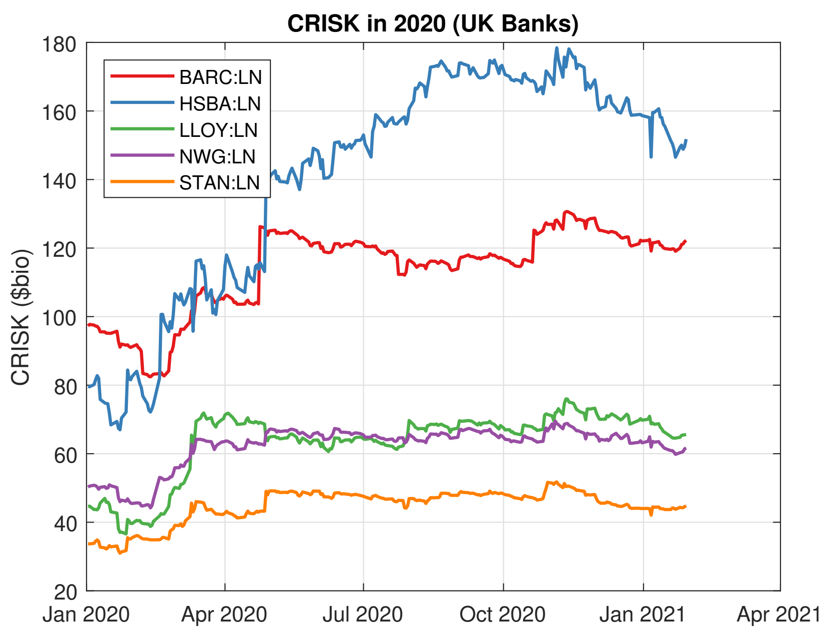


Table 3.3: UK Bank Exposure to the Oil & Gas Industry

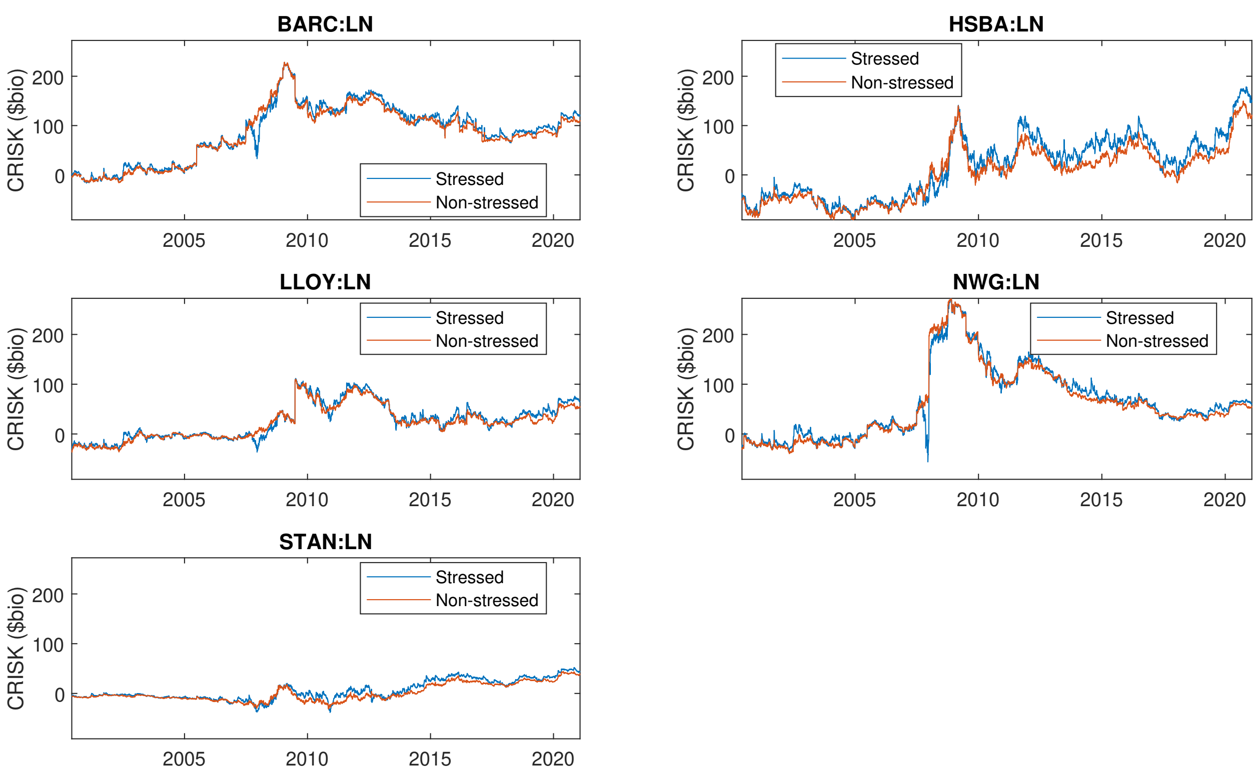
No	Name	Ticker	LenderAmt
1	Barclays	BARC	19,893
2	HSBC Banking Group	HSBC	7,546
3	Standard Chartered Bank	STAN	3,945
4	Royal Bank of Scotland	RBS	1,361
5	Lloyds Banking Group	LLOY	869

Table 3.4: CRISK Decomposition

CRISK(t) is the bank's CRISK at the end of 2020, and CRISK($t - 1$) is CRISK at the beginning of year 2020. dCRISK= CRISK(t)-CRISK($t - 1$) is the change in CRISK during 2020. dDEBT is the contribution of the firm's debt to CRISK. dEQUITY is the contribution of the firm's equity position on CRISK. dRISK is the contribution of increase in volatility or correlation to CRISK. All amounts are in billion USD.

Bank	CRISK(t-1)	CRISK(t)	dCRISK	dDEBT	dEQUITY	dRISK
BARC:LN	97.2645	122.0739	24.8094	19.4718	5.447	-0.95073
HSBA:LN	79.5661	158.6628	79.0967	31.6431	42.0474	5.1178
LLOY:LN	44.6264	69.7656	25.1392	6.0222	17.2107	1.0159
NWG:LN	50.2471	63.1696	12.9225	5.2206	7.3368	-0.33547
STAN:LN	33.7271	44.0041	10.277	5.2962	6.7744	-1.9492

Figure 3.15: Stressed vs. Non-stressed CRISK



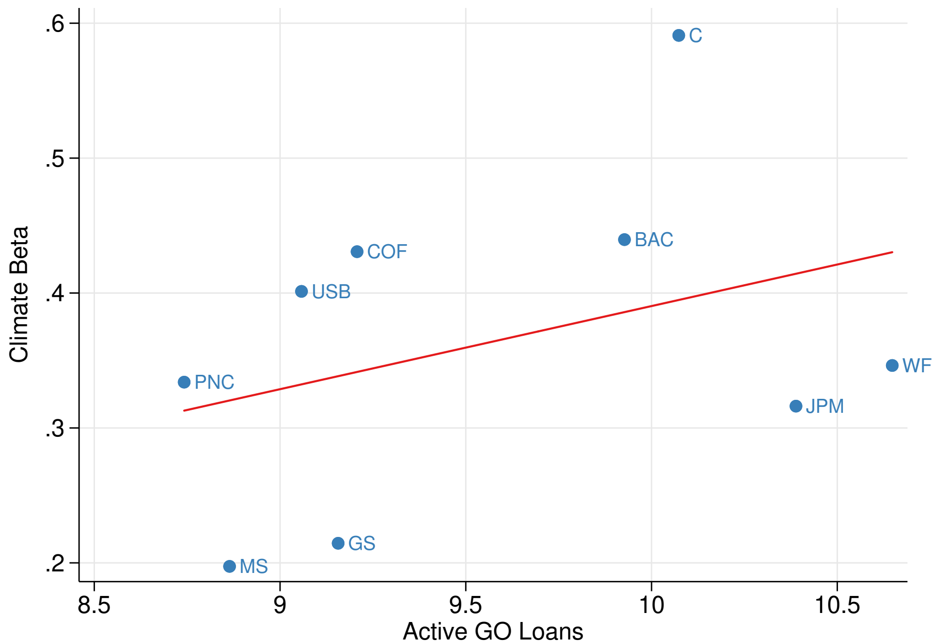
For completeness, we report the results for Canadian banks, Japanese banks, and French banks in the Appendix.

3.5 Robustness Check

As a robustness check, we first confirm the positive relationship between banks' climate beta and their exposure to oil and gas loans. Figure 3.16 shows that banks with higher amount of active syndicated loans had higher climate beta in the second quarter of 2020.

Figure 3.16: US banks' climate beta and exposure to oil and gas loans

US banks' average climate beta and log of active syndicated loans to oil and gas sector in the second quarter of 2020.[9]



To formally test the hypothesis, we use the following specification:

$$\Delta\beta_{it}^{Climate} = a + b \cdot GOLoans_{i,t-1} + \varepsilon_{it}$$

where $\beta_{it}^{Climate}$ is bank i's time-averaged dynamically-estimated daily climate beta during quarter t. $GOLoans_{it}$ is bank i's new syndicated loans to the US oil and gas industry (in log) in quarter t.[10] Standard errors are clustered by banks. Table C.19 in Appendix shows that the results are robust when the loan exposure is scaled by assets.

[10]The syndicated facility amount is equally allocated among the lead banks, and institutional term loans are excluded.

Table 3.5: Climate Beta and Gas & Oil Loan Exposure

	(1) $\Delta\beta^{Climate}$	(2) $\Delta\beta^{Climate}$	(3) $\Delta\beta^{Climate}$	(4) $\Delta\beta^{Climate}$
GO Loans	0.00607**	0.00622*	0.0111***	0.00904*
	(2.91)	(2.26)	(3.61)	(2.08)
Constant	0.00102	0.00496	-0.00920**	-0.0281
	(0.45)	(0.09)	(-2.48)	(-1.10)
Bank Controls	N	Y	N	N
Bank FE	N	N	Y	Y
Year FE	N	N	N	Y
N	462	462	462	462
RSqr	0.00611	0.00612	0.0140	0.176

t statistics in parentheses

$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

Table 3.5 reports the results. Column (2) adds bank size as control, column (3) includes bank fixed effect, and column (4) includes both bank and year fixed effects. Across all specifications, the coefficient b is positive and significant. This suggests that climate betas are higher for banks with higher loan exposure to the gas and oil industry.

3.6 Directions for Future Research

There are multiple directions for future research we plan to explore. First, our climate testing methodology can be extended to incorporate physical risks. Specifically, a proxy measure for physical risks could be included as the third factor in the second step. It would be interesting to test whether banks with high loan exposure to geographic regions with frequent or severe extreme climate events have high physical-risk-related climate beta. The positive result would add validity to the climate beta measures. Second, we plan to incorporate a large panel of loan-level data to analyze the relationship between the measured climate betas and the banks' loan portfolio composition. Third, we could perform the stress test using a different measure of climate factor. For instance, using records of historical changes in the climate-related policies across countries would be one useful way to analyze transition risks. Fourth, we can aggregate bank-level CRISK to country-level CRISK, which can be used as a warning signal of macroeconomic distress due to climate risks.

3.7 Conclusion

Climate change could impose systemic risk to the financial sector through either disruptions of economic activity resulting from the physical impacts of climate change or changes in policies as the economy transitions to a less carbon-intensive environment. We develop a stress testing procedure to test the resilience of financial institutions to climate-related risks. The procedure involves three steps. The first step is to measure the climate risk factor. We propose using stranded asset portfolio returns as a proxy measure of transition risks. The second step is to estimate time-varying climate beta of financial institutions. We estimate dynamically by using the DCB model to incorporate time-varying volatility and correlation. The third step is to compute the CRISK, the capital shortfall of financial institutions in a climate stress scenario. This step is based on the same methodology as SRISK, but the climate factor is added as the second factor. We use this procedure to study the climate risks of large global banks in the U.S., U.K., Canada, Japan, and France in the collapse in fossil fuel prices in 2020. We document a substantial rise in the climate beta and CRISK across banks during 2020 when energy prices collapsed. Further, we provide evidence that banks with a higher exposure to the fossil fuel industry tend to have higher climate betas, adding validity to our CRISK measure.

Chapter A

Appendix to Chapter 1

A.1 List of Bank Names

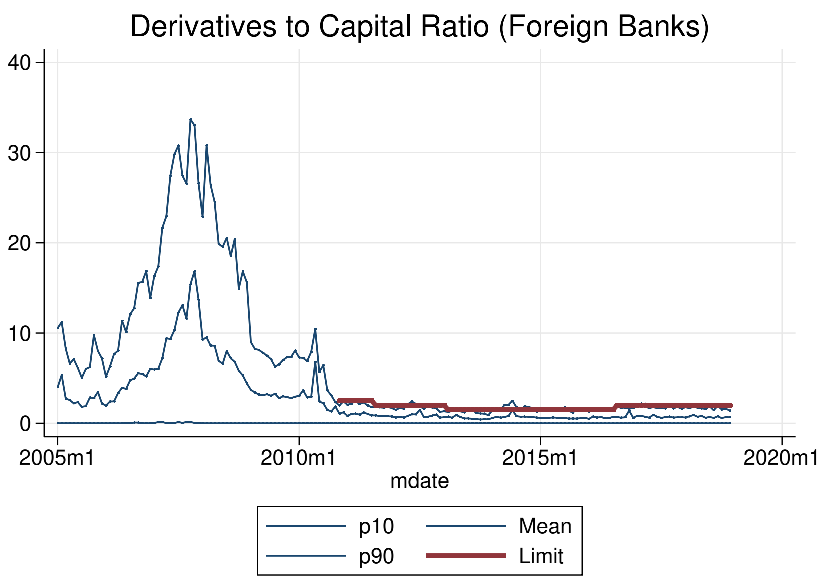
Table A.1: Sample Banks

	Bank	Full Name	Parent Country	Note
1	ANZ	Australia and New Zealand Bank	Australia	
2	BankComm	Bank of Communications	China	
3	BNP	BNP Paribas	France	
4	BNYMellon	BNY Mellon	US	
5	BOA	Bank Of America	US	
6	BOC	Bank Of China	China	
7	CCBC	China Construction Bank	China	
8	CIG	Credit Agricole Corporate and Investment Bank	France	
9	CS	Credit Suisse	Swiss	
10	DB	Deutsche Bank	Germany	
11	DBS	DBS	Singapore	
12	HSBC	HSBC	GB	
13	ICBC	Industrial and Commercial Bank of China	China	
14	ING	ING	Netherlands	
15	JPM	JP Morgan Chase	US	
16	Mellat	Mellat Bank	Iran	
17	MitsuiSumitomo	Mitsui Sumitomo	Japan	
18	Mizuho	Mizuho Bank	Japan	
19	MorganStanley	Morgan Stanley	GB	
20	MUFG	Mitsubishi UFJ	Japan	
21	Scotia	Scotia Bank	Canada	
22	SocGen	Societe Generale	France	
23	StateStreet	State Street	US	
24	UOB	United Overseas Bank	Singapore	
25	Yamaguchi	Yamguchi	Japan	
26	ABNRBS*	Royal Bank of Scotland	UK	RBS acquired ABN Amro in 2007 and RBS closed in 2014.
27	Barclays*	Barclays	UK	Closed in 2017.
28	GS*	Goldman Sachs International Bank	UK	Closed in 2017.
29	UBS*	UBS	Switzerland	Closed in 2017.
30	Busan	Busan Bank	Korea	
31	Citi	Citibank Korea	Korea	
32	Daegu	Daegu Bank	Korea	
33	IBK	Industrial Bank of Korea	Korea	
34	Jeju	Jeju Bank	Korea	
35	Jeonbuk	Jeonbuk Bank	Korea	
36	KB	Kookmin Bank	Korea	
37	KDB	Korea Development Bank	Korea	
38	KEBHana	KEB Hana Bank	Korea	Hana bank before acquiring KEB in Feb 2012.
39	Kwangjoo	Kwangjoo Bank	Korea	
40	Kyongnam	Kyongnam Bank	Korea	
41	NH	Nonghyup Bank	Korea	
42	SH	Suhyup Bank	Korea	
43	Shinhan	Shinhan Bank	Korea	
44	StandChar	Standard Chartered Bank Korea	Korea	
45	Woori	Woori Bank	Korea	
46	KEB*	Korea Exchange Bank	Korea	Hana bank (KEBHana) acquired KEB in Feb 2012.

A.2 Additional Figures

Figure A.1: FX Derivatives Position to Capital (DPTC) Ratio

The 10-percentile, mean and 90-percentile of the derivatives to position ratio for each month. The top panel is across foreign banks and the bottom panel is across domestic banks. The limit plots the change in the regulatory cap of DPTC ratio.



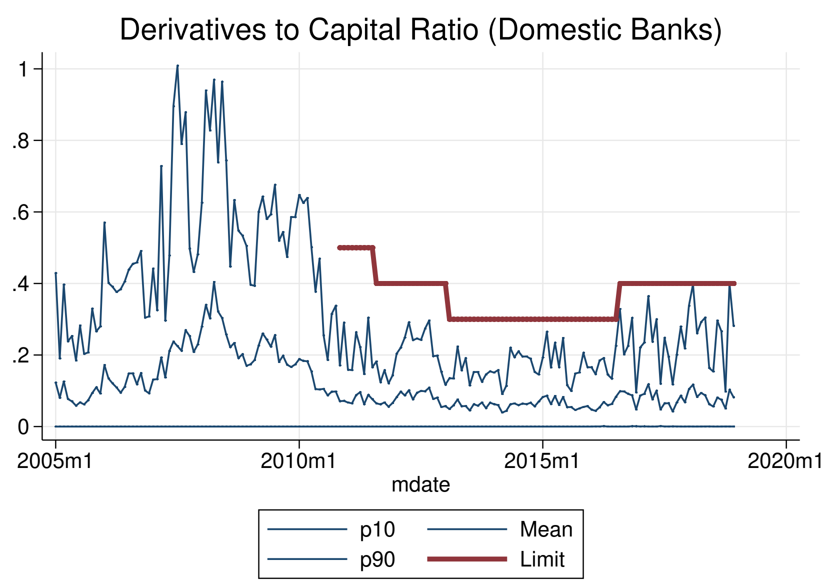


Figure A.2: Number of Firms

In 2009: Among 1682 listed firms, 1572 had non-zero FX gains or losses. About 300 firms had non-zero FX derivatives assets or liabilities.

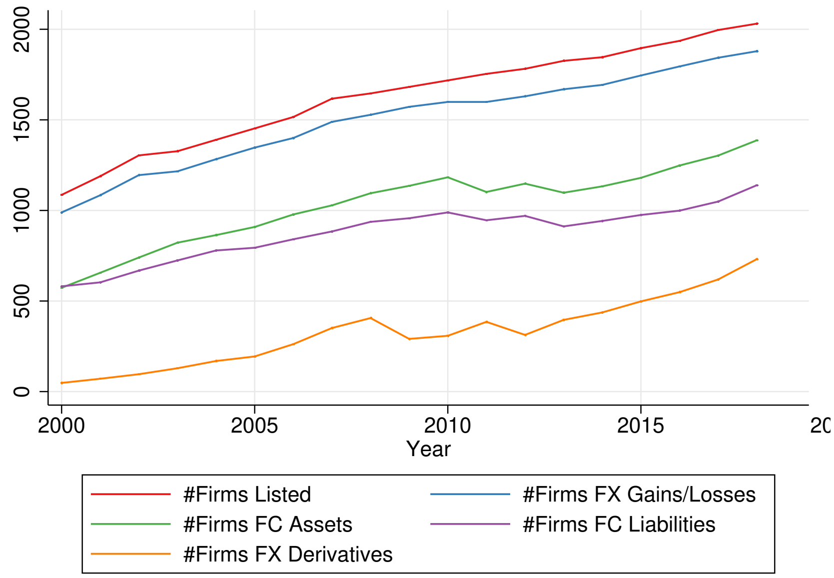


Figure A.3: Knock-in Knock-out (KIKO) Option Example

- If the exchange rate (value of 1 USD in terms of KRW) never trades above 930 during a window of time, typically a month, the option expires.
- If the exchange rate ever goes above 930 during the window:
  - If FX at maturity is between 930 and 945, option buyer has a right to sell **$0.5** at 945.
  - If FX at maturity is above 945, option buyer has an obligation to sell **$1** at 945.

The range of exchange rate during 2007 was 900–950.

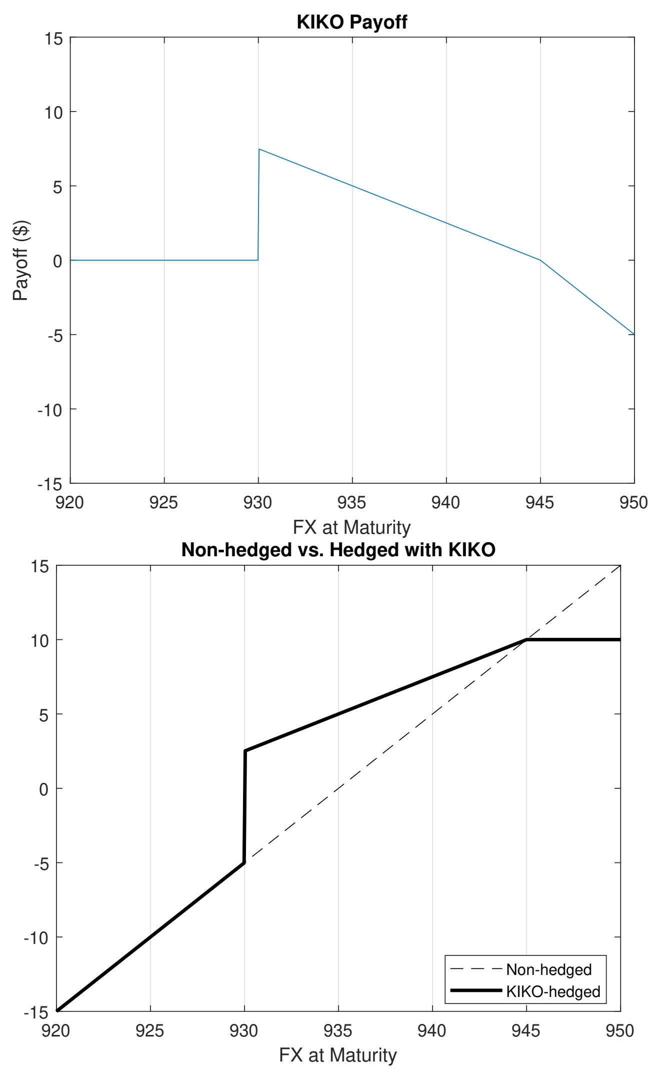
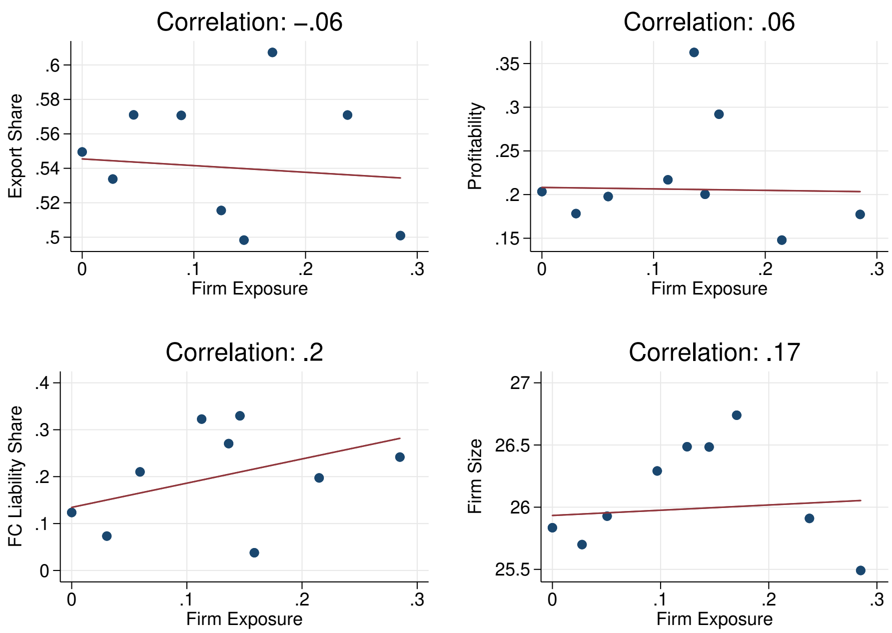


Figure A.4: Correlations between Firm Characteristics and Firm Exposure

Binned scatter plots of firm characteristics (export share, profitability, FC liability share, and firm size) and firm exposure to the regulation.



A.3 Additional Tables

Table A.2: FX Derivatives Contracts Summary Statistics (Exporters' Contracts)

	Full Sample		Constrained		Unconstrained		Difference	
	mean	sd	mean	sd	mean	sd	b	t
Notional Net (USD mio)	-19.8	41	-27.0	39	-16.6	41	10	(1.4)
FXDNet/Assets (%)	-7.9	10	-10.2	11	-6.9	9	3	(1.7)
Direction: Firm sells FC (%)	98.7	7	98.5	8	98.8	6	0	(0.2)
Pair: USD-KRW (%)	86.3	30	91.0	25	84.3	31	-7	(-1.3)
Pair: JPY-KRW (%)	9.3	25	2.6	16	12.3	28	10^{*}	(2.5)
Pair: EUR-KRW (%)	3.5	14	3.9	13	3.4	15	-1	(-0.2)
Type: Forwards (%)	80.9	38	66.0	46	87.5	32	21^{**}	(2.7)
Type: Swaps (%)	3.1	16	1.2	8	3.9	19	3	(1.1)
Type: Options (%)	15.3	35	32.7	46	7.5	25	-25^{**}	(-3.3)
Type: Futures (%)	0.8	9	0.0	0	1.1	11	1	(1.0)
Observations	129		40		89		129	

Table A.3: Firm Summary Statistics (Fully disclosed Firms)

	Full Sample		Exposed		Non-Exposed		Difference	
	mean	sd	mean	sd	mean	sd	b	t
Assets (USD mio)	1,619.693	5947.10	2,277.264	8795.78	1,231.489	3287.01	-1045.78	(-0.80)
FXDNet/Assets	-0.056	0.14	-0.052	0.15	-0.058	0.13	-0.01	(-0.25)
Sales (USD mio)	1,208.244	3400.29	1,500.800	4455.40	1,035.530	2601.87	-465.27	(-0.67)
FXDNet/Sales	-0.058	0.21	-0.037	0.21	-0.071	0.21	-0.03	(-0.88)
Number of Banks	2.288	2.21	2.531	2.14	2.145	2.25	-0.39	(-0.98)
Log Size	26.471	1.61	26.623	1.63	26.381	1.60	-0.24	(-0.83)
Leverage	0.467	0.17	0.500	0.16	0.448	0.18	-0.05	(-1.74)
Gross Profit Margin	0.218	0.17	0.213	0.19	0.222	0.16	0.01	(0.29)
FC Asset Share	0.099	0.12	0.091	0.12	0.103	0.11	0.01	(0.56)
FC Liab Share	0.198	0.20	0.246	0.19	0.169	0.21	-0.08^{*}	(-2.20)
Export Share	0.455	0.31	0.427	0.32	0.473	0.30	0.05	(0.79)
Export HedgeRatio	0.357	0.68	0.385	0.67	0.339	0.70	-0.05	(-0.34)
FCL HedgeRatio	0.295	0.46	0.314	0.45	0.283	0.47	-0.03	(-0.38)
Observations	132		49		83		132	

Table A.4: Firm Summary Statistics (Exporters)

	FullSample		Exposed		Non-Exposed		Difference	
	mean	sd	mean	sd	mean	sd	b	t
Assets (USD mio)	1,487.513	3745.06	1,325.730	3535.54	1,580.850	3891.48	255.12	(0.30)
FXDNet/Assets	-0.162	0.20	-0.164	0.18	-0.161	0.22	0.00	(0.08)
Sales (USD mio)	1,160.832	2869.75	1,071.161	2615.15	1,212.566	3030.44	141.41	(0.22)
FXDNet/Sales	-0.208	0.30	-0.184	0.25	-0.221	0.33	-0.04	(-0.57)
Number of Banks	1.817	1.03	1.833	1.05	1.808	1.03	-0.03	(-0.11)
Log Size	26.361	1.70	26.376	1.54	26.353	1.79	-0.02	(-0.06)
Leverage	0.477	0.19	0.500	0.17	0.464	0.19	-0.04	(-0.86)
Gross Profit Margin	0.204	0.14	0.210	0.19	0.200	0.12	-0.01	(-0.29)
FC Asset Share	0.130	0.12	0.124	0.12	0.134	0.12	0.01	(0.36)
FC Liab Share	0.178	0.22	0.205	0.19	0.163	0.23	-0.04	(-0.89)
Export Share	0.564	0.27	0.522	0.28	0.588	0.27	0.07	(1.04)
Export HedgeRatio	0.597	0.80	0.661	0.81	0.560	0.80	-0.10	(-0.54)
FCL HedgeRatio	0.457	2.84	1.011	4.55	0.118	0.53	-0.89	(-1.07)
Observations	82		30		52		82	

Table A.5: Adjustments in FX Derivatives Position and Capital (Full Sample, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{Avg} + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it}$$

Y_{it} is either log(FX Derivatives position), log(Capital) or FXD/Capital. $Constrained_i$ is dummy variable that takes 1 if bank i is constrained and 0 if otherwise. $Regulation_t^{Avg}$ is 0 before the regulation and takes **simple average** of foreign banks' and domestic banks' minimum FXD capital requirement. Higher $Regulation_t^{Avg}$ indicates tighter constraint. Columns (2), (4), and (6) add bank fixed effects:

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{Avg} + \delta_i + \gamma_t + \varepsilon_{it}$$

The sample period is 2008–2019 on a monthly basis. Standard errors are clustered by bank.

	(1)	(2)	(3)	(4)	(5)	(6)
	LogFXD	LogFXD	LogCapital	LogCapital	FXD/Capital	FXD/Capital
Constrained=1 x Regulation	-0.475***	-0.470***	0.0352	0.0370	-3.013***	-2.996***
	(-4.26)	(-4.09)	(0.39)	(0.42)	(-4.29)	(-4.28)
Constrained=1	0.499*		-2.152***		5.744***	
	(1.93)		(-5.50)		(4.44)	
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	5906	5906	5886	5886	5886	5886
Adj RSqr	0.191	0.400	0.488	0.893	0.410	0.502

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \delta_i + \gamma_t + \varepsilon_{it}$$

$Regulation_t^{WAvg}$ is the **weighted average** of the minimum FXD capital requirement, where the weight is the FXD position in each month.

	(1)	(2)	(3)	(4)	(5)	(6)
	LogFXD	LogFXD	LogCapital	LogCapital	FXD/Capital	FXD/Capital
Constrained=1 x Regulation	-0.662***	-0.656***	0.0287	0.0331	-3.936***	-3.915***
	(-3.71)	(-3.58)	(0.22)	(0.26)	(-4.33)	(-4.32)
Constrained=1	0.517*		-2.134***		5.602***	
	(1.80)		(-5.55)		(4.48)	
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	5906	5906	5886	5886	5886	5886
Adj RSqr	0.192	0.402	0.488	0.893	0.408	0.500

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.6: Adjustments in Derivatives Position and Capital (**Foreign banks**, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{FB} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)	(5)	(6)
	LogFXD	LogFXD	LogCapital	LogCapital	FXD/Capital	FXD/Capital
Constrained=1 x Regulation	-1.483***	-1.491***	-0.184	-0.182	-9.680***	-9.641***
	(-2.85)	(-2.80)	(-0.45)	(-0.46)	(-4.22)	(-4.21)
Constrained=1	0.271		-1.723**		5.818***	
	(0.72)		(-2.28)		(3.99)	
Constant	21.62***	20.23***	28.39***	25.87***	6.510***	11.91***
	(59.65)	(106.95)	(40.12)	(158.57)	(3.14)	(4.36)
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	3698	3698	3694	3694	3694	3694
Adj RSqr	0.246	0.424	0.369	0.815	0.480	0.542

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.7: Adjustments in Derivatives Position and Capital (**Domestic banks**, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{DB} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1) LogFXD	(2) LogFXD	(3) LogCapital	(4) LogCapital	(5) FXD/Capital	(6) FXD/Capital
Constrained=1 x Regulation	-0.128	-0.124	-0.0189	-0.0123	-0.0980***	-0.0983***
	(-1.01)	(-0.98)	(-1.06)	(-0.70)	(-8.94)	(-9.02)
Constrained=1	0.513**		-0.899***		0.424***	
	(2.28)		(-6.19)		(9.79)	
Constant	20.86***	18.70***	29.86***	28.35***	0.275***	0.267***
	(44.30)	(53.35)	(186.39)	(467.51)	(3.04)	(3.11)
BankFE	N	Y	N	Y	N	Y
TimeFE	Y	Y	Y	Y	Y	Y
N	2208	2208	2192	2192	2192	2192
Adj RSqr	0.171	0.481	0.578	0.956	0.680	0.745

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.8: Impact on Banks' FC Loans and FC Liabilities (**All banks**, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)
	FCLoanShr	FCLoanShr	FCLiabShr	FCLiabShr
Constrained=1 x Regulation	-0.102*	-0.108**	-0.0589***	-0.0579***
	(-1.97)	(-2.11)	(-3.08)	(-3.04)
Constrained=1	0.353**		0.0995**	
	(2.43)		(2.42)	
Constant	0.168**	0.924***	0.212***	0.456***
	(2.67)	(22.08)	(5.64)	(13.27)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	1523	1523	1680	1680
Adj RSqr	0.183	0.838	0.238	0.732

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.9: Impact on Banks' FC Loans and FC Liabilities (**Foreign banks**, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{FB} + \beta_2 Constrained_i + \gamma_t + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)
	FCLoanShr	FCLoanShr	FCLiabShr	FCLiabShr
Constrained=1 x Regulation	-0.474***	-0.469***	-0.138**	-0.133**
	(-4.00)	(-3.91)	(-2.51)	(-2.42)
Constrained=1	0.402*		0.137**	
	(2.02)		(2.79)	
Constant	0.221	0.922***	0.236***	0.508***
	(1.67)	(17.11)	(4.68)	(13.23)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	914	914	1071	1071
Adj RSqr	0.204	0.779	0.306	0.739

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.10: Impact on Banks' FC Loans and FC Liabilities (**Domestic banks**, Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{DB} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1) FCLoanShr	(2) FCLoanShr	(3) FCLiabShr	(4) FCLiabShr
Constrained=1 x Regulation	-0.00264	-0.00369	-0.00738	-0.00860
	(-0.21)	(-0.30)	(-1.36)	(-1.74)
Constrained=1	-0.0166		-0.0102	
	(-0.26)		(-0.24)	
Constant	0.124^{*}	0.0839^{***}	0.122^{**}	0.0789^{***}
	(2.12)	(3.72)	(2.81)	(7.01)
BankFE	N	Y	N	Y
TimeFE	Y	Y	Y	Y
N	609	609	609	609
Adj RSqr	0.207	0.901	0.202	0.947

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Impact on Banks' Security Holdings (Weighted LS)

Weighted least squares models where the weight is FXD position as of Dec 2009.

$$Y_{it} = \beta_0 + \beta_1 Constrained_i \times Regulation_t^{WAvg} + \delta_i + \gamma_t + \varepsilon_{it}$$

	(1) KTB/Asset	(2) KTB/Asset	(3) MSB/Asset	(4) MSB/Asset
Constrained=1 x Regulation	0.00147	0.00159	-0.0414^{***}	-0.0407^{***}
	(0.07)	(0.07)	(-2.87)	(-2.97)
Constrained=1	0.0498		0.0980^{**}	
	(0.92)		(2.27)	
BankFE	N	Y	N	Y
TimeFE				
N	1692	1692	1692	1692
Adj RSqr	0.0916	0.779	0.157	0.780

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.12: Net FXD Buyers (As of Dec 2009)

Industry code: 1=Construction/ 5=Agriculture and Fishing/ 6=Retail/ 12=Transportation and Shipping/ 13=Gas and Electricity/ 14=Science and Technology/ 15=IT and Tele-communication/ 16= Manufacturing

No	Stock	Firm	Net	Buy	Sell	DerivType	MainBank	binding	FCAShr	FCLShr	ExpShr	Industry	Size	FCLHedge	ExpHedge	NetPosExcFXD	NetPosIncFXD	FullDisc
1	036460	KoreaGas	2151	2401	250	FXFwd	KEB	0	0.02	0.20		13	30.8	0.81				0
2	030200	KT	1831	1831	0	FXSwap	JPM	0	0.01	0.21		15	30.8	0.74				1
3	096770	SKInnov	1633	1655	22	FXSwap	KDB	0	0.06	0.25	0.59	16	30.7	0.56	0.00	0.88	0.09	0
4	004170	SSG	1619	1619	0	FXSwap	CIG	1	0.00	0.32	0.00	6	30.0	1.00		-0.18	0.18	1
5	015760	Kepco	1051	1051	0	FXSwap	Barclays	1	0.00	0.11	0.00	13	31.9	0.40		-0.04	0.02	1
6	023530	LotteShop	880	880	0	FXSwap	Mizuho	0	0.00	0.23	0.00	6	30.6	0.70	0.00	-0.07	0.06	1
7	004990	LotteHoldings	313	313	0	FXSwap	Mizuho	0	0.00	0.38	0.05	14	28.9	0.92	0.00	-0.09	0.11	1
8	011170	LotteChem	301	301	0	FXSwap	Mizuho	0	0.09	0.41	0.62	16	29.4	0.44	0.00	0.60	0.06	1
9	097950	CJCheil	245	245	0	FXSwap	BNP	1	0.02	0.43	0.06	16	29.0	0.30	0.00	-0.16	0.07	0
10	071320	KoreaHeat	212	212	0	FXSwap	KB	0	0.00	0.12	0.00	13	28.7	1.00				1
11	051910	LGChem	203	208	5	FXSwap	MUFG	0	0.09	0.35	0.74	16	29.8	0.24	0.00	1.18	0.03	0
12	069960	HyundaiDept	201	201	0	FXSwap	DBS	1	0.00	0.26	0.00	6	28.6	1.00		-0.09	0.09	1
13	010950	SOil	200	200	0	FXFwd	DB	0	0.14	0.68	0.60	16	29.8	0.07	0.00	0.92	0.03	1
14	000210	Daelim	193	193	1	FXSwap	Shinhan	0	0.04	0.09	0.31	1	29.8	0.52	0.00	0.22	0.03	1
15	001120	LGIntl	182	202	19	FXFwd	ANZ	1	0.39	0.77	0.84	6	28.2	0.27	0.01	1.88	0.12	1
16	009830	HanhwaSol	115	121	6	FXSwap	Citi	1	0.01	0.12	0.48	16	29.2	0.55	0.00	0.26	0.03	1
17	011780	Kumho	107	107	0	FXSwap	Woori	0	0.04	0.16	0.67	16	28.8	0.29	0.00	0.50	0.04	1
18	003490	KoreanAir	90	90	0	FXSwap	HSBC	1	0.06	0.25	0.87	12	30.5	0.03	0.00	0.34	0.01	1
19	011930	Shinsung	66	66	0	FXFwd	Citi	1	0.04	0.40	0.10	16	26.3	1.03	0.00	-0.22	0.29	1
20	069620	Daewoong	50	50	0	FXSwap	StandChar	1	0.01	0.42	0.02	16	26.9	0.68	0.00	-0.14	0.12	1
21	007070	GSRetail	50	50	0	FXSwap	Shinhan	0	0.00	0.04	0.00	6	28.5	1.00		-0.02	0.02	1
22	006280	GreenCross	50	50	0	FXSwap	Citi	1	0.02	0.31	0.11	16	27.3	0.53	0.00	-0.04	0.08	1
23	003030	SeahSteel	45	55	10	FXSwap	Citi	1	0.04	0.34	0.31	14	27.7	0.43	0.03	0.27	0.05	1
24	001790	DaehanSugar	33	43	10	FXFwd	Citi	1	0.02	0.33	0.20	16	27.5	0.30	0.05	0.08	0.04	1
25	004000	LotteFineChem	31	31	0	FXFwd	Shinhan	0	0.04	0.41	0.45	16	27.7	0.53	0.00	0.43	0.04	1
26	002350	NexenTire	30	30	0	FXSwap	KEB	0	0.09	0.24	0.79	16	27.4	0.38	0.00	0.95	0.04	1
27	000070	Samyang	29	37	8	FXFwd	MUFG	0	0.02	0.37	0.33	14	27.9	0.22	0.02	0.25	0.03	0
28	006120	SKDiscovery	26	50	24	FXFwd	StandChar	1	0.03	0.09	0.38	14	28.3	0.57	0.06	0.22	0.02	0
29	009200	Moorim	22	22	0	FXSwap	StandChar	1	0.03	0.20	0.52	16	27.5	0.23	0.00	0.29	0.03	1
30	010060	OCI	21	30	9	FXSwap	KB	0	0.05	0.09	0.71	16	28.8	0.20	0.01	0.45	0.01	1
31	058650	SeahHoldings	20	20	0	FXSwap	KEB	0	0.00	0.14		16	27.5	1.00				1
32	049770	DongwonFB	20	20	0	FXSwap	KB	0	0.00	0.18	0.06	16	27.0	0.56	0.00	0.02	0.04	1
33	090350	NorooPaint	17	20	3	FXSwap	KB	0	0.02	0.16	0.12	16	26.5	0.92	0.12	0.04	0.06	1
34	001810	MoorimSP	16	16	0	FXSwap	Citi	1	0.01	0.37	0.12	16	26.0	0.72	0.00	-0.04	0.09	1
35	084010	DaehanSteel	15	15	0	FXSwap	StandChar	1	0.03	0.16	0.09	16	27.2	0.36	0.00	0.06	0.03	1
36	006840	AKHoldings	15	15	0	FXSwap	KEB	0	0.12	0.38	0.69	14	26.7	0.25	0.00	1.00	0.04	1
37	004140	Dongbang	11	11	0	FXSwap	KDB	0	0.00	0.10		12	26.8	0.47				1
38	117580	DaesungEnergy	11	11	0	FXSwap	KEBHana	0	0.00	0.04	0.00	13	26.9	1.00		-0.03	0.03	1
39	014190	Wonik	10	10	0	FXFwd	StandChar	1	0.00	0.28		6	25.2	0.77				1
40	002840	Miwon	10	10	0	FXSwap	KDB	0	0.05	0.40	0.59	16	25.5	0.73	0.00	0.77	0.09	1
41	005990	MaeilHoldings	10	10	0	FXSwap	Citi	1	0.01	0.06	0.02	16	26.9	0.80	0.00	0.02	0.02	1
42	067830	Savezone	9	9	0	FXSwap	Shinhan	0	0.00	0.04	0.00	6	26.9	1.00		-0.02	0.02	1
43	000320	Noroo	8	8	0	FXSwap	Woori	0	0.00	0.13	0.67	14	26.3	1.00	0.00	0.20	0.04	1
44	060540	SAT	8	8	0	FXSwap	KEB	0	0.00	0.35	0.00	16	24.6	1.00		-0.17	0.18	1
45	004710	HansolTech	7	22	15	FXFwd	Citi	1	0.14	0.59	0.97	16	26.2	0.42	0.02	4.50	0.04	1
46	155660	DSR	5	5	0	FXFwd	Busan	0	0.05	0.19		16	25.2	1.00				1
47	014160	Daeyoung	5	5	0	FXSwap	IBK	0	0.00	0.12	0.01	16	25.7	1.00	0.00	-0.03	0.04	1
48	010660	Hwacheon	4	4	0	FXFwd	KEB	0	0.00	0.10	0.23	16	25.6	1.00	0.00	0.24	0.04	1
49	166090	HanaMaterials	4	4	0	FXSwap	Citi	1	0.01	0.19		16	24.3	0.69				1
50	059090	MiCo	3	3	0	FXSwap	Citi	1	0.09	0.13		16	25.2	0.64				1
51	003160	DI	3	3	0	FXSwap	IBK	0	0.01	0.10	0.45	16	25.8	0.87	0.00	0.07	0.02	1
52	084870	TBH	3	3	0	FXSwap	HSBC	1	0.01	0.10	0.03	16	26.3	0.34	0.00	-0.01	0.01	1
53	041650	Sangsin	2	2	0	FXSwap	KEB	0	0.07	0.10	0.25	16	25.6	0.41	0.00	0.33	0.02	1
54	033320	JCHyun	2	2	0	FXFwd	KB	0	0.00	0.47	0.01	6	24.8	0.34	0.00	-0.08	0.03	1
55	013520	Hwaseung	1	1	0	FXSwap	KDB	0	0.13	0.05	0.61	16	26.8	0.12	0.00	0.65	0.00	1
56	049480	Openbase	1	1	0	FXFwd	Citi	1	0.00	0.34		15	24.8	0.20				1
Mean			218	225	7				0.04	0.25	0.31		27.6	0.60	0.01	0.35	0.06	
Median			24	30	0				0.02	0.21	0.23		27.3	0.56	0.00	0.14	0.04	

Table A.13: Net FXD Sellers (As of Dec 2009)

Industry code: 1=Construction/ 5=Agriculture and Fishing/ 6=Retail/ 12=Transportation and Shipping/ 13=Gas and Electricity/ 14=Science and Technology/ 15=IT and Tele-communication/ 16= Manufacturing

No	Stock	Firm	Net	Buy	Sell	DerivType	MainBank	binding	FCAShr	FCLShr	ExpShr	Industry	Size	FCLHedge	ExpHedge	NetPosExcFXD	NetPosIncFXD	FullDisc
1	9540	HyundaiHeavy	-15313	275	15588	FXFwd	KEB	0	0.05	0.04	0.9	16	30.8	0.49	0.96	0.79	-0.72	0
2	10140	SamsungHeavy	-13576	11606	25182	FXFwd	Barclays	1	0.06	0.03	0.93	16	30.6	24.97	2.42	0.64	-0.79	0
3	42660	DaewooShip	-13152	0	13152	FXFwd	KDB	0	0.09	0.15	0.97	16	30.3	0	1.28	0.78	-1.04	0
4	42670	DoosanInfra	-3052	0	3052	FXFwd	KDB	0	0.11	0.34	0.65	16	29.2	0	2.07	0.23	-0.75	0
5	10620	HyundaiMipo	-2991	0	2991	FXFwd	KEB	0	0.17	0.06	0.99	16	29.4	0	0.95	0.75	-0.58	0
6	34020	DoosanHeavy	-2940	1611	4551	FXFwd	KDB	0	0.09	0.13	0.61	16	29.8	2.42	1.4	0.42	-0.37	0
7	82740	HSDEngine	-2092	4	2097	FXOpt	KDB	0	0.09	0.2		16	28.5	0.01				0
8	6360	GSCons	-1432	564	1996	FXFwd	StandChar	1	0.08	0.09	0.23	1	29.8	1.35	1.36	0.22	-0.19	0
9	77970	STXEngine	-695	18	713	FXFwd	KDB	0	0.1	0.1	0.7	16	28.2	0.19	0.74	0.69	-0.48	0
10	36890	JinSungTEC	-380	0	380	FXFwd	Woori	0	0.07	0	0.68	16	26.3	0	9.95	0.23	-1.66	1
11	97230	HanjinHeavy	-235	0	235	FXFwd	KB	0	0.14	0.2	0.62	1	29.6	0	0.14	0.29	-0.04	0
12	21050	Seowon	-164	0	164	FXOpt	StandChar	1	0.06	0.18	0.41	16	25.9	0	2.01	0.48	-1.04	1
13	660	SKHynix	-161	0	161	FXSwap	KEB	0	0.1	0.43	0.96	16	30.2	0	0.03	0.38	-0.01	1
14	720	HyundaiCons	-156	0	156	FXFwd	StandChar	1	0.05	0	0.47	1	29.7	0	0.04	0.58	-0.02	1
15	83650	BHI	-149	30	179	FXFwd	Citi	1	0.15	0.26	0.45	16	26.3	0.75	1.73	0.43	-0.66	1
16	10120	LS	-136	29	165	FXFwd	Citi	1	0.05	0.02	0.32	16	27.9	2.33	0.42	0.39	-0.12	1
17	10130	KoreaZinc	-131	0	131	FXFwd	DB	0	0.03	0.62	0.75	16	28.6	0	0.08	0.64	-0.06	1
18	5850	SL	-122	0	122	FXFwd	KDB	0	0.14	0.24	0.48	16	26.8	0	0.93	0.38	-0.32	1
19	53660	Hyunjin	-98	5	103	FXOpt	StandChar	1	0.06	0.17	0.46	16	26.7	0.15	0.8	0.35	-0.28	1
20	4060	Segye	-92	0	92	FXFwd	StandChar	1	0.1	0.57	0.68	6	26.4	0	0.49	0.76	-0.38	1
21	12800	Daechang	-85	0	85	FXOpt	StandChar	1	0.12	0.19	0.45	16	26.7	0	0.44	0.58	-0.25	1
22	54950	JVM	-84	0	84	FXOpt	KEB	0	0.04	0.38	0.57	16	26.1	0	2.78	-0.1	-0.48	1
23	13570	DY	-71	0	71	FXFwd	KB	0	0.11	0.11	0.49	14	26.3	0	0.6	0.59	-0.31	1
24	68790	DMS	-56	0	56	FXFwd	KEB	0	0.35	0.06	0.28	16	26.6	0	1.53	0.44	-0.19	1
25	150	Doosan	-51	0	51	FXFwd	KEBHana	0	0.04	0.07	0.42	14	28.6	0	0.12	0.19	-0.02	1
26	91090	SewonCellon	-46	0	46	FXFwd	StandChar	1	0.35	0.07	0.79	16	26.4	0	0.26	1.02	-0.19	1
27	11790	SKC	-41	0	41	FXFwd	KEB	0	0.03	0.03	0.41	16	28.2	0	0.1	0.29	-0.03	1
28	9440	KCGreen	-39	0	39	FXOpt	Citi	1	0.08	0.01	0.23	14	26.1	0	1.4	0.23	-0.21	1
29	65130	TopEngi	-39	0	39	FXFwd	Busan	0	0.21	0.04		16	25.8	0				1
30	79960	DongyangENP	-38	0	38	FXOpt	Citi	1	0.43	0.24	0.91	16	25.7	0	0.16	2.29	-0.31	1
31	23810	Infac	-31	0	31	FXFwd	IBK	0	0.05	0.03	0.41	16	24.8	0	0.94	0.7	-0.61	1
32	5950	IsuChem	-29	1	30	FXFwd	KEB	0	0.08	0.09	0.37	16	27.3	0.06	0.09	0.61	-0.05	1
33	122900	IMarket	-28	1	29	FXFwd	Woori	0	0.07	0	0.13	6	26.6	2.8	0.21	0.52	-0.09	1
34	27580	Sangbo	-28	0	28	FXOpt	Citi	1	0.06	0.29	0.42	16	25.6	0	0.75	0.16	-0.24	1
35	35150	Baiksan	-23	0	23	FXOpt	Citi	1	0.18	0.25	0.93	16	25.7	0	0.28	0.68	-0.19	1
36	95500	MiraeNano	-22	0	22	FXOpt	Citi	1	0.3	0.07	0.7	16	26.3	0	0.13	1.02	-0.1	1
37	34730	SK	-22	36	57	FXFwd	StandChar	1	0	0.03	0.04	14	28.8	0.78	1.29	0	-0.01	1
38	16800	Fursys	-21	0	21	FXFwd	KEB	0	0.01	0	0.08	16	26.6		1.37	0.06	-0.07	1
39	14830	Unid	-20	0	20	FXFwd	Shinhan	0	0.05	0.56	0.51	16	26.9	0	0.1	0.34	-0.05	1
40	37070	Paseco	-20	0	20	FXFwd	Citi	1	0.02	0.25	0.53	16	25.2	0	0.41	0.58	-0.28	1
41	47310	PowerLogics	-18	0	18	FXOpt	Citi	1	0.38	0.56	0.78	16	26.2	0	0.09	1.04	-0.09	1
42	89030	TechWing	-18	0	18	FXFwd	Woori	0	0.31	0.05		16	24.5	0				1
43	11300	Seongan	-18	0	18	FXFwd	Daegu	0	0.02	0	0.97	16	25.6	0	0.29	0.56	-0.16	1
44	11760	HyundaiCorp	-17	2	20	FXFwd	KEB	0	0.47	0.76	0.96	6	27.4	0	0.01	2.91	-0.03	1
45	43150	Vatech	-17	0	17	FXFwd	Woori	0	0.33	0.04	0.53	16	25.4	0	0.4	0.77	-0.18	1
46	44340	Winix	-16	0	16	FXFwd	Citi	1	0.06	0.21	0.28	16	25.2	0	0.67	0.32	-0.22	1
47	53620	Taeyang	-16	0	16	FXFwd	IBK	0	0.17	0.02		16	25.3	0				1
48	9160	Simpac	-16	0	16	FXFwd	KEB	0	0.03	0	0.41	16	25.9	0	0.37	0.31	-0.1	1
49	67310	HanaMicron	-16	0	16	FXFwd	StandChar	1	0.04	0.14	0.82	16	25.9	0	0.13	0.67	-0.1	1
50	78890	KaonMedia	-14	0	14	FXFwd	KB	0	0.2	0.47	0.93	16	25.4	0	0.12	1.25	-0.16	1

Table A.14: Net FXD Sellers (As of Dec 2009), Continued

Industry code: 1=Construction/ 5=Agriculture and Fishing/ 6=Retail/ 12=Transportation and Shipping/ 13=Gas and Electricity/ 14=Science and Technology/ 15=IT and Tele-communication/ 16= Manufacturing

No	Stock	Firm	Net	Buy	Sell	DerivType	MainBank	binding	FCAShr	FCLShr	ExpShr	Industry	Size	FCLHedge	ExpHedge	NetPosExcFXD	NetPosIncFXD	FullDisc
51	079950	Invenia	-12	0	12	FXFwd	KDB	0	0.01	0.04	0.05	16	25.1	0.00	3.29	0.05	-0.18	1
52	036930	Joosung	-12	0	12	FXFwd	Citi	1	0.30	0.05	0.59	16	26.6	0.00	0.14	0.54	-0.04	1
53	109740	DSK	-12	0	12	FXFwd	IBK	0	0.12	0.00	0.61	16	24.1	0.00	1.19	0.50	-0.46	1
54	029460	KC	-12	0	12	FXFwd	Woori	0	0.05	0.01	0.23	16	25.9	0.00	0.63	0.17	-0.07	1
55	007630	PolusBioPharm	-10	0	10	FXOpt	Shinhan	0	0.14	0.01	0.32	6	25.2	0.00	0.94	0.28	-0.14	1
56	066110	Hanp	-10	0	10	FXOpt	Citi	1	0.34	0.37	0.93	16	24.9	0.00	0.19	1.18	-0.18	1
57	007860	Seoyon	-10	0	10	FXFwd	KEB	0	0.21	0.11	0.55	14	26.7	0.00	0.05	0.77	-0.03	1
58	079980	Huvis	-10	0	10	FXFwd	KEB	0	0.13	0.22		16	27.0	0.00				1
59	086450	DongkookPharm	-10	0	10	FXFwd	KEB	0	0.06	0.05	0.27	16	25.6	0.00	0.32	0.32	-0.09	1
60	049830	Seungil	-10	0	10	FXFwd	IBK	0	0.07	0.01		16	25.3	0.00				1
61	019490	Hitron	-9	0	9	FXFwd	KEB	0	0.44	0.72	0.98	16	25.3	0.00	0.08	1.44	-0.11	1
62	020150	IljinMaterials	-9	0	9	FXFwd	Citi	1	0.10	0.15	0.87	16	26.0	0.00	0.06	0.97	-0.06	1
63	027970	Seha	-9	0	9	FXFwd	KDB	0	0.29	0.04		16	26.1	0.00				1
64	046310	BGTNA	-8	0	8	FXFwd	Woori	0	0.41	0.11	0.96	16	24.6	0.00	0.16	1.57	-0.20	1
65	054540	SamyoungMT	-7	0	7	FXFwd	KEB	0	0.10	0.00	0.37	16	25.2		0.21	0.52	-0.09	1
66	066310	QSI	-7	0	7	FXFwd	Woori	0	0.17	0.19	0.79	16	24.2	0.00	0.49	0.65	-0.24	1
67	033530	Sejong	-6	0	6	FXFwd	Woori	0	0.16	0.00	0.65	16	26.4	0.00	0.03	0.96	-0.02	1
68	008970	DongyangPipe	-6	0	6	FXFwd	StandChar	1	0.01	0.25	0.14	16	25.6	0.00	0.35	0.06	-0.05	1
69	099320	Satrec	-4	0	4	FXFwd	KEB	0	0.11	0.07	0.49	16	24.4	0.00	0.42	0.39	-0.12	1
70	043340	EssenTech	-4	0	4	FXFwd	Citi	1	0.12	0.02	0.29	16	25.0	0.00	0.22	0.42	-0.07	1
71	053450	Sekonix	-4	0	4	FXFwd	KB	0	0.19	0.54	0.64	16	25.2	0.00	0.11	0.45	-0.05	1
72	001250	GSGlobal	-3	0	3	FXFwd	DB	0	0.43	0.87	0.95	6	25.8	0.00	0.00	7.21	-0.03	1
73	005670	Foodwell	-3	0	3	FXFwd	Daegu	0	0.05	0.00	0.32	16	25.0		0.22	0.31	-0.06	1
74	049550	Inktec	-3	0	3	FXFwd	Shinhan	0	0.16	0.01	0.64	16	25.1	0.00	0.12	0.54	-0.05	1
75	031980	PSK	-3	0	3	FXFwd	ING	1	0.09	0.33	0.48	16	25.6	0.00	0.21	0.19	-0.03	1
76	030720	DongwonFish	-2	0	2	FXFwd	StandChar	1	0.03	0.14	0.68	5	24.9	0.00	0.05	0.86	-0.04	1
77	051360	Tovis	-2	0	2	FXFwd	KB	0	0.37	0.20	0.97	16	25.0	0.00	0.01	2.96	-0.04	1
78	000500	GaonCable	-2	0	2	FXFwd	Citi	1	0.02	0.10	0.11	16	26.5	0.00	0.04	0.20	-0.01	1
79	092460	HanlaIMS	-2	0	2	FXFwd	IBK	0	0.03	0.02	0.66	16	24.7	0.00	0.10	0.47	-0.05	1
80	023960	SCEngi	-2	0	2	FXFwd	KB	0	0.10	0.01	0.59	1	24.8	0.00	0.06	0.71	-0.04	1
81	045100	HanyangENG	-2	0	2	FXFwd	Shinhan	0	0.02	0.00	0.04	14	25.5	0.00	0.45	0.06	-0.02	1
82	007980	Pacific	-2	0	2	FXFwd	KEB	0	0.18	0.46	0.90	16	25.7	0.00	0.01	1.24	-0.01	1
83	024800	YoosungTnS	-2	0	2	FXFwd	Woori	0	0.00	0.01		12	26.2	0.00				1
84	041910	Estech	-2	0	2	FXFwd	KEB	0	0.10	0.01	0.57	16	24.8	0.00	0.10	0.41	-0.03	1
85	052710	Amotech	-2	0	2	FXFwd	KEB	0	0.09	0.18	0.83	16	25.8	0.00	0.03	0.40	-0.01	1
86	070590	HansolInticube	-1	0	1	FXFwd	Citi	1	0.01	0.22	0.00	15	24.5	0.00	11.14	-0.09	-0.03	1
87	065950	Welcron	-1	0	1	FXFwd	IBK	0	0.11	0.01	0.74	16	25.1	0.00	0.02	0.88	-0.02	1
88	019540	IljiTech	-1	0	1	FXFwd	KEB	0	0.04	0.00	0.37	16	24.8		0.07	0.30	-0.02	1
89	092600	NCN	-1	0	1	FXFwd	StandChar	1	0.05	0.88	0.75	16	24.6	0.00	0.02	0.54	-0.01	1
90	105740	DKLok	-1	0	1	FXFut	KB	0	0.18	0.01	0.48	16	24.1	0.00	0.04	0.69	-0.02	1
91	059100	Icomponent	-1	0	1	FXFwd	IBK	0	0.02	0.00	0.24	16	24.6	0.00	0.08	0.18	-0.01	1
92	018880	Hanon	0	0	0	FXFwd	KEB	0	0.09	0.03	0.63	16	27.9	0.00	0.00	0.73	0.00	1
Mean			-633	154	787				0.13	0.17	0.56		26.3	0.41	0.77	0.68	-0.20	
Median			-16	0	16				0.10	0.08	0.57		25.9	0.00	0.22	0.52	-0.09	

Table A.15: Adjustments in FX Derivatives Position and Capital (**Excluding 3 banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i + \beta_2 Regulation_t + \beta_3 Constrained_i \times Regulation_t + \varepsilon_{it}$$

Y_{it} is either log(FX Derivatives position) or log(Capital). $Bind_i$ is dummy variable that takes 1 if bank i is constrained and 0 if otherwise. $Constraint_t^{Avg}$ is 0 before the regulation and takes **simple average** of foreign banks' and domestic banks' regulatory cap^{-1}. Higher $Constraint_t^{Avg}$ indicates tighter constraint. Columns (2) and (6) adds bank fixed effects:

$$Y_{it} = \beta_0 + BankFE_i + \beta_2 Regulation_t^{Avg} + \beta_3 Constrained_i \times Regulation_t^{Avg} + \varepsilon_{it}$$

Columns (3),(4),(7) and (8) are weighted least squares models, where the weights are the size of derivatives position as of Dec 2009. The sample period is 2008–2019 on a monthly basis. Standard errors are clustered by bank.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	LogDeriv	LogDeriv	LogDeriv (W)	LogDeriv (W)	LogCapital	LogCapital	LogCapital (W)	LogCapital (W)
Constrained=1	5.701^{***}		0.506^{*}		-0.721		-2.278^{***}	
	(3.86)		(1.86)		(-1.63)		(-6.17)	
Regulation	-0.0299	0.0315	-0.408^{***}	-0.412^{***}	0.263^{***}	0.286^{***}	0.270^{***}	0.266^{***}
	(-0.10)	(0.10)	(-4.85)	(-4.77)	(6.11)	(7.43)	(4.48)	(4.42)
Constrained=1 x Regulation	-0.883^{***}	-0.939^{***}	-0.485^{***}	-0.481^{***}	0.0385	0.0312	0.00434	0.0114
	(-2.86)	(-2.98)	(-4.20)	(-4.05)	(0.48)	(0.42)	(0.05)	(0.13)
Constant	15.81^{***}	20.18^{***}	21.25^{***}	20.16^{***}	27.65^{***}	26.14^{***}	29.52^{***}	26.19^{***}
	(10.75)	(164.83)	(92.55)	(194.60)	(78.43)	(320.85)	(129.98)	(339.08)
BankFE	N	Y	N	Y	N	Y	N	Y
N	5531	5531	5531	5531	5513	5513	5513	5513
Adj RSqr	0.124	0.803	0.132	0.342	0.0552	0.934	0.549	0.917

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

$$Y_{it} = \beta_0 + BankFE_i + \beta_2 Regulation_t^{WAvg} + \beta_3 Constrained_i \times Regulation_t^{Wavg} + \varepsilon_{it}$$

$Constraint_t^{WAvg}$ is the **weighted average** of the regulatory position limit, where the weight is the FXD position in each month.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	LogDeriv	LogDeriv	LogDeriv (W)	LogDeriv (W)	LogCapital	LogCapital	LogCapital (W)	LogCapital (W)
Constrained=1	5.699^{***}		0.526^{*}		-0.691		-2.241^{***}	
	(3.86)		(1.68)		(-1.57)		(-6.13)	
Regulation	-0.0522	0.0364	-0.495^{***}	-0.500^{***}	0.325^{***}	0.355^{***}	0.344^{***}	0.337^{***}
	(-0.14)	(0.09)	(-3.60)	(-3.56)	(6.15)	(7.51)	(4.21)	(4.16)
Constrained=1 x Regulation	-1.095^{***}	-1.178^{***}	-0.621^{***}	-0.617^{***}	0.0186	0.00594	-0.0300	-0.0200
	(-2.73)	(-2.88)	(-3.53)	(-3.42)	(0.19)	(0.07)	(-0.28)	(-0.18)
Constant	15.83^{***}	20.19^{***}	21.24^{***}	20.17^{***}	27.65^{***}	26.18^{***}	29.51^{***}	26.22^{***}
	(10.76)	(138.68)	(77.49)	(174.60)	(78.65)	(333.39)	(130.82)	(357.96)
BankFE	N	Y	N	Y	N	Y	N	Y
N	5531	5531	5531	5531	5513	5513	5513	5513
Adj RSqr	0.124	0.804	0.143	0.353	0.0552	0.934	0.549	0.917

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.16: Impact on Banks' FC Loans and FC Liabilities (**Excluding 3 banks**)

$$Y_{it} = \beta_0 + \beta_1 Constrained_i + \beta_2 Regulation_t + \beta_3 Constrained_i \times Regulation_t + \varepsilon_{it}$$

Columns (2) and (6) adds bank fixed effects:

$$Y_{it} = \beta_0 + BankFE_i + \beta_2 Regulation_t^{Avg} + \beta_3 Constrained_i \times Regulation_t^{Avg} + \varepsilon_{it}$$

Columns (3),(4),(7) and (8) are weighted least squares models, where the weights are the size of derivatives position as of Dec 2009. The sample period is 2008–2019 on a quarterly basis. Standard errors are clustered by bank. The outcome variables are share of foreign currency loans (*FCLoanShr*) and share of foreign currency liabilities (*FCLiabShr*).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	FCLoanShr	FCLoanShr	FCLoanShr	FCLoanShr	FCLiabShr	FCLiabShr	FCLiabShr	FCLiabShr
Constrained=1	0.305**		0.337**		-0.0346		0.0914**	
	(2.25)		(2.29)		(-0.49)		(2.15)	
Regulation	-0.0426*	-0.0398*	0.000801	0.0124	-0.0743***	-0.0750***	-0.0325***	-0.0320***
	(-2.01)	(-1.99)	(0.02)	(0.34)	(-3.01)	(-3.15)	(-4.35)	(-4.62)
Constrained=1 x Regulation	-0.0387	-0.0425	-0.0737	-0.0860*	-0.00579	-0.00460	-0.0508***	-0.0520***
	(-1.20)	(-1.37)	(-1.55)	(-1.81)	(-0.19)	(-0.15)	(-2.90)	(-2.97)
Constant	0.338***	0.959***	0.224***	0.950***	0.232***	6.79e-14	0.103***	-8.55e-15
	(4.78)	(38.45)	(3.56)	(28.82)	(4.08)	(0.97)	(3.41)	(-0.94)
BankFE	N	Y	N	Y	N	Y	N	Y
N	1450	1450	1450	1450	1611	1611	1611	1611
Adj RSqr	0.109	0.858	0.134	0.797	0.0603	0.763	0.161	0.663

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.17: Impact on Banks' Security Holdings (**Excluding 3 banks**)

The outcome variables are KTB holdings and MSB holdings scaled by assets. KTB is long-term Korean government bond with maturities: 3, 5, 10, 20, 30 yr.
MSB is issued by Bank of Korea and the maturities are: 91day, 1yr, 2yr.

$$Y_{it} = \beta_0 + BankFE_i + \beta_2 Regulation_t + \beta_3 Constrained_i \times Regulation_t + \varepsilon_{it}$$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	KTB/Asset	KTB/Asset	KTB/Asset	KTB/Asset	MSB/Asset	MSB/Asset	MSB/Asset	MSB/Asset
Constrained=1	0.0317		0.0455		0.145***		0.103**	
	(0.88)		(0.87)		(3.05)		(2.36)	
Regulation	-0.0102**	-0.00983*	-0.00616	-0.00569	-0.000494	0.0000609	-0.0106	-0.00949
	(-2.06)	(-1.98)	(-1.00)	(-0.86)	(-0.21)	(0.03)	(-1.44)	(-1.33)
Constrained=1 x Regulation	0.0115	0.0113	0.00406	0.00305	-0.0537***	-0.0538***	-0.0360**	-0.0374***
	(0.86)	(0.83)	(0.22)	(0.16)	(-2.80)	(-2.92)	(-2.67)	(-2.84)
Constant	0.0438***	2.88e-14	0.0567***	1.62e-14	0.0141**	3.61e-14	0.0420*	-5.13e-14
	(4.71)	(0.97)	(5.87)	(0.97)	(2.11)	(0.97)	(1.70)	(-0.97)
BankFE	N	Y	N	Y	N	Y	N	Y
N	1630	1630	1630	1630	1630	1630	1630	1630
Adj RSqr	0.0962	0.723	0.0615	0.753	0.249	0.752	0.146	0.761

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.18: FXD Contract level OLS

$$\Delta FXD_{i,j} = \alpha + \beta \; Constrained_b + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

The dependent variable is change in net FXD notional dealt between firm *j* and bank *b*, **scaled by sales**. $Bind_b$ is 1 if the contract is dealt with a binding bank. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank *b*'s share of firm *j*'s total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Constrained	0.0649***	0.0344**	0.00718	0.00437	0.0291***	0.00807
	(4.68)	(2.17)	(1.51)	(1.22)	(2.86)	(1.10)
Type Swaps		0.0106		-0.000135		0.00255
		(0.50)		(-0.01)		(0.33)
Type Options		0.137***		0		0.150***
		(3.69)		(.)		(4.66)
Type Futures		0.0253		0		0.0208*
		(1.10)		(.)		(2.01)
Pair EURKRW		0.0511*		0		0.0276*
		(1.96)		(.)		(1.76)
Pair JPYKRW		-0.0505*		0.0104		-0.0123
		(-2.12)		(1.05)		(-0.95)
Pair XXXKRW		0.0105		0.0315**		0.0111
		(0.58)		(2.36)		(1.30)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	129	129	122	122	251	251
RSqr	0.0841	0.461	0.0162	0.449	0.0333	0.435

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.19: FXD Contract level OLS

$$\Delta FXD_{i,j} = \alpha + \beta Constrained_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

FX Options contracts are excluded. The dependent variable is change in net FXD notional **scaled by sales**.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Constrained	0.0272*	0.0281*	0.00442	0.00329	0.0146***	0.00722
	(1.94)	(1.76)	(0.97)	(0.88)	(3.12)	(1.05)
Type Swaps		-0.00475		-0.00635		-0.00582
		(-0.21)		(-0.56)		(-0.73)
Type Options		0		0		0
		(.)		(.)		(.)
Type Futures		0.0275		0		0.0179**
		(1.54)		(.)		(2.68)
Pair EURKRW		0.0487		0		0.0317***
		(1.54)		(.)		(2.97)
Pair JPYKRW		-0.0296		0.0152		-0.00292
		(-1.25)		(1.65)		(-0.28)
Pair XXXKRW		0.00655		0.0181		0.00329
		(0.37)		(1.19)		(0.40)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	111	111	122	122	233	233
RSqr	0.0290	0.109	0.00719	0.322	0.0186	0.0714

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.20: FXD Contract level OLS

$$\Delta FXD_{i,j} = \alpha + \beta_{Shock} Shock_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

The dependent variable is change in net FXD notional dealt between firm j and bank b, **scaled by sales**. $Shock_b$ is the percentage of bank b's FXD position that needed to be reduced at the imposition of the regulation. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Bank controls include log size, loans to assets ratio, leverage ratio, and foreign bank indicator variable. Contract controls include bank b's share of firm j's total FXD notional, type, and currency pair. The omitted categories are forwards and USD-KRW pair. Standard errors are clustered at the bank level.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Shock	0.0360***	0.0179**	0.00252	0.000285	0.00894	0.000922
	(3.07)	(2.15)	(1.63)	(0.18)	(1.54)	(0.26)
Type Swaps		0.0136		-0.0000924		0.00318
		(0.66)		(-0.01)		(0.41)
Type Options		0.138***		0		0.151***
		(3.69)		(.)		(4.77)
Type Futures		0.0244		0		0.0212*
		(1.07)		(.)		(2.00)
Pair EURKRW		0.0418		0		0.0272*
		(1.58)		(.)		(1.84)
Pair JPYKRW		-0.0522*		0.00739		-0.0159
		(-2.10)		(0.77)		(-1.27)
Pair XXXKRW		0.00906		0.0374**		0.0145
		(0.54)		(2.64)		(1.59)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	129	129	122	122	251	251
RSqr	0.0654	0.458	0.0111	0.447	0.0131	0.434

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.21: FXD Contract level OLS

$$\Delta FXD_{i,j} = \alpha + \beta_{Shock} Shock_i + FirmControls_j + BankControls_i + ContractControls_{i,j} + \varepsilon_{i,j}$$

FX Options contracts are excluded. The dependent variable is change in net FXD notional dealt between firm j and bank b, **scaled by sales**.

	(1)	(2)	(3)	(4)	(5)	(6)
	Exporters	Exporters	Non-exporters	Non-exporters	Full Sample	Full Sample
Shock	0.0182**	0.0177**	0.00156	0.000781	0.00612***	0.00199
	(2.61)	(2.36)	(1.01)	(0.46)	(2.86)	(0.65)
Type Swaps		-0.0000793		-0.00627		-0.00527
		(-0.00)		(-0.54)		(-0.67)
Type Options		0		0		0
		(.)		(.)		(.)
Type Futures		0.0253		0		0.0181**
		(1.44)		(.)		(2.66)
Pair EURKRW		0.0414		0		0.0309***
		(1.41)		(.)		(3.07)
Pair JPYKRW		-0.0300		0.0139		-0.00494
		(-1.23)		(1.54)		(-0.46)
Pair XXXKRW		0.00289		0.0235		0.00592
		(0.15)		(1.45)		(0.67)
FirmControls	N	Y	N	Y	N	Y
BankControls	N	Y	N	Y	N	Y
N	111	111	122	122	233	233
RSqr	0.0331	0.109	0.00481	0.321	0.0141	0.0699

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.22: Firm level OLS (Exporters) after Coarsened Exact Matching based on FC Liability

$$\Delta Y_j = \beta_E \, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls_j + \varepsilon_j$$

Outcome variable is either change in firm *j*'s log export sales, net FXD notional scaled by assets, or log domestic sales. Independent variable *Exposure* is the weighted average shock of the firm's counterparty banks. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Results are after matching firms based on FC liability.

	LogExport	FXD/Asset	LogDomesticSales
Firm_highHR=1 × Exposure	-0.178*	0.0697**	-0.197
	(-1.95)	(2.08)	(-1.54)
Exposure	0.125**	0.0141	0.136
	(2.49)	(0.68)	(1.17)
Firm_highHR=1	0.0495	0.0411	0.336**
	(0.61)	(1.06)	(2.41)
Constant	-0.295	-0.548	1.532
	(-0.17)	(-1.55)	(1.37)
FirmControls	Y	Y	Y
N	68	68	68
RSqr	0.286	0.454	0.252

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.23: Firm level OLS (Exporters) after Coarsened Exact Matching based on FC Liability, Export Share, and Profitability

$$\Delta Y_j = \beta_E \, Exposure_j + \beta_h HighHedge_j + \beta_{Eh} Exposure_j \times HighHedge_j + FirmControls_j + \varepsilon_j$$

Outcome variable is either change in firm *j*'s log export sales, net FXD notional scaled by assets, or log domestic sales. Independent variable *Exposure* is the weighted average shock of the firm's counterparty banks. Firm controls include log size, net FXD notional (scaled by sales) before the shock, foreign-currency liability share, and 7 industry dummies. Results are after matching firms based on FC liability, export share, and profitability.

	LogExport	FXD/Asset	LogDomesticSales
Firm_highHR=1 × Exposure	-0.191*	0.0614***	-0.0317
	(-1.73)	(2.66)	(-0.29)
Exposure	0.0746	0.0165	-0.000762
	(1.27)	(1.49)	(-0.01)
Firm_highHR=1	0.0695	0.0291	0.104
	(0.71)	(1.58)	(1.02)
Constant	-1.474	-0.112	0.705
	(-1.07)	(-0.48)	(0.80)
FirmControls	Y	Y	Y
N	72	72	72
RSqr	0.312	0.323	0.0790

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Chapter B

Appendix to Chapter 2

B.1 Bases Summary Statistics

Table B.1: Indonesia

	IDR			
	Basis1M	Basis3M	Basis6M	Basis12M
N	210.0000	210.0000	210.0000	210.0000
Mean	-0.0161	-0.0087	-0.0055	-0.0026
SD	0.0806	0.0435	0.0295	0.0171
Min	-0.6746	-0.3115	-0.1777	-0.0982
Max	0.3121	0.0865	0.0367	0.0275
AC	0.4831	0.6164	0.7154	0.7181

Table B.2: India

	INR			
	Basis1M	Basis3M	Basis6M	Basis12M
N	223.0000	223.0000	223.0000	223.0000
Mean	-0.0048	-0.0034	-0.0029	-0.0025
SD	0.0255	0.0204	0.0158	0.0119
Min	-0.2191	-0.1577	-0.0934	-0.0593
Max	0.0488	0.0380	0.0290	0.0188
AC	0.6108	0.7843	0.8619	0.9014

Table B.3: Korea

	KRW			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	-0.0028	-0.0010	-0.0007	-0.0005
SD	0.0093	0.0034	0.0020	0.0012
Min	-0.0444	-0.0195	-0.0119	-0.0090
Max	0.0544	0.0172	0.0112	0.0046
AC	0.3850	0.3773	0.3334	0.4150

Table B.4: Taiwan

	TWD			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	0.0052	0.0047	0.0031	0.0008
SD	0.0249	0.0180	0.0142	0.0108
Min	-0.1126	-0.0603	-0.0464	-0.0312
Max	0.1758	0.0940	0.0552	0.0344
AC	0.5631	0.8012	0.8683	0.9121

Table B.5: Thailand

	THB			
	Basis1M	Basis3M	Basis6M	Basis12M
N	224.0000	224.0000	224.0000	224.0000
Mean	0.0349	0.0049	-0.0016	-0.0039
SD	0.1922	0.0583	0.0284	0.0152
Min	-0.2302	-0.1043	-0.0665	-0.0529
Max	1.2056	0.3755	0.1769	0.0837
AC	0.9046	0.8871	0.8760	0.8793

Table B.6: Thailand (Excluding URR Period)

	THB			
	Basis1M	Basis3M	Basis6M	Basis12M
N	208.0000	208.0000	208.0000	208.0000
Mean	-0.0093	-0.0079	-0.0073	-0.0064
SD	0.0156	0.0135	0.0116	0.0098
Min	-0.0953	-0.0867	-0.0665	-0.0529
Max	0.0136	0.0142	0.0119	0.0116
AC	0.6489	0.8202	0.8758	0.9141

B.2 Bases Correlation Across Currencies

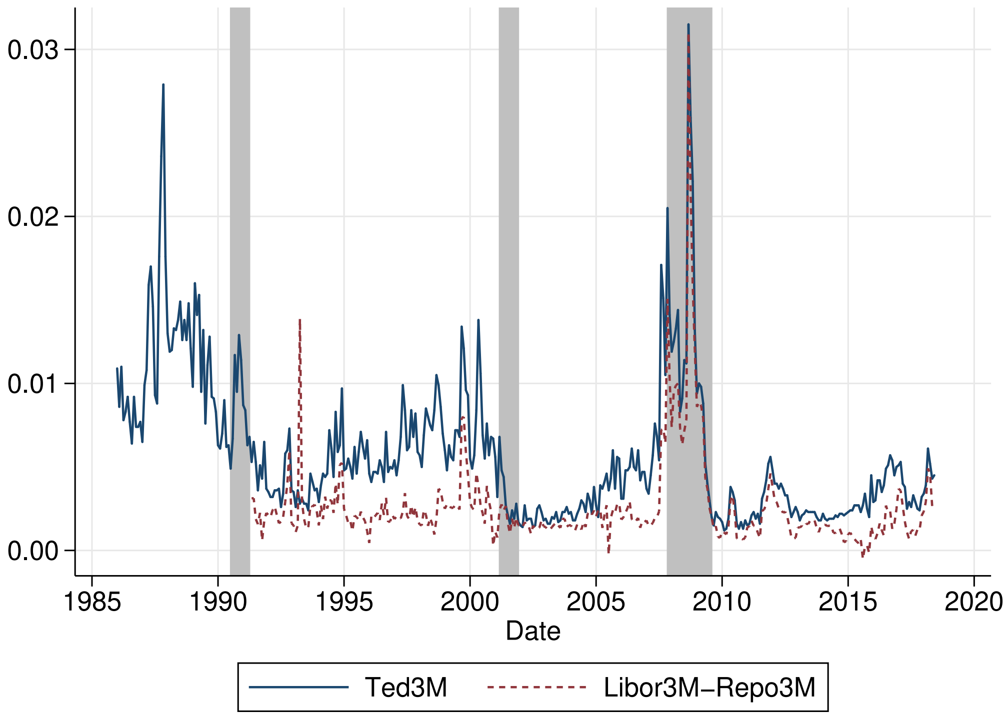
Correlation of 6-month bases across currencies

	Corr				
	IDR	INR	KRW	TWD	THB
IDR	1.0000	0.0000	0.0000	0.0000	0.0000
INR	0.6408	1.0000	0.0000	0.0000	0.0000
KRW	0.0151	0.2334	1.0000	0.0000	0.0000
TWD	0.5253	0.6390	0.2832	1.0000	0.0000
THB	0.4079	0.4735	0.2217	0.6420	1.0000

B.3 Other Proxies for Shadow Cost of Margin Constraint

Figure B.1: TED Spread and Libor-Repo Spread

The correlation between the two spreads is 0.8456.



Alternatively, Libor3M - Repo3M, IOER - Repo1W, IOER - OIS1W, and tenor basis swap 5 year are considered. Here are summary statistics of spreads and the correlation:

Table B.7: Summary Statistics of Spreads

	Spreads				
	TED3M	Libor-Repo3M	IOER-Repo1W	IOER-OIS1W	TenorBasisSwap5Y
N	390.0000	326.0000	117.0000	117.0000	252.0000
Mean	0.0058	0.0026	0.0008	0.0011	0.0006
SD	0.0044	0.0029	0.0009	0.0005	0.0005
Min	0.0012	-0.0005	-0.0022	0.0002	-0.0000
Max	0.0315	0.0310	0.0045	0.0045	0.0019
AC	0.8612	0.7532	0.5809	0.3769	0.9617

Table B.8: Correlation of Spreads

Corr	TED3M	Libor-Repo3M	IOER-Repo1W	IOER-OIS1W	TenorBasisSwap5Y
TED3M	1.0000	0.0000	0.0000	0.0000	0.0000
Libor-Repo3M	0.8456	1.0000	0.0000	0.0000	0.0000
IOER-Repo1W	0.0637	0.0966	1.0000	0.0000	0.0000
IOER-OIS1W	0.0438	-0.0223	0.6785	1.0000	0.0000
TenorBasisSwap5Y	-0.1238	-0.0227	-0.2861	-0.0721	1.0000

B.4 Term Structure of Bases

Annualized daily basis (10-day moving average) for 1M and 6M contracts.

Figure B.2: Indonesia

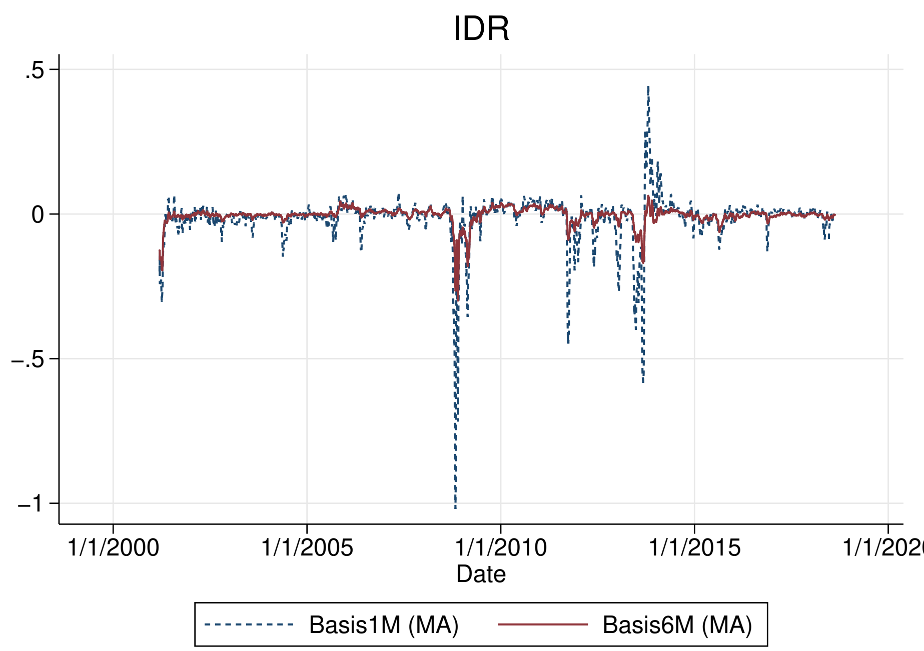


Figure B.3: Thailand

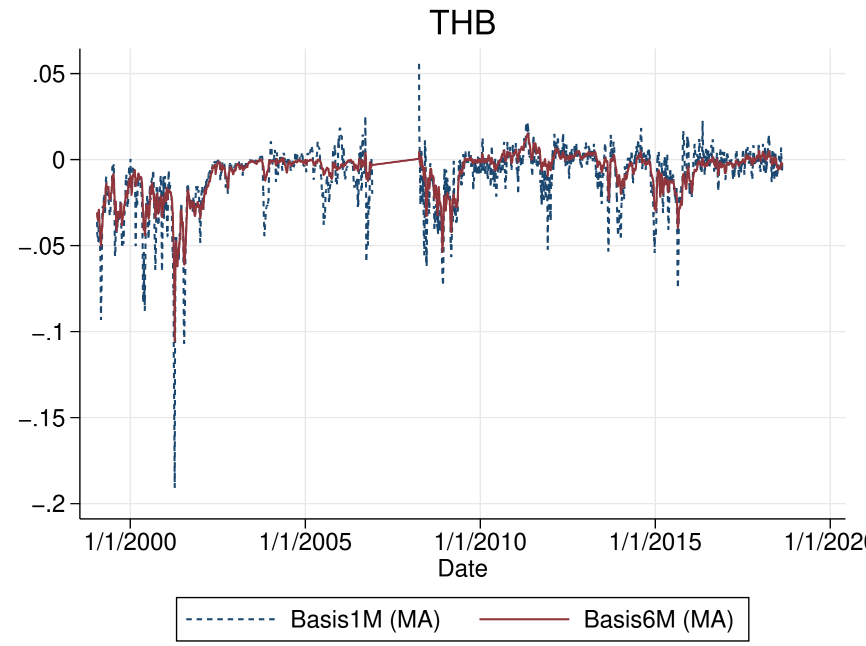


Figure B.4: India

Figure B.5: Taiwan

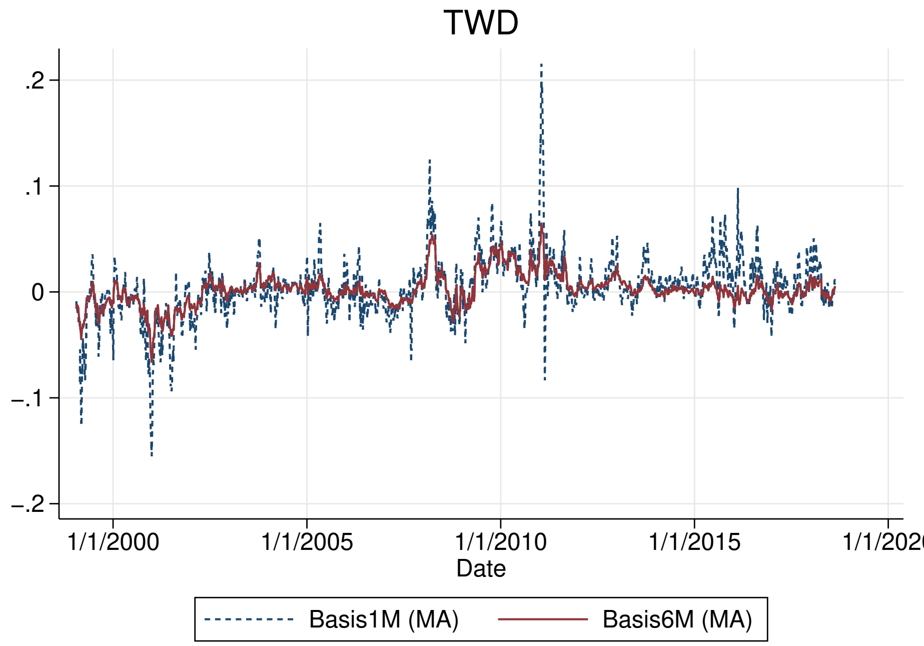
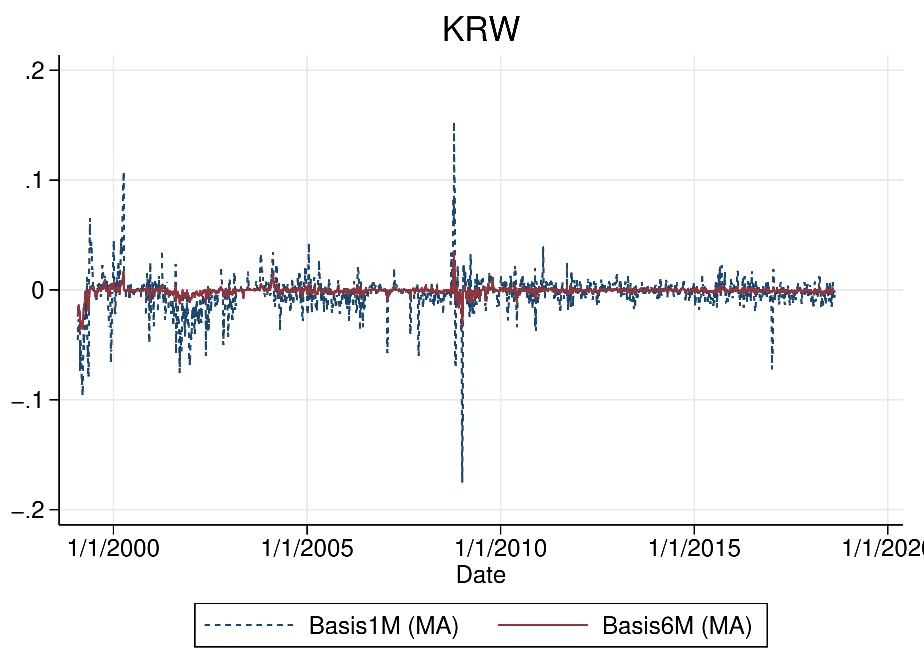


Figure B.6: Korea



B.5 Regulations

- Korean Won (KRW)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Allowed for limited size (since April 1999)
  - Non-resident Participation in DF: Not allowed
  - NOP Limit: 15% $\rightarrow$ 20% in 1999, $\rightarrow$ 30% in 2006 March 22, $\rightarrow$ 50% in 2006 May 22.
  - Derivatives Position Limit: Effective July 1, 2016, the limits on banks' foreign exchange derivatives contracts were increased to 40% from 30% of bank capital (for domestic banks) and to 200% from 150% (for foreign bank branches).

- Indian Rupee (INR)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed
  - Non-resident Participation in DF: Allowed only for hedging real (trade and investment) transactions.
  - NOP Limit: NOP should not exceed 25 percent of the total capital (Tier I and Tier II capital) of the bank. (RBI Circular 2013). Net Overnight Open Position Limits (NOOPL) were reduced[1] in December 2011 and relaxed in 2013.

- Indonesian Rupiah (IDR)
  - Not deliverable, Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed. [2]
  - Non-resident Participation in DF: Allowed but limited. [3]
  - NOP Limit: Banks in Indoensia can have maximum NOP of 20 percent of their capital.

[1] by 50-70% (not official)

[2] On 19 Jan 2001, BI prohibited onshore banks from lending or transferring IDR to offshore accounts, effectively making IDR non-deliverable offshore.

[3] For instance in 2012, permitted upto USD 1 million per counterparty without documentation.

- New Taiwan Dollar (TWD)
  - Convertible on current account but with limited convertibility on capital account.
  - Resident Participation in NDF: Not allowed. Initially in 1995, the CBC set up a firewall to limit the NDF trading position of authorized banks to one third of their total foreign exchange position. However, in 1998, CBC announced that only the authorized banks could carry out NDF trades with other authorized counterparts and their overseas branches or headquarters. [4]
  - Non-resident Participation in DF: Not allowed
  - NOP Limit: From July 1, 1996 onwards, each authorized bank has been allowed to determine its own overbought and oversold positions subject to the approval of the Bank.[5] The CBC requires authorized foreign exchange banks to follow the sum of position limits for NDF and foreign exchange options such that the combined amount may not exceed one-fifth of the total position limit. [6]

- Thailand Baht (THB)
  - Convertible on the current account, deliverable offshore with some restrictions on capital account.
  - BoT enacted an URR (unremunerated reserve requirement) regime in December 2006 (effective 18 December 2006) to slow speculative capital inflows. BoT applied 30% reserve requirement on investments into Thailand and restricted the movements of THB from onshore to offshore. This regime was dismantled in February 2008, effective 03 March 2008. [7]
  - Resident participation in offshore DF: Residents can sell/buy THB (and buy/sell USD) from offshore, but not the other way. The size of such transaction is limited to 300 million THB per day per bank (group).
  - Non-resident participation in onshore DF: Non-residents can buy/sell THB from onshore, but not the other way. The size of such transaction is limited to 300mio THB per day per bank (group). Non-residents can access the onshore forward market to hedge equity and other investments with valid documentation.

[4] https://www.cbc.gov.tw/public/Attachment/562515465471.PDF
[5] https://www.cbc.gov.tw/ct.asp?xItem=857&CtNode=481&mp=2
[6] https://www.cbc.gov.tw/public/Attachment/5101911345971.pdf
[7] https://www.bot.or.th/thai/pressandspeeches/press/news2551/n0951e.pdf

– NOP Limit: Financial Institutions are required to maintain net open positions in each currency of no more than 15 percent and an aggregate position of no more than 20 percent of total capital at the end of the day.

B.6 Global Banks

Global banks (FX dealers) with both onshore and offshore presences are well positioned for the arbitrage trades. Table B.9 lists the top 10 FX dealers in Asia region. The combined market shares of these banks is 76%.

Table B.10 shows the local presence of large global banks. The values (1 or 0) indicate whether the bank has onshore presence (either as a subsidiary or branch with FX forward dealing license). Due to local market closings, Singapore or Hong Kong is the offshore center that is useful for executing the arbitrage trades. The data sources are SNL and the websites of local central banks.

Table B.9: Top 10 Liquidity Provider in Asia (by Euromoney)

2018	2017	Liquidity Provider	Asia Regional Market Share
1	3	JPMorgan	17%
2	2	Bank of America Merrill Lynch	10%
3	4	UBS	8%
4	1	Citi	7%
5	10	Goldman Sahcs	7%
6	7	Deutsche Bank	7%
7	31	XTX Markets	6%
8	8	HSBC	5%
9	6	Standard Chartered	5%
10	5	Barclays	4%

https://www.euromoney.com/article/b18c1skvsyyk47/fx-survey-2018-market-share-by-region#APAC2

Table B.10: Local Presence of Global Banks

Bank Name	Hong Kong	Singapore	Korea	Indonesia	India	Philippines	Thailand	Taiwan	Malaysia	Total Assets	Ultimate Parent Country
Mitsubishi UFJ Financial Group	1	1	1	1	1	1	1	1	1	2722	Japan
JPMorgan Chase Co.	1	1	1	1	1	1	1	1	1	2533	USA
HSBC Holdings Plc	1	1	1	1	1	1	1	1	1	2521	United Kingdom
BNP Paribas SA	1	1	1	1	1	0	1	1	1	2353	France
Bank of America Corp.	1	1	1	1	1	1	1	1	1	2281	USA
Citigroup Inc	1	1	1	1	1	1	1	1	1	1842	USA
Mizuho Financial Group	1	1	1	1	1	1	1	1	1	1799	Japan
Deutsche bank AG	1	1	1	1	1	1	1	1	1	1770	Germany
Sumitomo Mitsui Financial Group Inc.	1	1	1	1	1	1	1	1	1	1660	Japan
Barclays Plc	1	1	1	0	1	0	0	1	0	1532	United Kingdom
Societe Generale	1	1	1	0	1	0	0	0	0	1531	France
ING Groep NV	1	1	1	1	0	1	0	1	1	1016	Netherlands
Royal Bank of Canada	1	1	1	0	0	0	0	0	0	940	Canada
UBS Group	1	1	1	0	0	0	0	1	0	939	Switzerland
Goldman Sachs Group Inc	1	1	1	0	0	0	0	0	1	917	USA
Morgan Stanley	1	1	1	1	0	0	0	1	0	851	USA
Credit Suisse Group AG	1	1	1	0	1	0	0	0	1	817	Switzerland
Bank of Nova Scotia	1	1	1	0	1	0	0	1	1	710	Canada
Australia and New Zealand Banking Group Ltd.	1	1	1	1	1	1	1	1	0	703	Australia
Standard Chartered	1	1	1	1	1	1	1	1	1	663	United Kingdom
Bank of New York Mellon Corporation	1	1	1	0	0	0	0	1	0	371	USA
Nomura holdings	1	1	1	0	1	0	1	1	1	365	Japan
DBS Group Holdings	1	1	1	1	1	0	0	1	0	333	Singapore
State Street Corporation	1	1	1	0	0	0	0	1	1	242	USA

Chapter C

Appendix to Chapter 3

C.1 Summary Statistics

Table C.1: Market Return and Climate Factor

	count	mean	sd	min	max
ret_spy	5257	0.0003	0.0123	-0.1159	0.1356
ret_acwi	5257	0.0002	0.0124	-0.1190	0.1170
CF	5257	-0.0002	0.0138	-0.1160	0.0964

	ret_spy	ret_acwi	CF
ret_spy	1		
ret_acwi	0.945	1	
CF	0.129	0.250	1

Table C.2: Stranded Asset Portfolio Return

The top row is fractional return and the bottom row is log return.

	count	mean	sd	min	p1	max
StrandedRet6M_Frac	5326	-0.0122	0.1776	-0.5689	-0.4360	0.6414
StrandedRet6M_Log	5326	-0.0294	0.1888	-0.8415	-0.5727	0.4955

C.2 Fixed Beta Estimation

For each firm i:

$$r_{it} = \alpha + \beta_i MKT_t + \gamma_i CF_t + \varepsilon_{it}$$

The beta and gamma in this regression reflect the sensitivity of bank i to broad market declines and to climate deterioration. One would expect that banks with many loans to the fossil fuel industry will be more sensitive to *CF* than average and will have positive γ. *MKT* is return on market SPY is used. For *CF*, the return on the stranded asset portfolio CF^{Str} is used. Full sample period is 01/01/2000–01/31/2021 and post-crisis sample period is 01/01/2010–01/31/2021. Standard errors are Newey-West adjusted with optimally selected number of lags.

U.S. Banks

Focus on top 10 banks by average total assets in year 2019.

Table C.3: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
BankofAmericaCorp	BAC	0.11	2.09	1.55	13.35	−0.0003	−0.84	0.45	5,257
CitigroupInc	C	0.09	1.89	1.68	15.92	−0.0007	−2.43	0.46	5,257
WellsFargoCo	WFC	0.06	1.41	1.28	11.07	−0.0001	−0.63	0.44	5,257
BankofNewYorkMellonCorpThe	BK	0.06	1.53	1.33	21.17	−0.0003	−1.65	0.51	5,257
PNCFinancialServicesGroupIncThe	PNC	0.01	0.35	1.25	11.1	0	0	0.42	5,257
CapitalOneFinancialCorp	COF	0.01	0.11	1.59	16.4	−0.0002	−0.77	0.43	5,257
GoldmanSachsGroupIncThe	GS	−0.01	−0.18	1.36	27.04	−0.0001	−0.27	0.54	5,257
USBancorp	USB	−0.02	−0.52	1.15	13.16	0	−0.17	0.43	5,257
MorganStanley	MS	−0.02	−0.61	1.83	16.58	−0.0004	−1.66	0.56	5,257
JPMorganChaseCo	JPM	−0.03	−0.85	1.47	17.26	−0.0001	−0.44	0.55	5,257

Table C.4: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
CitigroupInc	C	0.3	5.1	1.53	26.6	−0.0003	−1.16	0.61	2,832
BankofAmericaCorp	BAC	0.24	4.7	1.47	25.09	−0.0003	−0.86	0.55	2,832
MorganStanley	MS	0.23	4.89	1.53	26.79	−0.0002	−0.89	0.6	2,832
JPMorganChaseCo	JPM	0.18	4.01	1.27	35.75	0	0.02	0.62	2,832
CapitalOneFinancialCorp	COF	0.16	2.7	1.38	18	−0.0002	−0.64	0.52	2,832
GoldmanSachsGroupIncThe	GS	0.15	3.86	1.25	31.64	−0.0003	−1.23	0.57	2,832
BankofNewYorkMellonCorpThe	BK	0.14	3.5	1.15	31.74	−0.0003	−1.41	0.55	2,832
WellsFargoCo	WFC	0.13	2.13	1.27	24	−0.0004	−1.63	0.57	2,832
PNCFinancialServicesGroupIncThe	PNC	0.11	2.35	1.22	21.27	−0.0001	−0.33	0.58	2,832
USBancorp	USB	0.09	1.77	1.15	21.62	−0.0002	−1.03	0.58	2,832

U.K. Banks

Focus on top 5 banks by average total assets in year 2019.

Table C.5: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
NatwestPLC	NWG	0.29	4.74	0.87	11.37	−0.0006	−1.56	0.12	5,145
StandardCharteredPLC	STAN	0.27	5.34	0.78	15.78	−0.0001	−0.43	0.19	5,145
BarclaysPLC	BARC	0.25	4.43	0.96	11.72	−0.0003	−0.78	0.18	5,145
LloydsBankingGroupPLC	LLOY	0.24	4.27	0.83	8.11	−0.0005	−1.47	0.14	5,145
HSBCHoldingsPLC	HSBA	0.19	5.19	0.65	13.57	−0.0001	−0.35	0.24	5,145

Table C.6: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
StandardCharteredPLC	STAN	0.47	7.48	0.81	15.4	−0.0004	−1.36	0.25	2,768
BarclaysPLC	BARC	0.46	7.15	1.13	13.62	−0.0004	−1.03	0.28	2,768
NatwestPLC	NWG	0.41	6.55	0.95	10.34	−0.0004	−0.94	0.2	2,768
LloydsBankingGroupPLC	LLOY	0.36	6.27	0.98	12.86	−0.0004	−0.92	0.23	2,768
HSBCHoldingsPLC	HSBA	0.31	6.76	0.66	14.11	−0.0002	−1.06	0.29	2,768

To account for non-synchronous trading, I include a lagged value of each explanatory variable:

$$r_{it} = \alpha + \beta_{1i} MKT_t + \beta_{2i} MKT_{t-1} + \gamma_{1i} CF_t + \gamma_{2i} CF_{t-1} + \varepsilon_{it}$$

I report the bias-adjusted coefficients $\beta_{1i} + \beta_{2i}$ (labeled as MKT), $\gamma_{1i} + \gamma_{2i}$ (labeled as CF) and their t-statistics below.

Table C.7: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
StandardCharteredPLC	STAN	0.28	4.93	1.33	14.02	−0.0002	−1.03	0.25	5,143
NatwestPLC	NWG	0.23	3.01	1.48	13.17	−0.0008	−2.08	0.16	5,143
BarclaysPLC	BARC	0.23	3.34	1.63	15.41	−0.0004	−1.35	0.24	5,143
LloydsBankingGroupPLC	LLOY	0.18	2.65	1.35	11.42	−0.0006	−1.97	0.17	5,143
HSBCHoldingsPLC	HSBA	0.14	3.8	0.98	18.34	−0.0002	−0.9	0.28	5,143

Table C.8: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
StandardCharteredPLC	STAN	0.49	6.97	1.2	17.91	−0.0006	−1.87	0.28	2,766
BarclaysPLC	BARC	0.47	7.32	1.68	13.39	−0.0007	−1.65	0.32	2,766
NatwestPLC	NWG	0.38	5.4	1.5	13.46	−0.0007	−1.61	0.24	2,767
LloydsBankingGroupPLC	LLOY	0.31	4.66	1.48	12.23	−0.0007	−1.55	0.26	2,766
HSBCHoldingsPLC	HSBA	0.3	5.94	0.88	15.84	−0.0004	−1.5	0.31	2,766

Canadian Banks

Table C.9: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
BankofNovaScotiaThe	BNS	0.2	5.93	0.94	18.65	0.0002	1.5	0.38	5,120
RoyalBankofCanada	RY	0.18	6.1	0.92	20.3	0.0003	1.9	0.41	5,120
NationalBankofCanada	NA	0.16	4.59	0.94	12.58	0.0003	1.92	0.34	5,119
BankofMontreal	BMO	0.15	3.96	0.93	14.62	0.0002	1.22	0.38	5,120
Toronto-DominionBankThe	TD	0.15	5.53	0.96	22.08	0.0002	1.4	0.42	5,120
CanadianImperialBankofCommerceCanada	CM	0.14	3.85	1.02	16.64	0.0002	0.93	0.4	5,120

Table C.10: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
BankofNovaScotiaThe	BNS	0.36	7.6	0.95	12.66	0	−0.24	0.51	2,753
NationalBankofCanada	NA	0.32	7.32	1.01	7.56	0.0001	0.41	0.46	2,752
BankofMontreal	BMO	0.31	8.63	0.99	8.57	0	−0.03	0.51	2,753
CanadianImperialBankofCommerceCanada	CM	0.31	8.08	0.95	8.16	0	−0.06	0.48	2,753
Toronto-DominionBankThe	TD	0.29	8.64	0.93	13.54	0.0001	0.42	0.53	2,753
RoyalBankofCanada	RY	0.27	7.93	0.92	19.27	0	0.06	0.51	2,753

Japanese Banks

Table C.11: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
Sumitomo	8316	0.19	2.79	0.78	12.15	−0.0003	−0.85	0.11	4,345
Mizuho	8411	0.17	2.4	0.71	9.4	−0.0001	−0.29	0.09	4,283
MUFG	8306	0.13	2.55	0.73	10.96	−0.0003	−0.97	0.1	4,741

Table C.12: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
MUFG	8306	0.23	4.32	0.77	12.79	−0.0003	−0.88	0.14	2,657
Sumitomo	8316	0.23	4.56	0.73	12.2	−0.0002	−0.65	0.14	2,657
Mizuho	8411	0.15	2.94	0.65	11.47	−0.0003	−1.02	0.11	2,657

French Banks

Table C.13: Large Banks, SPY

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
CreditAgricoleSA	ACA	0.26	3.02	1.47	16.68	−0.0003	−1.02	0.26	4,810
BNPParibasSA	BNP	0.21	4.05	1.4	14	−0.0001	−0.55	0.27	5,189
SocieteGeneraleSA	GLE	0.2	3.29	1.61	17.63	−0.0004	−1.36	0.28	5,189

Table C.14: Large Banks, SPY, Post-crisis

Bank	Ticker	CF	tstatCF	MKT	tstatMKT	CONS	tstatCONS	Rsq	N
CreditAgricoleSA	ACA	0.49	6.19	1.6	13.98	−0.0005	−1.25	0.31	2,795
SocieteGeneraleSA	GLE	0.47	5.26	1.83	13.51	−0.001	−2.02	0.34	2,795
BNPParibasSA	BNP	0.4	5.31	1.56	13.84	−0.0006	−1.64	0.33	2,795

C.3 Rolling Window Beta Estimation

252-day rolling window regression.

U.S. Banks

Figure C.1: US Large Banks, SPY

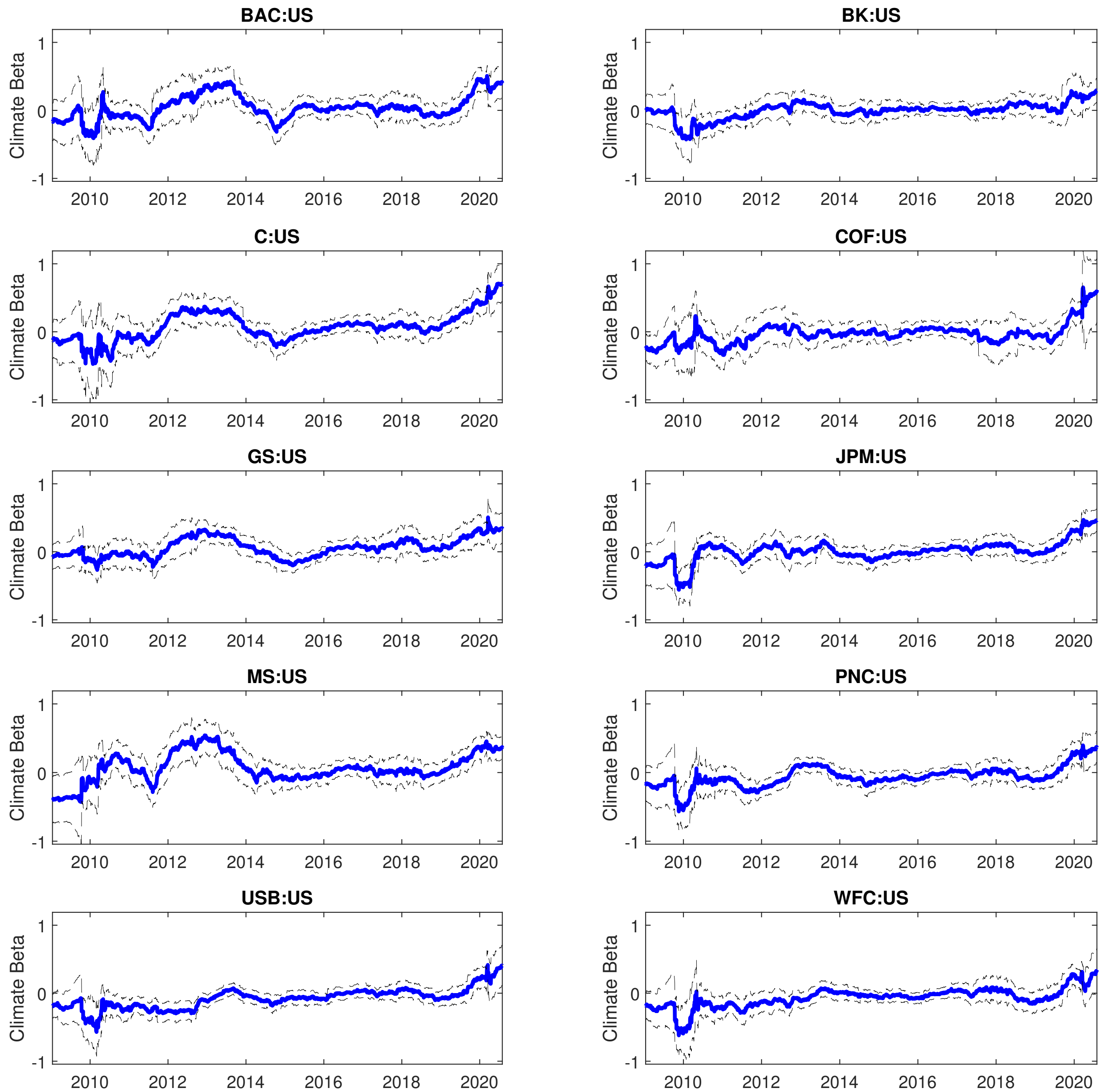
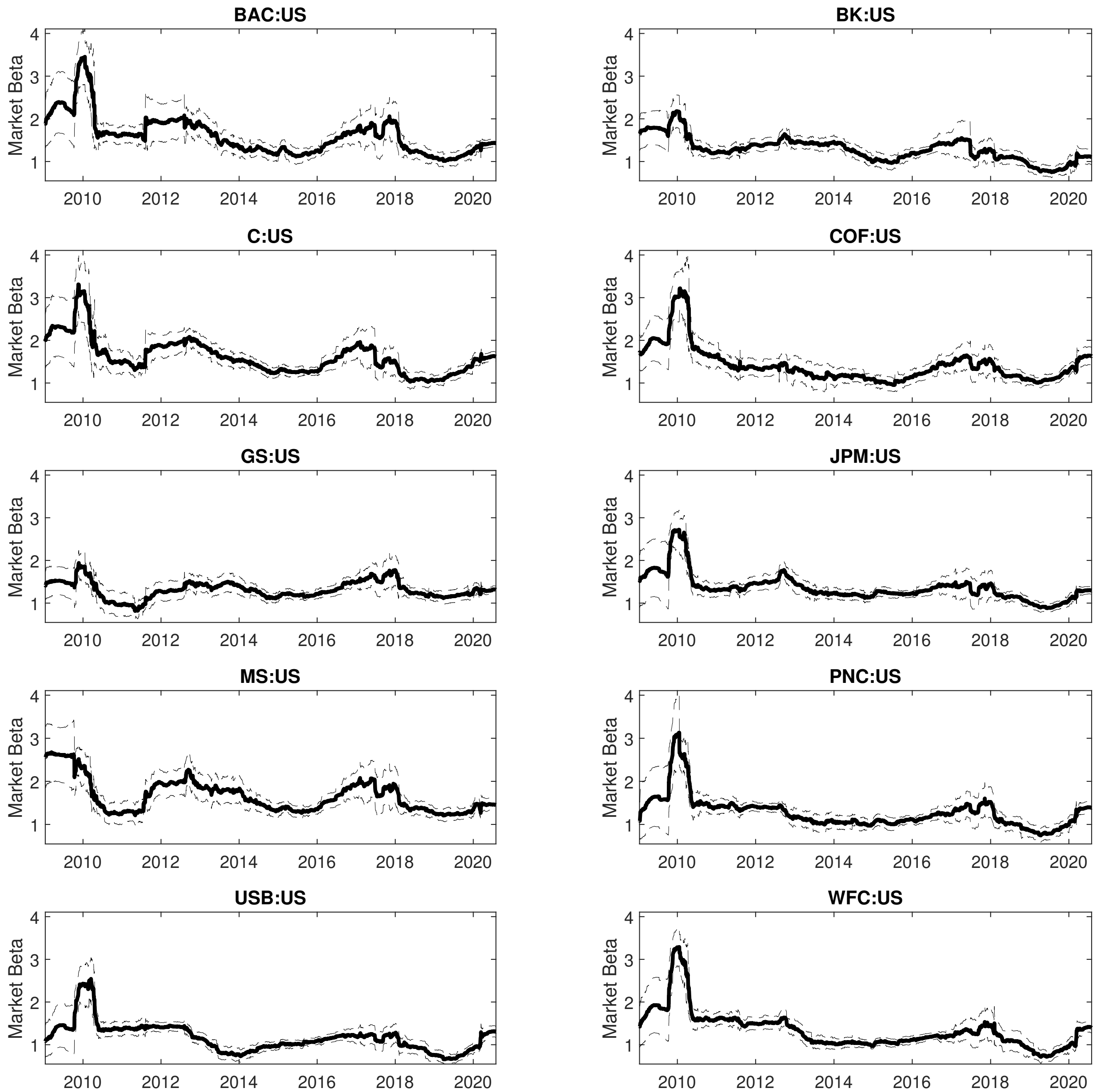


Figure C.2: US Large Banks, SPY



U.K. Banks

Figure C.3: UK Large Banks, SPY

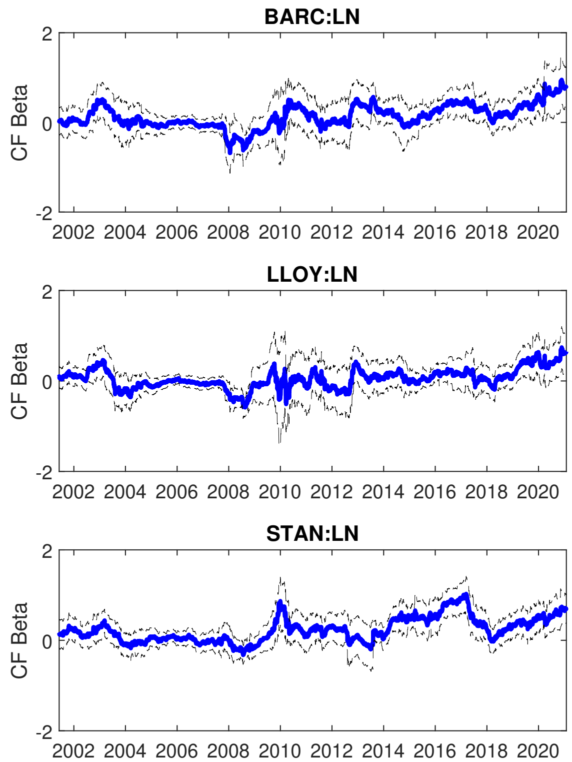
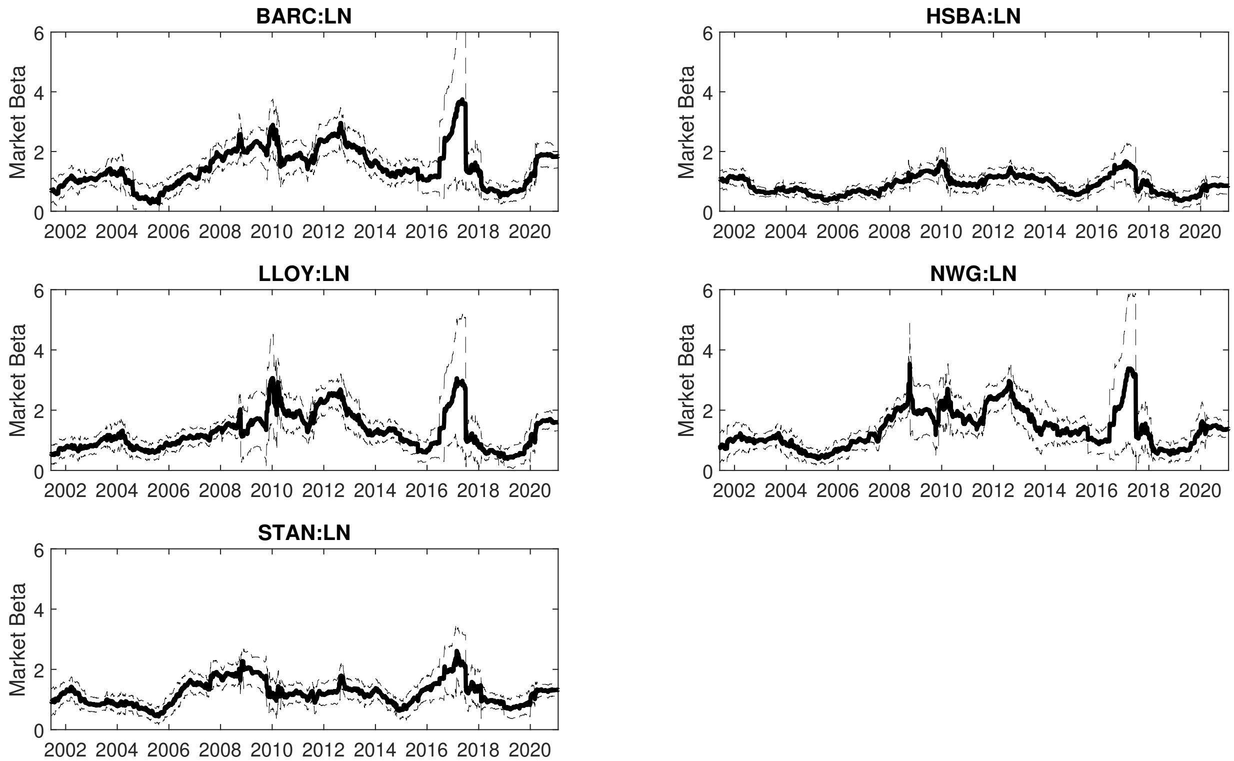


Figure C.4: UK Large Banks, SPY



Canadian Banks

Figure C.5: Canada Large Banks, SPY

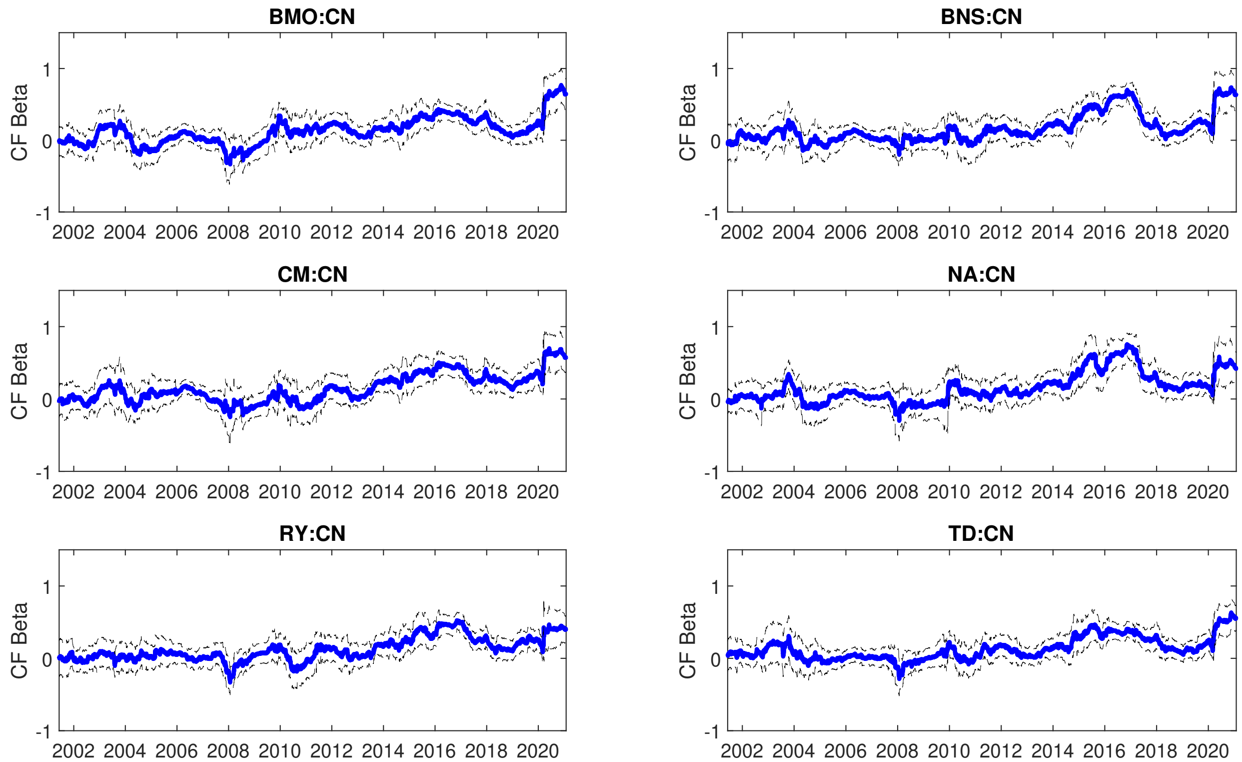
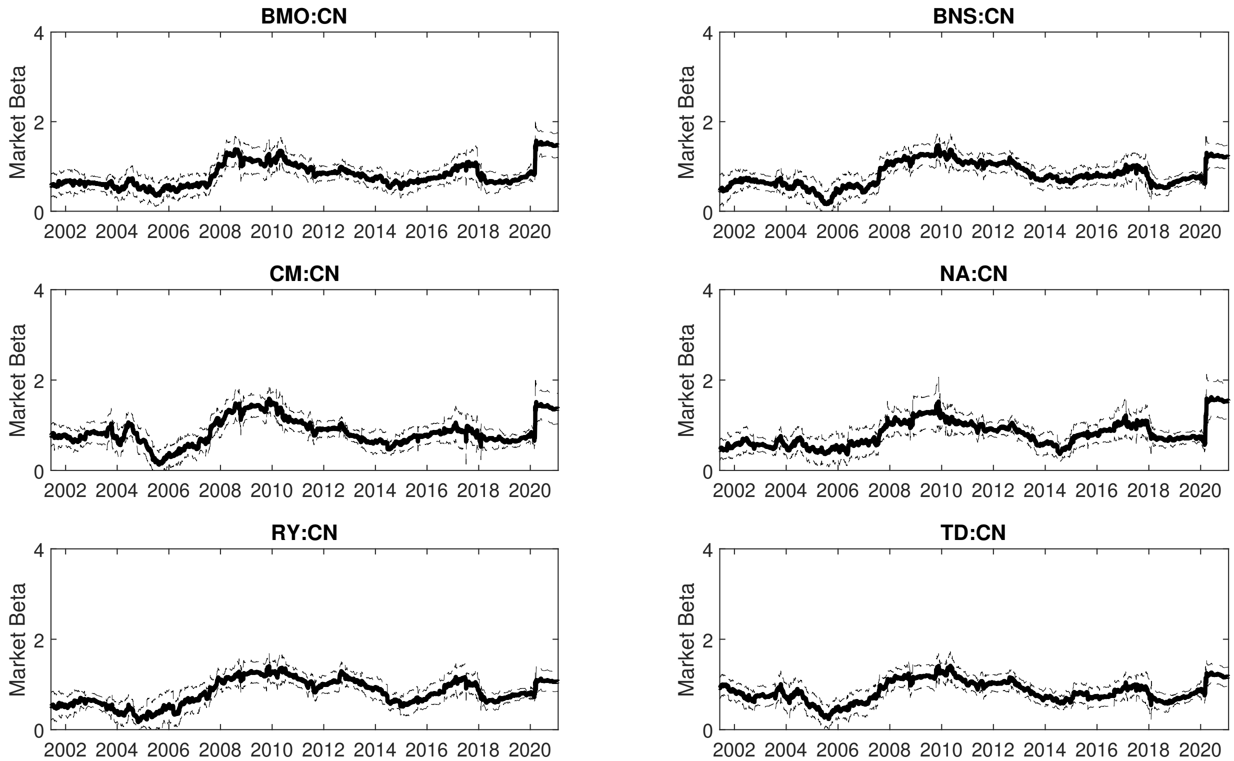


Figure C.6: Canada Large Banks, SPY



Japanese Banks

Figure C.7: Japan Large Banks, SPY

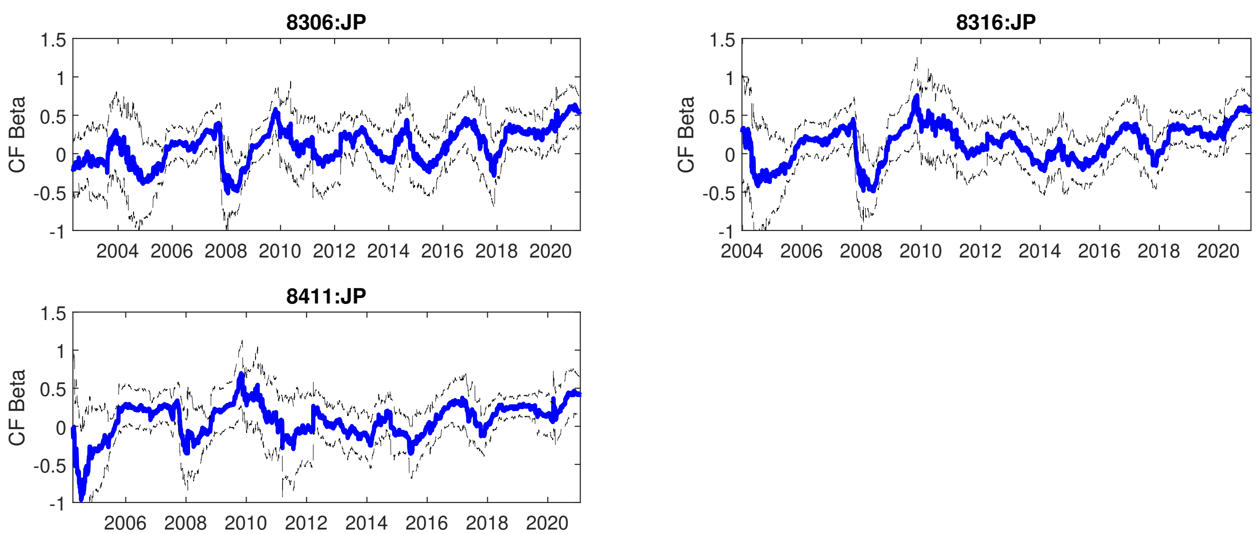
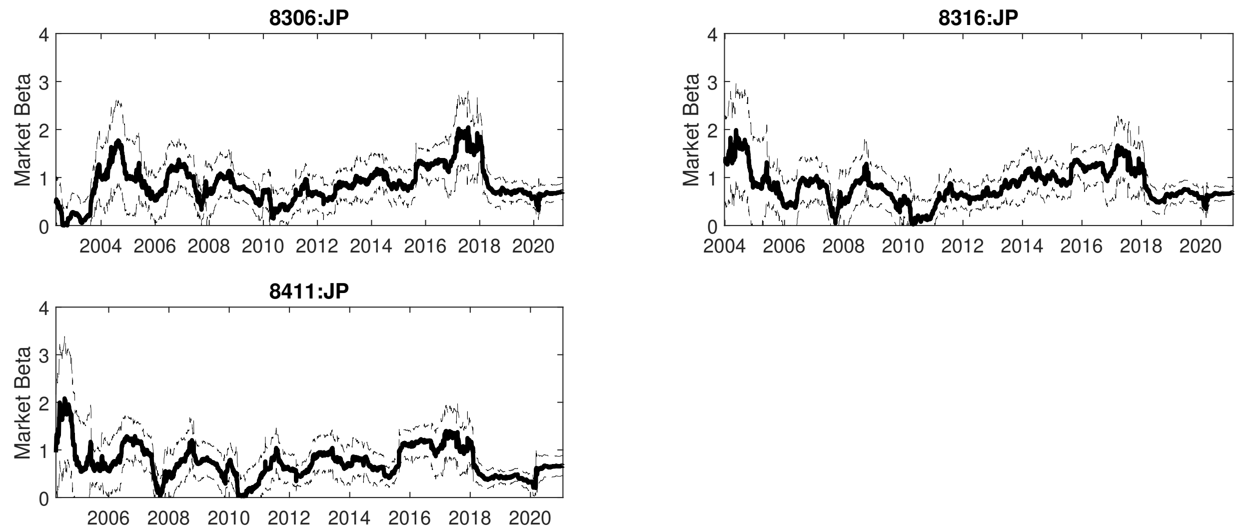


Figure C.8: Japan Large Banks, SPY



French Banks

Figure C.9: French Large Banks, SPY

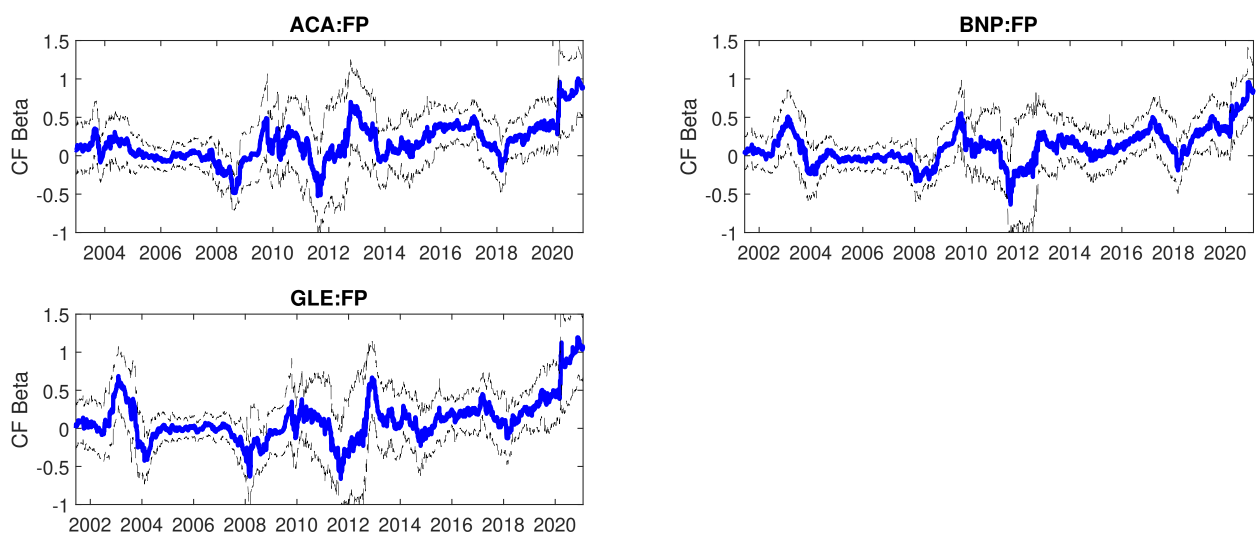
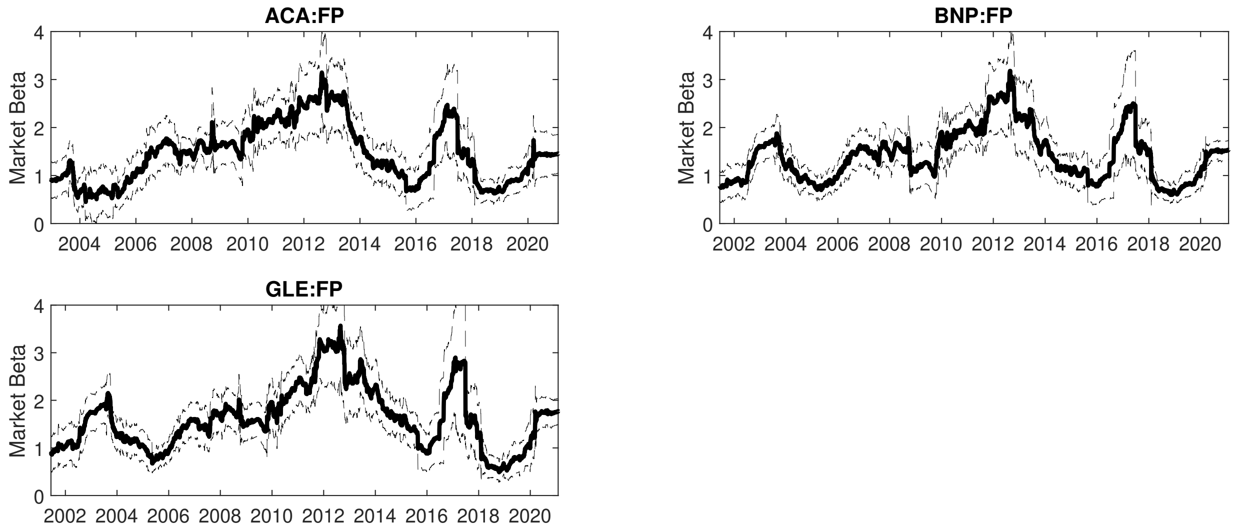


Figure C.10: French Large Banks, SPY



C.4 DCB Model Estimation

U.S. Banks

Figure C.11: Climate Beta of U.S. Banks

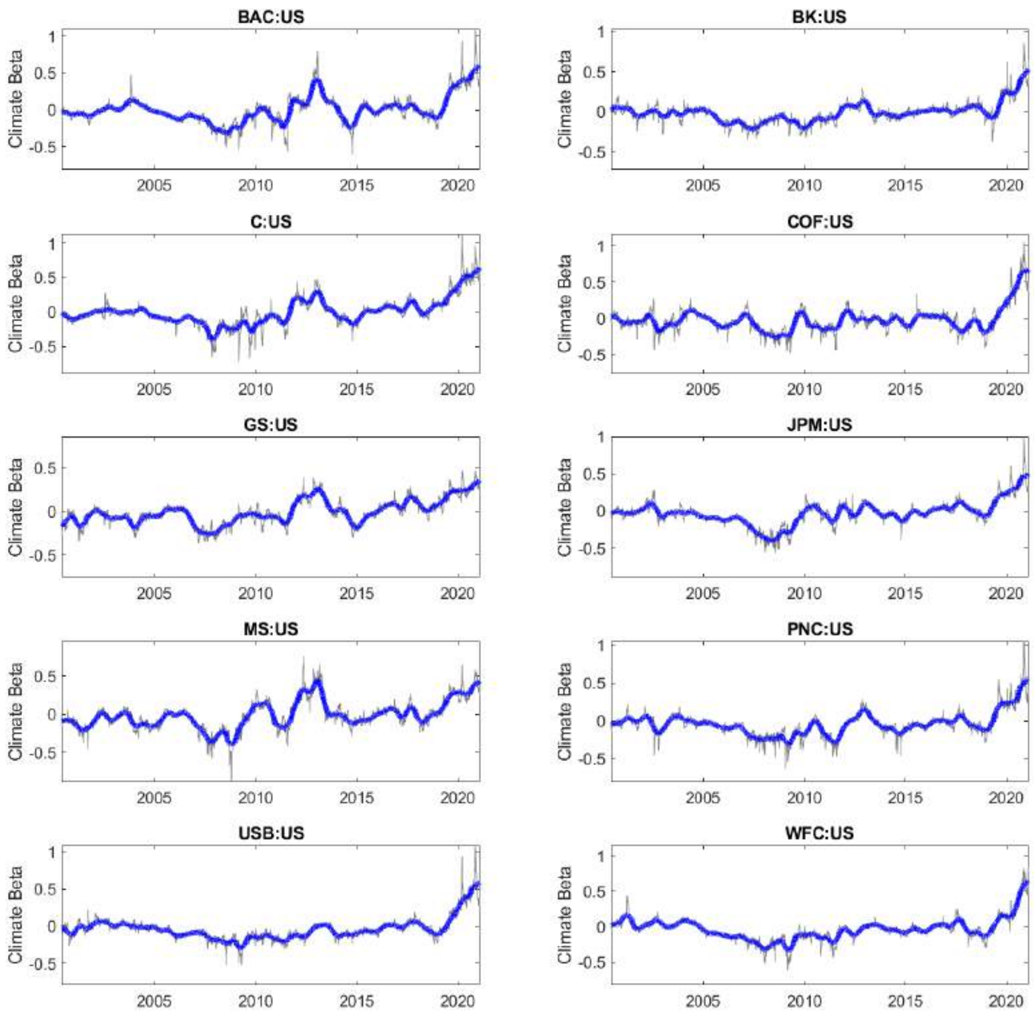
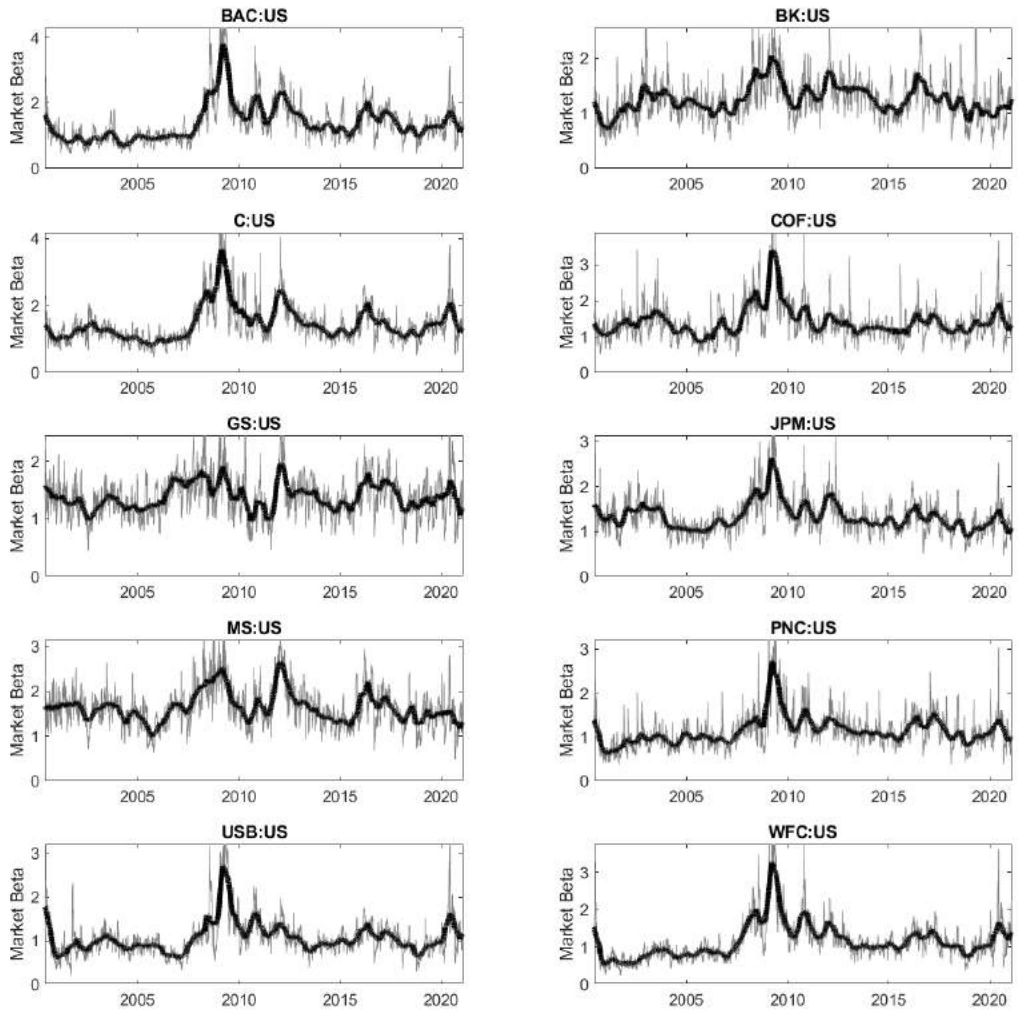


Figure C.12: Market Beta of U.S. Banks



U.K. Banks

Figure C.13: Climate Beta ($\gamma_{1it} + \gamma_{2it}$), U.K. Banks

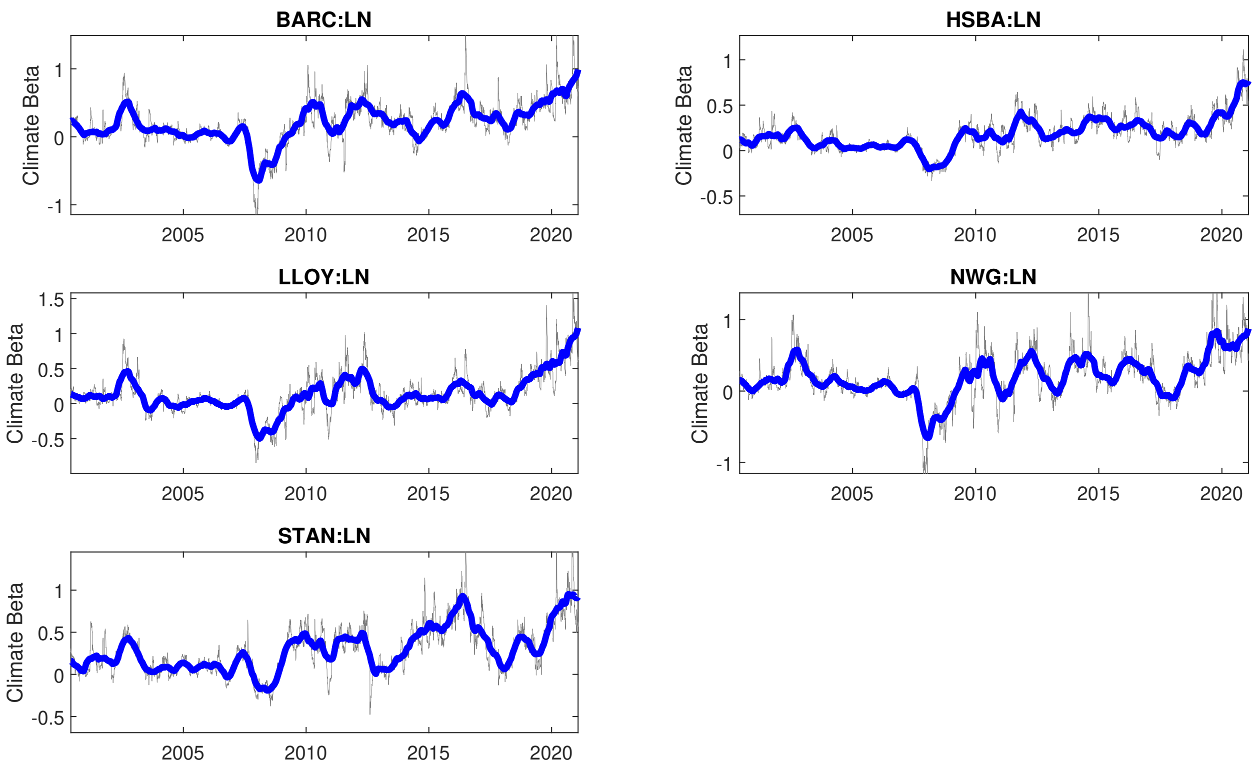
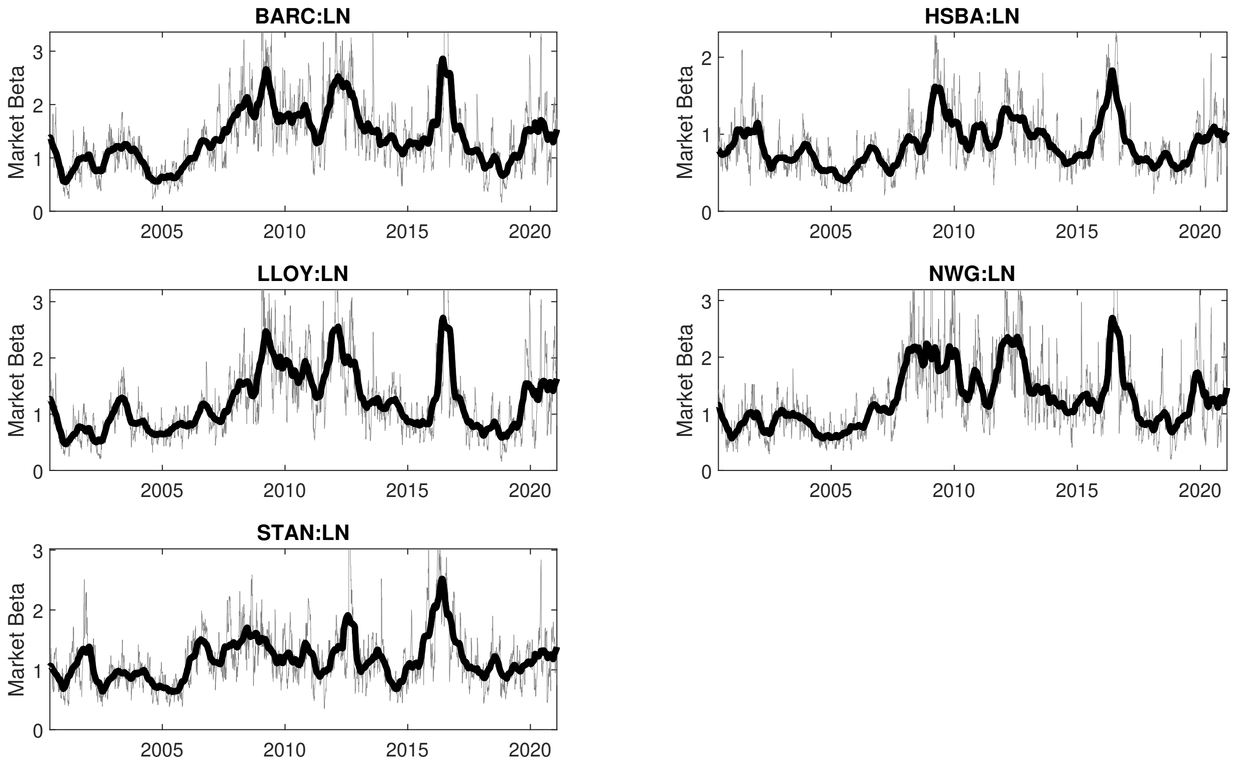


Figure C.14: Market Beta ($\beta_{1it} + \beta_{2it}$), U.K. Banks



Canadian Banks

Figure C.15: Climate Beta ($\gamma_{1it} + \gamma_{2it}$), Canadian Banks, SPY

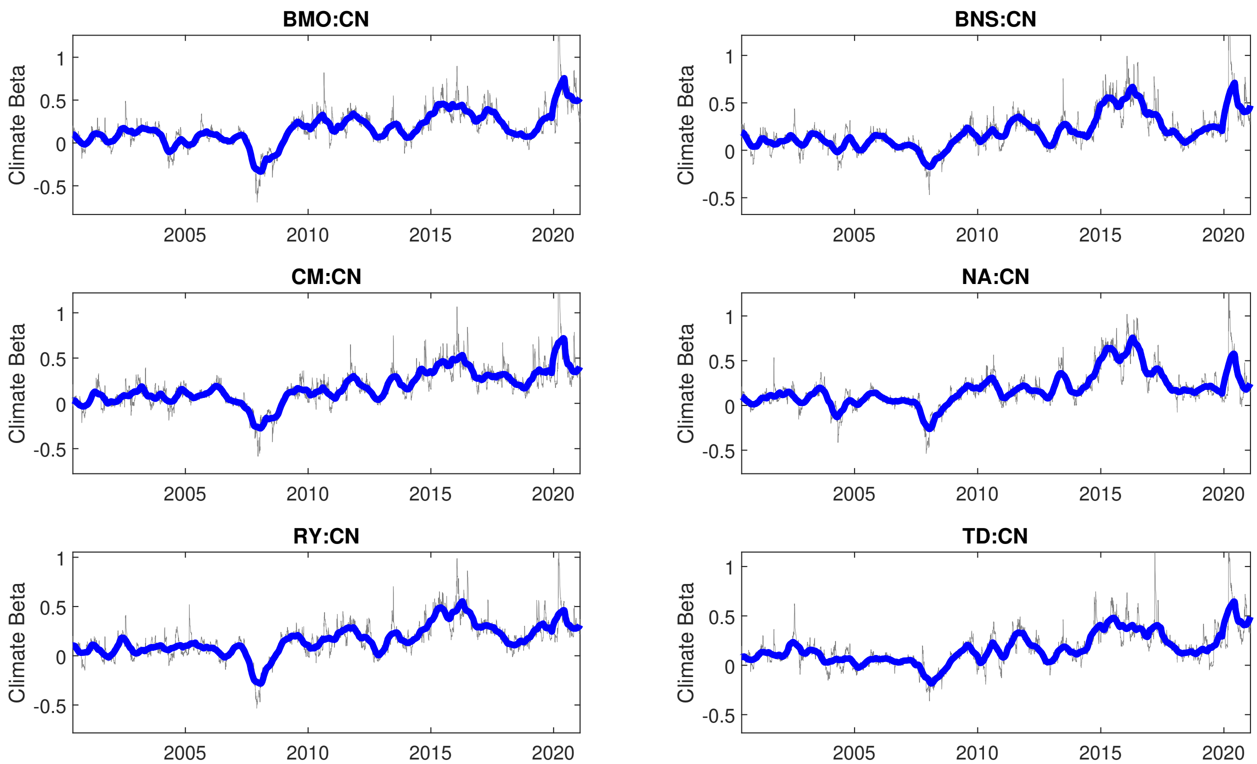
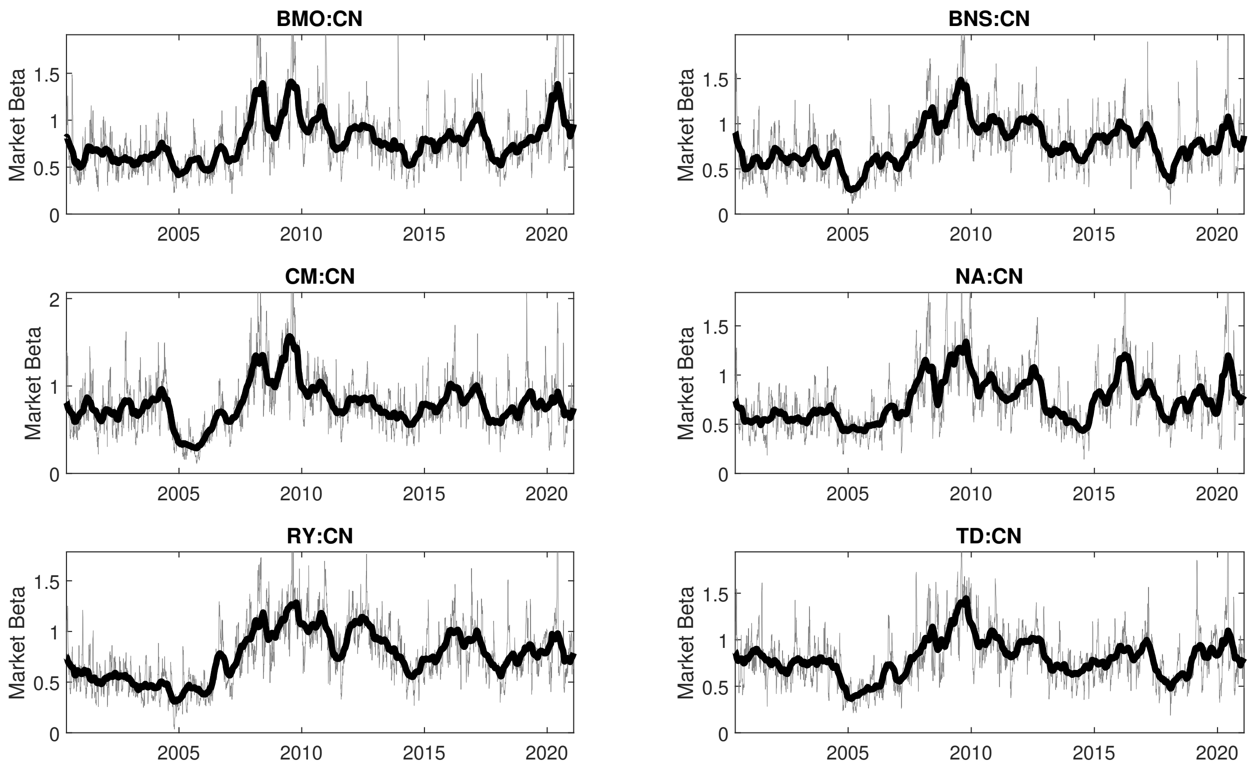


Figure C.16: Market Beta ($\beta_{1it} + \beta_{2it}$), Canadian Banks, SPY



Japanese Banks

Figure C.17: Climate Beta ($\gamma_{1it} + \gamma_{2it}$), Japanese Banks, SPY

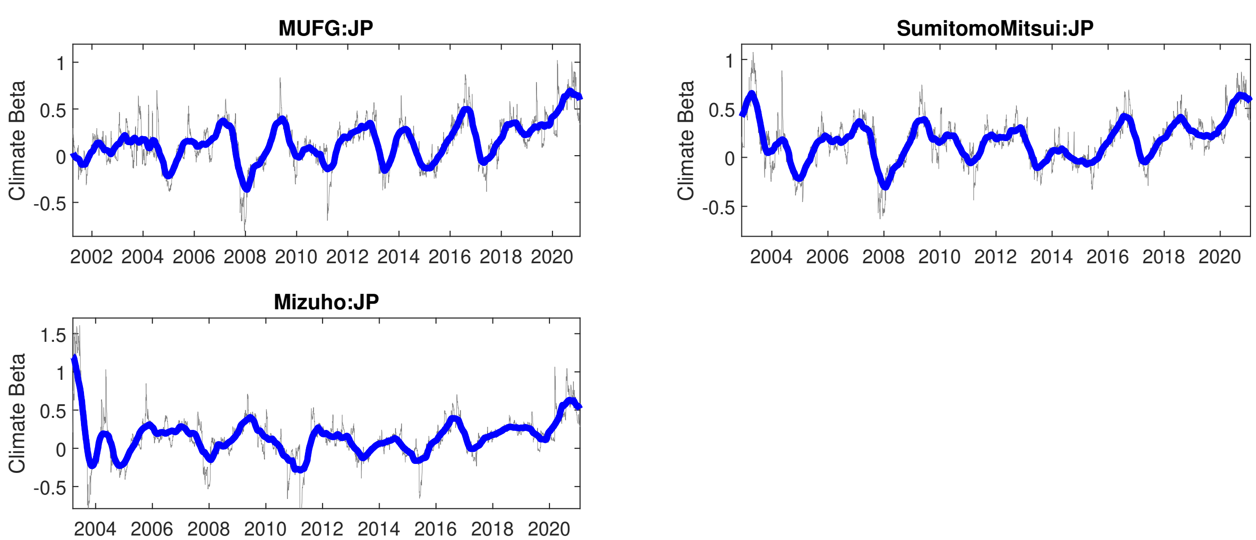
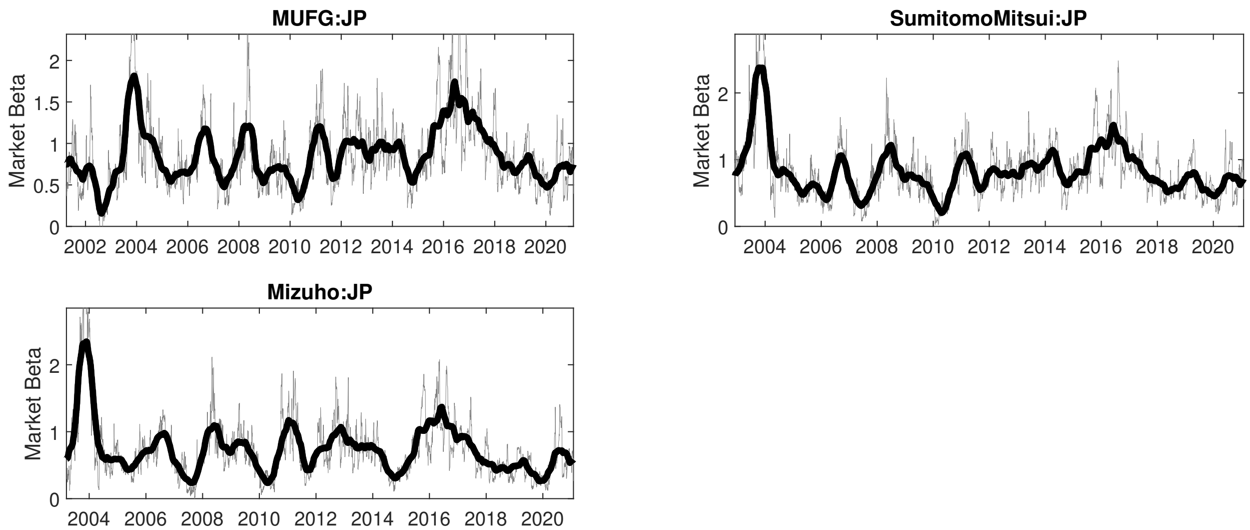


Figure C.18: Market Beta ($\beta_{1it} + \beta_{2it}$), Japanese Large Banks, SPY



French Banks

Figure C.19: Climate Beta ($\gamma_{1it} + \gamma_{2it}$), French Banks, SPY

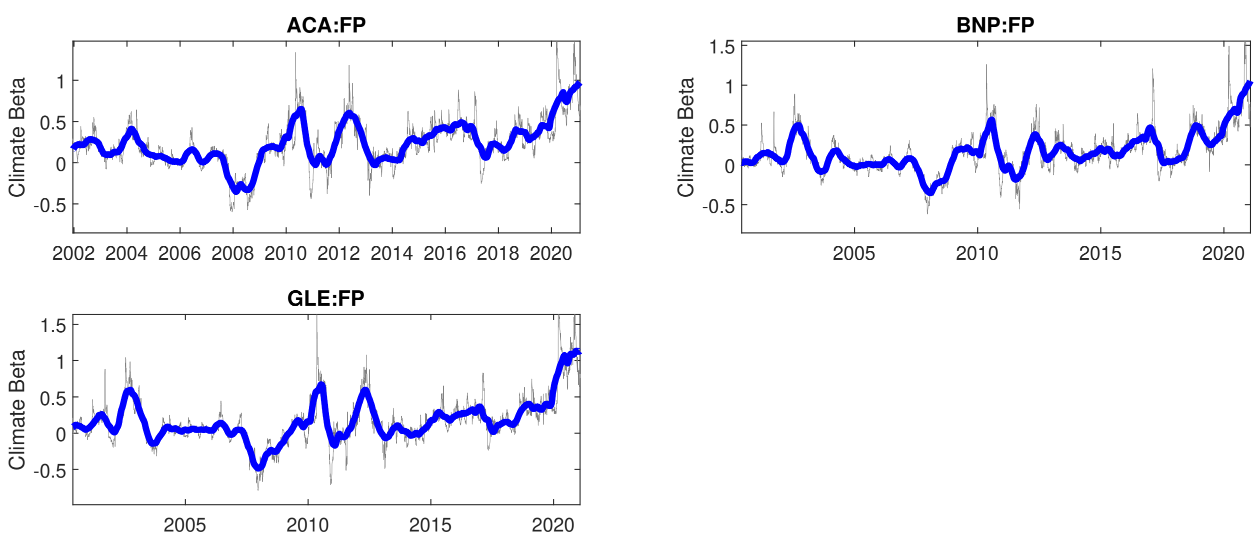
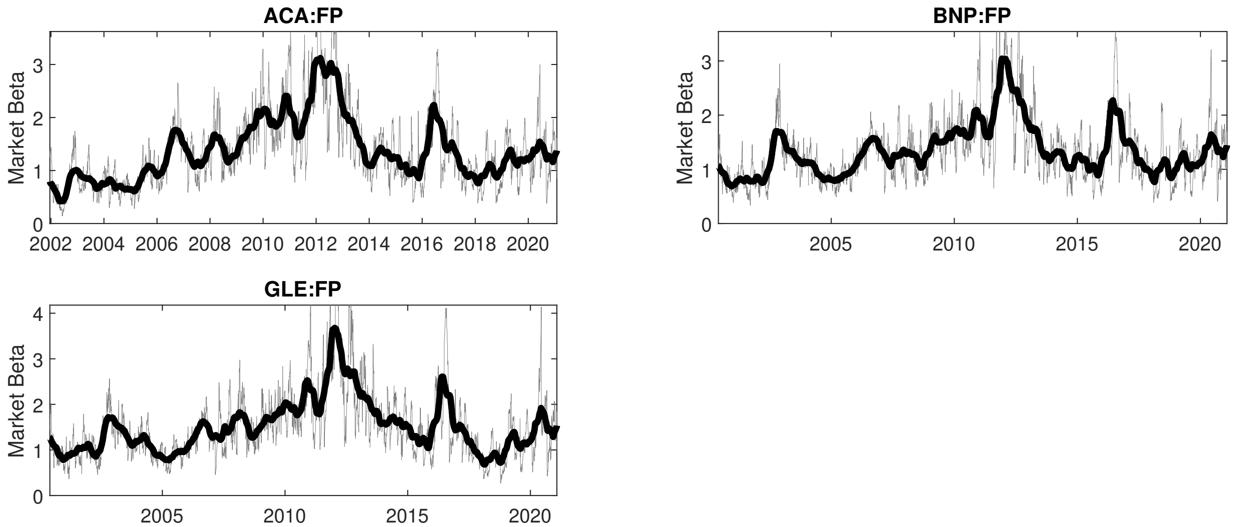


Figure C.20: Market Beta ($\beta_{1it} + \beta_{2it}$), Japanese Large Banks, SPY



C.5 CRISK during the year 2020

Canadian Banks

Figure C.21: Climate SRISK, Canadian Large Banks, SPY

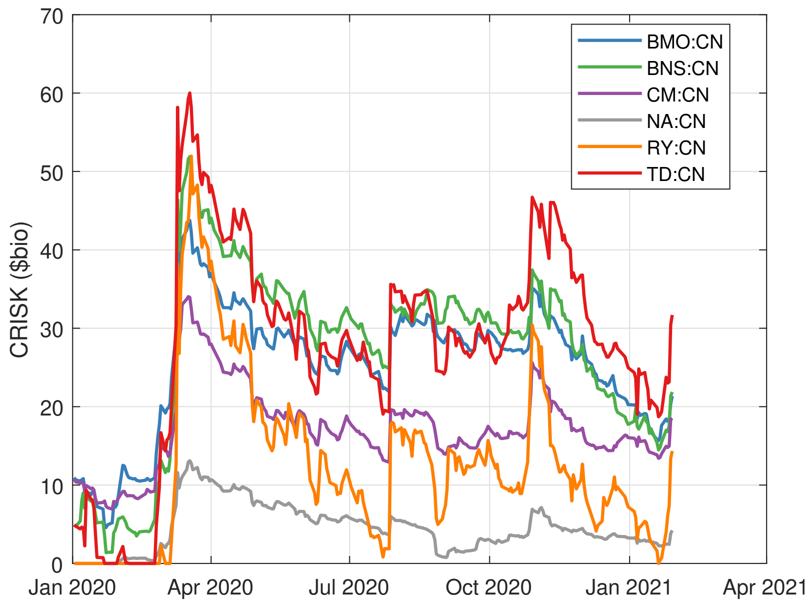


Table C.15: Climate SRISK Decomposition

SRISK(t) is Climate SRISK at the end of the first half of 2020, and SRISK(t-1) is Climate SRISK at the beginning of year 2020. dSRISK= SRISK(t)-SRISK(t-1) is the change in Climate SRISK during the first half of 2020. dDEBT is the contribution of the firm's debt to Climate SRISK. dEQUITY is the contribution of the firm's equity position on Climate SRISK. dRISK is the contribution of increase in volatility or correlation to Climate SRISK.

Bank	CRISK(t-1)	CRISK(t)	dCRISK	dDEBT	dEQUITY	dRISK
BMO:CN	10.9548	21.3558	10.401	8.4648	2.4641	-0.60693
BNS:CN	4.9275	21.8717	16.9442	6.7029	4.3385	5.6732
CM:CN	10.7674	18.5225	7.7551	9.1872	-0.50982	-1.1118
NA:CN	-0.60828	4.2192	4.8275	3.9944	0.19835	0.74084
RY:CN	-7.1409	14.3521	21.4929	16.5501	1.551	2.6546
TD:CN	4.9256	31.6962	26.7706	22.0538	3.0312	0.93249

Japanese Banks

Figure C.22: Climate SRISK, Japanese Large Banks, SPY

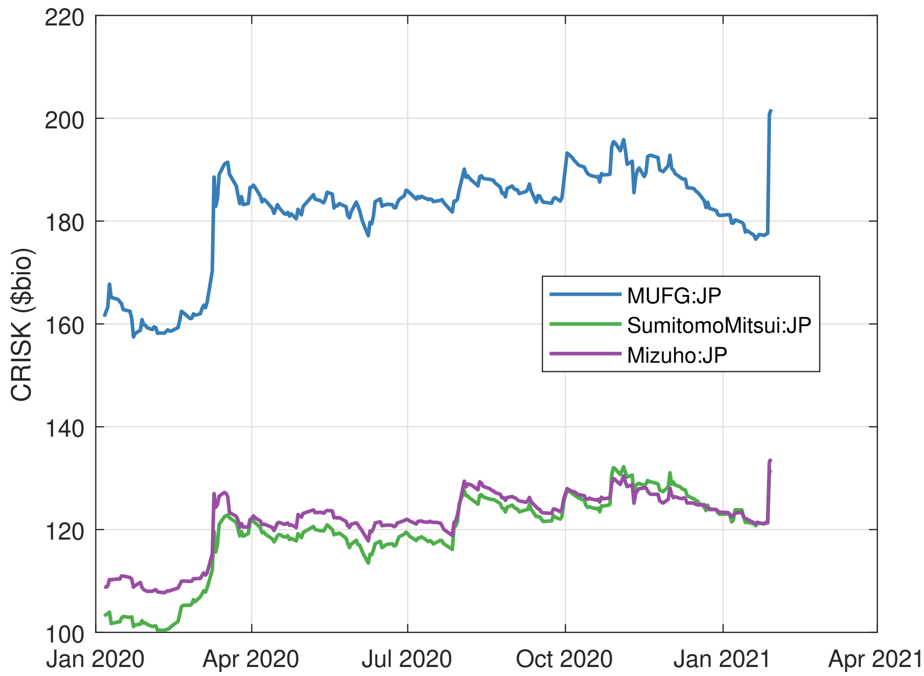


Table C.16: Climate SRISK Decomposition

SRISK(t) is Climate SRISK at the end of the first half of 2020, and SRISK(t-1) is Climate SRISK at the beginning of year 2020. dSRISK= SRISK(t)-SRISK(t-1) is the change in Climate SRISK during the first half of 2020. dDEBT is the contribution of the firm's debt to Climate SRISK. dEQUITY is the contribution of the firm's equity position on Climate SRISK. dRISK is the contribution of increase in volatility or correlation to Climate SRISK.

Bank	CRISK(t-1)	CRISK(t)	dCRISK	dDEBT	dEQUITY	dRISK
MUFG:JP	161.4246	201.7364	40.3118	32.6666	10.4816	-2.1486
SumitomoMitsui:JP	103.1496	131.5891	28.4395	20.8576	7.4704	0.40342
Mizuho:JP	108.9466	133.7309	24.7843	17.3518	5.8455	1.6807

French Banks

Figure C.23: Climate SRISK, Japanese Large Banks, SPY

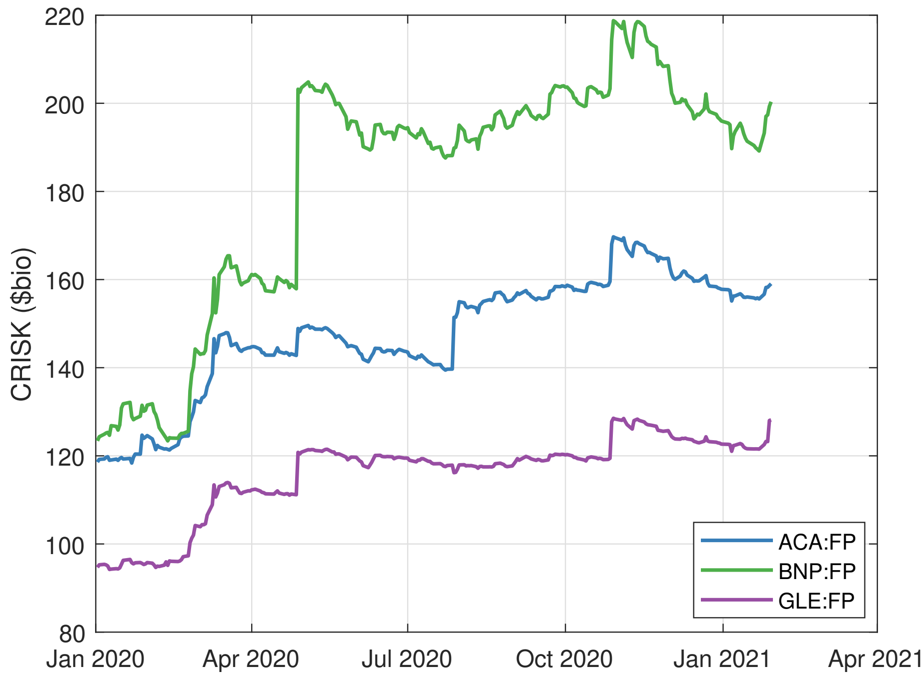


Table C.17: Climate SRISK Decomposition

SRISK(t) is Climate SRISK at the end of the first half of 2020, and SRISK(t-1) is Climate SRISK at the beginning of year 2020. dSRISK= SRISK(t)-SRISK(t-1) is the change in Climate SRISK during the first half of 2020. dDEBT is the contribution of the firm's debt to Climate SRISK. dEQUITY is the contribution of the firm's equity position on Climate SRISK. dRISK is the contribution of increase in volatility or correlation to Climate SRISK.

Bank	CRISK(t-1)	CRISK(t)	dCRISK	dDEBT	dEQUITY	dRISK
ACA:FP	118.573	159.0513	40.4784	28.6049	6.749	4.5903
BNP:FP	123.3987	200.3492	76.9504	54.8439	11.9687	9.4135
GLE:FP	94.6928	128.1609	33.4681	19.4558	7.7911	5.7895

C.6 Stressed vs. Non-stressed CRISK

Difference between CRISK and non-stressed CRISK:

$$(1-k)\left(1-\exp\left(\beta^{Climate}\log(1-\theta)\right)\right)W$$

Figure C.24: US Banks

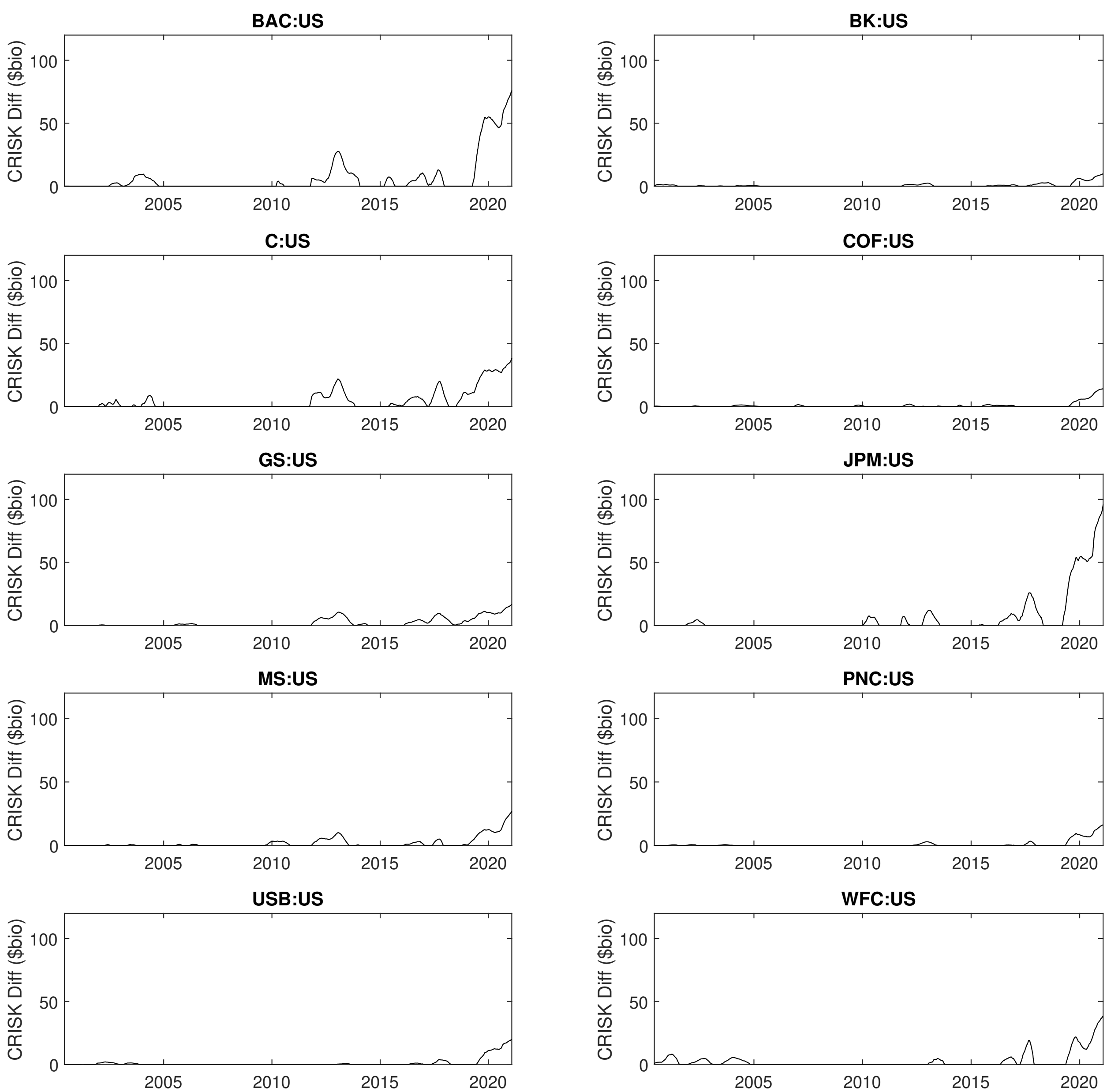


Figure C.25: US Banks

Difference between CRISK and non-stressed CRISK scaled by equity:

$$(1-k)\left(1-\exp\left(\beta^{Climate}\log(1-\theta)\right)\right)$$

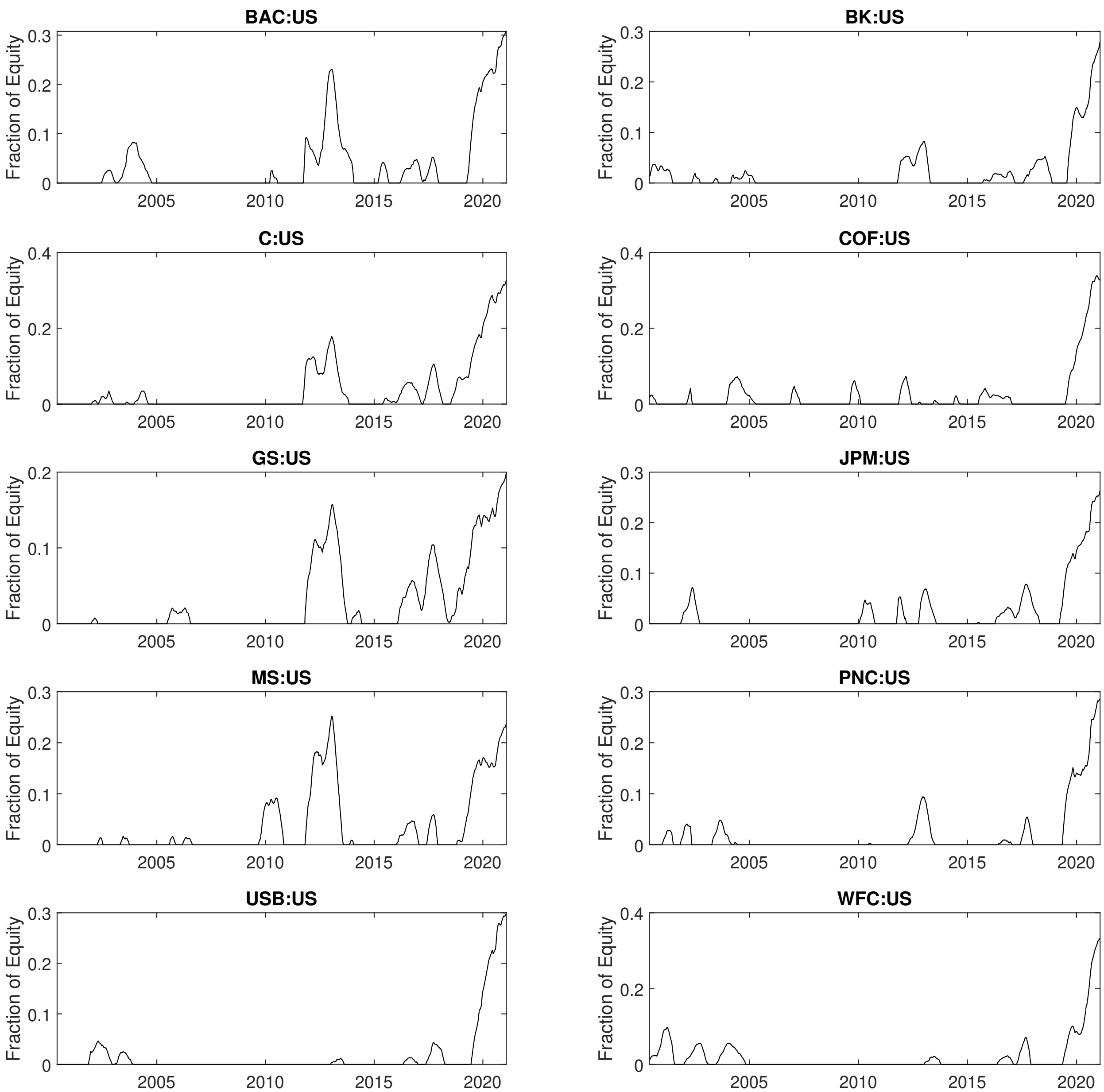


Figure C.26: Canadian Banks

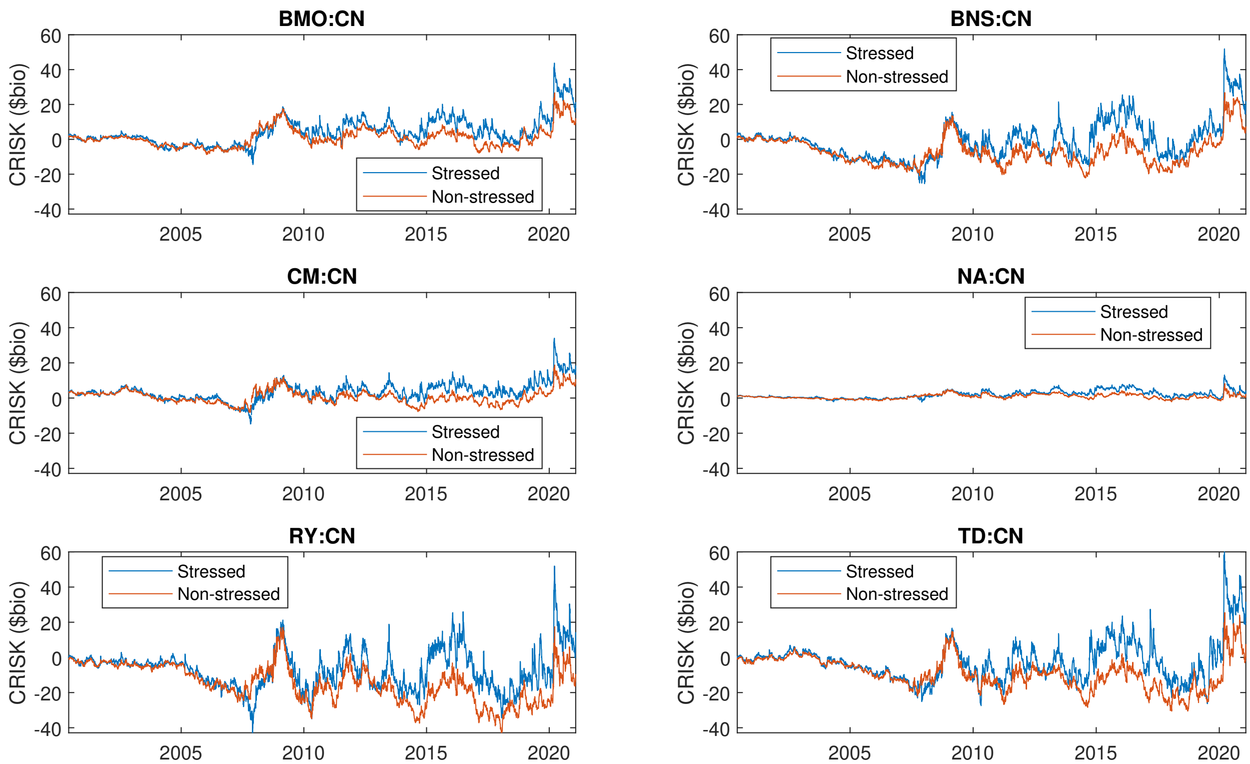


Figure C.27: Japanese Banks

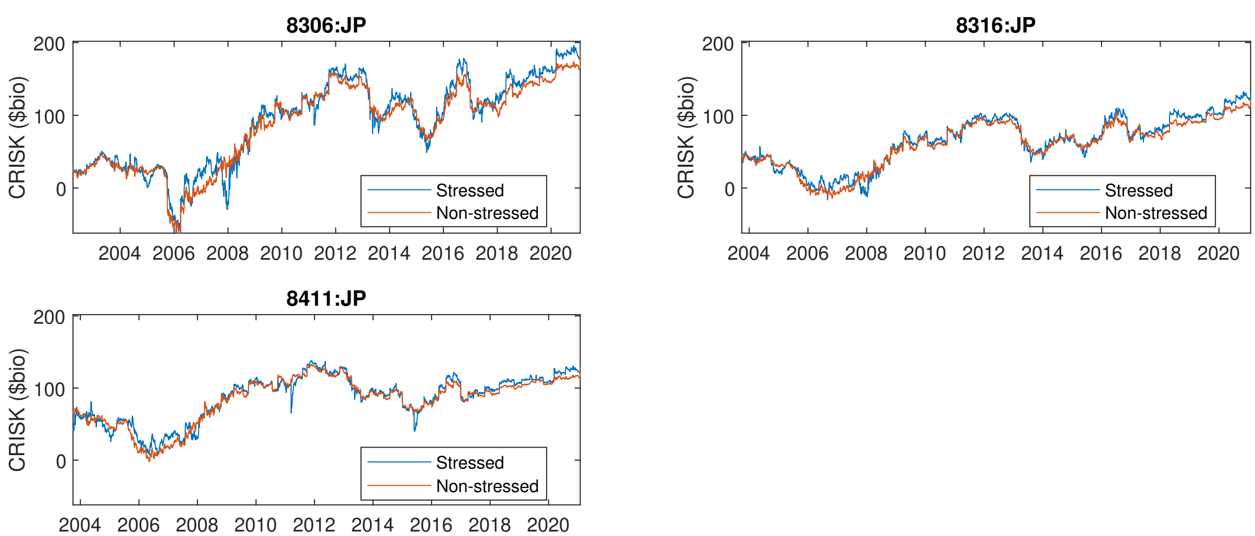


Figure C.28: French Banks

C.7 Global Banks

Figure C.29: US and UK Banks Exposure to Oil and Gas

Source: Bloomberg Loan League Table History[1]

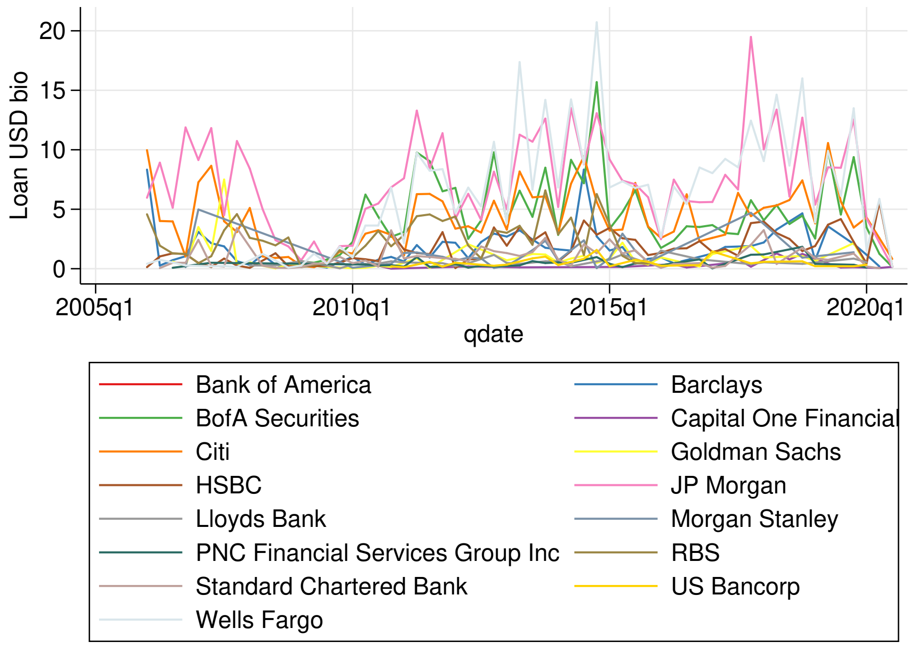


Table C.18: Top 50 Global Banks by Exposure to Oil and Gas

LoanRecent is loan amount in USD billion during Jan 2019 - June 2020.
Source: Bloomberg Loan League Table History

	bank	Country	LoanRecent	ShrRecent	CumShr
1	JP Morgan	US	42.588	0.08	0.08
2	Wells Fargo	US	42.168	0.08	0.15
3	BNP Paribas	France	37.926	0.07	0.22
4	BofA Securities	US	32.521	0.06	0.28
5	Citi	US	31.568	0.06	0.34
6	RBC Capital Markets	Canada	25.598	0.05	0.39
7	TD Securities	Canada	24.986	0.05	0.43
8	Mitsubishi UFJ Financial Group Inc	Japan	22.636	0.04	0.47
9	Mizuho Financial	Japan	22.174	0.04	0.51
10	Sumitomo Mitsui Financial	Japan	20.035	0.04	0.55
11	Scotiabank	Canada	19.292	0.04	0.59
12	BMO Capital Markets	Canada	19.2	0.04	0.62
13	HSBC	UK	18.44	0.03	0.66
14	CIBC	Canada	15.913	0.03	0.68
15	Societe Generale	France	13.75	0.03	0.71
16	Credit Agricole CIB	France	11.76	0.02	0.73
17	Barclays	UK	11.211	0.02	0.75
18	National Bank Financial Inc	Canada	8.779	0.02	0.77
19	ING Groep	Netherlands	7.888	0.01	0.78
20	First Abu Dhabi Bank PJSC	UAE	7.61	0.01	0.8
21	Bank of China	China	7.293	0.01	0.81
22	Natixis	France	7.089	0.01	0.82
23	Banco Santander	Spain	7.083	0.01	0.83
24	State Bank of India	India	6.222	0.01	0.85
25	Goldman Sachs	US	5.361	0.01	0.86
26	Standard Chartered Bank	UK	5.284	0.01	0.87
27	UniCredit	Italy	5.057	0.01	0.87
28	Credit Suisse	Switzerland	4.949	0.01	0.88
29	United Overseas Bank	Singapore	4.813	0.01	0.89
30	Deutsche Bank	Germany	3.886	0.01	0.9
31	ANZ Banking Group	Australia	3.504	0.01	0.91
32	PNC Financial Services Group Inc	US	3.212	0.01	0.91
33	DBS Group	Singapore	3.155	0.01	0.92
34	Oversea Chinese Banking Corp	Singapore	3.079	0.01	0.92
35	Westpac Banking	Australia	2.814	0.01	0.93
36	DNB ASA	Norway	2.473	0.00	0.93
37	Jefferies	US	2.442	0.00	0.94
38	Rabobank	Netherlands	2.403	0.00	0.94
39	Banco Bilbao Vizcaya Argentaria	Spain	1.861	0.00	0.94
40	Commerzbank	Germany	1.73	0.00	0.95
41	African Export Import Bank	Egypt	1.656	0.00	0.95
42	US Bancorp	US	1.651	0.00	0.95
43	Industrial Comm Bank of China	China	1.62	0.00	0.96
44	Nordea	Finland	1.534	0.00	0.96
45	Citizens Financial Group Inc	US	1.512	0.00	0.96
46	Lloyds Bank	UK	1.4	0.00	0.97
47	Commonwealth Bank Australia	Australia	1.251	0.00	0.97
48	Capital One Financial	US	1.247	0.00	0.97
49	UBS	Switzerland	1.019	0.00	0.97
50	National Australia Bank	Australia	0.9878754	0.00	0.97

Additional Robustness Results

$$\Delta\beta_{it}^{Climate} = a + b \cdot GOLoans_{i,t-1} + \varepsilon_{it}$$

where $\beta_{it}^{Climate}$ is bank i's time-averaged dynamically-estimated daily climate beta during quarter t. $GOLoans_{it}$ is bank i's new syndicated loans to the oil and gas industry (scaled by assets) in quarter t. The full sample includes 14 banks (9 U.S. banks and 5 U.K. banks) from the first quarter of 2008 to the second quarter of 2020. Standard errors are clustered by banks.

Table C.19: Climate Beta and Gas & Oil Loan Exposure

	(1)	(2)	(3)	(4)
	US	UK	FullSample	FullSample
OilGasLoan(Lag)	0.00632*	0.0791***	0.0109*	0.0105*
	(1.94)	(10.34)	(1.97)	(2.07)
Constant	0.00745***	0.0434***	0.00961***	0.0795***
	(4.41)	(6.03)	(4.64)	(5.40)
YearFE	N	N	N	Y
CtryFE	N	N	N	Y
N	441	245	686	686
RSqr	0.00223	0.0115	0.00213	0.0497

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

References

Acharya, Viral, Robert Engle, and Diane Pierret, "Testing macroprudential stress tests: The risk of regulatory risk weights," *Journal of Monetary Economics*, 2014, *65*, 36 – 53.

Acharya, Viral V. and Arvind Krishnamurthy, "Capital Flow Management with Multiple Instruments," December 2019, *26*, 169–203.

_ **and Siddharth Vij**, "Foreign Currency Borrowing of Corporations as Carry Trades: Evidence from India," *NBER Working Paper*, 2020.

_ **, Christian T. Brownlees, Farhang Farazmand, and Matthew Richardson**, "Measuring Systemic Risk," *Regulating Wall Street: The Dodd-Frank Act and the New Architecture of Global Finance, chapter 4*, 2011.

_ **, Robert F. Engle, and Matthew Richardson**, "Capital Shortfall: A New Approach to Ranking and Regulating Systemic Risks," *American Economic Review: Papers and Proceedings*, 2012.

Admati, Anat R., Peter M. Demarzo, Martin F. Hellwig, and Paul Pfleiderer, "The Leverage Ratchet Effect," *The Journal of Finance*, 2018, *73* (1), 145–198.

Adrian, Tobias, Erkko Etula, and Tyler Muir, "Financial Intermediaries and the Cross-Section of Asset Returns," *Journal of Finance*, 2014.

Ahnert, Toni, Kristin Forbes, Christian Friedrich, and Dennis Reinhardt, "Macroprudential FX regulations: Shifting the snowbanks of FX vulnerability?," *Journal of Financial Economics*, 2020.

Aiyar, Shekhar, Charles W. Calomiris, and Tomasz Wieladek, "Does Macro-Prudential Regulation Leak? Evidence from a UK Policy Experiment," *Journal of Money, Credit and Banking*, 2014, *46* (s1), 181–214.

Alam, Zohair, Adrian Alter, Jesse Eiseman, R. G Gelos, Heedon Kang, Machiko Narita, Erlend Nier, and Naixi Wang, "Digging Deeper–Evidence on the Effects of Macroprudential Policies from a New Database," *IMF Working Paper*, 2020.

Allahrakha, Meraj, Jill Cetina, and Benjamin Munyan, "Do higher capital standards always reduce bank risk? The impact of the Basel leverage ratio on the U.S. triparty repo market," *Journal of Financial Intermediation*, 2018, *34* (C), 3–16.

Allayannis, George and James P. Weston, "The Use of Foreign Currency Derivatives and Firm Market Value," *The Review of Financial Studies*, 06 2015, *14* (1), 243–276.

Anbil, Sriya and Zeynep Senyuz, "The Regulatory and Monetary Policy Nexus in the Repo Market," Finance and Economics Discussion Series 2018-027, Board of Governors of the Federal Reserve System (U.S.) April 2018.

Avdjiev, Stefan, Wenxin Du, Cathérine Koch, and Hyun Song Shin, "The Dollar, Bank Leverage, and Deviations from Covered Interest Parity," *American Economic Review: Insights*, September 2019, *1* (2), 193–208.

Ban, Hye Jung and Jeong Kyo Kim, "The Determinants of Hedging with Derivatives," *Korean Academic Society of Business Administration*, 2004, *33* (1), 25–49.

Behera, Harendra Kumar, "Onshore and offshore market for Indian rupee: recent evidence on volatility and shock spillover," *Macroeconomics and Finance in Emerging Market Economies*, 2011.

Bergant, Katharina, Francesco Grigoli, Niels-Jakob H Hansen, and Damiano Sandri, "Dampening Global Financial Shocks: Can Macroprudential Regulation Help (More than Capital Controls)?," *IMF Working Paper*, 2020.

Bernanke, Ben and Mark Gertler, "Agency Costs, Net Worth, and Business Fluctuations," *American Economic Review*, 1989, *79* (1), 14–31.

Bernanke, Ben S and Alan S Blinder, "Credit, Money, and Aggregate Demand," *American Economic Review*, May 1988, *78* (2), 435–439.

Bicu, Andreea, Louisa Chen, and David Elliott, "The leverage ratio and liquidity in the gilt and repo markets," Bank of England working papers 690, Bank of England November 2017.

Blackwell, Matthew, Stefano Iacus, Gary King, and Giuseppe Porro, "Cem: Coarsened Exact Matching in Stata," *The Stata Journal*, 2009, *9* (4), 524–546.

Bolton, Patrick and Marcin T. Kacperczyk, "Do Investors Care about Carbon Risk?," *Journal of Financial Economics*, 2020.

Brownlees, Christian T. and Robert F. Engle, "SRISK: A Conditional Capital Shortfall Index for Systemic Risk Measurement," *Review of Financial Studies*, 2017.

Brunnermeier, Markus K. and Yuliy Sannikov, "A Macroeconomic Model with a Financial Sector," *American Economic Review*, 2014.

Bruno, Valentina and Hyun Song Shin, "Assessing Macroprudential Policies: Case of South Korea*," *The Scandinavian Journal of Economics*, 2014, *116* (1), 128–157.

_ , Ilhyock Shim, and Hyun Song Shin, "Comparative assessment of macroprudential policies," *Journal of Financial Stability*, 2017, *28* (C), 183–202.

Cadarajat, Yayat and Alexander Lubis, "Offshore and onshore IDR market: an evidence on information spillover," *Bulletin of Monetary Economics and Banking*, 2012.

Campello, Murillo, Chen Lin, Yue Ma, and Hong Zou, "The Real and Financial Implications of Corporate Hedging," *The Journal of Finance*, 2011, *66* (5), 1615–1647.

Carter, David A., Daniel A. Rogers, and Betty J. Simkins, "Does Hedging Affect Firm Value? Evidence from the US Airline Industry," *Financial Management*, 2006, *35* (1), 53–86.

Cerutti, Eugenio, Stijn Claessens, and Luc Laeven, "The Use and Effectiveness of Macroprudential Policies: New Evidence," *IMF Working Papers*, 2015.

Chava, Sudheer, "Environmental Externalities and Cost of Capital," *Management Science*, 2014, *60* (9), 2223–2247.

Choi, Changho, "Impact of FX-Related Macroprudential Measures in Korea: An Assessment," in Kyuil Chung, Soyoung Kim, Hail Park, Changho Choi, and Hyun Song Shin, eds., *Volatile Capital Flows in Korea*, Palgrave Macmillan, New York, 2014, chapter 8, pp. 187–216.

Coffey, Niall, Warren B. Hrung, and Asani Sarkar, "Capital Constraints, Counterparty Risk, and Deviations from Covered Interest Rate Parity," *Federal Reserve Bank of New York Staff Reports*, 2009.

Dodd, Randall, "Exotic Derivatives Losses in Emerging Markets: Questions of Suitability Concerns for Stability," *IMF Working Paper*, 2009.

Du, Wenxin, Alexander Tepper, and Adrien Verdelhan, "Deviations from Covered Interest Rate Parity," *The Journal of Finance*, 2018, *73* (3), 915–957.

_ **, Benjamin M. Hebert, and Amy Wang**, "Are Intermediary Constraints Priced?," *NBER Working Paper*, 2019.

Duffie, Darrell, "Financial Regulatory Reform After the Crisis: An Assessment," *Management Science*, 2018, *64* (10), 4835–4857.

Engle, Robert F., "Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroscedasticity models," *Journal of Business and Economic Statistics*, 2002.

_ , "Anticipating correlations: A new paradigm for risk management," *Princeton, NJ: Princeton University Press*, 2009.

_ , "Dynamic Conditional Beta," *Journal of Financial Econometrics*, 2016.

Engle, Robert F, Stefano Giglio, Bryan Kelly, Heebum Lee, and Johannes Stroebel, "Hedging Climate Change News," *The Review of Financial Studies*, 02 2020, *33* (3), 1184–1216.

Fleckenstein, Matthias and Francis A. Longstaff, "Shadow Funding Costs: Measuring the Cost of Balance Sheet Constraints," *NBER Working Papers*, January 2018, (24224).

Frenkel, Jacob A. and Richard M. Levich, "Covered Interest Arbitrage: Unexploited Profits?," *Journal of Political Economy*, 1975, *83* (2), 325–338.

_ **and** _ , "Transaction Costs and Interest Arbitrage: Tranquil versus Turbulent Periods," *Journal of Political Economy*, 1977, *85* (6), 1209–1226.

Gabaix, Xavier and Matteo Maggiori, "International Liquidity and Exchange Rate Dynamics*," *The Quarterly Journal of Economics*, 03 2015, *130* (3), 1369–1420.

_ , **Arvind Krishnamurthy, and Olivier Vigneron**, "Limits of Arbitrage: Theory and Evidence from the Mortgage-Backed Securities Market," *Journal of Finance*, 2007.

Garleanu, Nicolae and Lasse Heje Pedersen, "Margin-based Asset Pricing and Deviations from the Law of One Price," *Review of Financial Studies*, 2011.

Giglio, Stefano, Bryan Kelly, and Johannes Stroebel, "Climate Finance," *Annual Review of Financial Economics*, 2020.

Gilje, Erik P. and Jérôme P. Taillard, "Does Hedging Affect Firm Value? Evidence from a Natural Experiment," *The Review of Financial Studies*, 07 2017, *30* (12), 4083–4132.

Ginglinger, Edith and Moreau Quentin, "Climate Risk and Capital Structure," *Université Paris-Dauphine Research Paper No. 3327185, European Corporate Governance Institute – Finance Working Paper No. 737/2021*, 2019.

Goyal, Rajan, Rajeev Jain, and Soumasree Tewari, "Non deliverable forward and onshore Indian rupee market: a study on inter-linkages," *Reserve Bank of India Working Paper Series*, 2013.

Greenwood, Robin, Samuel G. Hanson, Jeremy C. Stein, and Adi Sunderam, "Strengthening and Streamlining Bank Capital Regulation," *Brookings Papers on Economic Activitiy*, 2017, *Fall.*

Haynes, Richard, Lihong McPhail, and Haoxiang Zhu, "When Leverage Ratio Meets Derivatives: Running Out Of Options?," *CFTC Research Paper*, 2019.

He, Zhiguo and Arvind Krishnamurthy, "A Model of Capital and Crises," *Review of Economic Studies*, 2012.

_ **and** _ , "Intermediary Asset Pricing," *American Economic Review*, 2013.

_ , **Bryan Kelly, and Asaf Manela**, "Intermediary Asset Pricing: New Evidence from Many Asset Classes," *Journal of Financial Economics*, 2017.

Holmstrom, Bengt and Jean Tirole, "Financial Intermediation, Loanable Funds, and The Real Sector," *The Quarterly Journal of Economics*, 1997, *112* (3), 663–691.

Horen, Neeltje Van and Antonis Kotidis, "Repo market functioning: the role of capital regulation," Bank of England working papers 746, Bank of England 2018.

Ilhan, Emirhan, Zacharias Sautner, and Grigory Vilkov, "Carbon Tail Risk," *The Review of Financial Studies*, 06 2020, *34* (3), 1540–1571.

International Monetary Fund, "The Interaction of Monetary and Macroprudential Policies: IMF Background Paper," *IMF*, 2012.

Ivashina, Victoria, David S. Scharfstein, and Jeremy C. Stein, "Dollar Funding and the Lending Behavior of Global Banks*," *The Quarterly Journal of Economics*, 04 2015, *130* (3), 1241–1281.

Jermann, Urban J., "Negative Swap Spreads and Limited Arbitrage," *Working Paper*, 2018.

Jin, Yanbo and Philippe Jorion, "Firm Value and Hedging: Evidence from U.S. Oil and Gas Producers," *The Journal of Finance*, 2006, *61* (2), 893–919.

Keller, Lorena, "Capital Controls and Risk Misallocation: Evidence From a Natural Experiment," *Jacobs Levy Equity Management Center for Quantitative Financial Research Paper*, 2019.

Khwaja, Asim Ijaz and Atif Mian, "Tracing the Impact of Bank Liquidity Shocks: Evidence from an Emerging Market," *American Economic Review*, September 2008, *98* (4), 1413–42.

Kim, Kyungsoo and Chi-Young Song, "Foreign exchange liberalization and its implications: the case of the won," *Currency internationalization: global experiences and implications for the renminbi*, 2010.

Kim, Woochan, "Structural Issues in the Korean FX Market during the 2008 Global Financial Crisis: Empirical Investigation of FX Risk Management by Nonfinancial Public Firms," *Korea Development Institute Paper*, 2010.

Klinger, Sven and Suresh Sundaresan, "An Explanation of Negative Swap Spreads: Demand for Duration from Underfunded Pension Plans," *Journal of Finance, Forthcoming*, 2018.

Koijen, Ralph S. J. and Motohiro Yogo, "The Cost of Financial Frictions for Life Insurers," *American Economic Review*, 2015.

Krueger, Philipp, Zacharias Sautner, and Laura T Starks, "The Importance of Climate Risks for Institutional Investors," *The Review of Financial Studies*, 02 2020, *33* (3), 1067–1111.

Ma, Guonan, Corrinne Ho, and Robert N McCauley, "The markets for non-deliverable forwards in Asian currencies," *BIS Quarterly Review*, 2004.

Mancini-Griffoli, Tommaso and Angelo Ranaldo, "Limits to arbitrage during the crisis: funding liquidity constraints and covered interest parity," *Swiss National Bank Working Paper*, 2011.

McCauley, Robert, Chang Shu, and Guonan Ma, "Non-deliverable forwards: 2013 and beyond1," *BIS Quarterly Review*, 2014.

McCauley, Robert N and Jens Zukunft, "Asian banks and the international interbank market," *BIS Quarterly*, 2008.

Misra, S and H Behera, "Non-deliverable foreign exchange forward market: an overview," *Reserve Bank of India Occasional Papers*, 2006.

Moreira, Alan and Alexi Savov, "The macroeconomics of shadow banking," *The Journal of Finance*, 2017, *72* (6), 2381–2432.

NGFS, "Guide for Supervisors: Integrating climate-related and environmental risks into prudential supervision," Technical Report, Network for Greening the Financial System May 2020.

Ostry, Jonathan, Atish Ghosh, Marcos Chamon, and Mahvash Qureshi, "Tools for managing financial-stability risks from capital inflows," *Journal of International Economics*, 2012, *88* (2), 407–421.

Paravisini, Daniel, Veronica Rappoport, Philipp Schnabl, and Daniel Wolfenzon, "Dissecting the Effect of Credit Supply on Trade: Evidence from Matched Credit-Export Data," *The Review of Economic Studies*, 09 2014, *82* (1), 333–359.

Ree, Jack Joo K., Kyungsoo Yoon, and Hail Park, "FX Funding Risks and Exchange Rate Volatility – Korea's Case," *IMF Working Paper*, 2012.

Reinders, Henk Jan, Dirk Schoenmaker, and Mathijs A Van Dijk, "A Finance Approach to Climate Stress Testing," CEPR Discussion Papers 14609, C.E.P.R. Discussion Papers April 2020.

Reinhardt, Dennis and Rhiannon Sowerbutts, "Regulatory arbitrage in action: evidence from banking flows and macroprudential policy," *Bank of England working papers*, September 2015, (546).

Santaella, Julio A, "Currency carry trades in Latin America," *BIS Papers No 81*, 2015.

Schnabl, Philipp, "The International Transmission of Bank Liquidity Shocks Evidence from an Emerging Market," *The Journal of Finance*, 2012.

Schwert, Michael, "Bank Capital and Lending Relationships," *The Journal of Finance*, 2018, *73* (2), 787–830.

Siriwardane, Emil N., "Limited Investment Capital and Credit Spreads," *Journal of Finance, Forthcoming*, 2018.

Stein, Jermey C., "An Adverse-Selection Model of Bank Asset and Liability Management with Implications for the Transmission of Monetary Policy," *RAND Journal of Economics*, 1998, *29* (3), 466–486.

Wang, Yi David, "Convertibility restriction in China's foreign exchange market and its impact on forward pricing," *Journal of Banking and Finance*, 2015.