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CAPITAL FLOWS AND THE RISK-TAKING CHANNEL OF MONETARY POLICY

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ABSTRACT

We study the dynamics linking monetary policy with bank leverage and show that adjustments in leverage act as the linchpin in the monetary transmission mechanism that works through fluctuations in risk-taking. Motivated by the evidence, we formulate a model of the "risk-taking channel" of monetary policy in the international context that rests on the feedback loop between increased leverage of global banks and capital flows amid currency appreciation for capital recipient economies.

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An online appendix is available at:
http://www.nber.org/data-appendix/w18942

1 Introduction

Low interest rates maintained by advanced economy central banks have led to a lively debate on the nature of global liquidity and its transmission across borders. A popular narrative in the financial press has been that low interest rates in advanced economies act as a driver of cross-border capital flows, resulting in overheating and excessive credit growth in the recipient economies.[1] However, the precise economic mechanism behind such a narrative has been more difficult to pin down.

One way to shed light on the debate is to start with the empirical evidence on the cyclical nature of leverage and financial conditions. Gourinchas and Obstfeld (2012) conduct an empirical study using data from 1973 to 2010 for both advanced and emerging economies on the determinants of financial crises. They find that two factors emerge consistently as the most robust and significant predictors of financial crises, namely a rapid increase in leverage and a sharp real appreciation of the currency. Their finding holds both for emerging and advanced economies, and holds throughout the sample period. Shularick and Taylor (2012) similarly highlight the role of leverage in financial vulnerability, especially that associated with the banking sector. Thus, one way to frame the debate on the role of monetary policy in the transmission of global liquidity is to ask how monetary policy influences leverage and real exchange rates.[2]

Banks are intermediaries whose financing costs are closely tied to the policy rate chosen by the central bank, so that monetary policy may act directly on the economy through greater risk-taking by the banking sector. Borio and Zhu (2012) coined the term "risk-taking channel of monetary policy", and Adrian and Shin (2008, 2011) and Adrian, Estrella and Shin (2009) have explored the workings of the risk-taking channel for the United States. In this paper, we explore the workings of the risk-taking channel both domestically and in an international setting.

[1] See, for instance, the full page feature in the *Financial Times* entitled "Carried Away", April 30th, 2010.

[2] See also the IMF working paper by Lund-Jensen (2012) that presents similar evidence. Our question is related to the debate on whether monetary policy was "too loose" in the run-up to the crisis with respect to the Taylor Rule (Taylor (2007), Bernanke (2010)). However, our focus is narrower in that we examine the risk-taking channel more explicitly.

Our first contribution is to draw together two strands in the empirical literature and highlight the importance of leverage as the common thread that ties the two. Bekaert, Hoerova and Lo Duca (2012) conduct a VAR study of the relationship between the policy rate chosen by the Federal Reserve (the target Fed Funds rate) and measured risks given by the VIX index of implied volatility on US equity options, and show that there is a close interaction between the two variables. In particular, they show that a cut in the Fed Funds rate is followed by a dampening of the VIX index. Meanwhile, Eichenbaum and Evans (1995) find that a contractionary shock to US monetary policy leads to persistent appreciation in the US dollar both in nominal and real terms.

Our contribution is to show that these two sets of results may be seen as two sides of the same coin. We highlight bank leverage as the linchpin in the risk-taking channel of monetary policy that translates lower measures of risk into greater risk-taking, and then to other real and financial variables. Among the variables impacted by a shock to leverage are capital flows and exchange rates. We verify in our VAR analysis that a decrease in the Fed Fund rate leads to depreciations in the US dollar after about 14 quarters, while an increase in leverage is followed by a depreciation of the US dollar from 3 quarters but which persists for 20 quarters or more. These results are consistent with the so-called *delayed overshooting puzzle* found in Eichenbaum and Evans (1995) who find that a contractionary shock to US monetary policy leads to persistent appreciation in nominal and real US exchange rates, with a maximum impact that does not occur contemporaneously but at least 24 months after the shock. Our complementary finding is that the impact on exchange rates works through leverage and the VIX. In addition, we document an additional international dimension of the transmission of monetary policy through capital flows whereby a contractionary shock to US monetary policy leads to a decrease in the cross-border capital flows in the banking sector.

Recent papers have documented micro evidence in support of the risk-taking channel of monetary policy, showing how credit standards are influenced by the central bank policy rate. For instance, Jiménez, Ongena, Peydró and Saurina (2012) using data from Europe find that a low policy rate induces thinly capitalized banks to grant more loans to ex ante riskier firms.

Maddaloni and Peydró (2011) find that low rates erode lending standards, for both firms and households. Using US survey data, Dell'Ariccia, Laeven and Suarez (2013) find that low interest rates are associated with riskier lending according the internal ratings used by the banks themselves.

The existing literature has focused mainly on lending standards using individual loan data. Our complementary approach extends the existing micro studies by addressing the macro dynamics between monetary policy, the financial intermediary sector and the risk-taking channel through vector autoregression (VAR) methods. In particular, we explore the extent to which measures of risk drive the transmission of monetary policy, both domestically and in the international context and show that the leverage cycle of the intermediary sector as a whole takes up an important position in the transmission of monetary policy.

Our second contribution is theoretical. Motivated by the evidence, we construct a theory of the risk-taking channel of monetary policy in which banks intermediate dollar funds to local borrowers who hold local currency assets. Our model delivers the core result that bank leverage is increasing in the expected appreciation of the local currency, thereby connecting with the key empirical finding in Gourinchas and Obstfeld (2012) and Lund-Jensen (2012) that the combination of higher leverage and sharp appreciation of the currency signals greater vulnerability to reversals.

In our model, banks are subject to moral hazard in which they can choose an inferior portfolio of loans in terms of expected repayment, but which generates higher upside potential due to greater correlation in loan outcomes. The contracting problem that ensues has a unique solution in which banks' access to international funding is limited by a leverage constraint, which in turn depends on the stage of the business cycle. We show through comparative statics on the expected default rate that the unique solution to the contracting problem is associated with procyclical leverage of the banks (leverage is high when assets are large), and that expected currency appreciation is a key driver of the fluctuations in leverage. Our main proposition is that bank leverage is increasing in the extent of expected currency appreciation.

When our result is taken to realistic settings, we show the potential for amplified monetary policy spillovers across borders. Lowering of bank funding costs in financial centers gives an initial impetus for greater risk-taking in cross-border banking, and any initial appreciation of the currency of the capital-recipient economy strengthens the balance sheet position of the borrowers. From the point of view of the banks that have lent to them, their loan book becomes less risky, relaxing the funding constraints for banks and creating spare capacity to lend even more. In this way, the initial impetus is amplified through a reinforcing mechanism in which greater risk-taking by banks dampens volatility, which elicits even greater risk-taking, thereby completing the circle.

In formulating our theoretical framework, we follow Woodford's (2010) exhortation for "models in which intermediation plays a role, but in which intermediation is modeled in a way that better conforms to current institutional realities" (Woodford (2010, p. 21)). Our model of the risk-taking channel is designed to capture the key institutional features that we outline in the course of the paper, in particular the fluctuations in the claims given by the cross-border banking statistics of the Bank for International Settlements (BIS). In particular, our model captures the well-documented procyclical nature of leverage, which determines empirical magnitudes for macro fluctuations (Nuño and Thomas (2012)).

Our model highlights the impact of fluctuations in leverage, rather than of default itself. The leverage constraint addresses the *possibility* default, so that the *actual* probability of default is zero in the resulting contract, just as in Geanakoplos (2009). More recently, Fostel and Geanakoplos (2012) prove in a more general setting that the zero probability of default is a general feature in a class of general equilibrium models of leverage. Our model differs from Geanakoplos (2009) and Fostel and Geanakoplos (2012) in that we build an agency model with moral hazard rather than a micro-founded competitive equilibrium model. Our model is closer in spirit to Dell'Ariccia, Laeven and Marquez (2010) who examine a pass-through model of lending by banks in which changes in bank funding rates lead to fluctuations in leverage.

The risk-taking channel stands in contrast to models of monetary economics that have traditionally been used at central banks, which tend to downplay the importance of short-term interest rates as price variables in their own right. Instead, the emphasis falls on the importance of managing market expectations. The emphasis is on charting a path for future short rates and communicating this path clearly to the market, so that the central bank can influence long rates such as mortgage rates, corporate lending rates, as well as other prices that affect consumption and investment.

In contrast, our focus is on the impact of short-term rates on the feedback loop between leverage and measures of risk, especially in the international context. The combination of the theory and empirical evidence paints a consistent picture of the fluctuations in "global liquidity" and what role monetary policy has in moderating global liquidity. By identifying the mechanisms more clearly, we may hope that policy debates on the global spillover effects of monetary policy can be given a firmer footing. The recent BIS report on global liquidity (BIS (2011)) has served as a catalyst for further work in this area, and our paper can be seen as one component of the analytical follow-up to the report.

2 First Look at the Evidence

We begin with a preliminary look at the empirical evidence on the impact of monetary policy on risk-taking and market conditions, examining the dynamic relationship between the monetary stance of the central bank and measures of risk and credit availability.

The motivation for our initial empirical investigation comes from the close relationship that holds between bank balance sheet adjustment and measured risks in the financial system. An illustration of the relationship between bank lending behavior and risk is given in Figure 1 which shows the scatter chart of the changes in debt, equity and risk-weighted assets (RWA) to changes in total assets of Barclays, a typical global bank active in international markets. Figure 1 plots $\{(\Delta A_t, \Delta E_t)\}$, $\{(\Delta A_t, \Delta D_t)\}$ and $\{(\Delta A_t, \Delta \mathrm{RWA}_t)\}$ where ΔA_t is the two-year change in assets, and where ΔE_t, ΔD_t and $\Delta \mathrm{RWA}_t$ are the corresponding changes in equity, debt, and risk-weighted assets, respectively.

The first notable feature of Figure 1 is how the relationship between the changes in the total assets and its risk-weighted assets is very flat. In other words, the risk-weighted assets

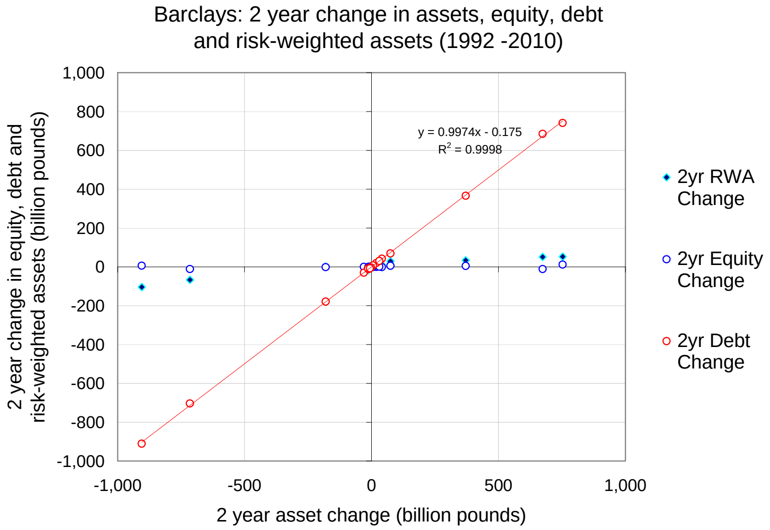


Figure 1. Scatter chart of relationship between the two year change in total assets of Barclays against two-year changes in debt, equity and risk-weighted assets (Source: Bankscope)

barely change, even as the raw assets change by large amounts. The fact that risk-weighted assets change little even as raw assets fluctuate by large amounts indicates the compression of measured risks during lending booms and heightened measured risks during busts. In other words, banks expand their lending when measures of risk point to tranquil conditions.[3]

For the risk-taking channel, the reverse causation is also important. When lending is expanding rapidly, the increased supply of credit is likely to compress risk spreads. To the extent that the VIX index is closely related to such measures of risk, we would expect that shifts in the leverage of the banking sector will have an impact on the VIX index itself. We will verify the existence of such a channel in our VAR exercise, thereby shedding light on the finding by Bekaert et al. (2012) that low policy rates lead to a dampening of the VIX. Our VAR exercise points to bank leverage as the channel for monetary policy to affect market conditions. Our theory section will build on our empirical findings.

[3]Adrian and Shin (2012) show that bank leverage is closely (negatively) aligned with the Value-at-Risk (VaR) of the banks.

The second notable feature of Figure 1 is how changes in assets are reflected dollar for dollar (or pound for pound) in the change in *debt*, not equity. We see this from the slope of the scatter chart relating changes in assets and changes in debt, which is very close to one. Leverage is thus procyclical; leverage is high when the balance sheet is large, and credit supply and leverage move one-for-one.

Our preliminary empirical investigation comes from recursive vector autoregressions (VAR) examining the dynamic relationship between the VIX index of implied volatility on the S&P index options, the real Feds Funds target rate of the Federal Reserve, and a proxy for the leverage of global banks. The real Fed Funds target rate is computed for the end of the quarter as the target Fed Funds rate minus the CPI inflation rate. In some specifications to be reported below, we also employ the Effective Fed Funds rate, which are the actual prices observed in the Fed Funds interbank lending market.

Our empirical counterpart for global bank leverage should ideally be measured as the leverage of the broker dealer subsidiaries of the global banks that faciliated cross-border lending. Shin (2012) shows that the European global banks were central in banking sector capital flows in the years before the crisis of 2008. However, the reported balance sheet data for European banks are the consolidated numbers for the holding company that includes the much larger commercial banking unit, rather than the wholesale investment banking subsidiary alone. For the reasons discussed in Adrian and Shin (2010, 2012), broker dealers and commercial banks will differ in important ways in their balance sheet management. For this reason, we use instead the leverage of the US broker dealer sector from the US Flow of Funds series published by the Federal Reserve as our empirical proxy for global bank leverage. To the extent that US broker dealers dance to the same tune as the broker dealer subsidiaries of the European global banks, we may expect to capture the main forces at work.

The left panel of Figure 2 plots the leverage series of the US broker dealer sector from 1995Q4.[4] Leverage increases up to 2007, and then falls abruptly with the onset of the financial

[4]Leverage is obtained from (1) "total liabilities" (FL664190005.Q) and (2) "total liabilities and equity" (FL664194005.Q) of the US broker dealer sector from the Flow of Funds. Leverage is defined as $2/(2-1)$.

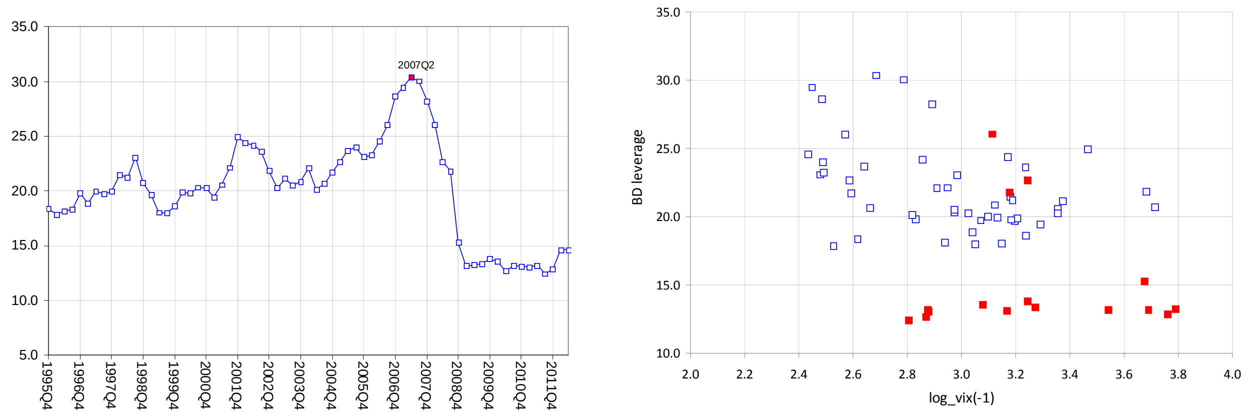


Figure 2. The left panel plots the leverage of the US broker dealer sector from the Federal Reserve's Flow of Funds series (1995Q4 - 2012Q2). Leverage is defined as (equity + total liabilities)/equity. The right panel plots the scatter chart of US broker dealer leverage against the log VIX index lagged one quarter. The dark shaded squares are the post-crisis observations after 2007Q4 (Source: Federal Reserve and CBOE)

crisis. The right panel of Figure 2 shows how US broker dealer leverage is closely associated with the risk measure given by the VIX index of the implied volatility in S&P 500 stock index option prices from Chicago Board Options Exchange (CBOE). The dark squares in the scatter chart are the observations after 2007Q4 associated with the crisis and its aftermath. The scatter chart adds weight to theories of leverage based on measured risk, such as Value-at-Risk as argued in Adrian and Shin (2010, 2012). The close relationship between leverage and VIX also provides a point of contact between Gourinchas and Obstfeld (2012) who point to the importance of leverage with Forbes and Warnock (2012) who have highlighted the explanatory power of the VIX index for gross capital flows.

Finally, in anticipation of our main empirical investigation into the international dimension to the risk-taking channel we include in the VAR the US dollar exchange rate as measured by the Real Effective Exchange Rate (REER) of the US dollar, which is a trade-weighted index of the value of the dollar, obtained from the IMF's IFS database. An increase in REER indicates an appreciation of the US dollar relative to its trade-weighted basket of other currencies. Our sample is for the period before the crisis in order to examine the workings of the risk-taking channel on the up-swing of the global liquidity cycle. We use quarterly data from the last quarter of 1995 to the last quarter of 2007. The fourth quarter of 2007 marks the beginning of the financial crisis, and our empirical results turn out to be sensitive to the zero lower bound on the policy rate after the crisis, as we explain below.

2.1 Recursive Vector Autoregressions

In our preliminary VAR analysis, the data consist of the real Fed Funds target rate, the log of the VIX index, the leverage of the US broker dealer sector, and the real effective exchange rate (REER) of the US dollar. The exchange rate series is included as a prelude to our more detailed examination of the cross-border effects. From tests for stationarity, we include the US dollar REER as the log difference.

The selection of the number of variables follows from the tradeoff between using a parsimonious model to avoid overfitting, while guarding against omitted variable bias that can undermine the interpretation of the results of the VAR. Sims (1980) and Stock and Watson (2001) describe the tradeoffs that are entailed in the selection of variables in the VAR. In our case, the selection of variables is motivated by the interaction between measured risks and banking sector leverage. By including both the VIX index and the broker-dealer leverage variable, we hope to capture the core mechanism that involve financial intermediaries.

Our interest is focused especially on the way that monetary policy interacts with measured risks and the risk-taking behavior of the banks. These questions motivate the choice of our variables. As well as the Fed Funds target rate itself, we also examine additional VARs where other proxies for US monetary policy shocks are used instead, such as the residual from a (backward-looking) Taylor Rule, the effective (market) Fed Funds rate and the growth in the M1 money stock in the United States.

We identify the impact of shocks by writing the vector autogression in recursive form. For the data series $\{y_t\}$ consisting of the vector y_t of the variables of interest, we consider the system

$$A(L)y_t = \varepsilon_t \tag{1}$$

where $A(L)$ is a matrix of polynomial in the lag operator L, and ε_t is a vector of orthogonalized distrurbances. For the four variable VAR, we impose the Cholesky restrictions by applying the following exclusion restrictions on contemporaneous responses in the matrix A to fit a just-identified model:

$$A = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \tag{2}$$

The ordering of the variables imposed in the recursive form implies that the variable with index 1 is not affected by the contemporaneous shocks to the other variables, while variable 2 is affected by the contemporaneous shock to variable 1, but not variables 3 and 4. In general, the recursive form implies that a variable with index j is affected by the contemporaneous shocks to variables with index $i < j$, but not by the contemporaneous shocks to variables with index $k > j$. Thus, slower moving variables (like the Fed Funds target rate) are better candidates to be ordered before the fast moving variables like REER and other market prices, although some caution is necessary even here, as explained in Stock and Watson (2001), since the realism of the assumptions underlying the recursive identification of shocks may depend on the frequency of the time series.

Formal lag selection procedures (Hannan and Quinn information criterion (HQIC) and the Bayesian information criterion (BIC)) suggest one lag. However, the Lagrange multiplier test for autocorrelation in the residuals of the VAR shows that only the model with two lags eliminates all serial correlation in the residuals. We therefore choose two lags. For a stable VAR model we want the eigenvalues to be less than one and the formal test confirms that all the eigenvalues lie inside the unit circle. We compute bootstrapped confidence intervals based on 1000 replications, and make the small-sample adjustment when estimating the variance-covariance matrix of the disturbances.

Of our four variables, two are market prices - VIX and the US dollar REER - which adjust instantaneously to news. The Fed Funds target rate reflects the periodic decision making process at the Federal Reserve and the slowly evolving implementation of monetary policy.

The adjustment of broker dealer (book) leverage will reflect the speed of the balance adjustment of market-based intermediaries and so we may see them as being of intermediate sluggishness.

2.2 Evidence from Impulse Response Functions

Figures 3 presents the impulse response functions from our four variable recursive VAR with 90 percent confidence bands. The ordering of the four variables is (1) Fed Funds target rate (2) broker dealer leverage (3) VIX and (4) US dollar REER. Figure 3 is organized so that the rows of the matrix indicates the variable whose shock we are following and the columns of the matrix indicate the variable whose response we are tracking. Each cell of the tables gives the impulse responses over 20 quarters to a one-standard-deviation variable shock identified in the first column.

Figure 4 collects together the key panels for the narrative. Consider first the impact of a shock to the Fed Funds target rate, interpreted as a monetary policy shock and examine the impact of the shock on the leverage of the US broker dealer sector.

We see from Figure 4 that a positive Fed Funds target rate shock leads to a decline in leverage after a fairly long lag of around 10 quarters and remains significant until quarter 17. The impact reaches a maximum response of -0.47 at quarter 12. When measured against the sample average of 21.94 for leverage, the one standard deviation shock to the Fed Funds rate entails a decline in leverage to around 21.5. The other panels reveal aspects of the mechanism for such an effect. The left panel of Figure 4 shows that the impact of tigher monetary policy is to raise the VIX measure from quarter 4, which corroborates the finding in Bakaert et al. (2012) who find a similar effect on the VIX starting between months 9 and 11.

Our distinctive finding is the middle panel in Figure 4 which shows that an increase in the VIX index lowers bank leverage. This panel provides indirect support for the proposition that the banking sector's balance sheet management is driven by risk measures such as Value-at-Risk, as argued by Adrian and Shin (2010, 2012). Thus, the conjunction of the first two panels tells the story underlying the final panel - of how an increase in the US dollar bank funding costs results in a decline in bank leverage.

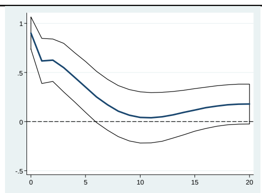
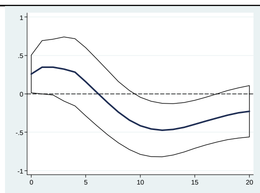
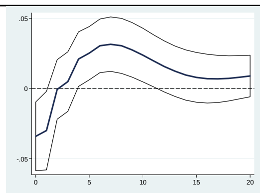
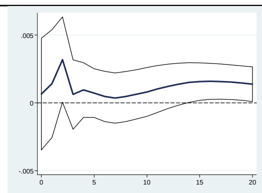
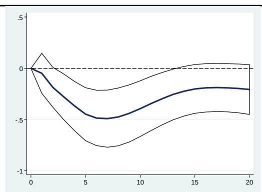
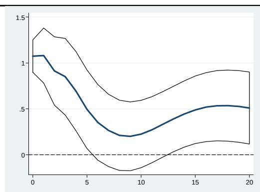
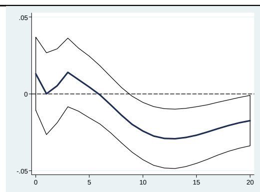
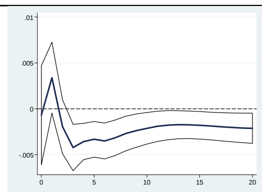
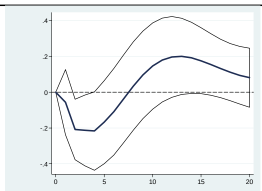
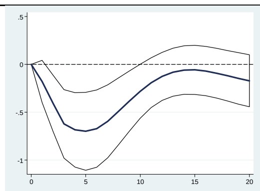
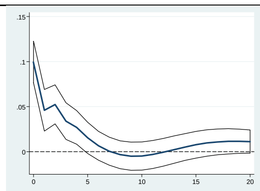
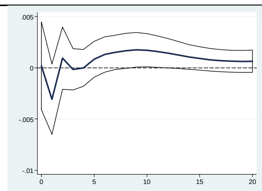
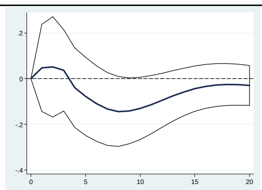
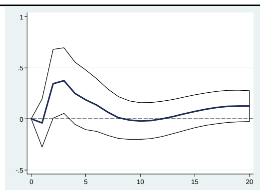
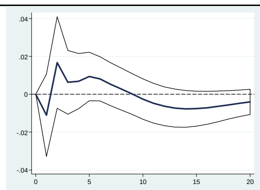
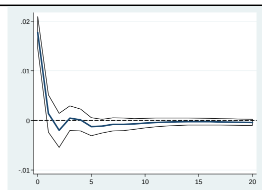
Recursive VAR	Ordering 1	2	3	4
Impact of (↓)	On Fed Funds	On BD Leverage	On VIX	On US dollar REER
Fed Funds				
BD Leverage				
VIX				
US dollar REER				

Figure 3. **Impulse response functions in recursive VAR.** This figure presents estimated impulse-response functions for the four variable recursive VAR (Fed Funds, BD leverage, VIX and REER) and 90 percent bootstrapped confidence intervals for the model with two lags, based on 1000 replications.

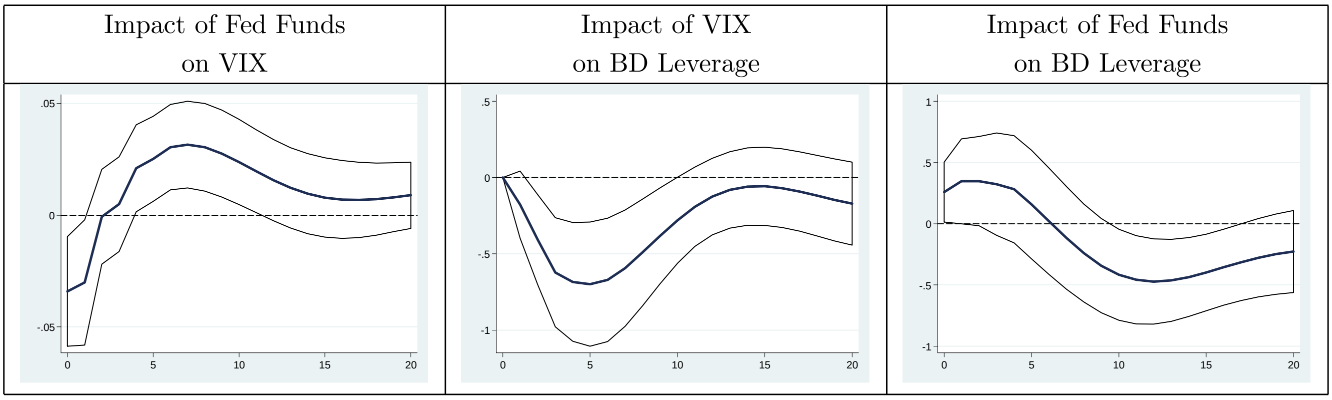


Figure 4. **Impulse response functions in recursive VAR.** This figure presents three panels from the impulse response functions of the four variable VAR (Fed Funds, BD leverage, VIX and REER) illustrating the impact of a Fed Funds target rate shock on the leverage of the US broker dealer sector. A positive Fed Funds target rate shock leads to a decline in broker dealer leverage, via the fall in theVIX index. The panels show 90 percent bootstrapped confidence intervals for the model with two lags, based on 1000 replications.

Finally, in anticipation of our examination of the international dimension to the risk-taking channel, Figure 5 collects together the panels that form a narrative of the impact of a shock to the Fed Funds target rate on the US dollar exchange rate as given by REER (real effective exchange rate). We see from Figure 5 that a positive Fed Funds target rate shock leads to an appreciation of the US dollar after a fairly long lag. The left panel of Figure 5 shows the fall in leverage of the banking sector induced by higher bank funding costs (seen already) while the middle panel shows that an increase in bank leverage leads to a fall in the value of the US dollar by 0.42% of the REER index in quarter 3, and with an impact that remains significantly negative for the entire 20 quarters. Thus, the conjunction of the first two panels tells the story underlying the final panel - of how a fall in the US dollar bank funding costs results in a decline in the value of the US dollar.

Our results are consistent with the "delayed overshooting puzzle" found in Eichenbaum and Evans (1995) who find that a contractionary shock to US monetary policy leads to persistent appreciation in nominal and real US dollar exchange rates, with an impact that does not occur contemporaneously but which comes between 24 and 39 months after the initial shock depending on the currency pair considered. Our complementary evidence shows that the impact of

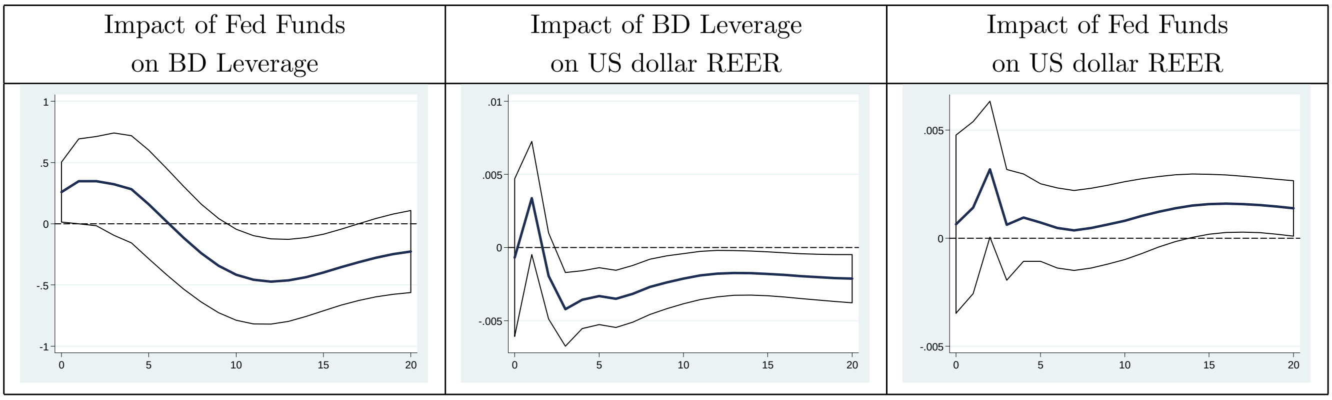


Figure 5. **Impulse response functions in recursive VAR.** This figure presents three panels from the impulse response functions of the four variable VAR (Fed Funds, BD leverage, VIX and REER) illustrating the impact of the Fed Funds rate shock on the US dollar exchange rate. A positive Fed Funds target rate shock leads to an appreciation of the US dollar, via the fall in the leverage of the banking sector. The panels show 90 percent bootstrapped confidence intervals for the model with two lags, based on 1000 replications.

monetary policy works through leverage and the VIX.

We return in the next section to delve deeper into the mechanisms underlying the international dimension of the risk-taking channel.

2.2.1 Variance Decompositions

We have seen that monetary policy has a medium-run (two to three years) impact on broker leverage and VIX, and that broker dealer leverage has a statistically significant effect on the US dollar exchange rate. As well as their statistical significance, such effects are also significant economically. Figure 6 shows what fraction of the structural variance of the four variables in the VAR is due to monetary policy shocks or BD leverage shocks. We see that monetary policy shocks account for almost 30% of the variance of VIX and between 10% and 20% of the variance of BD leverage at horizons longer than 10 quarters. On the other hand, we see that monetary policy shocks are less important drivers of the variance of US dollar exchange rate as given by REER.

BD leverage shocks account for more than 20% of the variance of the exchange rate and for almost 40% of the variance of the Fed Funds rate at horizons longer than 10 quarters. They also

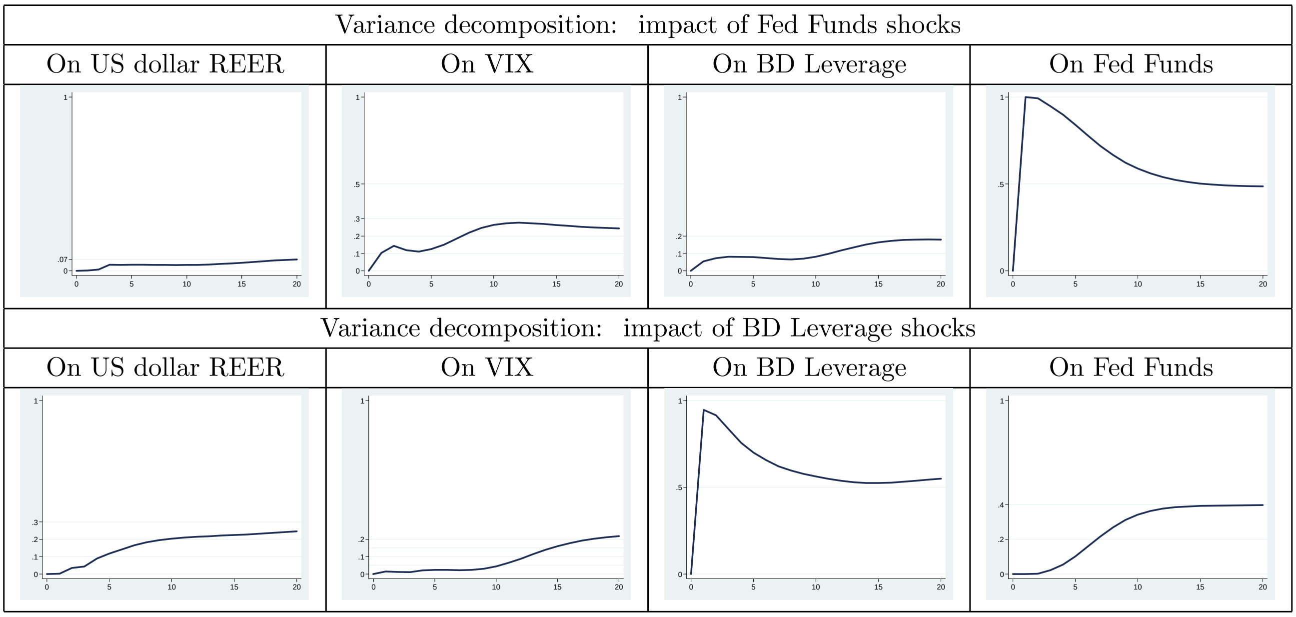


Figure 6. **Variance Decomposition.** This figure presents variance decompositions from the four variable VAR giving the fractions of the structural variance due to Fed Fund or Leverage shocks for the four variables REER, VIX, BD Leverage and Fed Fund (model with 2 lags).

count for about 20% of the variance of VIX at horizons longer than 15 quarters. Our variance decomposition reveals a considerable degree of interactions between the variables in our model, and point to the importance of the leverage cycle of the global banks as being a key determinant of the transmission of monetary policy shocks.

2.2.2 Alternative Measures of Monetary Policy Shocks

Figure 7 shows the impulse-response functions for alternative measures of monetary policy stance on REER, VIX and BD-leverage in the four-variable VAR with 2 lags and 1000 bootstrapped standard errors. Monetary policy shocks considered are residuals from a Taylor rule, M1 growth and nominal effective Fed Funds rate.

The first alternative measure of monetary policy stance is the difference between the nominal Fed Funds target rate and the Fed Funds rate implied by a backward looking Taylor rule. The Taylor rule rate we use assumes the natural real Fed funds rate and the target inflation rate to be 2%, while the output gap is computed as the percentage deviation of real GDP (from the IFS) from potential GDP (from the Congressional Budget Office). In the top row of Figure 7, we see that our qualitative conclusions using the Fed Funds target rate as the monetary policy shock remain unchanged. A positive interest rate shock leads to an appreciation of the US dollar after a lag of 10 quarters, and the mechanism is consistent with a decline in banking sector leverage after around 7 quarters. In turn, the "risk-taking channel" is clearly evident in the middle cell of the top row, where a monetary policy shock is associated with greater measured risks after two quarters.

We consider two further alternative measure of monetary policy shocks, shown in the second and third rows of Figure 7. One is the growth rate of the US M1 money stock, where a positive shock to M1 corresponding to monetary policy loosening. We see that the qualitative conclusions are borne out in the impulse responses for the exchange rate and the banking sector leverage. The impact on the VIX dissipates more quickly than for the other monetary shock measures. One reason for the qualitative difference for the M1 variable may be the greater search for safe assets during periods when markets become turbulent, as investors seek out

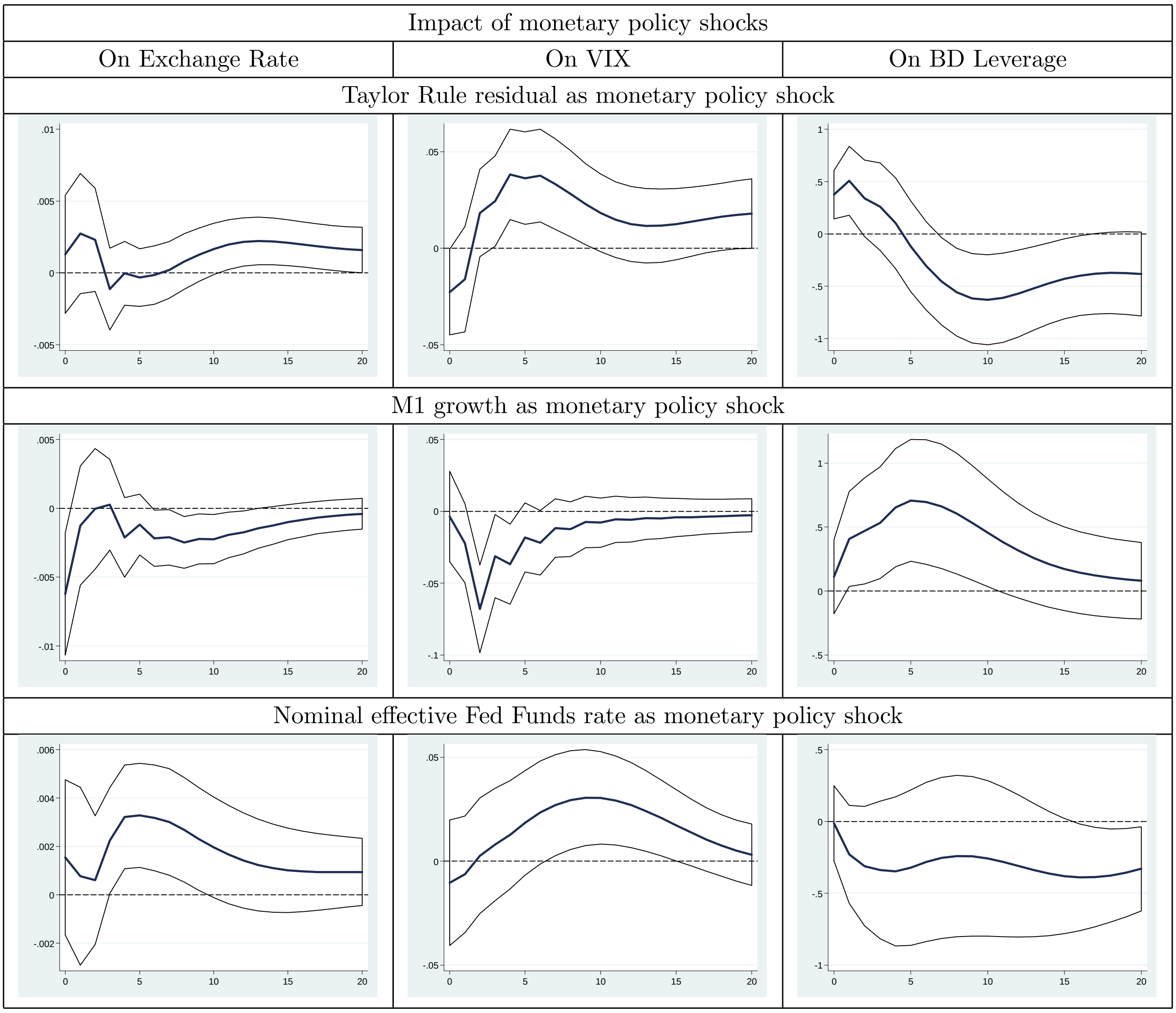


Figure 7. **Alternative definitions of monetary policy shocks.** This figure shows the impulse-response functions and 90 percent confidence bands for alternative monetary policy shocks on REER, VIX and BD-leverage in the four-variable model with two lags and 1000 bootstrapped standard errors. Monetary policy shocks considered are residuals from a Taylor rule, M1 growth and nominal effective Fed Funds rate.

bank deposits rather than riskier claims. Further empirical investigations may reveal more the reasons for the differences.

Our third measure of monetary policy shock is the nominal effective Federal Funds rate, which measures actual transactions prices used in the Fed Funds market of interbank lending, rather than the Fed Funds target rate itself. Our earlier conclusions using the Fed Funds target rate are confirmed. To the extent that the difference between the Fed Funds target rate and the effective Fed Funds rate are small, high frequency deviations, our results are perhaps not surprising.

2.2.3 Robustness Checks

In addition to the empirical findings reported in our paper, we also conduct robustness exercises for our VAR investigation, which are reported separately in an on-line appendix that accompanies our paper.[5] In the on-line appendix, we examine a number of variations in our VAR exercise and gauge the robustness of our findings to changes in the ordering of the variables and to the introduction of new variables.

The sensitivity of the recursive VAR to alternative ordering of the variables is a perennial theme in VAR analysis. The selection of our variables has been motivated by the risk-taking channel of monetary policy, and the different degrees of inertia inherent in our selected variables give some basis for the specification of our VAR analysis (see Kilian (2011) for discussion of this point). In the on-line appendix, we examine the alternative ordering: (1) Fed Funds target rate (2) broker dealer leverage (3) REER and (4) VIX, where the two price variables REER and VIX are switched. Our key findings on the risk-taking channel remain unchanged to such a change.

The on-line appendix also reports the impulse reponses for the VAR when the Fed Funds rate is ordered last[6] to investigate within-quarter policy responses of the Fed Funds rate to VIX or bank leverage. In the VAR with the ordering: (1) broker dealer leverage (2) VIX (3) REER and (4) Fed Funds target rate, our key results on the risk-taking channel are again qualitatively

[5] http://www.princeton.edu/~hsshin/www/capital_flows_risk-taking_channel_online_appendix.pdf

[6] We thank Chris Sims for suggesting this alternative ordering for our robustness tests.

unchanged.

Our results remain unchanged if we use the *nominal* effective exchange rate (NEER) instead of the real effective exchange rate (REER), as shown in the on-line appendix.

We also examine one spefication that includes the growth of US industrial production in the VAR to examine the impact of macroeconomic conditions as a backdrop to monetary policy. Our results (reported in the on-line appendix) indicate that including industrial production does not alter the main conclusions on the mechanism of the risk-taking channel through the leverage of the broker dealer sector.

Our sample period stops in 2007. The crisis period presents special challenges in the VAR estimation, especially since the post-crisis period is associated with the Fed Funds rate pressed against the zero lower bound (see Liu, Waggoner and Zha (2011) and Kilian (2011)). The VAR using an extended sample period that encompasses the zero lower bound period show markedly weaker VAR impulse responses, and many of the impulse response functions associated with shifts in the Fed Funds target rate fail to show significant effects. All the evidence points to a structural break in the relationships driving our key macro variables. Bekaert et al (2012) also find a similar structural break, suggesting that shifts in the autoregressive slope parameters may also have offsetting effects on the impulse response functions. For this reason, the results reported in this paper should be seen as applying mainly for the boom period preceding the onset of the crisis.

3 International Dimension

Given the promising nature of the evidence for the risk-taking channel driven by the banking sector, we turn our attention to the international dimension of the transmission mechanism of monetary policy. Taylor (2013) has argued that the potential for monetary policy spillovers operating through divergent policy interest rates has led to an enforced coordination of interest rate policy among central banks who fear that failure to follow suit in lowering rates would undermine other macro objectives. The role of global banks that channel wholesale funding

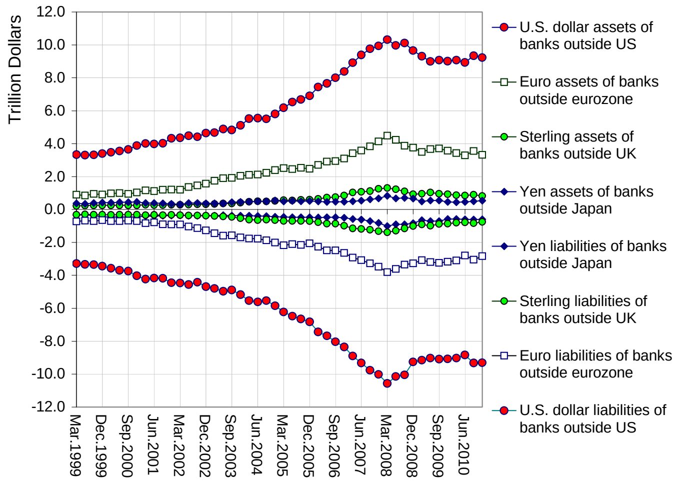


Figure 8. Foreign currency assets and liabilities of BIS reporting banks by currency (Source: BIS locational banking statistics, Table 5A)

across borders is perhaps the most important channel for such transmission of financial conditions. For instance, Cetorelli and Goldberg (2012) have found that global banks respond to changes in US monetary policy by reallocating funds between the head office and its foreign offices, thus contributing to the international propagation of domestic liquidity shocks.

Figure 8 is from the BIS locational banking statistics, and plots the foreign currency assets and liabilities of BIS-reporting banks, classified according to currency. The top plot represents the US dollar-denominated assets of BIS-reporting banks in foreign currency, and hence gives the US dollar assets of banks outside the United States. The bottom plot in Figure 8 gives the corresponding US dollar-denominated liabilities of banks outside the United States. It is clear from the Figure that the US dollar plays a much more prominent role in cross-border banking than does the euro, sterling or yen.

To gain some perspective on the size of the US dollar assets in Figure 8, we can plot the total assets series next to the aggregate commercial banking sector in the United States, which is given in Figure 9. We see that US dollar assets of banks outside the US exceeded \$10 trillion in 2008Q1, and briefly overtook the US chartered commercial banking sector in terms of total

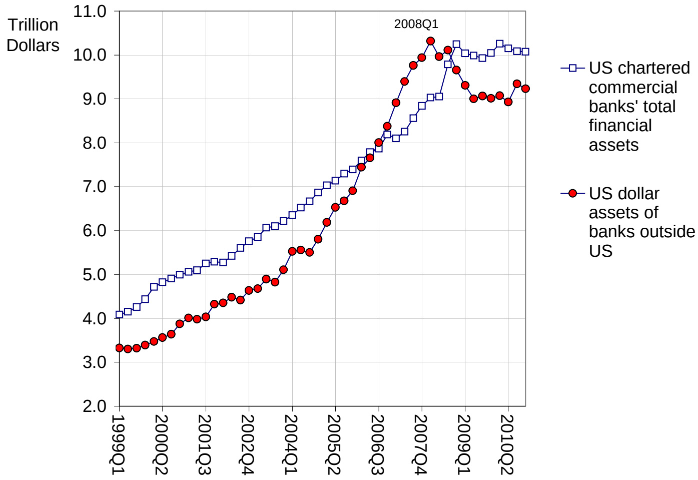


Figure 9. US dollar foreign currency claims of BIS-reporting banks and US commercial bank total assets (Source: Flow of Funds, Federal Reserve and BIS locational banking statistics, Table 5A)

assets. So, the sums are substantial. It is as if an offshore banking sector of comparable size to the US commercial banking sector is intermediating US dollar claims and obligations. Shin (2012) shows that the European global banks account for a large fraction of the US dollar intermediation activity that takes place outside the United States.[7]

3.1 VAR Analysis of Capital Flows

We augment our list of VAR variables by adding a measure of international banking sector flows into our existing VAR analysis. Bruno and Shin (2012) show that global "supply push" variables are responsible in driving cross-border banking sector flows, but they do not investigate the role of monetary policy shocks for bank leverage fluctuations and for the spillover effects on international capital flows. Our focus here is on how monetary policy affects such global factors.

[7]A BIS (2010) study describes how the branches and subsidiaries of foreign banks in the United States borrow from money market funds and then channel the funds to their headquarters. See also Baba, McCauley and Ramaswamy (2009), McGuire and von Peter (2009), IMF (2011) and Shin (2012), who note that in the run-up to the crisis, roughly 50% of the assets of U.S. prime money market funds were obligations of European banks.

The additional variable we include in the VAR is the first difference of the BIS 5A series for US dollar liabilities of banks located outside the US. This is the series given by the bottom time plot in Figure 8, but given positive sign. The objective is to capture the activities of the internationally active banks that were instrumental in channeling dollar funding globally. The objective is to shed further light on the mechanism involved in generating the result from the previous section that bank leverage is closely related to changes in the US dollar exchange rate.

We use the following Cholesky ordering: (1) Fed Funds target rate (2) broker dealer leverage (3) BIS banking flows (4) VIX and (5) US dollar REER. Capital flows reflect the speed of balance adjustment of the intermediaries and so we order them between the Fed Funds rate and the market variables, but after the broker dealer leverage. Figure 10 presents the impulse responses together with the 90% confidence bands for the model with two lags. As before, Figure 10 is organized so that the rows of the matrix indicates the variable whose shock we are following and the columns of the matrix indicate the variable whose response we are tracking. Each cell of the tables gives the impulse responses over 20 quarters to a one-standard-deviation variable shock identified in the first column.

As well as showing the impact of the risk-taking channel of monetary policy on the US dollar exchange rate as before, Figure 10 also reveals how capital flows through the banking sector is an important element of the narrative of the risk-taking channel. Figure 11 gathers three of the panels for a more succinct summary of the relationships. The left panel of Figure 11 shows the impact of a Fed Funds shock on banking sector leverage, showing very clearly the risk-taking channel of monetary policy associated with the leverage cycle of global banks. A positive shock in the Fed Funds rate reduces leverage markedly from after around 10 quarters reaching its maximum impact at quarter 12 (consistent with Figure 3).

The other two panels in Figure 11 shows the impact of the risk taking channel on capital flows through the banking sector. The middle panel in Figure 11 shows that an increase in broker dealer leverage leads to a marked increase in BIS bank flows after 11 quarters and reaching its maximum impact after 17 quarters. The right panel in Figure 11 shows the consequence of the chain reaction where the monetary policy shock works through leverage leading to a decrease

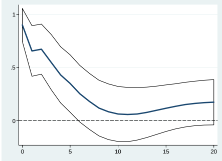
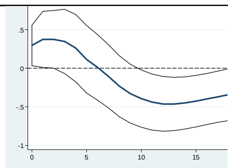
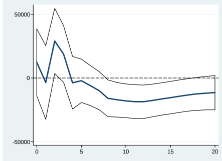
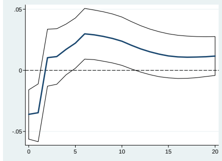
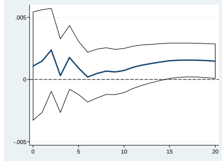
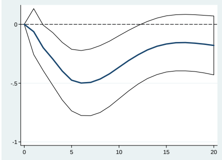
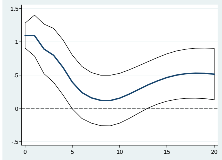
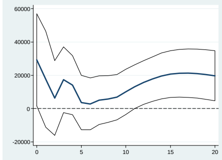
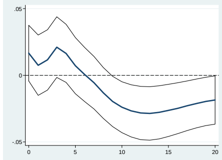
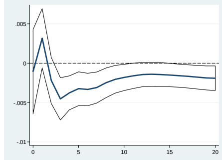
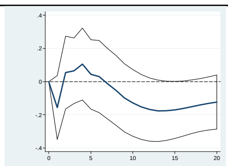
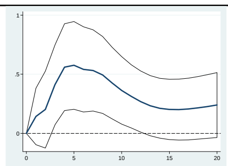
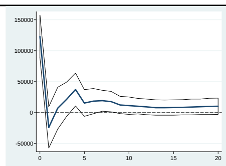
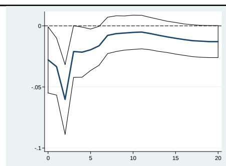
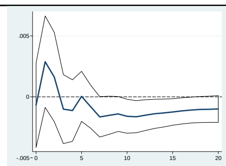
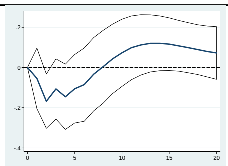
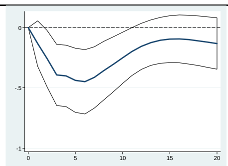
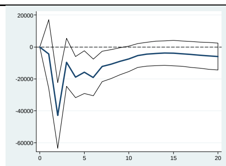
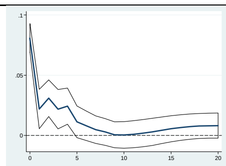
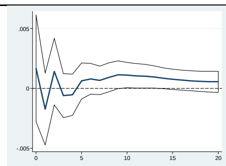
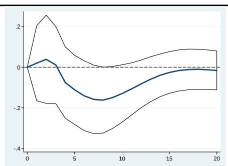
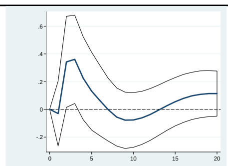
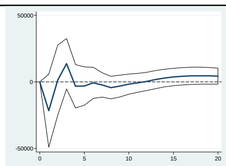
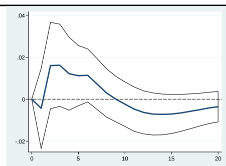
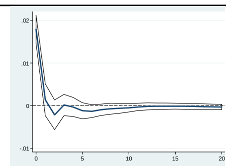
Recursive VAR	Ordering 1	2	3	4	5
Impact of (↓)	On Fed Funds	On BD Leverage	On BIS bank flows	On VIX	On USD REER
Fed Funds					
BD Leverage					
BIS Bank flows					
VIX					
USD REER					

Figure 10. **Impulse response functions in recursive VAR.** This figure presents estimated impulse-response functions for the five variable structual VAR (Fed Funds, BD leverage, BIS bank flows, VIX and REER) and 90 percent bootstrapped confidence intervals for the model with two lags, based on 1000 replications.

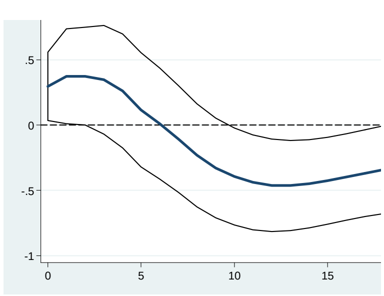
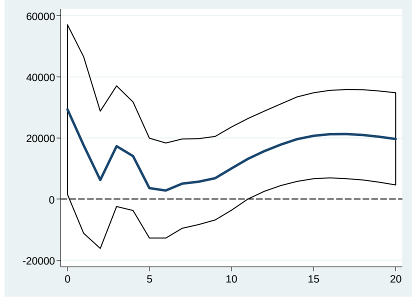
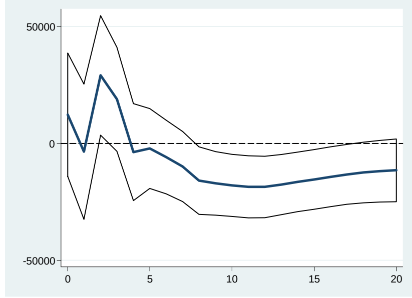
Impact of Fed Funds on BD Leverage	Impact of BD Leverage on BIS bank flows	Impact of Fed Funds on BIS bank flows
		

Figure 11. **Impulse response functions in recursive VAR.** This figure presents three panels from the impulse response functions of the five variable VAR (Fed Funds, BD leverage, BIS bank flows, VIX and REER) illustrating the impact of a Fed Funds target rate shock on BIS bank capital flows. A positive Fed Funds target rate shock leads to decline in bank capital flows, via the fall in the leverage of the banking sector. The panels show 90 percent bootstrapped confidence intervals for the model with two lags, based on 1000 replications.

in the capital flows in the banking sector starting in quarter 8 and remaining significant until quarter 17. In the on-line appendix we verify that these results hold under alternative ordering of the variables.

Figures 10 and 11 together show the risk-taking channel in action, where monetary policy and measured risks determine the leverage cycle of the banking sector, eventually leaving its mark on the US dollar exchange rate and the capital flows funded by the US dollar. The empirical regularities uncovered in our VAR results lend considerable weight to the informal account of the risk-taking channel sketched in our introductory section. The following key findings will provide the motivation for our theoretical framework for the risk-taking channel, to be developed below.

Empirical Feature 1. When the US dollar bank funding rate declines, there follows a depreciation of the US dollar.

Empirical Feature 2. When the US dollar bank funding rate declines, there follows an increase in the leverage of the banking sector and increased capital flows as measured by the BIS banking statistics.

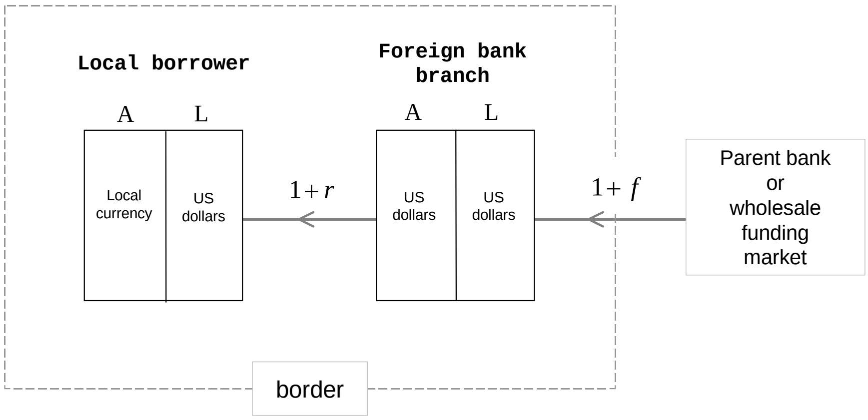


Figure 12. This figure depicts the lending relationships examined in the model. A foreign bank branch lends to local borrowers in dollars and finances its lending from the wholesale dollar funding market.

Empirical Feature 3. When banking sector capital flows accelerate, there follows a depreciation of the US dollar.

Empirical Feature 1 corroborates the finding in Eichenbaum and Evans (1995) that the US dollar tends to depreciate over a protracted period when the US dollar funding cost declines. The combination of these three findings motivates our theoretical exercise of constructing a model of the risk-taking channel.

4 Model of Risk-Taking Channel

4.1 Model Setting

Motivated by the evidence, we construct a model of the risk-taking channel built around the banking sector, based on the relationships depicted in Figure 12. A bank based in the capital flow-recipient economy lends to local borrowers in dollars and finances its lending by borrowing from the wholesale dollar funding market. Local borrowers could be either household or corporate borrowers. For corporate borrowers, borrowing in foreign currency and holding local currency assets is one way for exporting companies to hedge their future dollar export receivables.

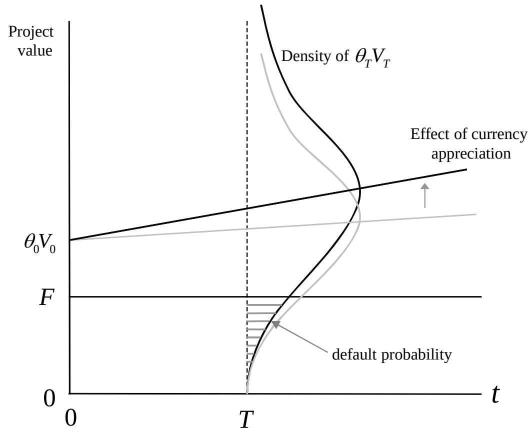


Figure 13. The borrower defaults when $\theta_T V_T$ falls short of the notional debt F. The effect of a currency appreciation is to shift the outcome density upward, lowering the default probability.

Even for non-exporters, borrowing in foreign currency is a means toward speculating on currency movements.

The banks in our model have well diversified loan portfolios consisting of loans to many local borrowers. Although the bank does not have a currency mismatch, the local borrowers do have a currency mismatch. They borrow in US dollars, but invest in projects whose outcome is denominated in local currency.

There are many identical borrowers indexed by j. Each borrower has a project maturing at date T which is financed by a loan of F dollars from the bank. Loans are granted at date 0 and repaid at date T. The value of the borrower's project in local currency terms at date t is denoted by V_t. Denote by θ_t the exchange rate at date t expressed as the price of local currency in dollars. Thus, an increase in θ_t corresponds to an appreciation of the local currency relative to the dollar. Let $\bar{\theta}_T$ denote the date 0 expected value of θ_T.

Credit risk follows the Merton (1974) model. There are many identical borrowers indexed by j. Suppose that the terminal value of the borrower's project in dollar terms is a lognormal random variable given by

$$\theta_T V_T = \theta_0 V_0 \exp\left\{\left(\mu\left(\bar{\theta}_T\right) - \frac{s^2}{2}\right) T + s\sqrt{T} W_j\right\} \tag{3}$$

where W_j is a standard normal, $s > 0$ is a constant, and $\mu(\cdot)$ is an increasing function of $\bar{\theta}_T$. The project outcome density reflects the higher expected return in dollar terms when the local currency appreciates relative to the dollar.

The borrower defaults when the terminal value of the project in dollar terms falls short of the notional dollar debt F. Hence, the borrower defaults when

$$\theta_T V_T < F \tag{4}$$

Figure 13 illustrates the payoff from the borrower's project and the default probability as the area under the project outcome density below F. The probability of default viewed from date 0 is given by

$$\begin{aligned} \text{Prob}\left(\theta_T V_T < F\right) &= \text{Prob}\left(W_j < -\tfrac{\ln(\theta_0 V_0/F)+\left(\mu-\frac{s^2}{2}\right)T}{s\sqrt{T}}\right) \\ &= \Phi\left(-d_j\right) \end{aligned}$$

where d_j is the *distance to default* measured in units of standard deviations of W_j.

$$d_j = \frac{\ln\left(\theta_0 V_0/F\right) + \left(\mu\left(\bar{\theta}_T\right) - \frac{s^2}{2}\right)T}{s\sqrt{T}}$$

Note that the distance to default is increasing in $\bar{\theta}_T$ reflecting the stronger balance sheet of borrowers following currency appreciation when they have borrowed in dollars.

Banks provide dollar-denominated credit (denoted C) to local borrowers at the rate $1 + r$. Our model will satisfy an aggregation feature (to be reported below), so that it is without loss of generality to assume there is a single bank. For simplicity, we will assume that there is an infinitely elastic demand for dollar-denominated credit at the rate $1+r$, so that we may assume r to be fixed.

The credit is funded by cross-border bank liabilities (denoted by L) drawn from wholesale markets or from the parent bank at the funding rate $1 + f$, which will be determined from the solution to the contracting problem. Both C and L are denominated in dollars. The bank's book equity (also in dollars) is denoted by E.

The bank has a well diversified loan portfolio consisting of loans to many local borrowers. Credit risk for the bank follows the Vasicek (2002) extension of the Merton model.[8] Assume that the standard normal W_j can be written as the linear combination:

$$W_j = \sqrt{\rho}Y + \sqrt{1-\rho}X_j \tag{5}$$

where Y and $\{X_j\}$ are mutually independent standard normals. Y is the common risk factor while each X_j are the idiosyncratic component of credit risk for the particular borrower j. The parameter $\rho \in (0, 1)$ determines the weight given to the common factor Y. Therefore, borrower j repays the loan when $Z_j \geq 0$, where Z_j is the random variable:

$$Z_j = d_j + \sqrt{\rho}Y + \sqrt{1-\rho}X_j \tag{6}$$

where d_j is the distance to default of borrower j. The probability of default by borrower j is $\varepsilon = \Phi(-d_j)$. Since d_j is a function of the expected terminal exchange rate $\bar{\theta}_T$, the probability of default ε is also a function of $\bar{\theta}_T$.

4.2 Moral Hazard

The bank is simultaneously both a lender and a borrower (it borrows in order to lend), but our contracting problem highlights the status of the bank as the borrower. The bank is the agent and the bank's wholesale creditor is the principal. We assume that the principal is risk neutral and operates in a competitive bank funding market.

The bank (the agent) has the choice of selecting its portfolio of loans, but faces a moral hazard problem in this choice. The bank chooses between two alterantive portfolios. The good portfolio consists of loans which have a probability of default ε, and low pairwise correlation of default across loans. The bad portfolio consists of loans with a higher probability of default $\varepsilon + k$, for known constant $k > 0$, as well as a higher pairwise correlation of default. For the bank, however, the greater correlation in defaults across loans generates greater dispersion in

[8]The Vasicek model is the workhorse credit risk model for banks, and has been adopted by the Basel Committee for Banking Supervision (2005) as the backbone of international bank capital rules.

the outcome density for the loan portfolio, which is associated with a higher option value of limited liability of using debt financing.

Specifically, we suppose that the good portfolio consists of loans with default probability of ε, but with zero correlation between defaults. The bad portfolio consists of loans with higher default probility $\varepsilon + k$, and pairwise correlation $\rho > 0$, which is a known constant.

Private credit extended by the bank is C at interest rate r so that the notional value of assets (the amount due to the bank at date T) is $(1+r)\,C$. Conditional on Y, defaults are independent. Taking the limit where the number of borrowers becomes large while keeping the notional assets fixed, the realized value of the bank's assets can be written as a deterministic function of Y, by the law of large numbers.

If the bank chooses the bad portfolio, the realized value of assets at date T is the random variable $w_B(Y)$ defined as:

$$\begin{aligned} w_B(Y) &= (1+r)\,C \cdot \Pr\left(\sqrt{\rho}Y + \sqrt{1-\rho}X_j \geq \Phi^{-1}(\varepsilon+k)\,|Y\right) \\ &= (1+r)\,C \cdot \Phi\left(\frac{Y\sqrt{\rho}-\Phi^{-1}(\varepsilon+k)}{\sqrt{1-\rho}}\right) \end{aligned} \tag{7}$$

It is convenient to normalize w_B by the face value of assets. We define $\hat{w}_B(Y) \equiv w_B(Y)/(1+r)\,C$. The c.d.f. of $\hat{w}_B$ is then given by

$$\begin{aligned} F_B(z) &= \Pr(\hat{w}_B \leq z) \\ &= \Pr\left(Y \leq \hat{w}_B^{-1}(z)\right) \\ &= \Phi\left(\hat{w}_B^{-1}(z)\right) \\ &= \Phi\left(\frac{\Phi^{-1}(\varepsilon+k)+\sqrt{1-\rho}\Phi^{-1}(z)}{\sqrt{\rho}}\right) \end{aligned} \tag{8}$$

If the bank chooses the good portfolio, the default probability is ε and correlation in defaults is zero. The outcome distribution for the good portfolio is obtained from (8) by setting $k = 0$ and letting $\rho \longrightarrow 0$. In this limit, the numerator of the expression inside the brackets is positive when $z > 1 - \varepsilon$ and negative when $z < 1 - \varepsilon$. Thus, the outcome distribution of the good portfolio is

$$F_G(z) = \begin{cases} 0 & \text{if } z < 1-\varepsilon \\ 1 & \text{if } z \geq 1-\varepsilon \end{cases} \tag{9}$$

so that the good portfolio consists of i.i.d. loans all of which have a probability of default of ε, and the bank can fully diversify across the i.i.d. loans.

Denote by φ the ratio $(1+f)\,L/\,(1+r)\,C$. Then, the bank's objective function can be written as

$$E(\hat{w}) - [\varphi - \pi(\varphi)] \tag{10}$$

where $E(\hat{w})$ is the expected realization of the (normalized) loan portfolio, and the expression in square brackets is the expected repayment by the bank to wholesale creditors, which can be decomposed following Merton (1974) as the repayment made in full in all states of the world minus the option value to default due to the limited liability of the bank. $\pi(\varphi)$ is the value of the put option when the strike price is given by $\varphi = (1+f)\,L/\,(1+r)\,C$.

The contracting problem takes equity E as given and chooses L, C and f to maximize the bank's expected payoff (10) subject to the incentive compatibility constraint for the bank to choose the good portfolio, and the break-even constraint for the wholesale creditors. The incentive compatibility constraint is

$$E_G(\hat{w}) - [\varphi - \pi_G(\varphi)] \geq E_B(\hat{w}) - [\varphi - \pi_B(\varphi)] \tag{11}$$

where $E_G(\hat{w})$ is the expected value of the good portfolio and $\pi_G(\varphi)$ is the value of the put option with strike price φ under the outcome distribution for the good portfolio. $E_B(\hat{w})$ and $\pi_B(\varphi)$ are defined analogously for the expected outcome and option values associated with the bad portfolio. Writing $\Delta\pi(\varphi) = \pi_B(\varphi) - \pi_G(\varphi)$, (11) can be written more simply as

$$\Delta\pi(\varphi) \leq k \tag{12}$$

The left hand side is the addtional option value to default from the bad portfolio and the right hand side is $E_G(\hat{w}) - E_B(\hat{w})$, the greater expected payoff from the good portfolio. Incentive compatibility is maintained by keeping leverage low enough that the higher option value to default does not exceed the greater expected payoff of the good portfolio.

Lemma 1 *There is a unique φ^* that solves $\Delta\pi(\varphi) = k$, where $\varphi^* < 1 - \varepsilon$.*

Lemma 1 can be proved as follows. From Breeden and Litzenberger (1978), the state price density is given by the second derivative of the option price with respect to its strike price. Given risk-neutrality, $\Delta\pi(\varphi) = \int_0^{\varphi} [F_B(s) - F_G(s)]\, ds$, which gives

$$\Delta\pi(\varphi) = \begin{cases} \int\limits_0^{\varphi} F_B(s)\, ds & \text{if } \varphi < 1-\varepsilon \\ \int\limits_0^{1-\varepsilon} F_B(s)\, ds - \int\limits_{1-\varepsilon}^{\varphi} [1 - F_B(s)]\, ds & \text{if } \varphi \geq 1-\varepsilon \end{cases} \tag{13}$$

Thus $\Delta\pi(\varphi)$ is single-peaked, reaching its maximum at $\varphi = 1 - \varepsilon$. In particular,

$$\begin{aligned} \int_0^1 [F_B(s) - F_G(s)]\, ds &= \int_0^1 [1 - F_G(s)]\, ds - \int_0^1 [1 - F_B(s)]\, ds \\ &= E_G(\hat{w}) - E_B(\hat{w}) = k \end{aligned} \tag{14}$$

so that $\Delta\pi(\varphi)$ approaches k from above as $\varphi \to 1$. Since $\varphi < 1$ for any bank with positive notional equity, we have a unique solution to $\Delta\pi(\varphi) = k$ where the solution is in the range where $\Delta\pi(\varphi)$ is increasing. Therefore $\varphi^* < 1 - \varepsilon$. This proves the lemma.

4.3 Leverage and Expected Appreciation

We can now fully solve the contracting problem and examine the implications for the risk-taking channel. The good portfolio has payoff $1 - \varepsilon$ with certainty (as seen in (9)). Since the bank has zero probability of default whenever $\varphi < 1 - \varepsilon$, Lemma 1 implies that the bank's probability of default is zero. From the break-even constraint of the wholesale creditors, the funding rate is therefore given by the risk-free rate. Finally, from the balance sheet identity $E + L = C$, we can solve for the bank's supply of credit as

$$C = \frac{E}{1 - \frac{1+r}{1+f}\varphi} \tag{15}$$

Note that C is proportional to the bank's equity E, and so (15) also denotes the *aggregate* supply of private credit when E is the *aggregate* equity of the banking sector. The leverage of the bank (and the sector) is the ratio of assets to equity, and is

$$\text{Leverage} \ = \frac{1}{1-\frac{1+r}{1+f}\varphi} \tag{16}$$

On the liabilities side of the balance sheet, the banks' demand for cross-border funding L can be solved from (15) and the balance sheet identity $E+L=C$. We can summarize our full solution to the contracting problem as follows.

Proposition 2 *The contracting problem has a unique solution. In this solution, the bank funding rate f is the risk-free rate, bank leverage is given by*

$$\frac{1}{1-\frac{1+r}{1+f}\varphi^{*}} \tag{17}$$

and total cross-border funding L is given by

$$L=\frac{E}{\frac{1+f}{1+r}\frac{1}{\varphi}-1} \tag{18}$$

The solution entails zero probability of default for the bank and it borrows at the risk-free rate. This result is reminiscent of Geanakoplos (2009) and Fostel and Geanakoplos (2012), which are set in a very different framework with a micro-founded competitive equilibrium model. The common thread is that *actual* default does not happen precisely because the contract addresses the *possibility* of default.

One remark on the generality of Proposition 2 is in order. The fact that $1+f$ is the risk-free rate derives from the feature of our model that the good portfolio consists of loans that are i.i.d. However, the uniqueness result is general, and depends only on the fact that F_H cuts F_L once from below. The qualitative features of our model are preserved when the good portfolio entails positive probability of default by the bank, provided that the funding rate incorporates the bank's option value of default. The funding rate is then determined by the creditors' break-even constraint.

The relationship between leverage and expected appreciation comes through the comparative statics of the default probability ε. The probability of default ε is given by $\varepsilon=\Phi^{-1}(-d)$, where

d is the distance to default, so that ε is a decreasing function of the expected appreciation $\bar{\theta}_T$ given by

$$\varepsilon\left(\bar{\theta}_T\right) = \Phi^{-1}\left(-\frac{\ln(\theta_0 V_0/F)+\left(\mu\left(\bar{\theta}_T\right)-\frac{s^2}{2}\right)T}{s\sqrt{T}}\right) \tag{19}$$

Meanwhile, from Lemma 1, the solution φ^* satisfies $k = \int_0^{\varphi^*} F_L(s)\, ds$, or

$$k = \int_0^{\varphi^*} \Phi\left(\frac{\Phi^{-1}(\varepsilon+k)+\sqrt{1-\rho}\Phi^{-1}(s)}{\sqrt{\rho}}\right) ds \tag{20}$$

Since the right hand side of (20) is increasing in ε and in φ^*, we have $d\varphi^*/d\varepsilon < 0$. We can therefore state the main theoretical result of our paper.

Proposition 3 *Leverage is increasing in the expected appreciation of the currency.*

Proposition 3 rationalizes the result of Gourinchas and Obstfeld (2012) on the association between currency appreciation and leverage. The default probability ε can be given an interpretation via the distance to default in the Merton (1974) model, and we may regard ε as a parameter that indicates the stage of the business cycle. Then, Propositions 2 and 3 tell us that bank leverage is procyclical over the cycle - that leverage is high and bank borrowing is large when fundamentals are strong. The additional feature flagged by Proposition 3 is that expected currency appreciation is one possible channel through which the probability of default can decline.

4.4 Amplification Channel

We will now examine how changes in the bank funding rate f will impact credit supply and the exchange rate. Uncovered Interest Parity (UIP) states that a low interest rate currency will tend to appreciate against a high interest currency, and that the extent of the appreciation is increasing in the interest rate differential. If we denote by $\hat{r}$ the local currency interest rate, the prediction of UIP is that

$$(1+\hat{r})\frac{\bar{\theta}_T}{\theta_0} = 1+f \tag{21}$$

The left hand side is the expected return to one dollar when it is used to buy local currency, and then converted back to dollars at the terminal date. UIP asserts that the expected return from such a strategy is equal to the dollar return from holding the unit in dollars.

However, in our VAR exercise, Empirical Feature 1 corroborates the finding in Eichenbaum and Evans (1995) that the US dollar tends to depreciate over a protracted period when the US dollar funding cost declines. Such a finding is also consistent with the finding in Fama (1984) that not only does the simple version of UIP fail empirically, but the interest rate differential term appears with the opposite sign. Although uncovering the precise mechanism for the failure of UIP is beyond the scope of our paper, the importance of Empirical Feature 1 is that it has the potential to generate an amplification mechanism where the appreciation of the capital recipient country currency fuels greater capital inflows, which in turn exerts further upward pressure on the value of the currency.

Empirical Feature 3 summarized our finding that the US dollar depreciates following an acceleration of cross border banking sector activity, including capital flows through the banking sector as described in our model. To the extent that the US dollar depreciates following greater capital flows, such a response implies an upward-sloping demand response and may seem counterintuitive at first. However, the theme of strong currency appreciation amid surging capital inflows is a familiar one in the literature on emerging market crises. Calvo, Leiderman and Reinhart (1993) pointed out the apparent mutually reinforcing relationship between capital inflows and currency appreciation in Latin America in the early 1990s, and such episodes have recurred with regularity across both time and distance since.

The key to understanding the amplification mechanism is the impact of currency appreciation on the credit risk of lending to local borrowers. Since borrowers have dollar liabilities but operate local currency assets, an appreciation of the local currency reduces the probability of default ε (see Figure 13 given earlier). When ε declines, bank lending becomes less risky through the first-degree stochastic shift in the outcome densities. For banks whose lending is dictated by measures of risk, the decline in ε leads to an increase in credit supply through an increase in leverage. We see this from our expression for total credit C in (15), which is increasing in

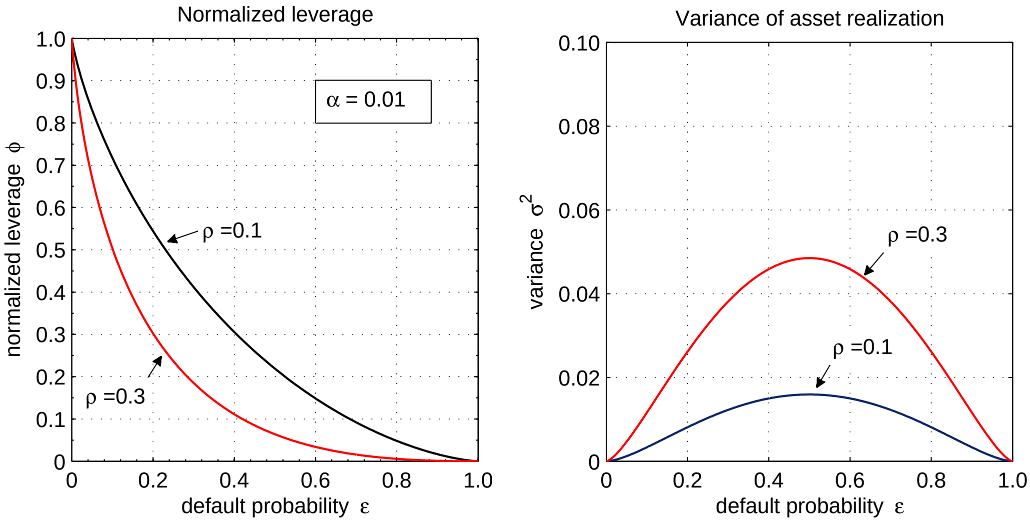


Figure 14. Left hand panel plots φ as a function of ε. The right hand panel plots σ^2 as a function of ε for two values of ρ.

φ. Finally, lending is financed with capital inflows and currency appreciation, bringing us full circle.

Denote by σ^2 the variance of $\hat{w}(Y)$. In the appendix, we show[9] that the variance σ^2 is given by

$$\sigma^2 = \Phi_2\left(\Phi^{-1}(\varepsilon), \Phi^{-1}(\varepsilon); \rho\right) - \varepsilon^2 \tag{22}$$

where $\Phi_2(\cdot, \cdot; \rho)$ is the cumulative bivariate standard normal with correlation ρ. The right hand panel of Figure 14 plots the variance σ^2 as a function of ε. The variance is maximized when $\varepsilon = 0.5$, and is increasing in ρ. The left hand panel of Figure 14 plots the ratio of notional liabilities to notional assets φ as a function of ε.

The initial shock that sets in motion the feedback mechanism between currency appreciation and capital inflows could be anything that increases the lending by the banking sector. The shock could be purely a domestic one, such as an improvement in domestic fundamentals.

[9]See Vasicek (2002), which states this and other results for the asset realization function $w(Y)$.

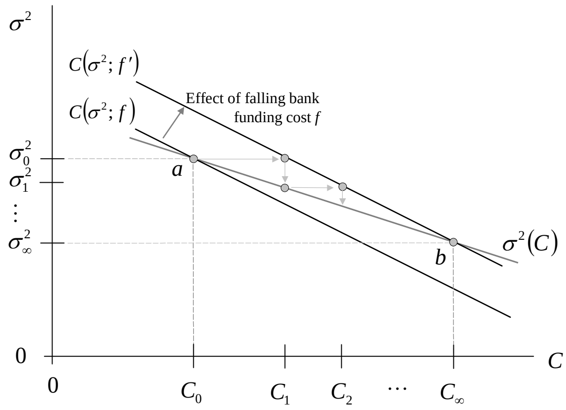


Figure 15. Impact of a decline in bank funding cost f consisting of the initial impact and the amplification effect.

However, in our model any increase in bank lending entails capital inflows to finance the lending, thereby setting the feedback mechanism in motion. Since the bank's leverage decision and hence its lending is sensitive to default risk, the decline in default risk creates an amplified response where the credit supply and currency appreciation feed off each other to create a credit boom in the capital recipient economy.

The amplified response following a cut in bank funding cost can be illustrated in schematically as follows. Consider a fall in the funding cost f. The impact of this fall in funding cost can be decomposed into the *initial impact* and the *amplification effect*. Figure 15 illustrates the two effects. The initial impact of the cut in funding cost f is depicted by the rightward pointing arrow in Figure 15. There is an increase in lending from C_0 to C_1 following the solution for bank credit supply given by (15). However, the increase in lending is mirrored on the liabilities side by an increase in L, as given by (18). In other words, a lowering of bank funding cost results in the increased capital inflow through the banking sector, as given by a larger L.

Then, provided that $\bar{\theta}_T/\theta_0$ is increasing in L, an expected appreciation of the currency associated with increased capital flows results in a first-degree stochastic shift of the outcome density as illustrated in Figure 13, resulting in a fall in the default probability. The decline in the default probability ε sets in motion the amplification mechanism where bank lending increases through an increase in φ, which implies even greater capital inflows through L, which then results in further declines in the default probability ε. Since the variance σ^2 of the asset realization is increasing in the default probability ε for $\varepsilon < 0.5$, we can state the amplification mechanism in terms of the mutually reinforcing effect of greater lending C financed with greater capital inflows L, which dampens the risks attached to the loan book, which in turn creates spare lending capacity of the banks. The stepwise adjustment process depicted in Figure 15 illustrates the amplification mechanism.

Formally, write $C(\sigma^2; f)$ as the total lending by the banking sector as a function of σ^2, with the funding rate f as a parameter. In turn, the variance of asset realization σ^2 can be written as a function of total lending C, since C determines the banking sector liabilities L and hence the credit risk ε. Thus, the consistency between f and σ^2 is captured by the pair of equations:

$$C = C\left(\sigma^2; f\right) \quad \sigma^2 = \sigma^2(C) \tag{23}$$

Both are downward-sloping that a decline in the funding cost f can result in substantial shifts in total lending and volatility. To gauge the size of the feedback effect, begin with the expression for credit supply C given by (15). Then

$$\frac{dC}{df} = -\frac{C}{\frac{1+f}{1+r}\frac{1}{\varphi} - 1}\left[\frac{\varphi'(\varepsilon)}{\varphi}\frac{d\varepsilon}{dC} \cdot \frac{dC}{df} - \frac{1}{1+f}\right] \tag{24}$$

Solving for the elasticity in credit supply with respect to the gross funding rate $1 + f$,

$$\frac{dC}{df}\frac{1+f}{C} = -\frac{1}{\frac{1+f}{1+r}\frac{1}{\varphi} - \left(1 + C \cdot \frac{\varphi'}{\varphi}\frac{d\varepsilon}{dC}\right)} \tag{25}$$

The term associated with the risk-taking channel is $d\varepsilon/dC$, which can be unpacked as follows:

$$
\begin{aligned}
\frac{d\varepsilon}{dC} &= \frac{d\varepsilon}{d\theta} \cdot \frac{d\bar{\theta}_T}{dL} \cdot \frac{dL}{dC} \\
&= \frac{dG\left(z^*/\theta\right)}{d\bar{\theta}_T} \cdot \frac{d\bar{\theta}_T}{dL} \\
&= -\frac{z^*}{\bar{\theta}_T^2} \cdot g\left(\frac{z^*}{\bar{\theta}_T}\right) \cdot \frac{d\bar{\theta}_T}{dL} \qquad (26)
\end{aligned}
$$

where $g(.)$ is the density over project outcomes for the borrowers and z^* is the default threshold. Note that $dL/dC = 1$ from the balance sheet identity with fixed equity. The magnitude of the risk-taking channel can be substantial when $|d\varepsilon/dC|$ is large, indicating a substantial drop in the credit risk of lending *due to the credit boom itself.* In other words, the credit boom acts to suppress measured credit risk, rather than make apparent immediately the greater risks inherent in lending.

5 Lessons and Implications

Our empirical results have highlighted the role played by the US dollar as the currency that underpins the global banking system, even if the intermediaries are non-US intermediaries. Shin (2012) emphasizes the combination of the US dollar as the currency of global banking, but the role of the European banks as the conduit for the transmission of financial conditions. The focus on the US dollar as the currency underpinning global banking lends support to studies that have emphasized the US dollar as a bellwether for global financial conditions, as recently suggested by Lustig, Roussanov and Verdelhan (2012) and Maggiori (2010).

More broadly, the role of the US dollar in the global banking system opens up important questions on the transmission of financial conditions across borders. Calvo, Leiderman and Reinhart (1993, 1996) famously distinguished the global "push" factors for capital flows from the country-specific "pull" factors, and emphasized the importance of external push factors in explaining capital flows to emerging economies in the 1990s. Bruno and Shin (2012) has verified the role of global factors associated with the leverage of the banking sector as being a key determinant of cross-border capital flows in panel regressions of capital flows to emerging and advanced economies. Eickmeier, Gambacorta and Hofmann (2013) and Chen et al. (2012) are two papers in a recent literature that has attempted to elucidate the concept of "global liquidity" that was first formally studied by the official sector in the BIS study on global liquidity (BIS (2011)). The results in our paper suggest that further research on the impact of the risk-taking channel of monetary policy may yield insights into the transmission of global liquidity conditions across borders.

Appendix

In this appendix, we present the derivation of the variance of the normalized asset realization $\hat{w}(Y) \equiv w(Y)/(1+r)C$ in Vasicek (2002). Let $k = \Phi^{-1}(\varepsilon)$ and $X_1, X_2, \cdots, X_n$ be i.i.d. standard normal.

$$\begin{aligned}
E[\hat{w}^n] &= E\left[\left(\Phi\left(\frac{Y\sqrt{\rho}-k}{\sqrt{1-\rho}}\right)\right)^n\right] \\
&= E\left[\prod_{i=1}^n \Pr\left[\sqrt{\rho}Y + \sqrt{1-\rho}X_i > k \middle| Y\right]\right] \\
&= E\left[\Pr\left[\sqrt{\rho}Y + \sqrt{1-\rho}X_1 > k, \ldots, \sqrt{\rho}Y + \sqrt{1-\rho}X_n > k \middle| Y\right]\right] \\
&= \Pr\left[\sqrt{\rho}Y + \sqrt{1-\rho}X_1 > k, \ldots, \sqrt{\rho}Y + \sqrt{1-\rho}X_n > k\right] \\
&= \Pr[Z_1 > k, \ldots, Z_n > k]
\end{aligned}$$

where $(Z_1, \ldots, Z_n)$ is multivariate standard normal with correlation ρ. Hence

$$E[\hat{w}] = 1 - \varepsilon$$

and

$$\begin{aligned}
\mathrm{var}[\hat{w}] &= \mathrm{var}[1 - \hat{w}] \\
&= \Pr[1 - Z_1 \leq k, 1 - Z_2 \leq k] - \varepsilon^2 \\
&= \Phi_2(k, k; \rho) - \varepsilon^2 \\
&= \Phi_2\left(\Phi^{-1}(\varepsilon), \Phi^{-1}(\varepsilon); \rho\right) - \varepsilon^2
\end{aligned}$$

where $\Phi_2(\cdot, \cdot; \rho)$ cumulative bivariate standard normal with correlation ρ.

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