The Adverse Feedback Loop and the Real Effects of Financial Sector Uncertainty*

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Abstract

This paper presents a model that shows the real effects of risk and uncertainty in the financial sector. I introduce a financial sector, and most importantly, financial sector uncertainty, into an international real business cycle model. The model shows that during periods of acute financial uncertainty, risk in the financial sector acts as an important mechanism for the transmission of real shocks. The model shows how an increase in financial sector uncertainty leads to higher interbank lending rates which lead to higher business cycle volatility, persistence, and international co-movement. During periods of acute financial uncertainty, an adverse feedback loop can arise whereby deteriorating conditions in the real economy have a detrimental effect on conditions in the financial sector, which has an adverse feedback effect on the real economy. When calibrated to match the levels of risk in the interbank lending markets since August 2007, the model is able to replicate many of the changes to the business cycle that have occurred since the beginning of the financial crisis.

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1 Introduction

August of 2007 saw the beginning a full scale banking and financial crisis that was largely unknown in the postwar economic history of developed economies.

Taylor and Williams (2009) detail the rapid increase in counterparty risk in the interbank lending markets beginning in August 2007, and contemporary accounts detail the dramatic rise in financial sector uncertainty ultimately linked to securitized mortgages.

Interbank lending spreads, the premium over the risk free rate that banks charge one another for short-term unsecured lending, has played a central role in the recent financial crisis. However most macroeconomic models, used for both academic and policy analysis, do not incorporate interbank lending spreads. Both Real Business Cycle models based on classical assumptions and models based on Keynesian assumptions assume perfect information and thus accept irrelevance of financial conditions implied by the Modigliani and Miller (1958) theorem.

A few papers move beyond the conditions of the Modigliani-Miller theorem and incorporate financial frictions into a general equilibrium model.[1] The most notable being Bernanke and Gertler (1989) who rely upon agency costs and asymmetric information to produce the "financial accelerator". In this model, borrowing costs are inversely related to a borrower's net worth. If this net worth is procyclical, then borrowing costs should fall in booms and rise in recessions, amplifying both. Carlstrom and Fuerst (1997) apply the agency cost problem to a quantitative real business cycle model, and find that the financial accelerator mechanism can help explain the hump-shaped dynamic of output in response to a technology shock. Furthermore, Bernanke et al. (1999) apply the financial accelerator in a model with sticky prices to show how financial frictions can affect the economy's response to monetary shocks. In a related strand of literature, Kiyotaki and Moore (1997) show how credit market

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[1] See Gertler (1988) for a survey of how the literature of financial frictions arose out of the literature incorporating imperfect information.

frictions, in the form of collateral requirements, introduce an important mechanism for the propagation of technology shocks.

These papers incorporate financial frictions, but they do not directly examine the role of a financial sector. Financial frictions affect the productive sector of the economy. Christiano, Motto, and Rostagno (2008) incorporate a financial sector into a model with a financial accelerator mechanism. They show that due to nominal debt contracts, the banking sector can play an important role in the amplification and propagation of monetary shocks. However, for other types of shocks, the nominal debt contracts are not as important and the banking sector plays a much less substantial role as a propagation mechanism.

Christiano et al. incorporate a banking sector into a quantitative business cycle model with a financial accelerator, but do not specifically allow for frictions *within* the banking sector. The dramatic rise in interbank lending spreads in many financial crises is a symptom of frictions a counterparty risk among banks. A few recent papers like Meh and Moran (2008), Gertler and Karadi (2009), and Gertler and Kiyotaki (2009) incorporate financial frictions, in the form of collateral constraints, directly into the financial sector.

The model in this paper is similar to these previous models which incorporate frictions that can affect a bank's cost of capital. However the financial frictions in this paper center on heterogeneity across banks with regard to their losses on loans to the real sector. This heterogeneity means that some banks will be overexposed to the set of non-preforming loans and a subset of those banks may themselves become insolvent. This possibility of bank insolvency means that lenders in the interbank market will require a default-risk premium on unsecured lending. The possibility of default and thus the default-risk premium is inversely related to the size of the bank's capital cushion.

This paper will show how this default risk in the financial sector can give rise to a feedback loop that acts as an internal propagation mechanism. This propagation mechanism amplifies the real effect of shocks to the economy, and in an international real business cycle model this propagation mechanism makes the real effect of TFP shocks more severe, more persistent, and it increases the degree of international transmission.

In any model with a financial accelerator, there is a feedback loop that acts as a propagation mechanism. In a real business cycle model, a negative TFP shock would lower manufacturing firm profits and thus raise firm debt ratios. The debt-elastic default risk premium implied by the bankruptcy risk in the model would then push up the firm's borrowing cost, which would further lower the firm's profits and raise their debt ratio.

The model in this paper also incorporates bankruptcy risk in the financial sector. This leads to a similar feedback loop. The shock to TFP affects firms in the productive sector. Some default on their debt, which results in a fall in the value of bank assets and an increase in their debt-asset ratios. In the presence of bankruptcy risk in the financial sector, banks face a higher cost of capital after their debt-asset ratio increases. Banks pass this higher cost along to firms in the form of higher rates on both physical capital loans and working capital loans. Higher rates charged to the manufacturing sector lead to more defaults, triggering a further erosion of bank balance sheets.

This paper shows that the feedback loop arising in a financial accelerator model is amplified in when risk is incorporated in the financial sector. This is due to two reasons. First, as discussed before, when a the banking industry faces a higher cost of capital, they raise their rates on both physical capital loans and working capital loans. This contrasts with a feedback loop concentrated in the manufacturing sector alone, where the rate on physical capital loans is the only rate affected by the debt-elastic interest premium. Second, and more importantly, the financial sector is more leveraged than the manufacturing sector. This means that any feedback effects are much more pronounced when bank's don't have a large capital cushion.

Most of the time the adverse feedback loop stemming from bankruptcy risk in the financial sector is not quantitatively significant. Normally, risk is low in the financial sector and therefore even a bank's relatively small capital cushion is large enough to keep real shocks from leading to heightened bankruptcy risk in the banking sector. However, during periods of acute financial sector uncertainty, like that experienced in the recent financial crisis, the feedback loop associated with bankruptcy risk in the financial sector can play a significant role in the propagation of real shocks. Making the effects of real shocks both more severe and more persistent.

This paper will proceed as follows. Section 2 discusses the recent financial crisis and with anecdotal evidence shows how many the events in the financial markets since August 2007 can be viewed as a story of counterparty risk and uncertainty in the financial sector. Section 3 provides empirical evidence of an adverse feedback loop operating through balance sheets and risk premiums. The empirical results show that risk in the financial sector leads to a stronger adverse feedback loop than risk in the manufacturing sector. Section 4 presents the international real business cycle model used to explain how financial uncertainty can act as a mechanism for the propagation of real shocks. The results from the model are presented in section 5. First, with impulse responses we show how financial uncertainty can lead to greater business cycle volatility, persistence, and international co-movement following a productivity shock. Then we compute business cycle moments from the model and show that the model, calibrated to match periods of acute financial stress, can largely explain the changes in business cycle volatility and co-movement that we have witnessed in the past few years. Finally, section 6 concludes and offers some suggestions for further research.

2 Financial sector uncertainty and the crisis of 2007-2009

The London Interbank Offered Rate (Libor) is a money market interest rate that measures the rate the largest banks charge one another for unsecured loans with maturity of a few months. Since these loans are unsecured, there is risk of large losses in the event of a borrower default between now and the maturity date. This risk is referred to as counterparty risk, and thus the spread between the 3-month Libor and the 3-month T-bill rate (the TED spread) is a measure of counterparty risk in the interbank lending market.

Figure 1 charts this spread using daily data from August 2002 to August 2009. Five key dates in the financial crisis are also marked on the chart. These are the tick marks lettered a-e. They correspond to the dates, August 9, 2007; March 14, 2008; September 15, 2008; February 25, 2009; and April 13, 2009.

In the five years prior to August 9, 2007 (point "a" on the chart) this spread averaged 29 basis points. On August 8th, the spread was 57 basis points. On August 9th, BNP Paribas, France's largest bank, announced that given the high amounts of market uncertainty and illiquid markets for certain securities, it was halting redemption on three of its investment funds. This news solidified what the market had suspected for months; the subprime mortgage securities in the U.S. backed by declining house prices were worth less than originally thought.

Finance companies that were over-exposed to the subprime mortgage market were early victims of the crisis. However, the process of securitization meant that in the early days of the crisis, a typical bank's exposure to these toxic assets was uncertain.

An article from the *Economist* from August 16, 2007 summed up the prevailing mood in the interbank market. The article stated that "banks no longer trust other banks enough to lend them money except on onerous terms." The article went on to say that "with everybody having sold on the risk to everyone else - and the risk often being carved up, repackaged and sold again - nobody is sure where the losses are...In the interbank market, every counterparty was potentially vulnerable." By August 20th, the TED spread reached a peak of 239 basis points.

The tick mark labeled "b" corresponds to March 14th, 2008, when the FED first announced that it was providing a financial guarantee for JPMorgan to acquire Bear Stearns. The figure shows a temporary jump in the TED spread right around that date. The spread was 162 basis points the day of the announcement. Early the next week, despite a 75 basis point FED rate cut, the Libor continued to increase, and on March 20th it reached 208 basis points. Following the announcement that the FED would ensure a smooth acquisition of Bear Stearns, one hedge-fund manager was quoted as saying, "If Bear Stearns had failed, banks would not have know where they were for days or weeks."(The Economist 2008)

The next two marks on the chart, labeled "c", correspond to September 15th and September 29th, 2008. These were the days that Lehman Brothers filed for bankruptcy and the House of Representatives rejected the initial version of the TARP program, respectively.

On September 15, Lehman Brother filed for chapter 11 bankruptcy protection in the largest bankruptcy in U.S. history. This sent the message through the interbank market that any bank, regardless of size, was vulnerable. The next day, AIG, a major counterparty in the Credit Default Swap (CDS) market received an emergency loan of $85 billion from the New York Fed. This created enough counterparty uncertainty in the interbank market that the TED spread, which was 151 basis points the Friday before the Lehman bankruptcy, increased to 475 basis points by the following Thursday.

The announcement over the weekend of the Treasury's plan to purchase $700 billion of troubled assets calmed the fears in the interbank market and the TED spread settled to just over 350 basis points by Monday the 22nd.

The second major shock in September 2008 came a week later. On Monday the 29th, the House of Representatives rejected the initial version of the Treasury's troubled asset purchase plan (TARP). Following that news, the Libor jumped by 100 basis points in one day. The peak of the TED spread was reached on October 10th, at 574 basis points.

In prepared remarks in mid-October, Chairman of the Federal Reserve Ben Bernanke summed up the prevailing mood in the financial markets when he said that "As in all past crises, at the root of the problem is a loss of confidence by investors and the public in the strength of key financial institutions and markets."

The interbank market recovered from the shocks of late September, but the TARP program stalled, and the spread stayed in a range of 130-160 basis points throughout the winter. On February 25, 2009 (point "d" on the chart), at the height of the bank nationalization scare, the Federal bank regulatory agencies announced that they would conduct stress tests on banks to determine their capital adequacy under different adverse scenarios.

On April 13th (point "e" on the chart), Goldman Sachs announced healthy first quarter earnings and sold shares to gain the funds necessary to pay off the TARP funds they had received in the fall. The increased certainty in the interbank market that came from seeing that some banks were healthy enough to do without government support caused the TED spread to fall throughout April, and on May 7th, when the stress test results were announced, the spread closed below 120 basis points. It continued to fall throughout May and broke below 100 basis points in early June.

3 Empirical Evidence of an Adverse Feedback Loop

In the model in this paper, risk in the financial sector creates a feedback loop that can amplify the effects of real shocks. Furthermore, this feedback loop is not nearly as strong when risk is localized in the manufacturing sector.

A number of recent event studies of previous financial crises in developed and developing countries find that economic downturns that are accompanied by banking crises tend to be more severe and more protracted than ordinary recessions (See, for example Reinhart and Rogoff 2008 and 2009, Cecchetti, Kohler, and Upper 2009, The IMF 2009a and 2009b, and Bordo and Haubrich 2010). In related studies Bernanke (1983), Bernanke and Lown (1991), Peek and Rosengren (2000), and Gilchrist et al. (2009) attempt to isolate exogenous frictions in the credit markets and find robust evidence that disturbances arising from *within* the financial intermediation process can have real effects.

This empirical evidence of how disturbances within the intermediation process can have real effects is evidence of an adverse feedback loop. An adverse feedback loop should lead to more severe and protracted economic downturns as the initial fall in output leads to a banking crisis, which leads to a further fall in output. This implies that the overall fall in output should be more severe than would have been without a banking crisis, and the normal economic recovery mechanisms are hampered by the banking crisis and poor availability of credit, prolonging the recession.

To provide some empirical backing for this conclusion, and to show how this adverse feedback loop is much more pronounced when frictions arise within the banking sector itself, in this section we consider the time series relationship between industrial production, the spread on lending to the manufacturing sector, and the spread on lending to the financial sector.

We begin by estimating a bivariate VAR(1) model with the month-over-month change in the log of the index of industrial production, ΔIP_t, and a measure of risk in lending to the real sector. RP_t^m is the spread on lending to the manufacturing sector, the spread between the rate on corporate bonds and the 3-month T-bill rate. The VAR(1) model takes the following form:

$$\begin{bmatrix} \Delta IP_t \\ RP_t^m \end{bmatrix} = \mathbf{c} + \mathbf{A} \begin{bmatrix} \Delta IP_{t-1} \\ RP_{t-1}^m \end{bmatrix} + \boldsymbol{\varepsilon}_t \tag{1}$$

Negative off-diagonial terms in the matrix $\mathbf{A}$ would be evidence of an adverse feedback loop where a real economic slowdown causes increased risk premiums, and these increased risk premiums cause a further economic downturn. However the model with the spread between corporate rates and the risk free rate, RP_t^m, doesn't specify whether the adverse feedback loop is due to financial frictions in the financial sector or frictions in the real sector.

To separate the effect of these two potential frictions, we then consider a trivariate VAR(1) model with the month-over-month change in the log of the index of industrial production, ΔIP_t, and measure of risk in lending to the real sector. However now the risk premium RP_t^m is divided into the spread between corporate bonds and the 3-month Libor, RP_t^{m*}, and the spread between the 3-month Libor and the 3-month T-bill, RP_t^f. Thus RP_t^f measures the risk premium on interbank lending and RP_t^{m*} measures the risk premium on lending to the real sector.

$$\begin{bmatrix} \Delta IP_t \\ RP_t^{m*} \\ RP_t^{f} \end{bmatrix} = \mathbf{c} + \mathbf{A} \begin{bmatrix} \Delta IP_{t-1} \\ RP_{t-1}^{m*} \\ RP_{t-1}^{f} \end{bmatrix} + \varepsilon_t \tag{2}$$

The results from the bivariate and trivariate estimations are presented in the tables 1 and 2. The top half of each table shows the results from estimating the bivariate model in (1), and the bottom half of each table shows the results from estimating the trivariate model in (2). The results in table 1 are found using the rates on Aaa rated corporate bonds and the results in table 2 are found using the rates on Baa rated corporate bonds.

The tables show evidence of the adverse feedback loop. In the bivariate VARs, lags of industrial production have a negative effect on the spread between corporate bonds and treasuries. The regressions using Baa corporate risk spreads show that lagged values of the risk spread have a significantly negative effect on industrial production growth. This channel is not significant in the estimation using Aaa corporate risk spreads, however the results from the bivariate VAR regressions can be interpreted as evidence of an adverse feedback loop where a fall in real economic activity causes an increase in risk premiums on lending to the real sector, and these higher risk premiums cause a further fall in real economic activity.[2]

The trivariate VARs in the bottom half of each table show the same adverse feedback loop. Lagged values of the risk premium have a negative effect on industrial production growth, however lagged values of industrial production growth negatively affect the risk premium on interbank lending but don't affect the risk premium on lending to the real sector. This implies that the adverse feedback loop in the bivariate VARs was primarily due to frictions in the interbank market. The adverse feedback loop requires that a slowdown in real economic activity lead to higher risk premiums. The results from the trivariate VAR show that a slowdown in real activity only has a significantly effect on interbank spreads;

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[2] At least when considering the spread on Baa rated corporate bonds.

thus in an environment with no frictions in the financial sector (interbank lending spreads are zero) there should be no evidence of an adverse feedback loop.

4 Model

In order to model the real effects of financial uncertainty, this paper incorporates the financial accelerator mechanism from Bernanke et al. (1999) in the workhorse international real business cycle model of Backus et al. (1992 and 1994) and Baxter and Crucini (1993).

The model consists of two countries, home and foreign. In each country there are households, a manufacturing sector, and a financial sector. The manufacturing sector uses domestic labor and capital to produce tradable consumption goods. Banks in the financial sector channel savings from domestic households to firms in the domestic manufacturing sector, and borrow and lend from banks in the foreign financial sector through the interbank lending market.

Manufacturing firms and banks both face idiosyncratic shocks to the value of their assets which may result in bankruptcy. The probability of bankruptcy is increasing in their debt-asset ratio. As a result, lenders must be compensated by a debt-elastic default risk premium. This gives rise to the financial accelerator mechanism.

In the model, the two countries are symmetric and in what follows we focus on the relevant equations for the home country, when foreign variables appear, they are distinguished by an asterisk ($*$).

4.1 Manufacturing Sector

The home manufacturing sector is made up of a continuum of firms, indexed by i, on the interval $[0, 1]$. Firm i owns a stock of physical capital $K_t\left(i\right)$. This physical capital is financed through equity and a loan from the domestic banks, $K_t\left(i\right) = E_t^M\left(i\right) + b_t^M\left(i\right)$.

Firms combine this capital with labor to produce a tradeable intermediate good. Total production by firm i in period t is:

$$Y_t\left(i\right) = A_t\left(N_t\left(i\right)\right)^{\alpha}\left(K_t\left(i\right)\right)^{1-\alpha} \tag{3}$$

where $Y_t\left(i\right)$ is total production by firm i, $N_t\left(i\right)$ is the firm's labor input, $K_t\left(i\right)$ is the capital input, and A_t is country specific total factor productivity.

Intermediate goods from each firm are combined to produce an aggregate intermediate good that can be used at home or exported:

$$\int_0^1 Y_t\left(i\right) di = y_t^d + y_t^x \tag{4}$$

where y_t^d are intermediate goods meant for domestic use and y_t^x are meant for export.

Domestic and imported intermediate goods are then combined to produce a final good that can either be used for consumption by domestic households or investment in the domestic manufacturing sector:

$$\left[\left(\gamma\right)^{\frac{1}{\rho}}\left(y_t^d\right)^{\frac{\rho-1}{\rho}} + \left(1-\gamma\right)^{\frac{1}{\rho}}\left(y_t^{x*}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}} = C_t + I_t \tag{5}$$

where $\left(1-\gamma\right)$ is the steady state import share, ρ is the import demand elasticity, C_t is household consumption, and I_t is aggregate investment in physical capital. Aggregate investment is equal to the sum of investment by individual firms, $I_t = \int_0^1 I_t\left(i\right) di$.

The firm sells its output for a price p_t^y. Assume that firms pay for labor in advance, therefore the total wage bill of the firm is $\left(1 + r_t^{wc}\right) w_t N_t\left(i\right)$, where r_t^{wc} is the interest rate on working capital loans. Therefore the firm's operating profit in period t is:

$$\Pi_t\left(i\right) = p_t^y Y_t\left(i\right) - \left(1 + r_t^{wc}\right) w_t N_t\left(i\right) \tag{6}$$

The firm's stock of physical capital evolves according to:

$$K_{t+1}(i) = \left(1 - \omega_t^M(i)\,\delta\right) K_t(i) + I_t(i) \tag{7}$$

where $\omega_t^M(i)$ is an i.i.d. shock to the firm's physical capital stock. It is lognormally distributed on the interval $\left[0, \frac{1}{\delta}\right]$ with mean 1 and a variance σ_M^2.

The firm specific shock $\omega_t^M(i)$ introduces heterogeneity among manufacturing firms and gives rise to the possibility that some manufacturing firms will receive an abnormally large shock and be forced to default on their debts. Since the shock has a mean 1, it has no effect on the aggregate capital stock, but since this shock is unknown when the bank makes a physical capital loan to the firm, the shock introduces incomplete information and thus the assumptions necessary for the irrelevance of financial conditions implied by the Modigliani-Miller (1958) theorem are not satisfied.

After the shock to the firm's assets in period t, the firm in the manufacturing sector is bankrupt if the depreciated value of its physical capital plus its operating profit in period t is less than the value of its loan from the financial sector plus any interest it is to pay on that loan in period t:

$$\left(1 - \omega_t^M(i)\,\delta\right) K_t(i) + \Pi_t(i) < \left(1 + r_t^M\right) b_t^M(i). \tag{8}$$

Since the variables $K_t(i)$, $\Pi_t(i)$, and $b_t^M(i)$ are all determined before the realization of the idiosyncratic shock, they are equal across all firms i.[3] Therefore the shock to the firm on the margin between bankruptcy and continuing operations is:

$$\bar{\omega}_t^M = \frac{K_t + \Pi_t - \left(1 + r_t^M\right) b_t^M}{\delta K_t}. \tag{9}$$

Thus if $\omega_t^M(i) \leq \bar{\omega}_t^M$ then firm i will continue operations, and if $\omega_t^M(i) > \bar{\omega}_t^M$ then firm i will declare bankruptcy.

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[3] The irrelevance of past history is due to the fact that there are no capital adjustment costs and the the shocks $\omega_t^M(i)$ are i.i.d. If the manufacturing firm i receives a particularly bad shock in the last period, it is able to completely replenish its capital stock by raising funds in the equity markets.

If a manufacturing firm defaults on its debts, equity investors get nothing and lenders receive a share of the firm's remaining assets. A fraction, μ, of the firm's assets are lost to liquation costs, so lenders receive $(1-\mu)\left(\left(1-\omega_t^M(i)\,\delta\right)K_t+\Pi_t\right)$ after liquidation. If the manufacturing firm does not default then the lender receives $\left(1+r_t^M\right)b_t^M$. The financial sector is populated by banks engaged in perfect competition, so the interest rate charged on physical capital loans, r_t^M, is determined by a bank's zero profit condition:

$$\left(1+r_t^b\right)b_t^M=\int_0^{\bar{\omega}_t^M}\left(1+r_t^M\right)b_t^M dF\left(\omega_t^M\right)+\int_{\bar{\omega}_t^M}^{\delta^{-1}}(1-\mu)\left(\left(1-\omega_t^M\delta\right)K_t+\Pi_t\right)dF\left(\omega_t^M\right) \tag{10}$$

where r_t^b is the bank's cost of capital and $F\left(\omega_t^M\right)$ is the c.d.f. of the truncated lognormal distribution of ω_t^M.

Thus the interest rate charged by banks for physical capital loans to manufacturing firms is:

$$1+r_t^M=\frac{\left(1+r_t^b\right)b_t^M-(1-\mu)\left[\left(K_t+\Pi_t\right)\left(1-F\left(\bar{\omega}_t^M\right)\right)-\delta K_t\int_{\bar{\omega}_t^M}^{\delta^{-1}}\omega_t^M dF\left(\omega_t^M\right)\right]}{F\left(\bar{\omega}_t^M\right)b_t^M} \tag{11}$$

where $F\left(\bar{\omega}_t^M\right)$ is the percent of manufacturing firms that repay. This interest rate, r_t^M, is decreasing in $F\left(\bar{\omega}_t^M\right)$ and thus decreasing in $\bar{\omega}_t^M$. $\bar{\omega}_t^M$ is decreasing in the manufacturing firm's debt-asset ratio, so r_t^M is increasing in the firm's level of indebtedness.

After the realization of the shock, firms that continue operations invest in new capital and return the rest of their net income as dividends to shareholders, while firms that go bankrupt pay no dividends:

$$d_t^M(i)=\begin{cases}\Pi_t-r_t^M b_t^M-I_t(i) & \text{if } \omega_t^M(i)\leq\bar{\omega}_t^M\\ 0 & \text{if } \omega_t^M(i)>\bar{\omega}_t^M\end{cases}. \tag{12}$$

Therefore the average dividend paid by firms in the domestic manufacturing sector is:

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\begin{aligned}
d_t^M &= \int_0^{\delta^{-1}} d_t^M(\omega)\, dF(\omega) = \int_0^{\bar{\omega}_t^M} d_t^M(\omega)\, dF(\omega) \qquad (13) \\
&= \left(\Pi_t - r_t^M b_t^M\right) F\left(\bar{\omega}_t^M\right) - \int_0^{\bar{\omega}_t^M} I_t(\omega)\, dF(\omega).
\end{aligned}
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4.2 Financial Sector

Banks in the financial sector serve as an intermediary between domestic savers and firms in the domestic manufacturing sector. Furthermore, banks engage in interbank lending and borrowing with their foreign counterparts. There is a continuum of banks indexed j on the interval $[0,1]$. In period t the book value of the equity of bank j is:

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E_t^F(j) = B_t^M(j) + B_t^{ib}(j) - b_t^s(j) - b_t^{ib}(j) \qquad (14)
$$

where $B_t^M(j)$ are the the bank's holdings of physical capital loans to the domestic manufacturing sector, $B_t^{ib}(j)$ are foreign bank bonds purchased in the interbank lending market, $b_t^s(j)$ are savings from domestic households, and $b_t^{ib}(j)$ is interbank borrowing from foreign banks.

The same stock of bonds may be a liability to a manufacturing firm but an asset to a bank, so when a stock of bonds is an asset is written with a capital B, but when it is a liability it is written with a lower case b. The same is true for interbank borrowing and lending. The domestic bank's interbank lending to foreign banks is represented on the bank's balance sheet as $B_t^{ib}(j)$, but the same bank's interbank borrowing from foreign banks is represented by $b_t^{ib}(j)$.[4]

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[4] Thus in equilibrium the total stock of physical capital loans that appear as liabilities to manufacturing firms is equal to the total stock of physical capital loans that appear as assets to bank, $\int_0^1 b_t^M(i)\, di = \int_0^1 B_t^M(j)\, dj$.

Similarly the total stock of interbank borrowing from foreign banks that appears as a liability to domestic banks is equal to the total stock of interbank lending that appears as an asset to foreign banks, $\int_0^1 b_t^{ib}(j)\, dj = \int_0^1 B_t^{ib*}(j)\, dj$.

Of the bank's liabilities, $1 - \chi$ are savings from domestic households and χ are loan from other banks in the interbank lending market. Later in this section, we discuss how the parameter $\chi = \frac{b_t^{ib}(j)}{b_t^s(j)+b_t^{ib}(j)}$ is calibrated to match levels of international credit market integration in the data.

Because of bankruptcy in both the domestic manufacturing sector and among foreign banks, the bank's assets, which have a book value of $B_t^M(j) + B_t^{ib}(j)$ at the beginning of period t, have a book value at the end of the period of:

$$\left(1 - \omega_t^F(j)\,\xi_t^M\right) B_t^M(j) + \left(1 - \xi_t^{F*}\right) B_t^{ib}(j) \tag{15}$$

where ξ_t^M is the percent of the average bank's portfolio of loans to the domestic manufacturing sector that is lost to bankruptcy and liquidation costs, and ξ_t^{F*} is the share of the bank's claims on foreign banks that is lost to bankruptcy and liquidation costs.

ξ_t^M is the percent of the average bank's loan portfolio that is lost to bankruptcy and liquidation costs, but $\omega_t^F(j)\,\xi_t^M$ is the percent of bank j's loan portfolio that is lost to bankruptcy and liquidation costs. $\omega_t^F(j)$ is an i.i.d. shock to the bank's loan portfolio. It is lognormally distributed on the interval $\left[0, \frac{1}{\xi_t^M}\right]$ with mean 1 and variance σ_F^2.

The shock implies that some banks may be over-exposed to the set of manufacturing firms that go bankrupt, and thus these banks may find themselves in financial trouble. This implies that banks do not hold fully diversified loan portfolios. This over exposure may be due to a regional bias in the bank's portfolio, or it may be because a bank has a certain core competency and is therefore overexposed to a certain sector of the economy.[5]

The bank specific shock $\omega_t^F(j)$ preforms the same function in the model as the manufacturing firm specific shock $\omega_t^M(i)$. The shock has a mean 1, so it has no effect on aggregate loans losses, but the shock introduces heterogeneity among banks, and thus ex-ante uncertainty and default risk. This ex-ante uncertainty ensures that the conditions of the

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[5] Like the banks, many of which are now bankrupt or were acquired by healthier rivals, who were overexposed to the subprime sector of the mortgage market during the recent crisis.

Modigliani-Miller theorem are not satisfied and the bank financial conditions are important.

In equilibrium, the zero profit condition among perfectly competitive banks implies that banks demand an expected return of $1+r_t^b$ to loans made to the manufacturing sector. Thus $E_t\left(\left(1+r_t^M\right)\left(1-\xi_t^M\right)\right) = 1+r_t^b$. In the next section, the household's savings decision is used to determine ξ_t^{F*}.

After the realization of the shock $\omega_t^F(j)$, bank j will declare bankruptcy if the value of its liabilities exceeds the value of its assets:

$$\left(1-\omega_t^F(j)\,\xi_t^M\right)B_t^M(j)+\left(1-\xi_t^{F*}\right)B_t^{ib}(j) < b_t^s(j)+b_t^{ib}(j) \tag{16}$$

The variables $B_t^M(j)$, $B_t^{ib}(j)$, $b_t^s(j)$, and $b_t^{ib}(j)$ are determined before the realization of the bank specific shock $\omega_t^F(j)$, and are therefore equal across all j. Therefore the value of $\omega_t^F(j)$ for the bank on the margin between bankruptcy and continuing operations is:

$$\bar{\omega}_t^F = \frac{B_t^M+\left(1-\xi_t^{F*}\right)B_t^{ib}-b_t^s-b_t^{ib}}{\xi_t^M B_t^M} \tag{17}$$

Thus if $\omega_t^F(j) \le \bar{\omega}_t^F$ then bank j will continue operations, and if $\omega_t^F(j) > \bar{\omega}_t^F$ then it will declare bankruptcy.

This expression for $\bar{\omega}_t^F$ shows how cross-border credit market integration, represented by a large $\chi = \frac{b_t^{ib}}{b_t^s+b_t^{ib}}$, can lead to the cross-border spread of financial crises. A crisis in the foreign financial sector would lead to a large ξ_t^{F*}. If the two countries have well integrated credit markets, then B_t^{ib} is a large portion of the domestic banks' assets. Therefore the large number of foreign bankruptcies causes a fall in $\bar{\omega}_t^F$, which means that the bankruptcy threshold among domestic banks is lower, leading to more bankruptcies in the domestic financial sector.

The bank's cost of capital, r_t^b, is determined from home and foreign household savings decisions. The bank's liabilities are considered unsecured, just as the Libor measures the rate on unsecured lending in the interbank market. Thus if the bank does not default on their debts, their creditors receive a gross return of $1+r_t^b$. If the bank does default on their debts, creditors receive nothing. The zero profit condition among risk neutral creditors implies:

$$1+r_t^f=\int_0^{\bar{\omega}_t^F}\left(1+r_t^b\right)dG\left(\omega_t^F\right) \tag{18}$$

where r_t^f is the risk free rate.

From (18) we can solve for the bank's cost of capital, r_t^b:

$$1+r_t^b=\frac{1+r_t^f}{G\left(\bar{\omega}_t^F\right)} \tag{19}$$

where $G\left(\bar{\omega}_t^F\right)$ is the percent of domestic banks that do not declare bankruptcy. Just as with the interest rate charged to manufacturing firms in equation (11), this interest rate, r_t^b, is decreasing in $G\left(\bar{\omega}_t^F\right)$ and thus decreasing in $\bar{\omega}_t^F$. $\bar{\omega}_t^F$ is decreasing in the bank's debt-asset ratio, so r_t^b is increasing in the bank's level of indebtedness.[6]

The expression for the bank's cost of capital in (19) explains how uncertainty in the early days of the subprime crisis in August 2007 lead to a dramatic rise in interbank lending rates. In this model, the bank's cost of capital, r_t^b, is essentially the Libor. Therefore the spread between the Libor and the risk free rate is decreasing in $G\left(\bar{\omega}_t^F\right)$. $G\left(\cdot\right)$ is the c.d.f. of the log-normal distribution, so for a given $\bar{\omega}_t^F$ it is strictly decreasing in the variance of the idiosyncratic bank shocks $\omega_t^F\left(j\right)$.

The variance of these shocks represents financial sector uncertainty. When the variance, σ_F^2, is low or zero, there is little or no ex-ante uncertainty about the health of a bank's assets, so lenders do not demand a high premium over the risk free rate. When σ_F^2 is large and banks are ex-ante uncertain about each other's financial position, $G\left(\bar{\omega}_t^F\right)$ decreases and the risk premium in the interbank market increases.

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[6] In addition to interbank lending, household savings are bank liabilities. By assuming that lending to the bank is unsecured, the model abstracts from the role of deposit insurance. In this model with risk neutral creditors, where the proceeds from bank profits or insolvent bank liquidation are returned lump-sum to the household, deposit insurance would not have a quantitative impact. If any of these conditions were not true, there could be a role for deposit insurance in the model.

After the realization of the shock, banks that continue operations return the period's cash flow as dividends to shareholders, while firms that go bankrupt pay no dividends:

$$d_t^F\left(j\right) = \begin{cases} \left(\begin{array}{c} \left(1 - \omega_t^F\left(j\right)\xi_t^M\right)\left(1 + r_t^M\right)B_t^M + \left(1 - \xi_t^{F*}\right)\left(1 + r_t^{b*}\right)B_t^{ib} \\ - \left(1 + r_t^b\right)\left(b_t^s + b_t^{ib}\right) - \left(B_{t+1}^M + B_{t+1}^{ib} - b_{t+1}^s - b_{t+1}^{ib}\right) \end{array} \right) & \text{if } \omega_t^F\left(j\right) \leq \bar{\omega}_t^F \\ 0 & \text{if } \omega_t^F\left(j\right) > \bar{\omega}_t^F \end{cases} \tag{20}$$

The average dividend paid by domestic banks is $d_t^F = \int_0^{1/\xi_t^M} d_t^F\left(\omega\right)dG\left(\omega\right)$.

4.3 Households

Households supply labor to domestic firms, own shares in domestic and foreign firms, and earn interest income from savings with domestic banks. The household maximizes discounted future utility,

$$U_t = \sum_{t=1}^{\infty} \beta^t \left(C_t\right)^{1-\theta}\left(1 - N_t\right)^{\theta} \tag{21}$$

subject to the household's budget constraint:

$$\begin{aligned} & C_t + B_{t+1}^s + \left(1 - F\left(\bar{\omega}_t^M\right)\right)E_t^M + \left(1 - G\left(\bar{\omega}_t^F\right)\right)E_t^F = \\ & w_tN_t + d_t^M + d_t^F + \Xi_t^M + \Xi_t^F + \chi_b\left(B_{t+1}^s - \bar{B}^s\right)^2 + \left(1 + r_t^b\right)\left(1 - \xi_t^F\right)B_t^s \end{aligned} \tag{22}$$

where N_t is the total labor supplied to domestic firms, and B_{t+1}^s is a stock of non-contingent bonds with the domestic financial sector purchased in period t that pay off in period $t+1$.[7]

E_t^M and E_t^F are the book values of the equity in the domestic manufacturing and financial

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[7] Since the stock of bonds is an asset to the household, it is written with a capital B_t^s. In equilibrium, the stock of savings that is an asset to the household is equal to the total stock of savings that is a liability to banks in the domestic financial sector, $B_t^s = \int_0^1 b_t^s\left(j\right)dj$.

sectors. Since $1-F\left(\bar{\omega}_t^M\right)$ percent of manufacturing firms and $1-G\left(\bar{\omega}_t^F\right)$ percent of banks declare bankruptcy, the equity in those firms is lost and must be replenished. Ξ_t^M and Ξ_t^F are losses to bankruptcy and liquidation in the manufacturing sectors that is returned lump-sum to the household. χ_b represents a small quadratic transactions cost to holding bonds. Finally, ξ_t^F is the percent of the household's savings with domestic banks that is lost to bankruptcy and liquidation costs, so of the B_t^s in savings with domestic banks, only $\left(1-\xi_t^F\right)B_t^s$ of the principle is returned. This principle earns a gross interest rate of $1+r_t^b$. In equilibrium, risk neutral households demand an expected return of $1+r_t^f$ to their savings. Thus $E_t\left(\left(1+r_t^b\right)\left(1-\xi_t^F\right)\right)=1+r_t^f$.

4.4 Model Parameterization and Solution

The dynamics of the model are determined from a first order approximation about the steady state. The steady state of the model is determined by the parameter values listed in table 3. Deviations from this steady state are driven by exogenous TFP shocks. The process describing the evolution of these exogenous productivity shocks appears at the end of this section.

The first seven parameters in table 3, the exponents in the household's utility function, the import demand elasticity, the discount factor, capital's share of income, the import share, the capital depreciation rate, and the household's quadratic transaction cost to holding bonds are all set to values commonly found in the literature.

The parameter χ measures the percent of a bank's liabilities are loans from foreign banks on the interbank lending market. This parameter is calibrated such that in the steady state, the ratio of a country's cross-border credit market holdings to GDP is one. This is similar to the ratio reported in Lane and Milesi-Ferritti (2007).

The next two parameters relate to the idiosyncratic manufacturing firm specific risks, $\bar{\sigma}_M$, and the cost of bankruptcy in the manufacturing sector, μ. These parameters are chosen such that in the steady state of the model the default rate of manufacturing loans is

1% per quarter, manufacturing firms have a steady-state debt-asset ratio of 0.5, and in the steady state, the annualized spread between the between bank rates and the rate paid by manufacturing firms ($r^M - r^b$) is 316 basis points. This is the average spread between the rate on Baa corporate bonds and the Libor between 1984 and 2007.

The final parameter, the cross bank heterogeneity in regards to loan losses, $\bar{\sigma}_F$, is calibrated such that in the steady state debt-asset ratio for banks is 0.9 and in the steady state there is a 53 basis point annualized spread between the risk free rate and interbank rates ($r^b - r^f$). This is the spread between the 3-month Libor and the 3-month T-bill between 1984 and 2007.

Like many real business cycle models, business cycles in the model are driven by shocks to total factor productivity (TFP).

To estimate the process that determines the evolution of country specific TFP shocks, we first estimate Solow residuals in the U.S. and the U.K. using quarterly GDP, employment, and investment data from the first quarter of 1984 to the second quarter of 2007.[8]

After finding the U.S. and U.K. Solow residuals, the process that determines the evolution of country specific TFP shocks is and is described by the following VAR(1) process:

$$\begin{bmatrix} \hat{A}_{t+1}^{US} \\ \hat{A}_{t+1}^{UK} \end{bmatrix} = \begin{bmatrix} 0.756 & 0.011 \\ 0.140 & 0.834 \end{bmatrix} \begin{bmatrix} \hat{A}_t^{US} \\ \hat{A}_t^{UK} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{US} \\ \varepsilon_t^{UK} \end{bmatrix}$$

where $\Omega = \begin{bmatrix} \varepsilon_t^{US} \\ \varepsilon_t^{UK} \end{bmatrix} \begin{bmatrix} \varepsilon_t^{US} \\ \varepsilon_t^{UK} \end{bmatrix}' = 10^{-5} \times \begin{bmatrix} 1.68 & 0.05 \\ 0.05 & 1.78 \end{bmatrix}$.

To ensure symmetry, this VAR estimation is averaged to describe the evolution of the home and foreign TFP shocks that drive business cycle fluctuations in the model.

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[8] The evolution of the capital stock is inferred from the evolution of gross investment by assuming a quarterly depreciation rate of 0.025. The Solow residual is inferred from the *GDP*, employment, and capital stock data assuming a capital share of 0.36.

$$\begin{bmatrix} \hat{A}_{t+1} \\ \hat{A}^*_{t+1} \end{bmatrix} = \begin{bmatrix} 0.8 & 0.08 \\ 0.08 & 0.8 \end{bmatrix} \begin{bmatrix} \hat{A}_t \\ \hat{A}^*_t \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \varepsilon^*_t \end{bmatrix}$$

where $\text{var}(\varepsilon_t) = \text{var}(\varepsilon^*_t) = 1.7 \times 10^{-5}$ and $\text{corr}(\varepsilon_t, \varepsilon^*_t) = 0.03$.

5 Results

To show how increased financial sector uncertainty can affect the business cycle, we start with impulse response diagrams to show how GDP and the components of GDP react to a shock to total factor productivity (TFP). We examine these responses under different levels of financial uncertainty to show how acute financial stress can affect the propagation of real shocks.

The model is then used to show the effect of higher financial uncertainty on the second moments of the business cycle. Specifically we use the model to show the effect of higher financial sector uncertainty on the volatility and co-movement of GDP and its components. We show how the behavior of the business cycle since 2007 can largely be explained by this model during times of increased financial uncertainty.

Furthermore, we show that the impact of higher financial sector uncertainty is partly due to the working capital channel in the model, which means that an increase in a bank's cost of capital is passed through to short term working capital loan rates. We also show that the propagation mechanism evident during times of high financial sector risk arises largely because of the high leverage ratios in the financial sector which magnify the feedback loop associated with the financial accelerator.

5.1 Impulse responses during times of increased financial uncertainty

In this section we calculate the response of GDP and its components to a shock to TFP, and show how this response depends on the level of financial sector uncertainty in the economy.

For this we consider multiple levels of uncertainty in both the manufacturing and financial sectors. Recall that σ_M is the standard deviation of the idiosyncratic firm specific shocks in the manufacturing sector and σ_F is the standard deviation of the idiosyncratic bank specific shocks in the financial sector. Thus σ_M governs the risk premium on loans to firms in the manufacturing sector and σ_F governs the risk premium on interbank loans.

In this and the next section where we examine the effect of uncertainty on business cycle moments, we consider five different cases, related to combinations of σ_M and σ_F.

1. $\sigma_M = 0$ and $\sigma_F = 0$. In this case there is no firm level risk in either the manufacturing or financial sectors. In this case, the model is a version of an international real business cycle model (IRBC).

2. $\sigma_M = \bar{\sigma}_M$ and $\sigma_F = 0$. Thus there is firm level risk in the manufacturing sector, but there is no risk in the financial sector. This is the classic case from the financial accelerator literature and the results are qualitatively comparable to Carlstrom and Fuerst (1997).

   In both the first and second cases, there is no bank level risk in the financial sector. In these cases, the financial sector in the model is nothing more than a bookkeeping entry.

3. $\sigma_M = \bar{\sigma}_M$ and $\sigma_F = \bar{\sigma}_F$ from table 3. As discussed in section 4, the values of $\bar{\sigma}_M$ and $\bar{\sigma}_F$ are chosen such that in the steady state the spread between the rate on manufacturing loans and the interbank rate is 316 basis points (annualized) and the spread between the interbank rate and the risk free rate is 53 basis points.

4. $\sigma_M = \bar{\sigma}_M$ and $\sigma_F = 1.1\bar{\sigma}_F$. Thus the fourth case represents a period of acute financial stress. A 10% increase in σ_F represents a 10% increase in financial sector uncertainty. In the model this results in an average spread between interbank rates and the risk free rate of 163 basis points. This is the average spread between the 3-month Libor and the 3-month T-bill between the third quarter of 2007 and the second quarter of 2009.[9]

5. $\sigma_M = 1.1\bar{\sigma}_M$ and $\sigma_F = 0$. This case is meant to answer the question of what if instead of thinking about financial sector risk, we just increase the risk in the manufacturing sector, but otherwise keep the same financial accelerator model.

The response of home and foreign GDP and investment to a negative home TFP shock under cases 1, 2, and 3 are found in figure 2. The figure shows that risk in the financial sector has almost no effect on the response of both GDP and investment, for the response under the model with just manufacturing risk is nearly indistinguishable from the response from the simple IRBC case. Adding financial sector risk has a slight affect and makes GDP deviations a little more persistent, but the effect is small.

Figure 3 shows these same impulse responses under heightened levels of manufacturing and financial sector risk. The impulse responses under the benchmark level of risk are included as well. These impulse responses show that heightened manufacturing sector risk has only a small effect on home and foreign GDP and investment, however heightened financial sector risk has a large effect and makes the initial drop in GDP and investment more severe, there is greater international transmission of the shock, and the response is

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[9] To highlight the role of financial sector uncertainty as a transmission mechanism for shocks to TFP, σ_F, is simply a parameter. Cases three and four are meant to highlight the role of acute levels of uncertainty in the financial sector, so the model is simply simulated under two different parameterizations.

Gilchrist et al. (2009) and Bordo and Haubrich (2010) empirically document the role of shocks in the intermediation process itself.

Within the framework of a financial accelerator model, a number of recent papers, like Christiano et al. (2008), Nolan and Thoenissen (2009) and Jermann and Quadrini (2009), have made the parameter governing risk in a financial accelerator model itself a stochastic process.

In this model, credit market shocks would be represented by stochastic fluctuations in σ_F. This is beyond the scope of this paper but is an interesting direction for further research.

much more persistent. Without the heightened financial sector risk, home and foreign GDP and investment have nearly returned to their steady state levels after 40 quarters, but with heightened financial sector risk, home and foreign GDP is still significantly below steady state levels even after 40 quarters.

The reason behind this increased international transmission and persistence can be found by examining the effect on risk premiums in figures 4 and 5. Specifically, the figures show the response of the spread between home and foreign interbank rates and the risk free rate, and the spread between home and foreign manufacturing rates and interbank rates. In figure 4, these responses are plotted for the case of no bankruptcy risk in either the manufacturing of financial sectors (IRBC), the case of bankruptcy risk in the manufacturing sector, and bankruptcy risk in the manufacturing and financial sectors.

First, the figure shows that the risk premiums are constant and zero in the classic IRBC case. Furthermore, the spread between interbank rates and the risk free rate is constant and zero when there is bankruptcy risk only in the manufacturing sector.

The figure shows that risk premiums increase in response to the negative home TFP shock, although the earlier impulse responses of GDP and investment show that under normal levels of risk in the financial sector, bankruptcy risk fails to act as a mechanism for the propagation of TFP shocks.

However, figure 5 shows that under heightened level of financial sector risk, the responses of these risk premiums become much greater and much more persistent. This explains why the responses of GDP and investment is much greater and more persistent under heightened levels of financial sector risk.

5.2 Financial uncertainty and business cycle volatility and co-movement

The impulse responses presented in the last section seem to suggest that greater financial uncertainty should lead to greater business cycle volatility and greater international cyclical co-movement.

In this section the model presented in section 4 is simulated under different values of σ_M and σ_F, the two parameters that represent firm level uncertainty, and therefore external finance premiums in the manufacturing and financial sectors.

The results from the benchmark parameterization of the model are presented in table 4. The table presents the average or steady state values of the two key interest rate spreads in the model, the standard deviation of GDP and the two interest rate spreads, the relative volatility of certain macro aggregates, the correlation between those aggregates and GDP, and cross-country correlations. In the first two columns, the moments are calculated from U.S. data, and the last five columns contain the theoretical moments implied by the model.[10]

The first column presents moments calculated from U.S. data from the first quarter of 1984 to the second quarter of 2007. In the second column, these same moments are calculated with data from the third quarter of 2007 to the second quarter of 2009, the time of the current financial crisis and recession. Admittedly, the data in the second column is calculated from a small sample, but it is clear that the financial crisis has lead to a dramatic increase in the level and volatility of interest rate spreads, a nearly 150% increase in GDP volatility, a similar increase in the volatility of the other components of GDP, and higher co-movement across the board, whether it be co-movement between a variable and GDP or cross-country co-movement.

The third column presents the results from the model when $\sigma_M = 0$ and $\sigma_F = 0$. This "turns-off" the financial accelerator mechanism in the model, and risk spreads drop to zero. When these two variances are set to zero, the model is a version of the benchmark international real business cycle model.

In the fourth column, the standard deviation of the idiosyncratic bank shocks is set to zero, but the standard deviation of shocks in the manufacturing sector is set to its benchmark level, $\bar{\sigma}_M$, in table 3. This implies that there is no spread between the interbank rate and the

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[10] The data in the first two columns is calculated from U.S. data and the cross-country correlations and calculated between the U.S. and the EU-12.

risk free rate, but there is a spread between the rate at which manufacturing firms borrow and the interbank rate. Now the model becomes an international version of the financial accelerator model in Carlstrom and Fuerst (1997). There is a financial sector, but without financial sector risk the financial sector is nothing more than a bookkeeping entry in this model without nominal rigidities.

Comparing columns three and four shows that adding a financial accelerator and manufacturing sector risk in this real model has little effect on the business cycle. The one place where the manufacturing sector risk seems to have an effect is in investment volatility. Risk in the manufacturing sector and thus a positive and volatile risk premium, affects firms' borrowing costs and thus affects their investment decision, but it has little direct effect on the rest of the economy.

In the fifth column $\sigma_M = \bar{\sigma}_M$ and $\sigma_F = \bar{\sigma}_F$. The idiosyncratic default risk in both the manufacturing and financial sectors is calibrated to match the Baa-Libor spread and the Libor-Tbill spread over the period from the first quarter of 1984 to the second quarter of 2007. A comparison of the fourth and fifth column shows that introducing a small amount of financial sector risk into the model has some effect on business cycle volatility and co-movement, but not much. The table shows that GDP volatility is about 10% higher when financial sector risk is taken into account, and there is little change in business cycle co-movement, either the co-movement of a variable with GDP or cross-country co-movement. The only major difference is now the spread between the interbank rate and the risk free rate is non-zero and very countercyclical.

In the sixth column, the variance of the bank specific shock, σ_F, is higher by 10%. This implies that there is greater uncertainty, and thus greater risk, in the financial sector. The spread between the interbank rate and the risk free rate increases after the increase in financial sector uncertainty. Comparing the first row in columns two and six shows that this 10% increase in uncertainty is sufficient to match the increase in the TED spread that occurred during the recent crisis.

Comparing columns five and six shows that the model predicts a 70% increase in GDP volatility following a 10% increase in financial sector uncertainty. Thus the model is able to replicate nearly half of the increase in GDP volatility observed in the recent crisis.

The model can replicate the fact that in the recent crisis, most macro aggregates have become more procyclical. The model also is able to replicate the fact that interest rate spreads, both the Baa-Libor spread and the Libor-Tbill spread, become more countercyclical during times of high financial uncertainty.

Comparing cross-country correlations shows that the model is able to replicate the increase in cross-country business cycle co-movement during the recent crisis. Moving from a state with low financial sector uncertainty to one with high financial sector uncertainty results in a 25 percentage point increase in cross-country GDP co-movement.

To show that the business cycle effects of an increase in financial sector uncertainty are actually due to increased uncertainty in the *financial sector* and not just an overall increase in risk, in column seven uncertainty in the financial sector, σ_F, is set to zero, but uncertainty in the manufacturing sector is 10% higher than its benchmark level. Thus in column seven, the model is the usual model of the financial accelerator, but with higher than normal risk. Without idiosyncratic default risk in the financial sector, the financial sector acts as a bookkeeping entry in this real business cycle model.

The higher uncertainty in the manufacturing sector leads to a 150 basis point increase in the risk premium for loans to the manufacturing sector. However, comparing the results in column four to those in column seven shows that GDP volatility barely increases following an increase in default risk in the usual financial accelerator model with flexible prices. The only clear effect of the higher uncertainty is the higher investment volatility.

5.2.1 The effect of the working capital channel

In table 5 the same results are calculated, but without a working capital channel in the model. Thus firms are not required to pay employees ahead of time, $r^{wc} = 0$. When there is a working capital channel in the model, $r^{wc} = r^b$, so removing the working capital channel removes a significant channel whereby events in the interbank market affect the labor market.[11] The table shows that removing the working capital channel significantly reduces the effect of financial uncertainty, but even without the working capital channel, financial uncertainty has a significant effect on the business cycle.

With the working capital channel in the model, increased financial uncertainty leads to a 70% increase in *GDP* volatility. Without the working capital channel, increased financial uncertainty leads to a little more than a 50% increase in volatility. Similarly, without the working capital channel, increased financial sector uncertainty leads to about a 19 percentage point rise in cross-country *GDP* correlation. With a working capital channel, increased financial sector uncertainty leads to a 25 percentage point increase. Financial uncertainty still has a significant effect on the business cycle, but the magnitude of this effect is reduced when the working capital channel is removed, and thus events in the interbank market no longer have a direct effect on the labor market.

5.2.2 The effect of financial sector leverage

In table 6 the same results from the model are calculated, but this time the model is parameterized such that the debt-asset ratio of banks is 0.5. This means that banks and manufacturing firms have the same leverage. Thus testing the implications of the model when banks have a debt-asset ratio of 0.5 amounts to testing the hypothesis that a high leverage ratio among banks is what makes financial sector uncertainty so important in this model.

The results in table 6 confirm this hypothesis. When the financial sector has a leverage ratio akin to that in the manufacturing sector, increased financial sector uncertainty plays almost no role in the propagation of real shocks. Therefore the results from the table confirm

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[11] In the benchmark model, $r^{wc} = r^b$, which implies that banks charge no markup on short term working capital loans. This reflects the fact that the rate on 3-month non-financial commercial paper is similar in levels to the Libor.

that the high leverage ratios in the financial sector are the main cause of the strong feedback loop related to uncertainty in the financial sector and why financial sector risk plays a role in the propagation of real shocks while risk in the manufacturing sector does not.

The special role of financial sector leverage as a propagation mechanism is also shown in figures 6 and 7. These figures plot the GDP volatility and cross-country GDP co-movement as a function of the steady state debt-asset ratio in the financial sector. These moments are from the model simulated under high levels of financial sector uncertainty, column six in table 4 and column four in table 6.

The figures plot GDP volatility and co-movement over the range of steady state values of the debt-asset ratio in the financial sector from 0.5 to 0.9. Thus the rightmost end point in the figure corresponds to the benchmark parameterization of the model in table 4 and the leftmost end point corresponds to the alternative parameterization in table 6.

The figures show that financial sector uncertainty acts as an important propagation mechanism as the steady-state debt asset ratio gets higher, and GDP volatility and co-movement seem to grow exponentially as the debt-asset ratio gets closer to 0.9. This rapid increase in the strength of the propagation mechanism as the debt-asset ratio approaches 0.9 implies that even a small increase in banks' steady state leverage, and thus a small increase in their capital cushion would do a lot to arrest the potential adverse feedback loop that arises during times of increased financial sector uncertainty.

6 Conclusion

This paper shows that financial sector uncertainty can serve as an important mechanism for the propagation of real shocks.

Uncertainty in the financial sector creates a potential feedback loop that can increase persistence, volatility, and co-movement following a shock. Most of the time, the financial sector is calm and the effects arising from this feedback loop are small. However, during periods of acute financial stress, financial sector uncertainty combines with the high leverage ratio of financial institutions and the fact that higher bank lending rates are passed on to all sectors of the economy, to make a particularly strong feedback loop.

This implies that during times of high uncertainty in the financial sector, the "financial accelerator" mechanism applied to banks in the financial sector has a much greater quantitative effect than a financial accelerator mechanism applied to the productive sector alone.

The paper focused on the effects of financial sector uncertainty in a real model. Prices were flexible and business cycles were driven by TFP shocks. An interesting direction for further research would be to study the effect of financial sector uncertainty in a model with sticky prices and monetary shocks. Such a model could also be used to assess how periods of increased financial sector uncertainty affect the monetary transmission mechanism.

Mainstream macroeconomic models assume that the central bank sets the interest rate that borrowers face. But with a financial sector, banks lend to each other at an overnight rate targeted by the central bank, but financial frictions may drive a wedge between overnight interbank rates determined by a central bank and longer term rates faced by consumers. This paper shows how uncertainty in the financial sector leads to an important feedback loop that can amplify the effects of real shocks, an important direction for further research would be to use this model to assess if financial sector uncertainty dampens the effect of central bank stabilization policies, and how should a central bank respond to periods of increased financial sector uncertainty.

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Table 1: Results from the estimation of a VAR(1) model with the log change in industrial production and interest rate spreads

1: Bivariate VAR with change in industrial production and the Aaa-Tbill spread.

	ΔIP_t	RP_t^m
ΔIP_{t-1}	0.191^{**} (0.055)	-0.080^{**} (0.023)
RP_{t-1}^m	-0.031 (0.027)	0.982^{**} (0.011)
$\bar{R}^2$	0.038	0.963
Obs.	309	309

2: Trivariate VAR with change in industrial production, the Aaa-Libor spread and the Libor-Tbill spread.

	ΔIP_t	RP_t^{m*}	RP_t^f
ΔIP_{t-1}	0.149^{**} (0.056)	0.006 (0.025)	-0.089^{**} (0.022)
RP_{t-1}^{m*}	-0.032 (0.027)	1.003^{**} (0.012)	-0.022^{**} (0.010)
RP_{t-1}^f	-0.322^{**} (0.075)	0.138^{**} (0.034)	0.833^{**} (0.029)
$\bar{R}^2$	0.087	0.963	0.784
Obs.	309	309	309

Notes: ΔIP_t is the month-over-month change in the log of U.S. industrial production, RP_t^m is the spread between the rate on Aaa rated corporate bonds and the 3-month T-bill rate, RP_t^{m*} is the spread between the rate on Aaa rated corporate bonds and the 3-month Eurodollar contract, and RP_t^f is the spread between the 3-month Eurodollar contract and the 3-month T-bill. Data is from 1984:2 to 2009:10.

Table 2: Results from the estimation of a VAR(1) model with the log change in industrial production and interest rate spreads

1: Bivariate VAR with change in industrial production and the Baa-Tbill spread.

	ΔIP_t	RP_t^m
ΔIP_{t-1}	0.171^{**} (0.056)	-0.105^{**} (0.026)
RP_{t-1}^m	-0.058^{**} (0.023)	0.978^{**} (0.011)
$\bar{R}^2$	0.053	0.967
Obs.	309	309

2: Trivariate VAR with change in industrial production, the Baa-Libor spread and the Libor-Tbill spread.

	ΔIP_t	RP_t^{m*}	RP_t^f
ΔIP_{t-1}	0.138^{**} (0.056)	-0.004 (0.025)	-0.093^{**} (0.022)
RP_{t-1}^{m*}	-0.045^{**} (0.023)	0.998^{**} (0.010)	-0.021^{**} (0.009)
RP_{t-1}^f	-0.318^{**} (0.071)	0.184^{**} (0.032)	0.842^{**} (0.028)
$\bar{R}^2$	0.094	0.969	0.783
Obs.	309	309	309

Notes: ΔIP_t is the month-over-month change in the log of U.S. industrial production, RP_t^m is the spread between the rate on Baa rated corporate bonds and the 3-month T-bill rate, RP_t^{m*} is the spread between the rate on Baa rated corporate bonds and the 3-month Eurodollar contract, and RP_t^f is the spread between the 3-month Eurodollar contract and the 3-month T-bill. Data is from 1984:2 to 2009:10.

Table 3: Parameter Values

Symbol	Value	Description
θ	0.75	exponent on leisure in the utility function
ρ	2	import demand elasticity
β	0.99	discount factor
α	0.36	capital share
γ	0.85	one minus the import share
δ	0.025	capital depreciation rate
χ_b	0.02	household's quadratic cost to holding bonds
χ	0.217	percent of a bank's liabilities that are loans from foreign banks
$\bar{\sigma}_M$	1.377	standard deviation of shocks to a firm's capital
μ	0.836	manufacturing firm's bankruptcy cost
$\bar{\sigma}_F$	1.030	standard deviation of shocks to a bank's loan portfolio

Table 4: Benchmark results from the model

				Model Simulations				
		1984:1-2007:2	2007:3-2009:2	$\sigma_F = 0$ $\sigma_M = 0$	$\sigma_F = 0$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = \bar{\sigma}_F$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = 1.1\bar{\sigma}_F$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = 0$ $\sigma_M = 1.1\bar{\sigma}_M$
Steady State	$r^b - r^f$	0.536	1.628	0.000	0.000	0.536	1.633	0.000
	$r^m - r^b$	3.162	3.941	0.000	3.162	3.162	3.163	4.646
Volatility (%)	GDP	0.900	2.180	1.285	1.241	1.380	2.357	1.252
	$r^b - r^f$	0.366	1.236	0.000	0.000	0.069	0.444	0.000
	$r^m - r^b$	1.458	2.072	0.000	0.152	0.199	0.534	0.263
Volatility relative to GDP	C	0.894	0.739	0.521	0.537	0.548	0.617	0.559
	I	4.025	4.055	3.993	5.086	5.081	4.191	5.628
	N	1.033	0.755	0.711	0.720	0.711	0.556	0.721
	X	3.936	3.656	1.004	1.021	1.021	1.002	1.032
	IM	3.448	3.689	1.004	1.021	1.021	1.002	1.032
Correlation w/ GDP	C	0.827	0.947	0.394	0.383	0.404	0.682	0.387
	I	0.908	0.974	0.899	0.884	0.878	0.850	0.873
	N	0.763	0.971	0.861	0.808	0.806	0.749	0.771
	X	0.528	0.976	0.504	0.469	0.515	0.768	0.417
	IM	0.808	0.978	0.871	0.890	0.885	0.908	0.891
	$r^b - r^f$	0.378	-0.295	NaN	NaN	-0.727	-0.876	NaN
	$r^m - r^b$	-0.617	-0.900	NaN	-0.696	-0.724	-0.876	-0.717
Cross-Country Correlation	GDP	0.481	0.989	0.380	0.388	0.429	0.679	0.349
	C	0.682	0.976	0.618	0.505	0.534	0.737	0.381
	I	0.573	0.988	-0.033	-0.017	0.023	0.217	-0.058
	N	0.758	0.973	0.153	0.184	0.213	0.298	0.148
	X	0.618	0.991	0.370	0.332	0.372	0.673	0.267
	IM	0.769	0.995	0.370	0.332	0.372	0.673	0.267

Notes: Individual country Moments calculated from the data are from the U.S. from 1984:1 to 2009:2. Cross-country moments are calculated from the U.S. and the EU-12 from 1995:1 to 2009:2

Table 5: Results from the model when there is no working capital requirement.

		$\sigma_F = 0$ $\sigma_M = 0$	$\sigma_F = 0$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = \bar{\sigma}_F$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = 1.1\bar{\sigma}_F$ $\sigma_M = \bar{\sigma}_M$	$\sigma_F = 0$ $\sigma_M = 1.1\bar{\sigma}_M$
Steady State	$r^b - r^f$	0.000	0.000	0.536	1.633	0.000
	$r^m - r^b$	0.000	3.162	3.162	3.163	4.646
Volatility (%)	GDP	1.318	1.281	1.418	2.133	1.296
	$r^b - r^f$	0.000	0.000	0.070	0.371	0.000
	$r^m - r^b$	0.000	0.155	0.200	0.447	0.268
Volatility relative to GDP	C	0.516	0.533	0.542	0.594	0.555
	I	4.029	5.129	5.150	4.597	5.676
	N	0.731	0.742	0.737	0.630	0.745
	X	1.004	1.021	1.023	1.010	1.033
	IM	1.004	1.021	1.023	1.010	1.033
Correlation w/ GDP	C	0.371	0.361	0.373	0.574	0.365
	I	0.901	0.886	0.881	0.856	0.875
	N	0.860	0.810	0.806	0.746	0.775
	X	0.504	0.472	0.514	0.712	0.421
	IM	0.875	0.892	0.887	0.900	0.891
	$r^b - r^f$	NaN	NaN	−0.719	−0.835	NaN
	$r^m - r^b$	NaN	−0.692	−0.716	−0.834	−0.713
Cross-Country Correlation	GDP	0.384	0.393	0.433	0.629	0.355
	C	0.618	0.509	0.539	0.700	0.387
	I	−0.023	−0.005	0.036	0.194	−0.047
	N	0.174	0.205	0.236	0.319	0.168
	X	0.373	0.336	0.371	0.596	0.270
	IM	0.373	0.336	0.371	0.596	0.270

Table 6: Results from the model when both banks and manufacturing firms have a steady state debt-asset ratio of 0.5

		$\sigma_F = 0$	$\sigma_F = 0$	$\sigma_F = \bar{\sigma}_F$	$\sigma_F = 1.1\bar{\sigma}_F$	$\sigma_F = 0$
		$\sigma_M = 0$	$\sigma_M = \bar{\sigma}_M$	$\sigma_M = \bar{\sigma}_M$	$\sigma_M = \bar{\sigma}_M$	$\sigma_M = 1.1\bar{\sigma}_M$
Steady State	$r^b - r^f$	0.000	0.000	0.536	1.190	0.000
	$r^m - r^b$	0.000	3.162	3.162	3.163	4.646
Volatility (%)	GDP	1.285	1.241	1.281	1.302	1.254
	$r^b - r^f$	0.000	0.000	0.031	0.056	0.000
	$r^m - r^b$	0.000	0.152	0.170	0.184	0.264
Volatility relative to GDP	C	0.521	0.536	0.541	0.547	0.558
	I	3.991	5.083	5.125	5.167	5.621
	N	0.710	0.719	0.714	0.708	0.720
	X	1.007	1.025	1.025	1.024	1.037
	IM	1.007	1.025	1.025	1.024	1.037
Correlation w/ GDP	C	0.396	0.385	0.396	0.412	0.390
	I	0.899	0.884	0.881	0.877	0.873
	N	0.861	0.809	0.807	0.804	0.772
	X	0.503	0.468	0.484	0.499	0.415
	IM	0.867	0.886	0.884	0.882	0.883
	$r^b - r^f$	NaN	NaN	-0.701	-0.710	NaN
	$r^m - r^b$	NaN	-0.696	-0.707	-0.717	-0.717
Cross-Country Correlation	GDP	0.380	0.387	0.402	0.414	0.346
	C	0.624	0.512	0.520	0.529	0.385
	I	-0.032	-0.016	0.000	0.012	-0.058
	N	0.156	0.188	0.201	0.211	0.151
	X	0.360	0.320	0.333	0.348	0.252
	IM	0.360	0.320	0.333	0.348	0.252

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Figure 1: The TED spread, the spread between the 3 month Eurodollar contract and the 3-month T-bill rate.

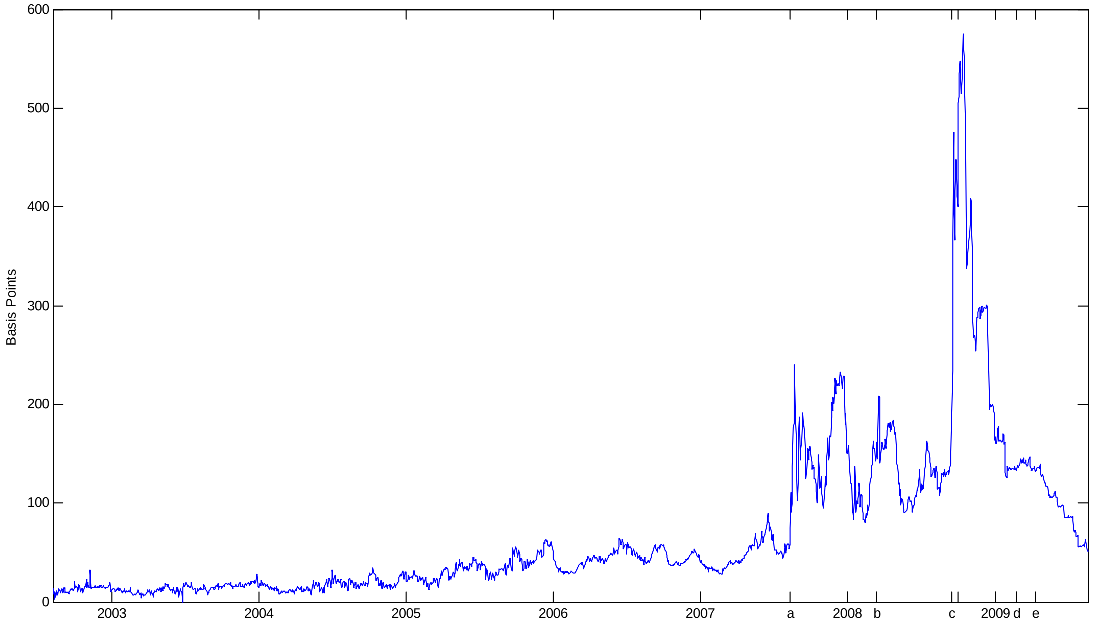


Figure 2: Impulse responses to a negative home TFP shock under various scenarios pertaining to risk in the manufacturing and financial sectors.

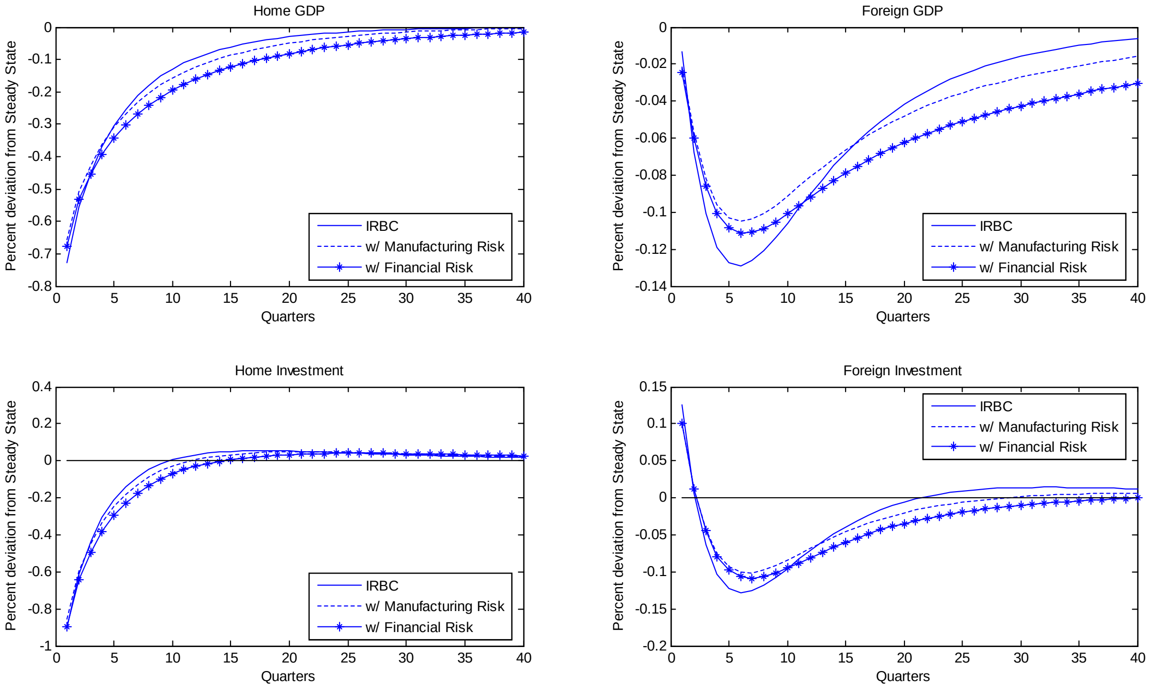


Figure 3: Impulse responses to a negative home TFP shock under various scenarios pertaining to risk in the manufacturing and financial sectors.

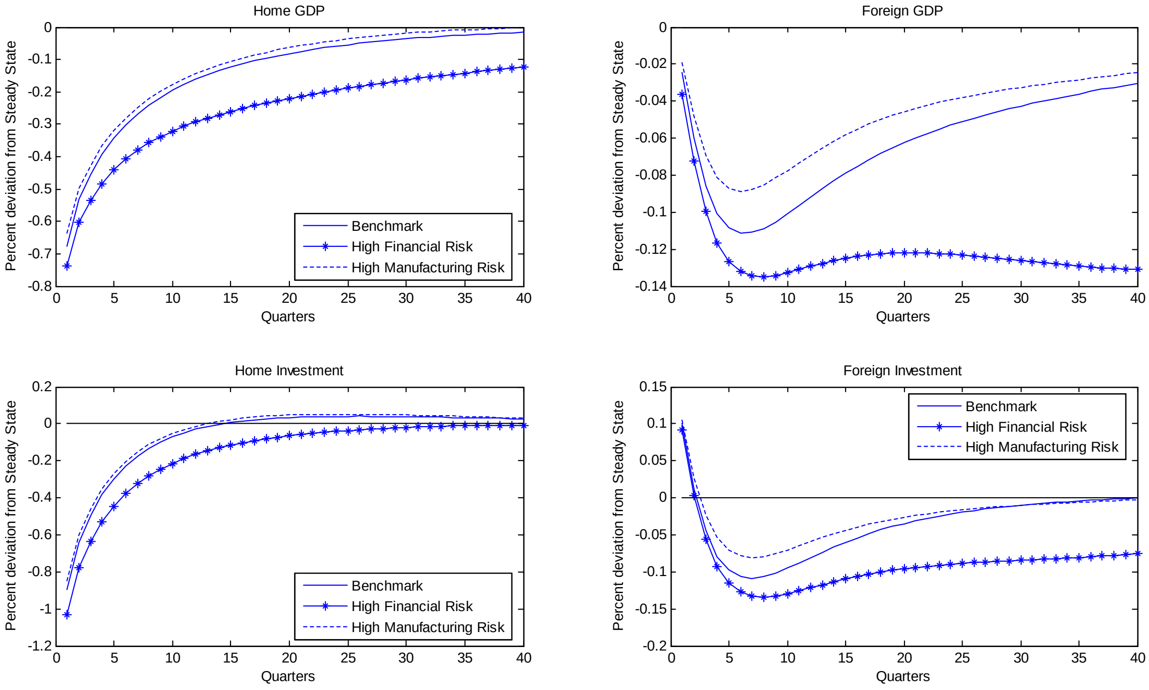


Figure 4: Impulse responses to a negative home TFP shock under various scenarios pertaining to risk in the manufacturing and financial sectors.

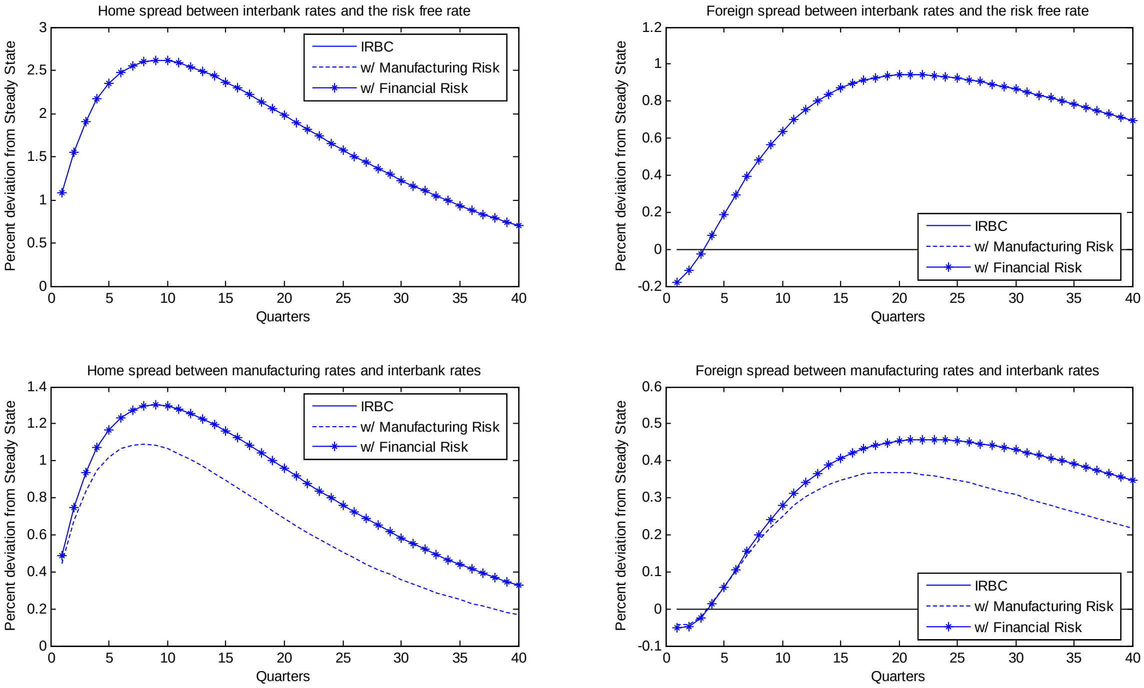
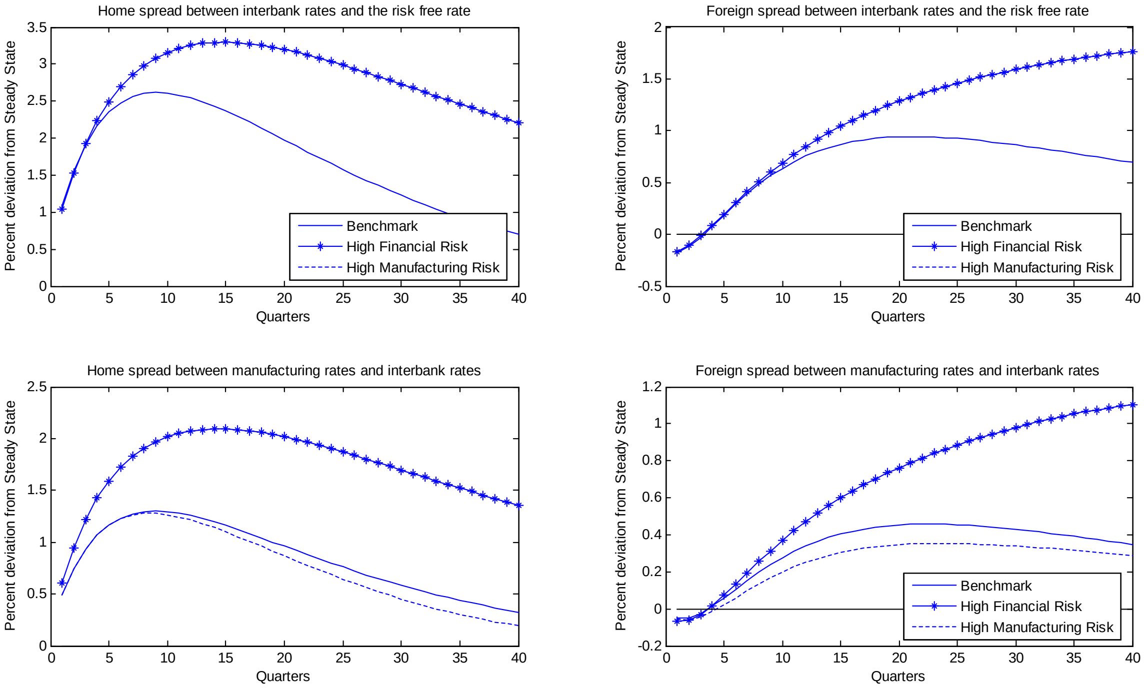


Figure 5: Impulse responses to a negative home TFP shock under various scenarios pertaining to risk in the manufacturing and financial sectors.



Home spread between interbank rates and the risk free rate

Foreign spread between interbank rates and the risk free rate

Home spread between manufacturing rates and interbank rates

Foreign spread between manufacturing rates and interbank rates

Figure 6: GDP Volatility as a Function of Steady State Debt-Asset Ratios in the Financial Sector.

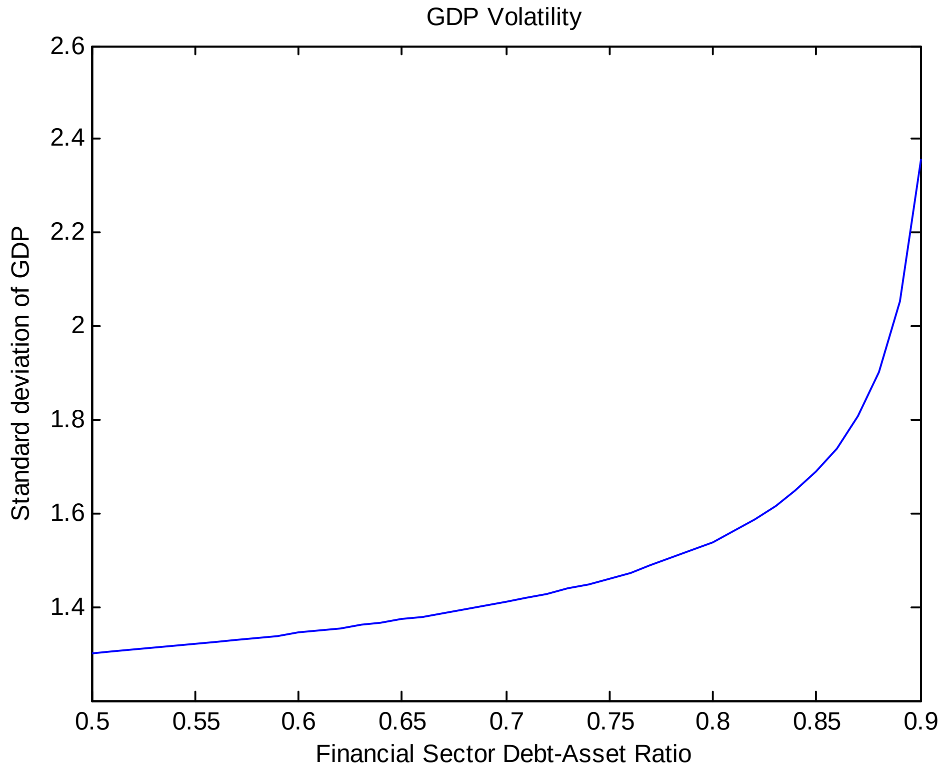


Figure 7: Cross-Country GDP co-movement as a Function of Steady State Debt-Asset Ratios in the Financial Sector.