Leveraged Financial Intermediation, Default, and the Design of Public Debt[1]

Yves Nosbusch

London School of Economics

This version: November 2011

[1]Contact: Department of Finance, London School of Economics, Houghton Street, London WC2A 2AE, UK. Phone +44-20-7955-7319, email y.nosbusch@lse.ac.uk. I am grateful to Sudipto Bhattacharya, Jack Favilukis and David Webb for helpful comments and discussions.

Abstract

Few papers in the existing literature model financial intermediaries explicitly in a general equilibrium framework. Those that do either assume an exogenous riskless rate or they imply no defaults of financial intermediaries in equilibrium, or both. In contrast, this paper captures the idea that in a financial crisis, riskless rates fall endogenously due to "flight-to-quality" and that financial intermediaries default with positive probability in the absence of government intervention. The result that the equilibrium riskless rate is procyclical stands in stark contrast to tax smoothing models. It has novel implications for the design of public debt, in particular the optimal maturity structure and the desirability of adding call features to government bonds.

JEL classifications: [G21, G32, G33, G12, G28, G01, E51]

Keywords: [financial intermediaries, leverage, bankruptcy, interest rates, government policy, financial crises, credit]

1 Introduction

One of the striking features of the financial crisis of 2007-2008 was the extreme behavior of interest rates. On the one hand, rates on government bonds which were perceived to be free of default risk fell to extremely low levels while on the other, spreads on credit-risky instruments rose sharply. In particular, the spread on uncollateralized bank lending shot up to extreme levels.[2] Qualitatively similar patterns occurred in the aftermath of the collapse of the hedge fund Long Term Capital Management in the fall of 1998 and again more recently with the unfolding European sovereign debt crisis.

A second central feature of the financial crisis was the fact that a significant number of financial institutions would effectively have been forced into default in the absence of government intervention. Indeed a number of them did collapse, perhaps most prominently the investment bank Lehman Brothers, with dramatic consequences.

This paper has two main objectives. The first one is positive in nature. I present a simple general equilibrium model with a financial intermediation sector where episodes characterized by low riskless rates and high interbank credit spreads arise endogenously and are directly related to the leverage of the financial intermediation sector and the possibility that financial intermediaries can default in equilibrium during such episodes. Existing models cannot simultaneously match these patterns in riskless rates and bank credit spreads since they either assume an exogenous riskless rate or they imply that financial intermediaries do not default in equilibrium, or both.

There are four types of agents in the model: entrepreneurs, households, financiers, and the government. Entrepreneurs have exclusive access to valuable investment projects

[2] Brunnermeier (2009) provides a detailed discussion of the movements in various interest rates following the collapse of the investment bank Lehman Brothers.

but lack the funds required to start these projects. Households have an inelastic supply of savings. Financiers have equity stakes in financial intermediaries which channel household savings as well as the capital of financiers towards entrepreneurs with valuable investment projects. The assumption is that direct matching between savers (households) and investors (entrepreneurs) is less efficient than intermediation. The final agent is the government which, in the first part of the paper, just issues an exogenous amount of short-term debt. Households can allocate their savings between deposits with financial intermediaries and government debt. Financiers can invest their wealth in government debt or financial intermediaries. They benefit from limited liability so that they cannot lose more than their equity stake in the financial intermediaries. The financial intermediaries themselves can lend to entrepreneurs or invest in government debt. All agents have logarithmic utility.

The financiers maximize the discounted infinite sum of utilities from consumption in all future periods. Each period they face two choices: they must decide how much of their wealth to keep outside the financial intermediary, i.e., how to adjust their equity stake, and how to allocate the portfolio inside the financial intermediary between loans and government bonds. The problem of the financiers thus has two state variables (wealth and a variable that indicates whether the financial intermediary is solvent) and two choice variables (the payout ratio and the size of the loan portfolio). For a given riskless rate, this problem can be solved using numerical dynamic programming techniques.

Examining the general equilibrium properties of this setup yields a number of implications. First, the financial intermediation sector is generally leveraged in equilibrium because it invests the savings of households alongside the equity of the financiers. The riskless rate is endogenous in the model and it is effectively determined by the financial intermediation sector for a given supply of government debt. It is simply the rate at which the demand for government bonds by the financial intermediation sector equals a given supply. Since the financial intermediaries are leveraged and investments in projects are risky, they can default and do so with positive probability in equilibrium. The model thus also implies a credit spread on uncollateralized bank lending. The setup generates endogenous flight-to-quality episodes in response to large losses on the loan portfolios held by financial intermediaries. Such periods are characterized by significant falls in riskless rates, rises in credit spreads, and a contraction in the supply of loans.[3] Financial intermediaries can become insolvent during such episodes, leading to systemic crises.

The second objective of the paper is normative. To the extent that such crises have negative effects on the real economy, what can the government do to reduce their frequency and mitigate them when they occur? One possibility would be to force down the leverage of financial intermediaries, thereby reducing the probability of financial crises. A blunt way of achieving this would be to increase the supply of government debt and to force the financial intermediaries to hold this debt through a minimum capital requirement. However such a policy would have an important cost since it would crowd out loans made to entrepreneurs in equilibrium and thus result in valuable projects being foregone due to lack of financing. Thus there is a trade-off in the model between reducing the likelihood of costly financial crises and curtailing aggregate financing of valuable projects and thus ultimately economic growth. In general, the optimal outcome involves a leveraged financial intermediation sector, some periods of high leverage, flight-to-quality episodes, and occasional financial crises.

[3] This is consistent with the findings in Becker and Ivashina (2011). Their firm-level evidence points towards significant contractions in credit supply (rather than demand) during recessions.

The paper suggests a way of improving this trade-off through a government debt issuance policy which involves a combination of callable and non-callable long-dated bonds. At the heart of the mechanism is the fact that riskless rates fall endogenously during flight-to-quality episodes. This prediction of the model stands in stark contrast to the tax smoothing paradigm, which is the leading framework for the normative analysis of public debt. Indeed, tax smoothing models make the counterfactual prediction that riskless rates are high in bad states of the world. In the present framework this prediction is reversed, which leads to novel implications for the optimal maturity structure and the desirability of making government debt callable.

Suppose that the government issues a mix of callable and non-callable long-dated noncontingent bonds and that it imposes a minimum capital requirement in terms of non-callable government bonds on financial intermediaries. The idea is that in equilibrium financial intermediaries hold the supply of non-callable government debt while households (savers) invest in callable government bonds in addition to their deposits with financial intermediaries. During a crisis, the value of the long-dated noncontingent bonds rises rapidly, as does the value of the call option held by the government on the bonds placed with savers. This effectively allows the government to engineer a state contingent transfer from savers to financial intermediaries in the event of a crisis. This is welfare improving because it reduces the frequency of financial crises (and mitigates their severity when they occur) and the resulting loss of some valuable technologies due to lack of financing. A critical difference with current policy is that this contingent transfer would be priced *ex ante* in the government bond market. Effectively, financial intermediaries would have to pay a premium (in the form of a low return on their noncontingent government bond holdings) during good times to compensate savers for the crisis-contingent transfer. Savers would effectively collect a spread in good times through the premium on the call option they have sold to the government. While callable debt issuance by the government has been important historically,[4] this motivation for issuing callable bonds is, to the best of my knowledge, novel.

2 Related Literature

The positive part of the analysis relates to a number of papers which explore the interaction between credit markets and the macroeconomy. Kiyotaki and Moore (1997) show how credit limits which are endogenously determined by asset values can provide a powerful amplification mechanism whereby small exogenous shocks can have large and persistent effects on output and asset prices in equilibrium. In their model there are two types of agents ("farmers" and "gatherers"). The farmers borrow from the gatherers on a fully collateralized basis.[5] There are no defaults in equilibrium and the riskless interest rate is constant and pinned down by the gatherers' rate of time preference.

In a series of papers, Bernanke and Gertler (1989) and Bernanke, Gertler, and Gilchrist (1996, 1999) analyze how credit market frictions can give rise to a "financial accelerator" when entrepreneurs are subject to an external finance premium. The external finance premium arises in the model because of an agency problem between the borrower and the lender and the assumption of costly state verification along the lines of Townsend (1979). In the setup of Bernanke, Gertler, and Gilchrist (1999) there

[4]Longstaff (1992) and Bliss and Ronn (1998) give historical overviews of callable bond issuance by the U.S. government. Callable bonds constituted a large proportion of government issuance for most of the twentieth century but the U.S. Treasury stopped issuing them in 1984. The main focus of both these papers is on negative option value anomalies in the government bond market and particularly on whether the U.S. Treasury's exercise decisions on the call options have been optimal.

[5]In the model, the farmer's technology is idiosyncratic and the farmer's human capital inalienable in the sense of Hart and Moore (1994). A highly indebted farmer may find it optimal to renege on the debt contract and the lender cannot force repayment beyond the value of collateral. Because of this, lenders will ensure that the value of debt never exceeds the value of the collateral in equilibrium.

are three types of agents: entrepreneurs, households and financial intermediaries. In equilibrium all aggregate risk is absorbed by the entrepreneurs and the financial intermediaries just hold a diversified portfolio which earns the riskless rate. Thus there are no defaults of financial intermediaries in the model and the (shadow) interbank rate is just equal to the riskless rate (the external finance premium faced by entrepreneurs on the other hand is countercyclical and inversely related to the entrepreneurs' net worth). The riskless rate is pinned down by the household's Euler equation in equilibrium in the standard way.

Aghion, Banerjee, and Piketty (1999) present a general equilibrium model where the presence of two groups of agents (savers and investors) and endogenous borrowing constraints due to an ex post moral hazard problem give rise to endogenous cycles in output, investment and the riskless rate. Interestingly, the equilibrium riskless rate is strongly procyclical in their model. The basic intuition for this result is that when growth is slow, savings are plentiful relative to the debt capacity of investors. Clearing of the loan market requires a fall in the riskless rate. These authors do not model financial intermediaries or credit spreads.

The papers discussed so far emphasize the effects of credit constraints on non-financial borrowers. In a recent paper, Gertler and Kiyotaki (2011), building on Gertler and Karadi (2011) and Kiyotaki and Moore (2008), shift the focus towards credit constraints on financial intermediaries, which appear to have been at the heart of the 2007-08 financial crisis. The basic idea is that banks face endogenous balance sheet constraints because of an agency problem. More specifically, the assumption is that banks can divert a fraction of borrowed funds and this gives rise to an incentive constraint whereby the value of banks' net worth always needs to exceed the value of what they could divert by defaulting. The optimal contract ensures that banks never default in equilibrium.

The model reproduces the empirical pattern that interbank rates rise as banks' net worth falls and borrowing constraints tighten. Importantly however, this rise in the interbank rate is not due to default risk but rather to lower equilibrium asset prices (and thus higher expected returns on bank capital going forward). The equilibrium riskless rate is again pinned down by the household's Euler equation.

Brunnermeier and Sannikov (2011) think of financial intermediaries as experts who are better at investing in productive assets than households. They assume that both groups are risk neutral. In equilibrium experts are leveraged as they borrow from households. In contrast to the present paper, Brunnemeier and Sannikov (2011) assume that borrowing is limited due to a moral hazard problem. The optimal contract they propose ensures that financial intermediaries never default in equilibrium so that the (shadow) interbank rate is equal to the riskless rate. They focus on the price volatility of risky assets rather than funding markets. In particular they assume a constant and exogenous riskless rate, another key difference with the present paper.

In the model of He and Krishnamurthy (2011), agents are risk averse and households can invest in risky assets only via specialists. A moral hazard problem caps the household exposure at a multiple of the specialist exposure. In contrast to the present model, households and specialists hold the same portfolio of risky assets in equilibrium and the optimal contract again ensures that there are no defaults, so that credit spreads are always equal to zero. The model yields interesting asset price dynamics. In particular, as specialist wealth falls, the riskless rate is driven down both because the precautionary savings motive becomes more important and because households need to reduce their exposure to the risky asset and shift into riskless bonds to ensure the intermediary's incentive constraint continues to hold. This yields endogenous flight-to-quality episodes through a channel which is complementary to the one described in this paper. The model also predicts that (non-default) risk premia rise during such episodes. Yet another way to generate flight-to-quality episodes is through liquidation risk as in Vayanos (2004). In his model, fund managers' effective risk aversion increases with volatility because they become more concerned with possible liquidation by outside investors. The riskless rate is constant by assumption in the model.

To sum up, in all of these papers financial intermediaries, to the extent that they are modelled at all, never default in equilibrium. In contrast, default risk of financial intermediaries is at the heart of the present analysis. On the positive side this is, to the best of my knowledge, the first model which can simultaneously replicate three key patterns of financial crises as general equilibrium outcomes: sharp falls in riskless rates, large increases in bank credit spreads, and defaults of financial intermediaries in the absence of government intervention.

The second part of the paper deals with normative issues and particularly the role of public debt in financial crisis prevention and management. The emphasis is on *ex ante* policies rather than optimal *ex post* intervention. A number of papers motivate policy intervention in an economy with credit constraints by pointing to various externalities that may not be fully taken into account by borrowers. This is the case for instance in the work of Brunnermeier and Sannikov (2011), Gertler and Kiyotaki (2011), Gromb and Vayanos (2008), Jeanne and Korinek (2011), and Lorenzoni (2008). The focus of these papers is typically on price externalities. Farhi and Tirole (2010) derive the optimal ex post bailout mix using mechanism design in a setup with strategic complementarities in the leverage choices of individual banks.

In contrast, in the present paper, the rationale for government intervention is a coordination failure which prevents efficient intermediation in a crisis. In the absence of government intervention this leads to the loss of valuable technologies due to lack of financing. This motivation for government intervention is thus closer in spirit to the analysis in Panageas (2010) who assumes that defaults incur excessive deadweight costs. In contrast to Panageas (2010), the present paper concentrates on *ex ante* rather than *ex post* intervention.

The analysis of public debt relates to several strands of the literature. Holmström and Tirole (1998) provide an alternative rationale for the use of public debt. In their model, firms face liquidity shocks at an intermediate date which may force them to abandon projects with positive net present value. In such a setting, having a positive supply of public debt can improve welfare because it allows firms to access liquidity in the face of an aggregate shock. Woodford (1990) presents a related model. In these models, the fundamental issue to be addressed is the temporary illiquidity of producer-firms with fundamentally sound investment projects. In contrast, in the present paper the issue is the potential insolvency of financial intermediaries when there is a negative shock to the fundamental value of the loan portfolio.

Most of the macroeconomics literature on the optimal design of public debt is cast in terms of a tax smoothing objective. Following the seminal insight of Barro (1979), a number of papers have explored how the government debt portfolio can be structured to achieve optimal tax smoothing across states and over time. Prominent examples of this approach include Lucas and Stokey (1983), Aiyagari, Marcet, Sargent, and Seppälä (2002), Angeletos (2002), and Buera and Nicolini (2004). An implication of this framework is that the equilibrium riskless rate should be high in bad states of the world.[6]

[6] A related pattern arises in some leading models of financial intermediation. For example in the model of Diamond and Rajan (2011) periods of high liquidity demand are associated with high real rates and low net worth of financial intermediaries. This provides a rationale for interest rate intervention in their setting.

The reason is that the riskless rate is pinned down by the consumer's Euler equation and bad times are associated with low contemporaneous consumption and high expected consumption growth going forward. The riskless rate thus needs to be high in bad times for the Euler equation to be satisfied. A fundamental difficulty with using this type of framework to analyze debt policy in the context of financial crises is that during such crises, the opposite tends to hold, i.e., riskless rates tend to be low. In contrast, the present paper naturally generates this positive correlation between riskless rates and the state of the economy.

3 The Model

There are three types of private agents in the model: entrepreneurs, households and financiers. I will return to the role played by the government in Section 6. For now, the government may be thought of as just supplying an exogenous amount B of riskless noncontingent one-period bonds to the market. I assume that all agents have logarithmic utility over consumption, $u(C_t) = \ln C_t$, and a discount factor β. This section describes the optimal behavior of private agents for a given riskless rate. The next section examines how the riskless rate is determined in equilibrium in this economy.

3.1 Financial intermediation

Entrepreneurs have the ability or knowledge to invest in valuable projects but they do not have the funds required to start these projects. Households, on the other hand, have savings which they would like to invest but they lack the ability to start projects themselves. Financiers operate financial intermediaries and hold an equity stake in these firms. The idea is that financial intermediaries have the ability to channel the savings of households to productive entrepreneurs in a way that is more efficient than direct matching. The literature provides a number of ways to motivate this assumption. For example there may be economies of scale in screening projects ex ante and/or monitoring them ex post.

I assume that financiers maximize the present value of the utility derived from lifetime consumption

$$E_t \left[\sum_{i=0}^{\infty} \beta^i u(C_{t+i}) \right]. \tag{1}$$

This type of objective is standard in the general equilibrium and macroeconomics literature but less commonly used in the literature on financial intermediation.

The wealth of the financiers in period t is denoted by W_t. This is a key state variable of the problem. Each period, the financiers decide how much to consume out of their wealth and how to invest the remainder. With logarithmic utility, the optimal policy is to consume a constant fraction of wealth

$$C_t = (1 - \beta) W_t. \tag{2}$$

Financiers split the fraction of their wealth which they do not consume βW_t between investments inside the financial intermediary and investments outside the financial intermediary. Their investment in the financial intermediary takes the form of equity and is denoted by Eq_t. I assume that the fraction of their wealth held outside the financial intermediary is simply invested in government debt.

The balance sheet of the financial intermediary can be summarized as follows. On the asset side it includes risky loans to entrepreneurs L_t and government bond holdings inside the financial intermediary, denoted by B_t^I. The gross rate charged on loans between periods t and $t+1$ is denoted by R_{t+1}^L. Loans are risky because individual entrepreneurs may default. The fractional loss on the loan portfolio in period t is denoted by λ_t, with $0 \leq \lambda_t \leq 1$. I discuss the modelling of credit risk on the loan portfolio and the determination of the loan rate in more detail in the next subsection. The one-period gross interest rate on government bonds between periods t and $t+1$ is denoted by R_{t+1}^B. The liability side of the financial intermediary balance sheet consists of deposits D_t and the equity Eq_t of the financiers. This implies the following budget constraint for the financial intermediary in period t

$$L_t + B_t^I = D_t + Eq_t. \tag{3}$$

The one-period gross interest rate on deposits is denoted by R_{t+1}^D and households have a choice between depositing their savings with the financial intermediary or investing in government bonds directly.[7] I assume the existence of a government-backed deposit insurance scheme so that, from the perspective of an individual household, both of these investments are riskless.[8] In equilibrium households are thus indifferent between the two and the absence of arbitrage requires that

$$R_{t+1}^B = R_{t+1}^D. \tag{4}$$

[7] The empirical evidence is that U.S. households exhibit surprisingly limited participation in stock markets (Mankiw and Zeldes, 1991) and risky assets markets more generally (Campbell, 2006). This pattern is likely to be even stronger in other countries. On the other hand, the vast majority of U.S. households do have some investment in "safe" assets, including checking and savings accounts.

[8] The assumption is that the government will not default on either its own debt or its obligations under the deposit insurance scheme but rather increase taxes in bad states of the world. Thus a failure of a financial intermediary is costly for households-taxpayers because it increases future tax rates but it does not affect the return on their deposits directly. With such a deposit insurance scheme in place, it is rational for an individual household to ignore the possible cost of future tax hikes when making its investment decision.

Financiers enjoy limited liability so that they cannot lose more than their equity stake in the financial intermediary. The financial intermediary defaults in equilibrium if the fractional loss on the loan portfolio is sufficiently large. For simplicity, I assume that if the financial intermediary defaults, current financiers lose access to the financial intermediary technology. Conditional on the financial intermediary being solvent in period t, the net worth of the financial intermediary in period $t+1$ for a financiers' equity stake of Eq_t and a loan portfolio of size L_t in period t is given by

$$Max\left\{0, L_t\left(1-\lambda_{t+1}\right)R_{t+1}^L - \left[L_t - Eq_t\right]R_{t+1}^B\right\}. \tag{5}$$

In summary, once they have decided how much to consume, the financiers face two choices. They must decide how much of their remaining wealth to keep invested outside the financial intermediary and they must decide on the size of the loan portfolio L_t extended by the financial intermediary. Letting θ_t denote the fraction invested outside the financial intermediary and assuming that the fraction of wealth invested outside the financial intermediary is held in government bonds, outside bond holdings, denoted by B_t^O, are given by

$$B_t^O = \theta_t \beta W_t. \tag{6}$$

The equity stake of the financiers is then given by

$$Eq_t = (1-\theta_t)\beta W_t. \tag{7}$$

The financiers thus face the following constraint on their investments in period t

$$\beta W_t = L_t + B_t^I - D_t + B_t^O, \tag{8}$$

where the left-hand-side is the fraction of their wealth which they do not consume, the first three terms on the right-hand-side represent their holdings inside the financial intermediary and the last term is what they hold outside the financial intermediary.

The overall wealth of the financiers evolves as follows

$$W_{t+1} = \theta_t \beta W_t R_{t+1}^B + Max\left\{0, L_t\left(1-\lambda_{t+1}\right) R_{t+1}^L - \left[L_t - (1-\theta_t)\beta W_t\right] R_{t+1}^B\right\} I_t, \quad (9)$$

where $I_t = 1(Eq_t > 0)$ denotes an indicator function which takes the value 1 if the financial intermediary is solvent in period t and 0 otherwise. This captures the idea that the financier can only invest in the financial intermediary in period t if the intermediary is solvent in period t.

The value function of the financiers can be stated as the solution to a sequence problem

$$v(W_t, I_t) = \sup_{\{L_{t+i},\theta_{t+i}\}_{i=0}^{\infty}} E_t\left[\sum_{i=0}^{\infty} \beta^i \ln\left[(1-\beta)W_{t+i}\right]\right], \quad (10)$$

subject to Equation (9).

3.2 The loan portfolio

The financial intermediary faces an inverse demand function for loans by entrepreneurs which takes the following form[9]

$$R_{t+1}^L = f(L_t), \text{ with } f'(.) < 0. \quad (11)$$

[9] In the calibrations, I assume a linear specification $f(L_t) = a - bL_t$, with $a > 0$ and $b > 0$. Holmström and Tirole (2001), and Acharya, Shin and Yorulmazer (2011) use similar functional forms.

In order to increase the size of the loan portfolio, the financial intermediary needs to attract more entrepreneurs with valuable projects. It entices marginal entrepreneurs by offering a lower loan rate. The idea is that at the margin, the next project requires more effort by the entrepreneur who will undertake it. All else equal, the marginal entrepreneur is willing to exert this effort only if induced to do so by a lower rate on the loan.

Project financing takes the form of noncontingent one-period loans. Projects are risky and entrepreneurs may default on their loans. For simplicity, I assume that the default probability on individual loans is equal to a constant p and that the recovery rate conditional on default is equal to 0.[10] In order to model correlation across loans, I use a one-factor generalization of the classic model of Merton (1974). This approach to modelling credit risk on a portfolio of loans, described in Vasicek (2002), is commonly used in the structural credit risk and regulatory literature.

In this setup, the financial intermediary optimally chooses to hold a portfolio of loans, thus diversifying away any idiosyncratic project risk. The one-factor structure in Vasicek (2002) implies the following convenient cumulative distribution function for the fractional loss λ_{t+1} to the financial intermediary on a diversified portfolio of loans[11]

$$P\left[\lambda_{t+1} < x\right] = \Phi\left[\frac{\sqrt{1-\rho}\,\Phi^{-1}(x) - \Phi^{-1}(p)}{\sqrt{\rho}}\right], 0 \leq x \leq 1, \tag{12}$$

where ρ denotes a common correlation coefficient between any two project returns and $\Phi(.)$ is the cumulative distribution function of a standard normal random variable. This

[10] Allowing for non-zero recovery rates is straightforward.

[11] This modelling approach was heavily used by credit departments of international banks in the years leading up to the recent financial crisis, partly because it is the framework required by regulators under the Basel II agreements.

implies an unconditional expected fractional loss on the portfolio equal to p. The loss distribution captured by this cumulative distribution function is right skewed, consistent with empirical evidence of left skew in the returns on credit portfolios. Increasing the correlation coefficient ρ puts more mass into the tails of the distribution, thus making extreme losses more likely.

It is worth noting a key difference here with the assumptions in models along the lines of Kiyotaki and Moore (1997) or Bernanke, Gertler, and Gilchrist (1999). A central element of these models is the channel whereby collateral values can feed back into asset prices, essentially because they relax borrowing constraints. In contrast, in the present setup, this particular channel is shut down by assumption since loan values follow an exogenously specified process.

3.3 Optimal policies

For a given value of the riskless rate R^B, the Bellman equation corresponding to the sequence problem in Equation (10) is given by

$$v(W, I) = \sup_{\substack{L>0 \\ 0<\theta<1}} \{\ln[(1-\beta)W] + \beta E v(W_+, I_+)\}, \tag{13}$$

where

$$\begin{aligned} W_+ &= \theta\beta W R^B + Max\left\{0, L(1-\lambda) f(L) - [L - (1-\theta)\beta W] R^B\right\} I && (14) \\ I_+ &= 1\{L(1-\lambda) f(L) - [L - (1-\theta)\beta W] R^B > 0\} I. && (15) \end{aligned}$$

The two state variables for the problem are W, the wealth of the financiers, and I, which indicates whether the financial intermediary remains solvent. The problem also has two choice variables: L, the size of the loan portfolio and θ, the fraction of wealth invested outside the financial intermediary. For a given riskless rate and parameter values, it is possible to solve numerically for the value function and optimal policy functions by iteration of the Bellman operator on an initial guess for the value function.

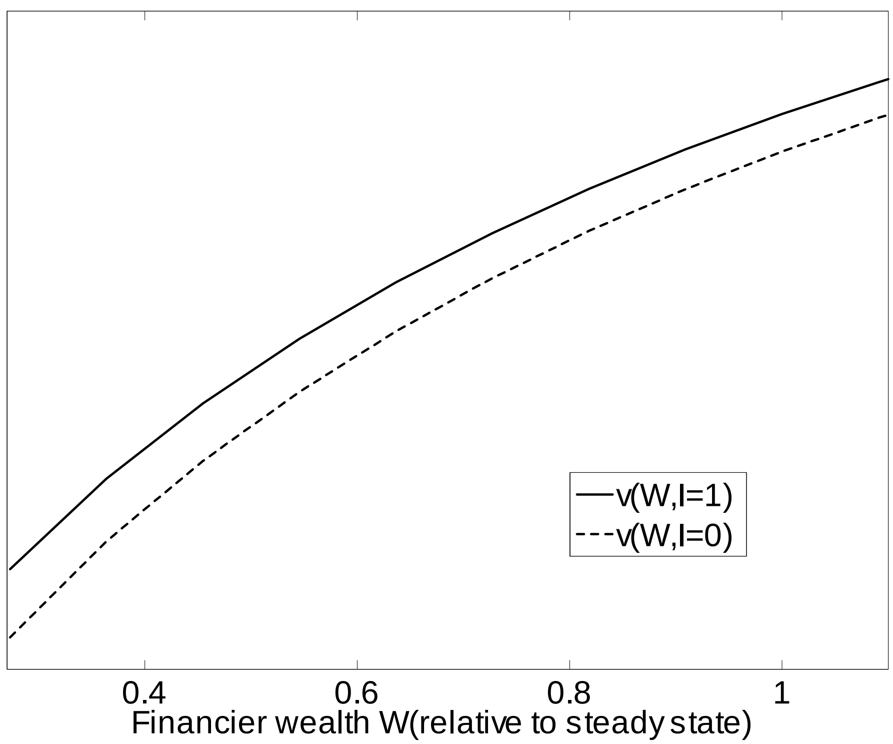

Figure 1. Value function

Figure 1 shows the resulting value functions for $I = 1$ and $I = 0$.[12] The assumption that financiers lose the ability to operate the financial intermediary once it defaults means that when $I = 0$, the problem of the financiers reduces to a version of the standard "cake-eating" problem.

For a given riskless rate (equal to its steady state value), Figure 2 plots the optimal

[12] The parameters used in the numerical analysis are discussed in Section 4.3.

amount of loans $L^*(W, I = 1)$ extended by financial intermediaries as a function of the wealth of financiers in the state where the financial intermediary is solvent. As is apparent from the figure, in response to a fall in the wealth of financiers, there is a sharp contraction in the supply of credit. I will return to the intuition for this effect in Section 4.4.

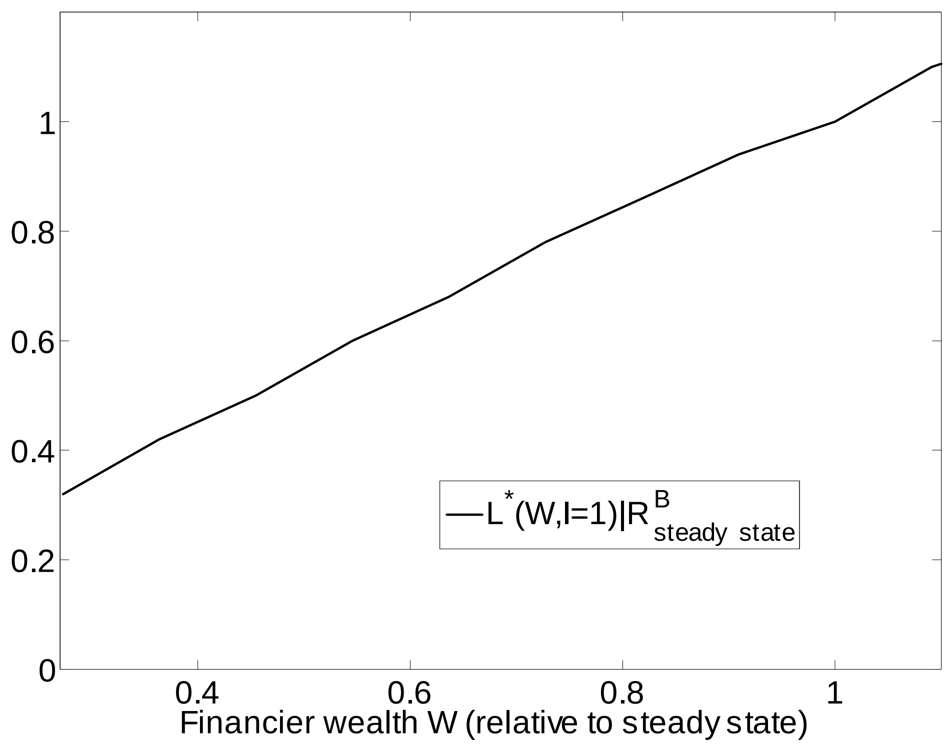

Figure 2. Optimal loan supply (relative to steady state)

4 Equilibrium

For simplicity, I consider the case of a monopolistic financial intermediary in what follows. It may be helpful to think of the financial intermediary in the paper more broadly as the financial intermediation sector. I also assume that the total supplies of deposits

D_t and government debt B_t are inelastic.[13] In equilibrium households are indifferent between deposits and government bonds and so, without loss of generality, I assume that they only hold deposits.

4.1 Equilibrium riskless rate

A key feature of the model is that the riskless rate is endogenous. In particular, it is not pinned down by some riskless technology or otherwise exogenously given as is often the case in macroeconomic models. Instead it is determined by the demand for government bonds by financiers, or equivalently their demand for loans. More specifically it is the rate at which the exogenous supply of government bonds is equal to the demand by financiers

$$B_t = B_t^I + B_t^O. \tag{16}$$

From equation (8), the market-clearing condition may be rewritten as

$$B_t = \beta W_t + D_t - L_t^*(R_{t+1}^B), \tag{17}$$

where R_{t+1}^B now denotes the equilibrium riskless rate. Asset prices are effectively set by the financiers.

[13] In reality, there may of course be some adjustments to the supply of deposits and government bonds. I will return to government bond issuance in Section 6. The aggregate supply of bank deposits is likely to be rather inelastic in practice.

4.2 Equilibrium default of the financial intermediary

Another distinguishing feature of the model is that the financial intermediary can default in equilibrium. Indeed the financial intermediary is solvent at date $t+1$ if and only if

$$L_t\left(1-\lambda_{t+1}\right)R^L_{t+1}-\left[L_t-Eq_t\right]R^B_{t+1}\geqslant 0,\ \text{ or} \tag{18}$$

$$\lambda_{t+1}\leq 1-\left(1-\frac{Eq_t}{L_t}\right)\frac{R^B_{t+1}}{R^L_{t+1}}. \tag{19}$$

Using the expression for the cumulative distribution of the portfolio loss in Equation (12), the equilibrium default probability of the financial intermediary is given by

$$pd^{FI}_{t+1}=1-\Phi\left[\frac{\sqrt{1-\rho}\,\Phi^{-1}\left[1-\left(1-\frac{Eq_t}{L_t}\right)\frac{R^B_{t+1}}{f(L_t)}\right]-\Phi^{-1}\left[p\right]}{\sqrt{\rho}}\right]. \tag{20}$$

4.3 Steady state and calibration

Suppose that the portfolio loss is equal to its expected value each period, i.e., $\lambda_t = E[\lambda_t]\equiv\overline{\lambda}$ for all t, and that agents follow the policies derived in Section 3.3. As discussed in Section 3.2, I will focus for simplicity on the case where the inverse demand function for loans is linear: $f(L)=a-bL$.

In this case the expression for the evolution of the wealth of financiers simplifies to[14]

$$W_{t+1}=\beta R^B_{t+1}W_t+L_t\left[\left(1-\overline{\lambda}\right)\left(a-bL_t\right)-R^B_{t+1}\right].$$

The payout ratio drops out of this expression because the returns to financiers on

[14]This is the relevant expression provided that the financial intermediary does not default if the portfolio loss is at its mean. This holds for the parameter values used in the calibration.

government bonds held inside and outside the financial intermediary are the same when the financial intermediary does not default. Existence of a steady state characterized by a constant value for the wealth of financiers $W_t = \overline{W}$, a constant size of the loan portfolio extended by financial intermediaries $L_t = \overline{L}$, and a constant riskless rate $R^B_{t+1} = \overline{R^B}$, is ensured provided there is a value $\overline{R^B}$ such that

i) $\overline{L}(\overline{W}, I = 1)$ is optimal for the financiers given a riskless rate of $\overline{R^B}$.

ii) The government bond market clears.

iii) $0 < \beta\overline{R^B} < 1$.

These conditions are easily satisfied and hold in particular for all the parameter values used in the calibrations. The last condition ensures that the wealth of the financiers converges. The value of $\beta\overline{R^B}$ determines the speed of convergence to the steady state. The half-life of a deviation from the steady state is given by $\ln(0.5)/\ln(\beta\overline{R^B})$.

The calibration proceeds as follows. The parameters are chosen to give are chosen to give empirically plausible steady state values for the riskless rate, financial intermediary leverage, financial intermediary default probability, and the half-life of a response to an exogenous shock. In the benchmark calibration, I set $\beta = .8$, $a = 1.14$, $b = .015$, $p = 0.06$, $\rho = 0.1$, $B = 1$, and $D = 0.6$.[15]

4.4 Flight to quality

Figure 3 illustrates the equilibrium behavior of the riskless rate as a function of financial intermediary equity, where the equity is measured relative to its steady state value. As can be seen from the figure, the equilibrium riskless rate is increasing in financial

[15] The values for supply of government debt B and deposits D only affect the calibration through the difference $B - D$.

intermediary equity. The magnitudes are significant: if the equity of financiers falls to 25% of its steady state value, the equilibrium riskless rate falls by close to 3 percentage points.

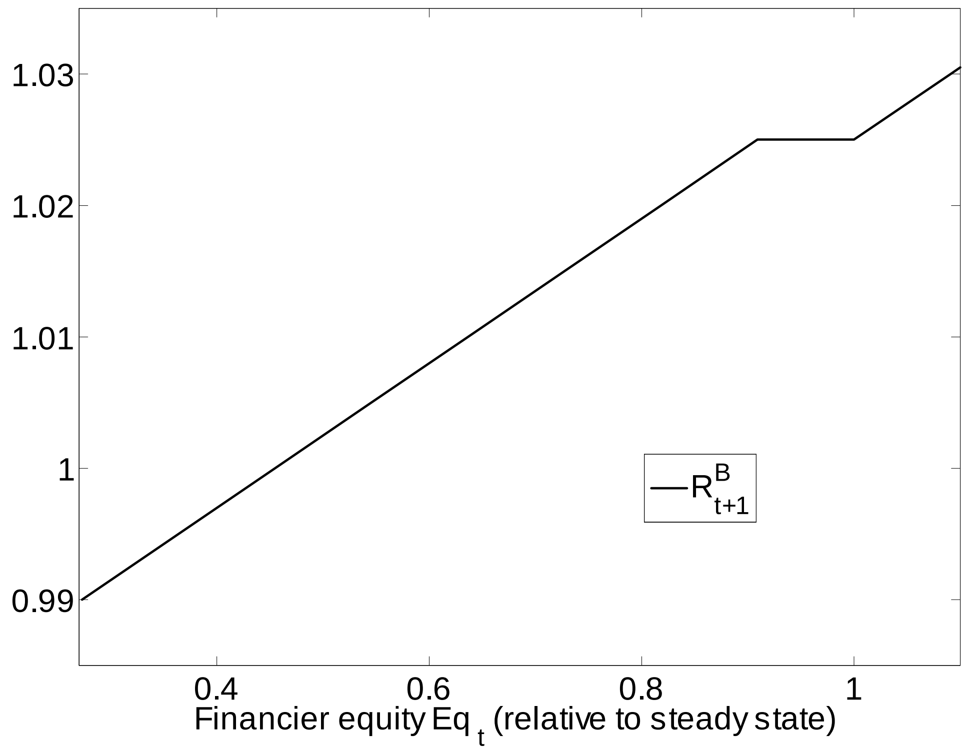

Figure 3. Equilibrium riskless rate

The intuition for the behavior of the riskless rate is the following. When choosing how to allocate their portfolio between loans and government bonds, the financiers face a trade-off. A higher amount of loans increases the expected flow payoff from the portfolio next period[16] but it also increases the probability of default of the financial intermediary by making the overall portfolio more risky. A higher default probability implies a lower expected continuation value since the use of the financial intermediary

[16] With the linear specification $f(L) = a - bL$ this is the case provided $L < \frac{1}{2b}\left[a - \frac{R^B_{t+1}}{1-\bar{\lambda}}\right]$. This inequality holds for all the examples provided in the paper.

is lost if it becomes insolvent. The first order condition of the problem faced by the financiers in (13) equalizes the value of the marginal flow payoff from an incremental loan with the expected marginal loss of continuation value due to the increase in default probability of the financial intermediary.

When the financial intermediary faces losses on its loan portfolio, its equity is depleted and this increases the probability of default. For a given riskless rate, this increased default probability reduces the expected marginal continuation value but leaves the expected marginal flow profit from the marginal loan unaffected. As illustrated in Figure 2, financiers would therefore like to rebalance their portfolio in the face of a fall in equity, reducing their holdings of loans and increasing their allocation to government bonds, up to the point where the expected marginal values of flow payoff and continuation value are again equalized. This is the sense in which there can be a flight to quality in the model: following a fall in financial intermediary equity, there is a decrease in demand for risky loans and a corresponding increase in demand for government bonds.

However market clearing requires that

$$L_t(R^B_{t+1}) = \beta W_t + D_t - B_t. \tag{21}$$

For given supplies of deposits and government bonds, bond market clearing therefore requires that the contraction in the loan portfolio is equal to the fall in the wealth of the financiers multiplied by the discount factor. For a given riskless rate, the financiers would actually like to cut back their lending significantly more than this in a flight to quality. This is illustrated in Figure 4, which shows the demand for loans by the financial intermediary holding the riskless rate constant at its steady-state value as well as the market-clearing level of loans. The only way to mitigate the fall in demand for loans by financiers (or equivalently to reduce their relative demand for government bonds) and thus to allow the bond market to clear is for the equilibrium riskless rate to fall.

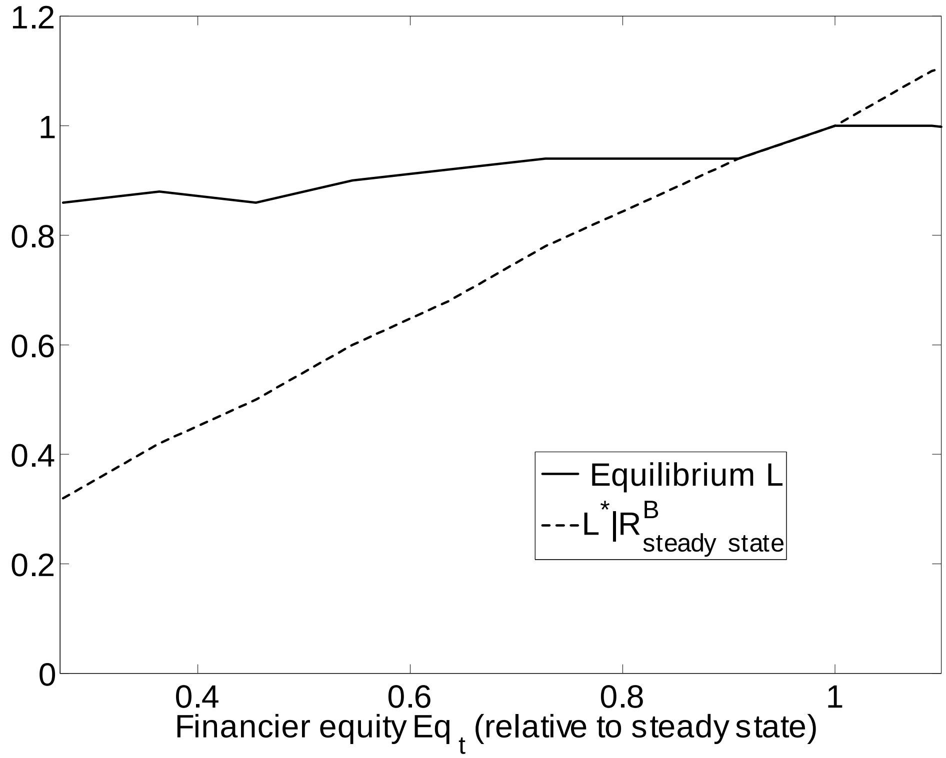

Figure 4. Equilibrium credit supply (relative to steady state)

Figure 4 also illustrates how a fall in the equity of financiers following losses on the loan portfolio leads to a contraction in the supply of credit in equilibrium. This contraction in lending would be sharper if the riskless rate did not adjust downwards. It is also worth noting that the amount of credit extended in equilibrium in the model is driven by the supply of loans rather than its demand. This is consistent with recent empirical evidence by Becker and Ivashina (2011).

Figure 5 plots the equilibrium payout ratio. It shows how financiers increase the share of their wealth held outside the financial intermediary in a flight to quality.

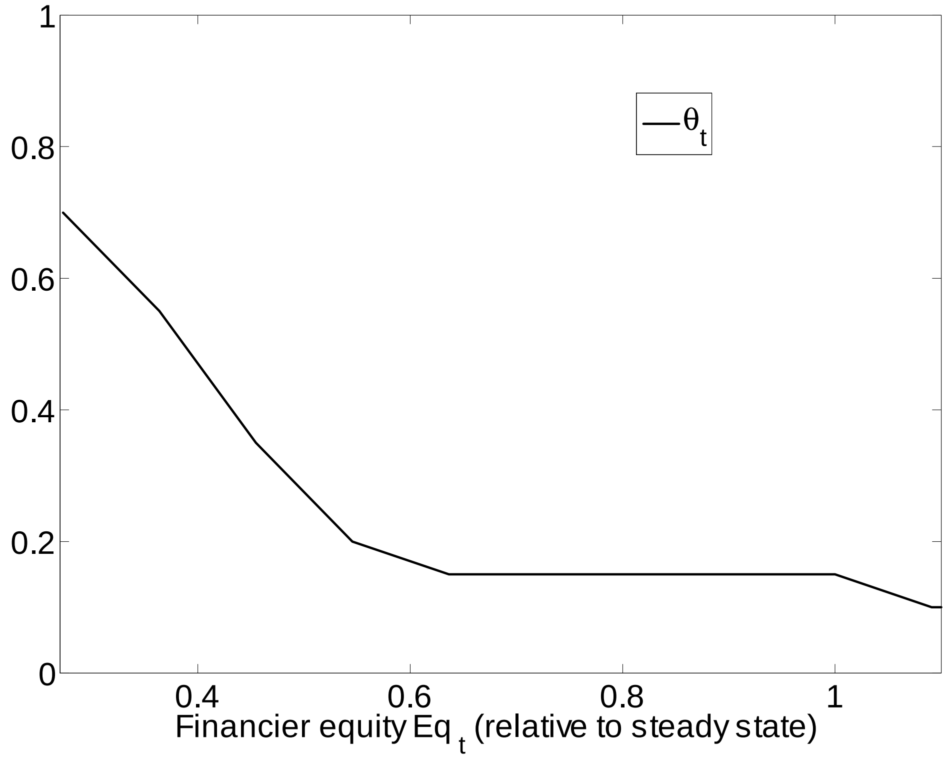

Figure 5. Equilibrium payout ratio

In a flight-to-quality episode the leverage of financial intermediaries can increase significantly. Leverage Lev_t is defined as the ratio of loans to equity

$$Lev_t = \frac{L_t}{Eq_t}.$$

Using the expression for the equity of financiers in Equation (7) and the market clearing condition (17), equilibrium leverage in the model can be rewritten as

$$Lev_t = \frac{1}{1-\theta_t}\left[1 + \frac{D_t - B_t}{\beta W_t}\right].$$

This expression is illustrated in Figure 6. In the benchmark calibration, the steady state leverage ratio of the financial intermediary is around 6.5. Figure 6 illustrates how quickly the equilibrium leverage ratio rises as the equity of financiers is depleted. At a level of equity of 25% relative to the steady state value, the leverage ratio is above 50.

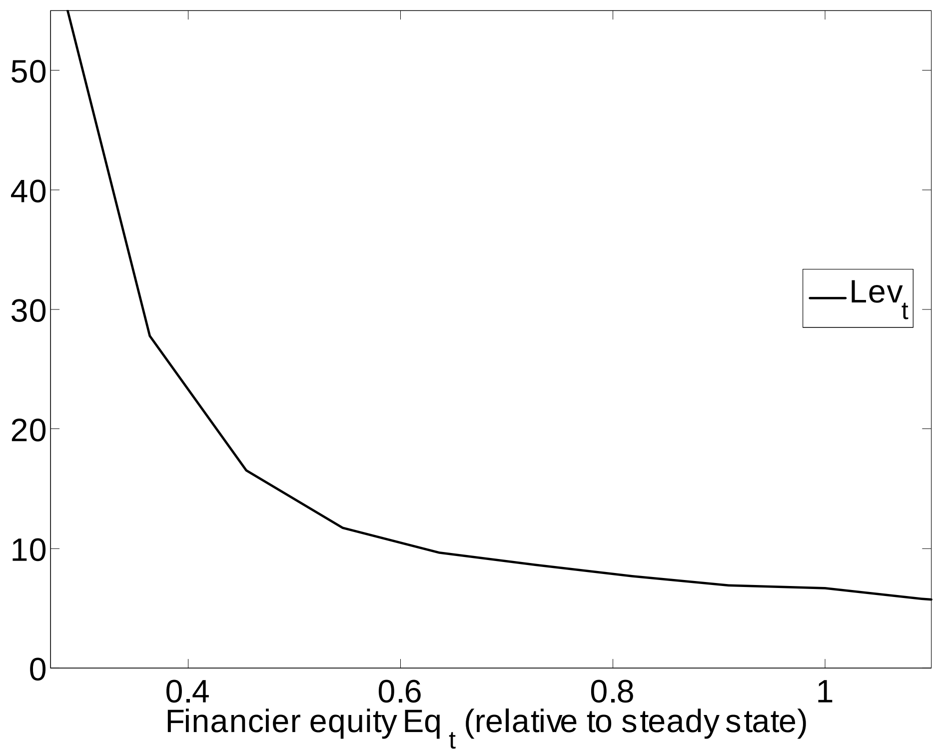

Figure 6. Equilibrium leverage

Finally, the increase in the leverage of the financial intermediary in response to losses on the loan portfolio translates into an increased default probability. This is illustrated in Figure 7 which plots the default probability of the financial intermediary in Equation (20) against the value of equity. In the benchmark calibration, the steady state default probability of the financial intermediary is around 0.3% per year. This is of the same order of magnitude as the default probabilities implicit in the current regulatory framework. Under the Basel II agreements, financial institutions are required to hold enough capital to withstand a loss corresponding to a 99.9% credit Value at Risk (VaR) at the annual horizon, where the VaR is calculated using the Vasicek (2002) model. Thus the Basel II framework implies an annual default probability of 0.01%. Figure 7 illustrates how the default probability rises as the equity of financiers is depleted. If equity falls to 25% of its steady state value, the default probability is multiplied by a factor of more than 10.

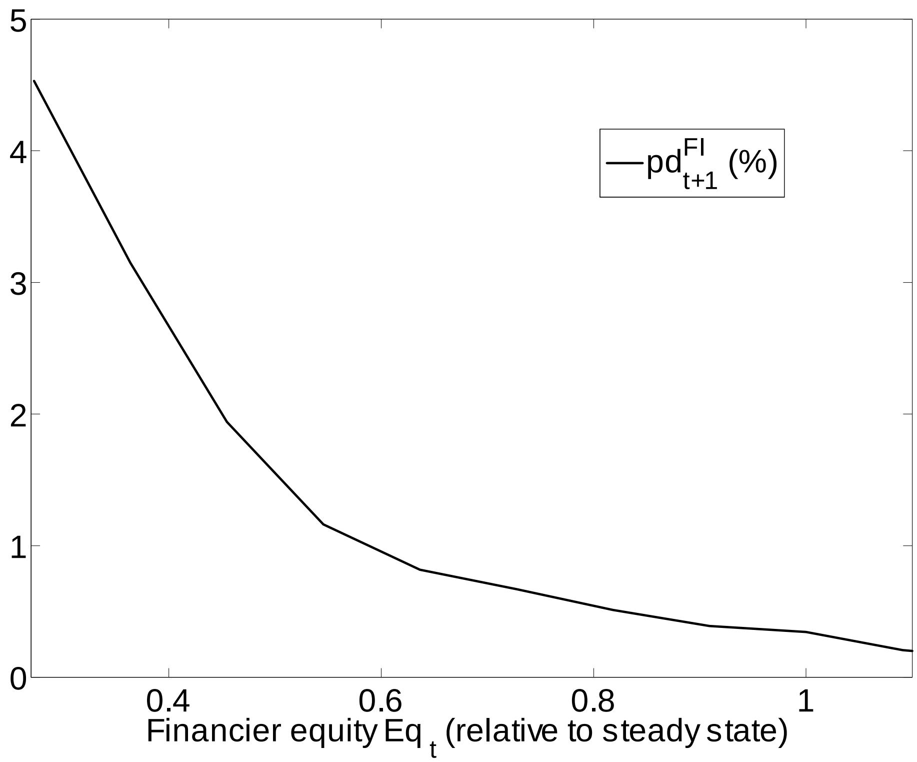

Figure 7. Equilibrium default probability of the financial intermediary

As discussed in the introduction, some of the salient features of the crisis were the sharp decline in T-Bill rates, a contraction in lending, and an increase in the perceived default probabilities of financial intermediaries, as evidenced for instance by the sharp rise in the LIBOR-OIS spread.[17] Most institutions also experienced a sharp increase in

[17] LIBOR refers to the London Interbank Offered Rate and OIS to the Overnight Index Swap rate. There may of course be components of this spread which are not related to default risk but given

leverage on impact which was then followed by a period of active deleveraging. I will return to implications for deleveraging in the next section. Overall, the model matches the key patterns of the flight to quality associated with the recent financial crisis that were set out in the introduction.

5 Dynamics

5.1 Impulse response functions

The first part of this section analyzes impulse response functions of key variables to an unexpected shock. More precisely, suppose that the economy starts off in the steady state and then there is an unexpected 10% increase in the loss λ on the loan portfolio.

---

that the spread essentially measures the difference between rates on uncollateralized and collateralized lending by similar institutions, one would expect most of the spread to be directly linked to default risk.

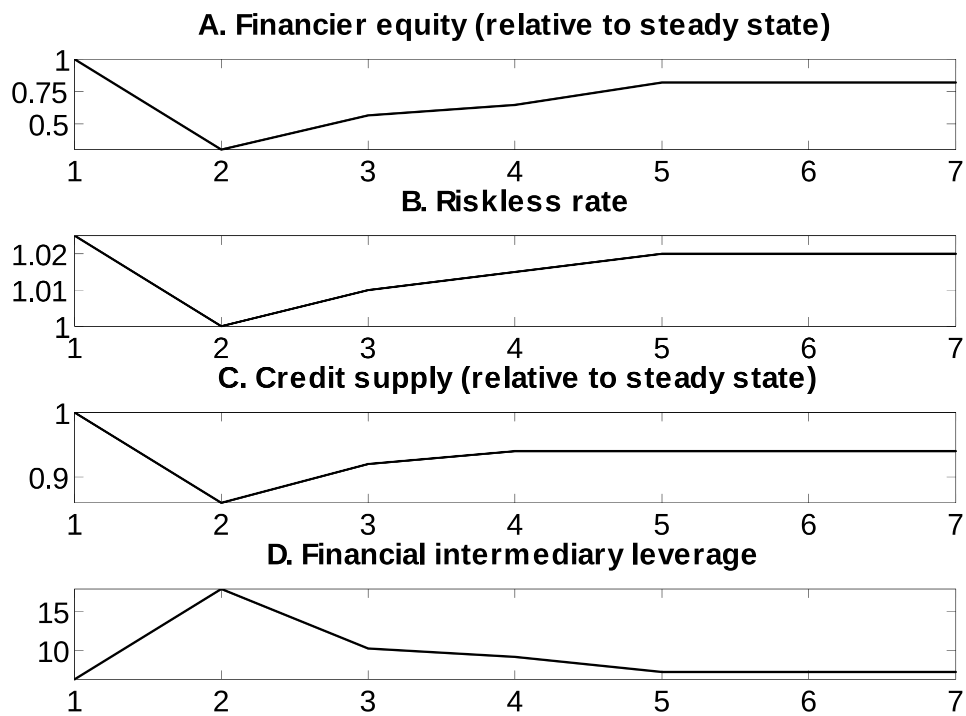

Figure 8. Impulse response functions for a 10% unexpected increase in the portfolio loss (years on the horizontal axis)

Figure 8 plots the dynamic response of the equity of the financiers relative to its long-run steady state value as well as the evolution of the equilibrium riskless rate, credit supply, and financial intermediary leverage following the shock. The impact of the unexpected portfolio loss on financial intermediary equity is amplified by the initial leverage. Thus a relatively modest loss on the portfolio can all but wipe out the financial intermediary equity if leverage is sufficiently high.

There is a sharp endogenous drop in the riskless rate on impact, which is one of the key empirical features of financial crises which the paper set out to match. Unless the equilibrium riskless rate adjusts downwards, a large drop in financial intermediary equity would induce a large portfolio shift from loans into government bonds by the financial intermediary. This may be thought of as a flight-to-quality episode. The only way for the bond market to clear is for the equilibrium riskless rate to drop significantly.

As can be seen from Figure 8, the supply of credit, measured by L, contracts on impact. At the same time, leverage rises significantly. These effects can be understood from Equation (17). Unless D_t and B adjust immediately, leverage has to increase in response to a fall in financial intermediary equity. This is because the financial intermediary still needs to invest the same quantity of deposits with a much smaller amount of equity. Put differently, on impact the fall in the size of the financial intermediary's balance sheet is much smaller than the fall in equity, leading to an unavoidable temporary spike in leverage.

An interesting feature of the impulse response of leverage is the extended period of gradual deleveraging which follows the initial spike in leverage. It takes time for the financial intermediary to accumulate equity and re-build its balance sheet. In the baseline calibration, the half-life of the shock is around 3.5 years. This type of extended deleveraging is a typical empirical feature of the aftermath of financial distress episodes, in particular it has been the subject of much discussion following the recent credit crisis. It is also worth noting that riskless rates are persistently low during the deleveraging process as apparent in Panel B, another feature which is consistent with recent experience.

I now discuss what happens when the fractional loss on the loan portfolio is large enough for the solvency condition in Equation (19) to be violated. In this case, the financial intermediary defaults in the absence of government intervention. In the model the financial intermediary represents the entire financial intermediation sector rather than an individual institution. Thus a financial intermediary default in the model may be interpreted as a systemic banking crisis. I assume that the consequence of financial intermediary default is a temporary reduction in the efficiency of financial intermediation. More specifically I assume that, following default, it takes one period for a new set of financiers to come into the market and set up a new intermediary.[18] During this transition period only a fraction of household deposits gets to the entrepreneurs because there are significant search costs if the households and entrepreneurs try to match directly. The reduction in intermediation following default by the financial intermediary is inefficient in the model since the distribution of future project returns is stationary and unrelated to the solvency of the financial intermediary.

5.2 Simulated history

In order to illustrate the dynamics of this type of economy, Figure 9 shows one simulated path of losses on the loan portfolio for a century of data and the corresponding evolution of financial intermediary equity, the riskless rate, and leverage. In the particular path shown in Figure 9, there is a first "double-dip" crisis in the fourth decade and a close miss towards the end of the sample.

[18] In the simulations, the initial level of equity capital of the new financial intermediary is set equal to half the steady state value.

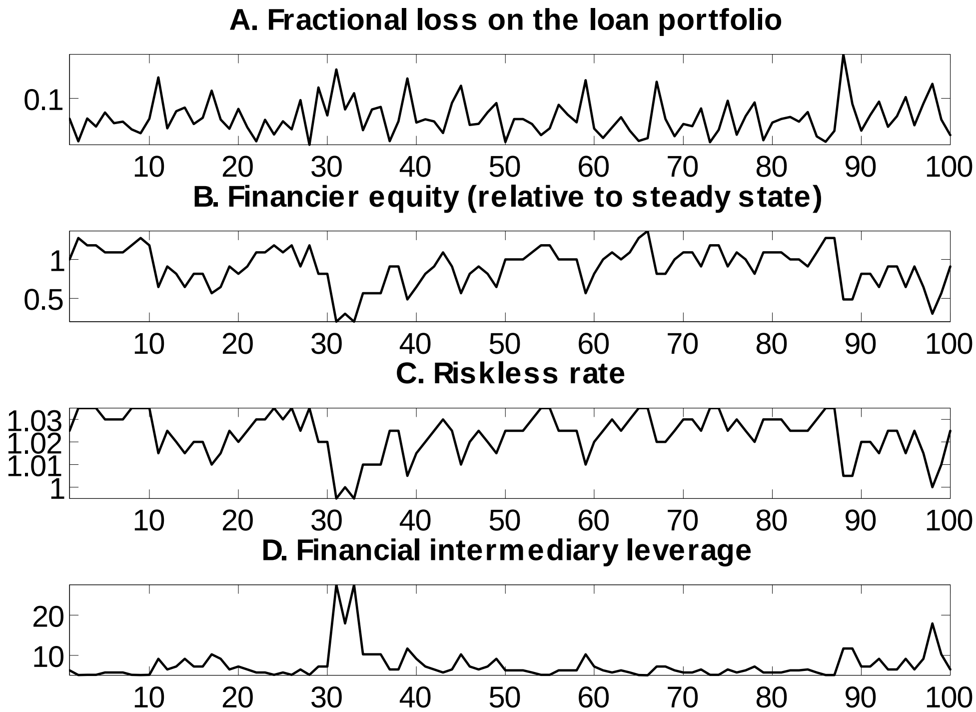

Figure 9. Example of a simulated path over a century

6 Implications for the Design of Public Debt

6.1 The role of government

A loss of financial intermediation following a default is inefficient because it ultimately results in a reduction of the number of valuable projects being financed. Households and entrepreneurs would have an incentive to renegotiate their contracts *ex post* with the financial intermediary to keep the financial intermediary solvent. The basic idea is that there is a coordination problem which prevents the three groups from renegotiating the terms of the contracts and thus preventing a collapse of the financial intermediation sector. The coordination problems that prevent renegotiation of the contracts and direct matching between households and entrepreneurs are not modelled directly in this paper but it seems plausible that search costs and asymmetric information problems in matching and holdout problems in debt renegotiation with dispersed creditors are significant. The only party that can effectively facilitate an efficient *ex post* renegotiation is the government.

This type of rationale seems to have been at the heart of the public justifications for government intervention in the recent crisis. The idea that a large-scale collapse in financial intermediation is likely to have devastating macroeconomic effects and that its prevention may require and justify government intervention is also consistent with some of the most prominent studies of the Great Depression, in particular Bernanke (1983).

6.2 *Ex post* intervention

The next natural question is what form government intervention should take. A first possible approach is to only intervene *ex post*, once it has become clear that the financial intermediation sector faces imminent collapse. What is required is effectively a state contingent transfer from the households to the financial intermediaries to prevent their bankruptcy. The government can facilitate this transfer on behalf of households by issuing additional debt which it sells it to households, and recapitalizing the financial intermediaries with the proceeds. Of course this debt will need to be repaid in the future, which leads to an increase in expected future tax rates. These tax increases may be imposed on future households, entrepreneurs, financiers, or a combination of all three. A key point is that even increasing taxes on financiers in the future would lead to some inefficient redistribution in practice since the government would be dealing with the next generation of financiers, not the generation who benefited from the original subsidy. While such a government engineered transfer is costly to taxpayers, it is still *ex post* optimal for them. However it would only be second best since the additional distortions associated with future increases in taxation lead to deadweight losses which could be largely avoided with a scheme along the lines described in the next subsection. In any event, this is effectively the best the government can do *ex post*. It is also perhaps not a bad first order description of the response of governments around the world to the recent financial crisis.

6.3 *Ex ante* intervention

Can the government improve on this outcome? In particular, the present paper is interested in the question of whether a different *ex ante* design of public debt instruments and issuance choices, coupled with regulatory capital requirements, can improve on the outcome described in the previous section.

The analysis so far implicitly assumed that the government only issues one-period bonds. A first observation is that changing the supply of one-period debt *ex ante* (without introducing any other securities) changes the equilibrium allocation. Indeed, increasing the supply of government debt will crowd out some of the loans to entrepreneurs in equilibrium. This can be seen from Equation (17). As a result, it will also decrease equilibrium leverage of the financial intermediary sector and hence the probability of default and of a financial crisis. This implies a trade-off. An increase in the supply of debt reduces the probability of a costly financial crisis but it also crowds out investment in good projects and thereby ultimately reduces long-run growth.

This trade-off can be made more favorable with other forms of government debt. In particular, two instruments which have been used extensively historically are long-dated bonds and callable bonds. For simplicity, I will think of long-term bonds as perpetuities and callable bonds as perpetuities with an embedded call option which the government has the right to exercise at any time.

A key observation is that, as riskless rates fall across the term structure in response to an unexpectedly large loss on the loan portfolio, the price of government-issued perpetuities will rise much more quickly than that of shorter dated Treasury bills (duration effect). At the same time, the value of the call option embedded in a callable perpetuity increases rapidly and, if the shock is sufficiently large, it will actually be optimal for the government to exercise this option and redeem the bonds early.

This suggests the following idea. Suppose the financial intermediary holds a minimum level of non-callable government perpetuities in equilibrium. The government could force this outcome by imposing a minimum capital requirement and restricting the type of securities that are eligible. Suppose that the households on the other hand only hold callable government perpetuities. This could be ensured by issuing exactly the amount of non-callable perpetuities required to satisfy the financial intermediary's minimum capital requirement and issuing the remaining government debt in callable form. This type of arrangement could implement the state contingent transfer described in the previous section and thus require no or minimal *ex post* intervention. How would it work?

First, the financial intermediary would face capital gains on its holdings of perpetuities in the face of an adverse shock to the loan portfolio because of the large price appreciation on these bonds in that state. If the financial intermediary bond holdings are large enough, this capital gain may save the financial intermediary from bankruptcy altogether. Qualitatively, the government would still face a trade-off when choosing capital requirements. Larger capital requirements, particularly in the form of non-callable long-dated government bonds will reduce the probability of a crisis but they will also crowd out lending to entrepreneurs and thus valuable investment projects. Critically however, the trade-off is more favorable with longer-dated bonds because you get more insurance for the same market value of debt which mitigates the crowding out effect.

Second, households, contrary to the financial intermediaries, have an additional short position in a call option on the perpetuity on which they face a significant capital loss in the face of large losses on the financial intermediary loan portfolio, again due to the endogenous fall in riskless rates. This rise in the value of the call option effectively relaxes the government's budget constraint in those states of the world where *ex post* intervention would be required and hence reduces future tax distortions.

In effect this type of issuance strategy makes the financial intermediary pay *ex ante* for the insurance the taxpayers effectively provide in crisis situations. The financial intermediary "pays" by being forced to hold low yielding non-callable government bonds in good times. The households are effectively compensated for the insurance they provide by collecting the premium on the call option they have sold to the government in the form of a higher interest rate on the callable bonds they are holding. The government can be thought of as a "clearing house" that facilitates a contract which would be extremely difficult or impossible to implement in a decentralized fashion.[19]

[19] An alternative policy would be to impose a levy on the FI during good times, put the proceeds into a contingency fund and then use that fund to recapitalize the FI in the event of a crisis. A drawback of such an approach is that a government administered fund could easily be directed towards other uses under political pressure or at least be inefficiently invested. It may therefore be preferable to just pay the taxpayers the call option premium each period directly, thus compensating them for the insurance they are effectively providing. In any event, even with a fund taxpayers would still have to be relied upon in case of losses that exceed the value of the fund.

7 Conclusion

This paper presents a general equilibrium model with a financial intermediation sector. The riskless rate is endogenous and effectively determined by the demand of financiers. The model generates endogenous flight-to-quality episodes characterized by low riskless rates, high bank credit spreads, and a contraction in the supply of credit. Financial intermediaries default in equilibrium with positive probability. On the normative side, the paper suggests a novel rationale for issuing part of the government debt in the form of callable long-dated bonds. It also suggests that capital requirements on financial intermediaries in the form of non-callable long-dated government bonds may be desirable.

References

Acharya, Viral, Hyun-Song Shin and Tanju Yorulmazer, 2011, "Crisis Resolution and Bank Liquidity", *Review of Financial Studies* 24: 2166-2205.

Aghion, Philippe, Abhijit Banerjee, and Thomas Piketty, 1999, "Dualism and Macroeconomic Volatility", *Quarterly Journal of Economics*, 1359-1397.

Aiyagari, S. Rao, Albert Marcet, Thomas J. Sargent, and Juha Seppälä, 2002, "Optimal Taxation without State Contingent Debt", *Journal of Political Economy* 110, 1220-1254.

Angeletos, George-Marios, 2002, "Fiscal Policy with Noncontingent Debt and the Optimal Maturity Structure", *Quarterly Journal of Economics* 117, 1105-1131.

Barro, Robert J., 1979, "On the Determination of the Public Debt", *Journal of Political Economy* 87, 940-971.

Becker, Bo and Victoria Ivashina, 2011, "Cyclicality of Credit Suppply: Firm Level Evidence", unpublished paper, Harvard Business School.

Bernanke, Ben, 1983, "Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression", *American Economic Review* 73, 257-276.

Bernanke, Ben and Mark Gertler, 1989, "Agency Costs, Net Worth, and Business Fluctuations", *American Economic Review* 70, 14-31.

Bernanke, Ben, Mark Gertler, and Simon Gilchrist, 1996, "The Financial Accelerator and the Flight to Quality", *Review of Economics and Statistics* 78, 1-15.

Bernanke, Ben, Mark Gertler, and Simon Gilchrist, 1999, "The Financial Accelerator in a Quantitative Business Cycle Framework", in John B. Taylor and Michael Woodford eds., *Handbook of Macroeconomics*, vol.1c, North-Holland, Amsterdam.

Bliss, Robert R. and Ehud I. Ronn, 1998, "Callable U.S. Treasury Bonds: Optimal Calls, Anomalies and Implied Volatilities", *Journal of Business* 71, 211-252.

Brunnermeier, Markus, 2009, "Deciphering the 2007-08 Liquidity and Credit Crunch", *Journal of Economic Perspectives* 23: 77-100.

Brunnermeier, Markus and Yuliy Sannikov, 2011, "A Macroeconomic Model with a Financial Sector", unpublished paper, Princeton University.

Buera, Francisco and Juan Pablo Nicolini, 2004, "Optimal Maturity of Government Debt without State Contingent Bonds", *Journal of Monetary Economics* 51, 531-554.

Campbell, John Y., 2006, "Household Finance", *Journal of Finance* 61, 1553-1603.

Diamond, Douglas and Raghuram Rajan, 2011, "Illiquid Banks, Financial Stability, and Interest Rate Policy", unpublished paper, University of Chicago.

Farhi, Emmanuel and Jean Tirole, 2010, "Collective Moral Hazard, Maturity Mismatch and Systemic Bailouts", forthcoming, *American Economic Review.*

Gertler, Mark and Peter Karadi, 2011, "A Model of Unconventional Monetary Policy", *Journal of Monetary Economics* 58, 17-34.

Gertler, Mark and Nobuhiro Kiyotaki, 2011, "Financial Intermediation and Credit Policy in Business Cycle Analysis", forthcoming, *Handbook of Monetary Economics.*

Gromb, Denis and Dimitri Vayanos, 2008, "Liquidity Dry-ups: A Framework and Policy Implications", unpublished paper, Insead and London School of Economics.

Hart, Oliver and John Moore, 1994, "A Theory of Debt Based on the Inalienability of Human Capital", *Quarterly Journal of Economics* 109, 841-879.

He, Zhiguo and Arvind Krishnamurthy, 2011, "A Model of Capital and Crises", forthcoming, *Review of Economic Studies.*

Holmström, Bengt and Jean Tirole, 1998, "Private and Public Supply of Liquidity", *Journal of Political Economy*, 106: 1-40.

Holmström, Bengt and Jean Tirole, 2001, "LAPM: A Liquidity-Based Asset Pricing Model", *Journal of Finance*, 56:1837-1867.

Jeanne, Olivier and Anton Korinek, 2011, "Managing Credit Booms and Busts: A Pigouvian Taxation Approach", unpublished paper, Johns Hopkins University and University of Maryland.

Kiyotaki, Nobuhiro and John Moore, 1997, "Credit Cycles", *Journal of Political Economy* 105, 211-248.

Kiyotaki, Nobuhiro and John Moore, 2008, "Liquidity, Business Cycles, and Monetary Policy", unpublished paper, Princeton University and London School of Economics.

Longstaff, Francis A., 1992, "Are Negative Option Prices Possible? The Callable U.S. Treasury-Bond Puzzle", *Journal of Business* 65, 571-592.

Lorenzoni, Guido, 2008, "Inefficient Credit Booms", *Review of Economic Studies*, 809-833.

Lucas, Robert E., Jr. and Nancy L. Stokey, 1983, "Optimal Fiscal and Monetary Policy in an Economy without Capital", *Journal of Monetary Economics* 12, 55-93.

Mankiw, N. Gregory and Stephen Zeldes, 1991, "The Consumption of Stockholders and Nonstockholders", *Journal of Financial Economics* 29, 97-112.

Merton, Robert C., 1974, "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates", *Journal of Finance* 29: 449-470.

Panageas, Stavros, 2010, "Optimal Taxation in the Presence of Bailouts", *Journal of Monetary Economics* 57, 101-116.

Townsend, Robert,1979, "Optimal Contracts and Competitive Markets with Costly State Verification", *Journal of Economic Theory* 21, 265-293.

Vasicek, Oldrich A., 2002, "The Distribution of Loan Portfolio Value", *Risk Magazine*.

Vayanos, Dimitri, 2004, "Flight to Quality, Flight to Liquidity, and the Pricing of Risk", unpublished paper, London School of Economics.

Woodford, Michael, 1990, "Public Debt as Private Liquidity", *American Economic Review P. & P.* 80: 382-388.