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Nikolaj Schmidt

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Nikolaj Schmidt joined the FMG as a research student in 2005. He holds an MSc in Finance and Economics and a master's degree in Economics. Prior to joining the FMG he worked as a derivatives trader and structurer in an investment bank. His research is focussed on financial intermediation with a particular focus on financial stability and the interaction between foreign and local banks in emerging markets. Any opinions expressed here are those of the authors and not necessarily those of the FMG. The research findings reported in this paper are the result of the independent research of the authors and do not necessarily reflect the views of the LSE.

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Nikolaj Schmidt
London School of Economics
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Abstract

Motivated by the credit crisis 2007-08, this paper presents a theory of "capital market banks"; banks that use derivative programs to exploit inefficiencies in the capital markets. I model banks' use of asset backed commercial paper (ABCP) programs as a local game, and analyse how these programs affect financial stability. In a financial market where banks are subject to costly capital requirements and investors are heterogeneous, the ABCP program arises endogenously in response to inefficient risk sharing. The sustainability of the ABCP program depends crucially on the sponsoring bank's capital. Small shocks to the bank's capital can lead to a failure of the ABCP program. This amplifies the shock and pushes the the bank into bankruptcy. I link the dynamics of the ABCP market to the interbank market, and argue that an unravelling of the ABCP market can cause a seizure of the interbank market. The model indicates, that traditional monetary policy is unable to alleviate seizures of the interbank market, but that targeted liquidity measures, such as the "Term Securities Lending Facility", the "Term Auction Facility", the "Troubled Asset Relief Program", the "Money Market ABCP Program" and the launch of a "super fund", could end the unravelling of the ABCP market and ease the pressures in the interbank market.

1 Introduction

The conditions in the financial markets during 2007 and 2008 may well be characterised as the most tumultuous since the great depression of the 1930s. An increase in the default rates on US subprime mortgages in early 2007, a tiny market relative to the global capital markets, had by August 2008 led to the first bank run in more than 100 years in the United Kingdom, brought Bear Stearns, Merril Lynch and Wachovia Bank to the brink of default, lead to the bankruptcy of Lehman Brothers, resulted in the recapitalisation of several of the German landesbanks by the German state bank, and imposed close to USD 1000bn of losses on the banks from the developed economies.[1] How could problems in a corner of the financial market have such a ferocious impact on the state of the financial system at a time of otherwise high and stable growth? Much evidence points to modern banks growing dependence on the capital markets and complex derivative programs as an integrated part of their daily business. Northern Rock, the stricken UK mortgage lender, was heavily reliant on the ability to securitize its assets, and the recapitalisations of the German landesbanks were caused by their failure to refinance their asset backed commercial paper programs.

In the extant literature, banks are modelled as simple entities that take deposits and extend loans. Their balance sheets are static, and their loan portfolios are held until maturity (Diamond and Dybvig (1983)). In these frameworks, the financial intermediaries have no use for the capital markets, and the banks and the capital markets are treated as competing sources of finance (Jacklin (1987), Diamond (1997), Allen and Gale Allen and Gale (1997), Boot and Thakor (2001)). The current turmoil has assigned a preeminent role to the interaction between the banks and capital markets through the banks' use of derivative programs. Thus, to understand why problems in the US subprime market could bring the financial system to its knees, we need a theory that explains modern banks' use of derivative programs, and which highlights how a seemingly small event, through these programs, can propagate and destabilise the financial system.

This paper presents a theory of modern financial intermediation, and illustrates modern banks', "capital market banks", increasing reliance on derivative programs as an integrated part of their

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[1] Bloomberg.

business. In existing theories, banks arise as an efficient mechanism to resolve complex contracting problems. Banks are viewed either as an insurance mechanism which, through an intertemporal transfer of cash flows, enhances risk sharing among consumers (Diamond and Dybvig (1983)) and firms (Holmström and Tirole (1998)), or as a mechanism to resolve agency problems arising from information processing (Diamond (1984)). In contrast, the primary role of the capital market banks is not to engage in intertemporal transfers, nor to alleviate information processing problems. The capital market banks exploit derivative programs to dissect the risk of a stream of cash flows, and structure securities which meet specific regulatory requirements or fill the demand of a specific group of investors. By customizing the securities and distributing the risks to those best suited to carry them given the regulatory environment, capital market banks enhance risk sharing.

One of the derivative programs which have attracted particular attention is the asset backed securities (ABCP) program (See Brunnermeier (2009), Fitch Ratings (2007) or Taylor and Williams (2008)). Attention has turned to this segment of the capital market, due to the astronomical size of the programs and the speed with which they have been unravelling. In July 2007, the size of the ABCP market was USD 1.2trn, and in May 2008, the market had contracted to USD 700bn (Fitch Ratings (2008)). In parallel with this contraction, banks stopped lending to each other in the interbank markets. In the public debate, the seizure of the interbank markets has been attributed directly to the unravelling of the ABCP market.[2] In more rigorous empirical work, Taylor and Williams (2008) find, that the main factors explaining the development in the interbank market during 2007-08 was the credit spread on senior bank debt and the banks' exposure to ABCP programs. Despite the suggested link between the ABCP market and the interbank market, no theory has been put forward to expose the exact mechanism that links the two markets. This paper suggests one theory of how a small shock to the banks' capital, such as a shock to the US subprime mortgage market, can lead to an unravelling of the ABCP market, and thereby be amplified to create a seizure of the interbank markets. Importantly, by identifying the underlying cause of the seizure of the interbank market, the model provides a framework against which the public and

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[2] See for example IMF (2008).

private sector's responses to the development in the interbank markets can be evaluated.

Last, by exposing the vulnerability in the structure of the ABCP programs, the paper contributes to the ongoing debate among practitioners about how the seemingly riskless ABCP market could grind to a sudden halt.[2] The model of the ABCP market presented in this paper, illustrates that the vulnerability of the ABCP programs derives from losses that occur if the programs are forced into a fire-sale of their assets. Thus, contrary to popular beliefs (see footnote 2), an unwind of the ABCP market can occur even if the sponsoring bank's capital is adequate to shoulder the potential losses from the assets held in the program.

The main idea in the model is as follows. Consider a financial market with two types of agents, risk neutral banks and risk averse investors. Optimal risk sharing requires the banks to own the risky assets, but, due to minimum capital requirements, the banks' cost of funds exceeds the investors' cost of funds. When the cost of capital is sufficiently high, the risk averse investors become the most competitive buyers of the risky assets, and the market price of the assets incorporates a risk premium. To circumvent the inefficient asset allocation, the banks sponsor ABCP programs. Under the ABCP program, a special investment vehicle (SIV) issues short-term liabilities (ABCP) to the risk averse investors and uses the proceeds to purchase risky assets. Through a series of derivative contracts, the risk of the assets is passed on to the bank. The ABCP program is structured such that the banks' regulatory capital requirement under the derivatives contracts are zero. By passing the risk of the assets on to the bank, the SIV reduces the risk of the ABCP which is owned by the risk averse investors. Thus, the ABCP program improves risk sharing and is profitable to the banks as they acquire the risk of the assets at a price which incorporates a risk premium.

As an important feature of the equilibrium, the ABCP programs can amplify small shocks to the banks' stock capital and increase the vulnerability of the financial system. Initially, the ABCP

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[2] The practitioners' confusion about the cause of the unravelling of the ABCP market, is captured well by the following quote from Fitch Ratings, *"...Not all RMBS/CDO exposures are subprime-related, and the complete seizure of the ABCP market, in Fitch's opinion, is an extreme over-reaction by investors. It also reflects the fact that investors may not have placed much reliance on fundamental analysis of the structure of the conduit, particularly how liquidity lines and credit enhancement work in the event of a market disruption. If the underlying US Subprime RMBS assets in conduits default, banks, as providers of credit enhancement lines, may need to absorb these losses up to the committed amount of the credit enhancement facility. Most banks, with the exception of a few, have robust balance sheets and are well placed to absorb these losses for the amount of their commitment."* (Fitch Ratings (2007)).

programs enhance risk sharing and lead to a contraction of the risk premium. Under the derivative contracts, if the SIV fails to refinance the ABCP, the sponsoring bank is obliged to purchase the SIV's assets. This purchase is executed at a price which ensures full repayment of the ABCP investors, and not at the price at which the assets can be sold in the market. When the SIVs assets are brought on to the banks balance sheet, they become subject to the capital requirement which renders it inefficient for the bank to hold the assets. This leads to a fire-sale of the assets, and, since the only buyers of the assets are the risk averse investors, a surge in the risk premium and a loss to the bank.

This is the ABCP program's Achilles heal. Consider the behaviour of an investor who contemplates investing either in ABCP or in a risk-free asset. If the investor believes that the SIV can refinance the ABCP in the subsequent period, it is optimal for the investor to invest in ABCP. However, if the investor believes that the SIV will fail to refinance the ABCP in the subsequent period, and if the sponsoring bank's capital is insufficient to shoulder the losses from the fire-sale, the ABCP investor will not be repaid in full and therefore will not invest in the ABCP. Although this suggests that the model exhibits multiple equilibria, with a beliefs determined equilibrium selection, the specific structure of the model, a local game, ensures the existence of a unique equilibrium.[3] In this equilibrium, the investors employ a trigger strategy and refinance the SIV only if the sponsoring bank's capital exceeds a specific threshold. Consequently, a small shock to the sponsoring bank's capital can push it below the refinancing threshold, and can lead to an unwind of the ABCP program. The idea that a small change in fundamentals can lead to a fire-sale of the risky assets has some similarities with the mechanism explored in Morris and Shin (2004). As in Morris and Shin (2004), the fire-sale arises due to a coordination problem and the risk averse investors' downward sloping demand curve.[4]

The sponsoring bank's stock of capital is important to the investors, because it determines the

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[3] See for example Morris and Shin (2003) for an extensive survey of the literature on the unique equilibrium of local and global games.

[4] Despite this similarity, the model presented in Morris and Shin (2004) differ from the model presented here both in objective and modelling methodology. Morris and Shin use a global game with imperfect information, to analyse the importance of model based risk management for the liquidity of securities markets.

bank's ability to withstand a fire-sale of the assets from the ABCP program. This suggests, that when the potential losses from a fire-sale are large, the ABCP program can fail to be refinanced even if the sponsoring bank's capital is sufficient to shoulder the potential losses from the assets.

The liquidation of the ABCP program pushes the sponsoring bank into bankruptcy. This provides the link between the ABCP market and developments in the interbank market. As suggested by Taylor and Williams (2008), the model attributes the seizure of the interbank market to concerns about counterparty risk. In the model, short-term liquidity is plentiful, but seizures of the interbank market arise when the banks attempt to obtain loans which mature post the refinancing of the ABCP programs. The model predicts, that the market for long-term interbank credit remains open only to banks with adequate capital relative to the size of their ABCP programs.

An important contribution of the model is to uncover a link between the ABCP programs through which the failure of one program, in a contagious fashion, can lead to the failure of other programs. When the banks are heterogeneous with respect to their stock of capital, a shock to the banks' capital may initially force one bank to liquidate its ABCP program. All the ABCP programs hold the same risky assets, so the subsequent fire-sale creates an externality for the remaining programs. By reducing the price at which the remaining programs can be liquidated, the failure of one program reduces the expected return on ABCP and impairs the investors' incentives to refinance the other programs. In turn, this can force other programs into liquidation and lead to additional fire-sales. This contagion is akin to the forced selling mechanism explored in Brunnermeier and Pedersen (2005). Brunnermeier and Pedersen analyse the strategic interaction between traders in the financial market, and illustrate that when agents are subject to credit constraints, the asset sales of one trader can have an adverse price impact which turns other traders into forced sellers.

The model provides a setting in which the public and private sector's responses to the credit crisis of 2007-08 can be evaluated. In the model, traditional monetary policy, interest rate cuts and injection of short-term liquidity, is ineffective in alleviating the seizure of the interbank market and the unravelling of the ABCP market. This is so, since the fundamental problem is a shortage capital, and not a lack of short-term liquidity. In contrast, the model suggests that the central banks'

targeted liquidity measures, the Term Auction Facility and the Term Securities Lending Facility, can ease the seizure of the interbank market and alleviate the pressure for banks to liquidate their ABCP programs. By allowing distressed banks to repo the risky assets from the ABCP program, the central bank provides the banks with an alternative to the fire-sales. However, for these measures to be efficient, it is a prerequisite that the central bank is willing to supply more liquidity under the repo transactions than the banks could have obtained from the fire-sale, i.e. it requires the central bank to take risk.

The private sector's initiative, the super fund, corresponds to an insurance mechanism under which the banks pool their capital to support the ABCP programs. This mechanism involves a cross pledging of capital, under which banks with excess capital pledge capital to banks with a capital deficit. The model suggests, that this mechanism could have halted the unravelling of the ABCP market by improving the resilience of the most vulnerable banks.

The theory presented in this paper is related to the literature which analyses the interaction between financial intermediaries and the capital market. This literature finds, that the bilateral nature of bank finance and banks' ability to monitor borrowers implies that bank finance is better when moral hazard problems are severe (Diamond (1991), Holmström and Tirole (1997), Boot and Thakor (1997)) or when R&D and project development is costly (Bhattacharya and Chiesa (1995)). Capital maket finance is superior when borrowers face soft budget constraints (Dewatripont and Mashkin (1995)) or when projects are subject to diversity of oppinion (Allen and Gale (1999)). As a common trait, this literature models the banks and the capital markets as competing sources of finance. The banks do not rely on the capital market as an integrated part of their business and the capital market expands at the expence of bank finance (and vice versa). In contrast, it the model presented below the ability to transact in the capital market is at the core of the capital market banks' business model. Further, the theoretical framework does not emphasize the bilateral nature of bank-borrower relationships or the banks' ability to monitor borrowers.

Closely related to the work presented in this paper is Song and Thakor (2007) and Allen and Gale (1997). Song and Thakor illustrate that banks can reduce their cost of funds by securitizing

their loan portfolio and selling it in the capital market. Thus, as in the model presented in this paper, Song and Thakor emphasise that the ability to transact in the capital markets is an integral part of modern banks' business. In contrast with Song and Thakor's work, in the model presented below the banks' desire to transact in the capital market arises not out of a need to reduce the cost of funds, but to circumvent inefficient cross-sectional risk sharing. Also related is Allen and Gale (1997) which illustrates that banks are better at intertemporal risk sharing whereas the capital markets are superior in cross-sectional risk sharing. The capital market banks presented in the model below transact in the capital markets exactly to enhance their ability to engage in cross-sectional risk sharing.

This paper complements the literature on the economic implications of coordination problems.[5] The notion that coordination problems eliminate multiple equilibria is well developed in the global game models. In these games, agents face strategic uncertainty and in equilibrium they employ trigger strategies which cause the outcome of the game to change as the model's fundamentals breaches a specific threshold. Consequently, small changes in fundamentals can have a significant impact on asset prices (Morris and Shin (2004), Plantin and Shin (2008)) and financial stability (Morris and Shin (1998) and Goldstein and Pauzner (2005)). The model presented below is a local game, and the structure of the model is most closely related to Oyama (2004). Oyama illustrates, that intertemporal strategic uncertainty can create a coordination problem and lead to path dependent FDI's. In the model presented below, the intertemporal strategic uncertainty arises as the return to ABCP investors in period t depends on the actions of the investors at time $t+1$. In addition to the difference in objective, the model presented in this paper embeds and asset pricing framework into the local game, and allows for a contemporaneous link between the ABCP programs through which shocks can spill from one financial intermediary to another.

The paper is also related to the work in Allen and Gale (2000) and Diamond and Rajan (2005) on the micro foundations of financial contagion. Similar to Diamond and Rajan (2005), ex ante there are no links between the banks and the transmission of a shock from one financial intermediary

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[5] See Morris and Shin (2003) for an outstanding survey of this literature.

to another arises endogeneously through the asset market. Diamond and Rajan (2005) focus on liquidity shocks, and illustrate how these can be transmitted through the interbank market. In the model below, the shock affects the banks' stock of capital and the shock is amplified and transferred through the ABCP market. The shock only affects the banks' access to liquidity through its impact on the their solvency.

The paper proceeds as follows. To illustrate the capital market banks' business model and to develop a banckdrop for the theorecial model, section 2 contains a detailed description of the generic structure of an ABCP program. Section 3 presents the baseline model which leads to inefficient risk sharing. Section 4 contains the body of the analysis. This section illustrates how the capital market banks profit from inefficiencies in the financial markets and exposes the vulnerability of the ABCP programs. Section 5 ties the link between the interbank market and the ABCP market, and section 6 evaluates the public and private sector's responses to the credit crisis. Section 7 contains a detailed discussion of the contagion mechanism and section 8 concludes.

To preserve continuity, all proofs have been related to the Appendix.

2   Structure of an asset backed commercial paper program

Financial intermediaries which are subject to capital requirements, use ABCP programs to raise secured financing of specific assets. Under the ABCP program, the financial intermediary retains the risk of the assets and, since the structure of the ABCP program reduces the capital requirement to zero, it is a particularly compelling source of finance when the cost of capital is high.

To initiate an ABCP program, the bank sets up a SIV which raises finance by issuing short-term liabilities (ABCP). The proceeds from the issuance are invested in risky assets in compliance with a set of investment guidelines. Typically, the guidelines impose a lower bound on the credit quality of the assets through a requirement on the assets' credit rating.[6] If any of the assets held by the SIV slip below the minimum requirement, the SIV is obliged to dispose of the assets.

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[6] The ratings requirement depends on the details and rating of the program, but are generally quite strict as the SIV is typically not allowed to hold securites with a credit rating below AAA.

The SIV enters into a set of derivative contracts with the sponsoring bank; a liquidity facility, a credit facility and a swap agreement. The objective of these contracts is to eliminate the SIV's exposure to the risk of the assets. Under the swap agreement, the SIV pays the cash flows received under the assets minus its operating costs against receiving the interest due under the ABCP. Under the credit facility, the sponsoring bank receives a fee against the promise to reimburse the SIV for potential losses on the assets. Typically, the credit facility is subject to a collateral agreement which requires the bank to post collateral if the market value of the SIV's assets drop. Under the liquidity facility, the sponsoring bank receives a fee against the promise to refinance the SIV if the ABCP cannot be refinanced in the market. The liquidity facility can take several forms as the sponsoring bank can either purchase the assets held by the SIV or purchase the maturing ABCP. The net effect of the derivatives contracts is that ABCP investors are secured by the assets held by the SIV and by the credit facility with the sponsoring bank. In addition, the liquidity facility eliminates the risk that the SIV fails to repay ABCP investors due to illiquidity of the ABCP market. The short tenure of the ABCP reduces the risk that the credit quality of the derivative counterparties deteriorate prior to the maturity of the ABCP. Finally, if one of the counterparties to the derivative transactions is pushed into bankruptcy, the SIV automatically makes the largest possible drawdown under the liquidity facility.

Despite the potentially long tenure of the assets held by the SIV, the stated maturity of the credit and liquidity facility is less than one year (typically 364 days). As the facilities roll to maturity, the original counterparties must declare whether they are interested in renewing the facilities. This declaration must be made some period, say X days, prior to the maturity of the facilities. If the counterparties refuse to enter into new facilities, the SIV is instructed to draw liquidity equal to the notional amount of its outstanding ABCP under the liquidity facility. The notice period for this drawdown is Y days, where $Y < X$. This structure ensures, that if the derivative counterparties refuse to renew the facilities, then the SIV obtains enough liquidity to redeem the outstanding ABCP from the liquidity facility. In effect, this leads to an evergreening of the facilities. The original tenure of the credit and liquidity facility is less than one year, so they receive preferential

regulatory treatment. In particular, undrawn committed facilities with an original tenure of less than one year is subject to a capital requirement of 0% (FSA (2001)). The economic outcome of this structure is, that ABCP investors provide low risk finance to the SIV, whilst the derivative counterparties own the risk of the assets.

3　The model

The model has an infinite number of periods and three types of agents; banks, long-term investors and short-term investors. There are N infinitely lived risk neutral banks and a measure 1 of each type of investor. Short-term investors live for one period and long-term investors live for n periods. To obtain pleasant convergence properties, I assume that n is large. Upon his death, each investor is replaced by a new investor with similar characteristics. The investors derive utility only from their terminal wealth and the utility of an investor living until time τ is given by,

$$U_t \left(W_\tau \right) = \left\{ \begin{array}{c} 0 \text{ if } t \neq \tau \\ -\exp \left(-\xi W_\tau \right) \text{ for } t = \tau \end{array} \right. ,$$

where W_τ is the investors' wealth at time τ, and ξ is the common constant absolute risk aversion coefficient. Both types of investors are born without endowments and raise finance at the interest rate r_I which is normalized to zero.

The two types of investors are introduced to capture institutional features of the capital markets. The short-term investors is a modelling abstraction for the money market funds and the long-term investors represents strategic investors with longer investment horizons (typically pension and insurance funds). I take the existence of these investor classes as given, and assume that long-term investors can only hold assets with an original tenure of more than one period and that short-term investors can only hold assets with an original tenure of one period.[7],[8]

The banks are financed by deposits which are insured by a deposit insurance fund, and they are subject to capital requirements which require them to hold k units of capital for each unit of

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[7]A theoretical rationale for the optimality of constraining investors to particular market segments falls outside the scope of this paper but is provided in He and Xiong (2008), Dewatripont et. al (1999) or Holmström and Milgrom (1991).

[8]The constraint on the investors' allocations implies that the portfolio allocation of the long-term investor is independent of the portfolio allocation of the short-term investor. This simplifies the analysis and permits closed form solutions.

deposits they raise. The banks are liquidated if they fail to meet this requirement. At time t, bank i uses its stock of deposits, D_t^i, and its stock of capital, θ_t^i, to finance its operations. The absolute return from bank i's operations are at time $t+1$ given by $\theta_t^i r_e + D_t^i r_D + \tilde{\varepsilon}_t$ where r_D is the banks deposit rate, r_e is the banks cost of capital and $\tilde{\varepsilon}_t$ is a random variable which is realized at the end of period t (just prior to time $t+1$).[9] $\tilde{\varepsilon}_t$ has two equally likely outcomes, $\tilde{\varepsilon}_t \in \{-\varepsilon, \varepsilon\}$. At time zero, the banks' stock of capital is drawn from a distribution with cumulative distribution function $G(\theta)$ and support $[\theta_0, \infty)$.

At each point in time, the economy has two risk-free assets which differ only with respect to their maturity. The risk-free assets yield the risk-free rate of return which has been normalised to zero, and have an original maturity of respectively 1 and n periods. The risk-free assets are in perfectly elastic supply, and are upon their maturity replaced by new risk-free assets with similar characteristics. In addition to the risk-free assets, the economy has n risky assets. Each risky asset has a tenure of n periods and is in supply S. The maturity of the risky assets is staggered such that, out of the n assets outstanding at time t, there is exactly one asset with j periods to maturity for $j = \{1, 2, ..., n\}$. Upon maturity, each risky asset is replaced by a new asset with similar characteristics. In period t (just prior to time $t+1$), each risky asset pays a dividend of $\tilde{r}_t \in \{-r, r\}$, $r > 0$, where each outcome is equally likely. In addition, the risky asset pays the non-stochastic cash flow 1 at maturity. I assume that $\tilde{\varepsilon}_t$ and $\tilde{r}_t$ are independent, and both variables are serially uncorrelated.[10]

4 Analysis

The subsequent analysis is split into three sections. In the first section, I analyse the equilibrium prior to the introduction of the ABCP program. This section illustrates how the regulatory capital requirement leads to inefficient risk sharing and serves as a benchmark for the analysis of the ABCP

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[9] This specification ensures that the net return from the banks' operations is a random variable with a mean of zero. The model's qualitative conclusions are invariant to alternative specifications under which the banks' have positive expected profits from their operations. Under these alternative specification, the banks' profits can be interpreted as the information rents which traditionally justifies the existence of banks.

[10] This assumption is not crucial to the model's qualitative conclusions but it simplifies the exposition.

program. The second section models the ABCP program, and the third section illustrates that the banks can improve risk sharing and raise their profits by sponsoring ABCP programs.

4.1 Equilibrium without ABCP program

There is a deposit insurance so the supply of deposits is perfectly elastic at $r_D = 0$. At time t, bank i's weighted average cost of capital $r^i_{wacc,t}$ is therefore

$$r^i_{wacc,t} = \frac{\theta^i_t}{\theta^i_t + D^i_t} r_e \geq k r_e. \tag{1}$$

Let the price of the risky asset with j periods to maturity be given by P^I_j when the investors own the entire stock of the risky asset, and by $P^{i,B}_{t,j}$ if bank i, at time t, owns the entire stock of the risky asset.

Lemma 1 *If the risky assets are held entirely by the investors, then the price of the risky asset with j periods until maturity is given by,*

$$P^I_j = 1 - \xi \sigma^2_j S,$$

where $\sigma^2_j = j r^2$ is the variance of the asset with j periods until maturity.

The banks are risk neutral so since $E_t(\tilde{r}_s) = 0$ for $s > t$, it follows that

$$P^{i,B}_{t,j} = E_t \left[\prod_{s=1}^{j} \left(1 + r^i_{wacc,t+s}\right) \right]^{-1} \leq \frac{1}{(1 + k r_e)^j},$$

where the inequality follows from (1).[11] Let, $P^B_j \equiv \frac{1}{(1+k r_e)^j}$. The investors are the most competitive bidders for the risky asset if $P^I_j > P^B_j$. This condition is fulfilled if,

$$r_e > \frac{1}{k} \left[\left(\frac{1}{1 - \xi j r^2 S} \right)^{\frac{1}{j}} - 1 \right]. \tag{2}$$

The right hand side of condition (2) is increasing in j, so a sufficient condition for $P^I_j > P^B_j$ is

$$r_e \geq \frac{1}{k} \left[\left(\frac{1}{1 - \xi n r^2 S} \right)^{\frac{1}{n}} - 1 \right]. \tag{3}$$

Throughout the analysis, I assume that condition (3) is fulfilled.

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[11] Since $\tilde{r}_t$ is an i.i.d. variable and θ^i_t determined prior to $\tilde{r}_t$, it follows that $E_t \left[\frac{\tilde{r}_s}{1 + r_{wacc,t+s}} \right] = 0$.

Lemma 2 *In equilibrium, the price of the risky asset with j periods to maturity is given by P_j^I and the stock of risky assets is held entirely by the long-term investors. The short-term investors invest only in the short-term risk-free asset. The banks allocate their capital and deposits to their operations and obtain zero expected profits.*

Under condition (3) the banks refrain from investing in the risky assets. Although optimal risk sharing requires the banks to own the risky assets, the combination of a high cost of capital and the regulatory capital requirement implies, that the risk averse long-term investor is the most competitive bidder for the risky assets. The banks can enhance risk sharing and increase their profits by sponsoring ABCP programs. The following section describes the modelling of the ABCP program.

4.2   The ABCP program

To initiate an ABCP program, bank i enters into a swap agreement and a liquidity/credit facility (the "facility") with a SIV.[12] At time t, the SIV sponsored by bank i issues liabilities (ABCP) with a tenure of one period and an interest rate of $r_{cp,t}^i \equiv r_{cp}\left(\theta_t^i\right)$. The proceeds from the issuance are invested in risky assets at the prevailing market price. At time t, the market price of the risky asset with j periods to maturity is given by P_j^{cp}. At each point in time, the SIV refinances the maturing ABCP by issuing new ABCP. Under the swap agreement, the bank receives the return from the assets held by the SIV and pays the interest due under the ABCP. I assume, that the notional amount of each ABCP program is exogenously fixed at A, and that each SIV acquires a notional amount of $\frac{A}{n}$ of each of the risky assets. Let the issue price of the ABCP (per unit of notional amount) be given by I. To ensure that the ABCP program is fully collateralised, the issue price of the ABCP is equal to the average price of the assets held by the SIV, that is

$$I = \frac{1}{n}\sum_{j=1}^{n} P_j^{cp}.$$

Under the swap agreement, the sponsoring bank receives a net cash flow of,

$$\left[\tilde{r}_t - r_{cp,t}^i\right] A.$$

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[12]To keep the analysis simple, I assume that the ABCP program has one combined credit and liquidity facility.

Under the facility, the bank provides liquidity to the SIV if this fails to refinance its maturing ABCP. To provide this liquidity, the bank acquires the SIV's assets at the price which ensures full repayment of the maturing ABCP. If at any point the sponsoring bank is forced into liquidation, the SIV immediately makes the largest possible drawdown under the facility and liquidates its remaining assets (if any). The proceeds from this procedure are used to redeem outstanding ABCP as this matures. The fee for the facility is set to ensure that the net cash flows to the SIV are zero. The ABCP is redeemed at the price at which it was issued, so the fee for the facility corresponds to the change in the price of the assets held by the SIV.[13] Thus, at time t, the fee for the facility is given by,

$$A \left[\frac{1}{n} \sum_{j=0}^{n-1} P_j^{cp} - I \right] = \frac{A}{n} \left(P_0^{cp} - P_n^{cp} \right).$$

The fee for the facility is consumed immediately by the bank, so the dynamics of the bank's capital is given by,[14]

$$\theta_{t+1}^i = \theta_t^i + \left[\tilde{r}_t - r_{cp,t}^i \right] A + \tilde{\varepsilon}_t. \tag{4}$$

Lastly, I impose the constraint that the volatility of the banks operations is large relative to the volatility of the assets held in the ABCP program, $\varepsilon > rA$.[15]

With the modelling of the ABCP program in hand, I turn to the equilibrium analysis.

4.3 Equilibrium with ABCP program

In the following, I derive the equilibrium under the assumption that it is optimal for the banks to sponsor the ABCP programs. Lemma 9 verifies that this is indeed the case.

Given the CARA utility function, the long-term investors' demand for the risky asset with j

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[13] If this price change is negative, the fee for the facility captures that the sponsoring bank must transfer additional collateral to the SIV under the credit facility.

[14] The banks' consumption takes the form of wages to employees and distributions to shareholders.

[15] This assumption permits a ranking of the banks' level of capital following various relisations of $\tilde{\varepsilon}_t$ and $\tilde{r}_t$. In particular, it implies that the banks' capital is higher if $(\tilde{\varepsilon}_t, \tilde{r}_t) = (\varepsilon, -r)$ than if $(\tilde{\varepsilon}_t, \tilde{r}_t) = (-\varepsilon, r)$. The significance of the assumption is only that it allows a ranking of banks' capital following different realisations of the random variables. All the models qualitative results prevail with the alternative assumption $\varepsilon \leq rA$. Given the investment guidelines imposed on the SIV, it appears appropriate to assume that the variance of the assets held by the SIV is low relative to the variance of the revenues from the banks' operations.

periods to maturity is given by $\frac{1-P_j^{cp}}{\xi\sigma_j^2}$.[16] The SIVs demand $N\frac{A}{n}$ of each of the risky assets, so market clearing requires,

$$\frac{1-P_j^{cp}}{\xi\sigma_j^2} + N\frac{A}{n} = S,$$

which implies,

$$P_j^{cp} = 1 - \xi\sigma_j^2\left(S - N\frac{A}{n}\right).$$

The ABCP programs permit short-term investors to participate in the financing of the risky assets. This raises the demand for the risky assets which, through a contraction of the risk premium, leads to a surge in the price of the risky assets, i.e. $P_j^{CP} > P_j^I$.

The analysis of the ABCP program and the behaviour of short-term investors proceeds in four steps. In the first step, I note that the return on ABCP depends on the refinancing of the ABCP in the subsequent period. The second step illustrates that the sponsoring bank may incur a loss if it is forced to refinance the ABCP under the facility. Step three shows the potential for multiple equilibria, and the final step exploits that the game is a local game and derives a the unique equilibrium strategy for short-term investors.

Consider an investor that at time t invests AI into an ABCP program sponsored by bank i. Given the price of the ABCP, the notional amount of the investment is A. If the SIV refinances the ABCP at time $t+1$ (either through the market or through the facility) the ABCP investor is repaid $\left(I + r_{cp,t}^i\right)A$ and obtains utility,[17]

$$U_{t+1}\left(W_{t+1}\right) = -\exp\left[-\xi\left(I + r_{cp,t}^i\right)A\right].$$

If the SIV fails to refinance the ABCP at time $t+1$, an event that occurs only if bank i is pushed into bankruptcy when it is required to meet its obligations under the facility, the SIV obtains as much liquidity from the bank as possible and thereafter liquidates its remaining assets. This gives the ABCP investor a repayment of

$$\theta_{t+1}^i + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i},$$

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[16] See the proof of Lemma 1 for details.

[17] The term ABCP investors refer to short-term investors who have invested in ABCP.

where $P_j^{u,i}$ is the price of the risky asset with j periods until maturity contingent on the unwind of bank i's ABCP program. Thus, if the ABCP is not refinanced, the ABCP investor obtains a utility of,

$$U_{t+1}(W_{t+1}) = -\exp\left[-\xi\left(\theta_{t+1}^i + \frac{A}{n}\sum_{j=0}^{n-1} P_j^{u,i}\right)\right].$$

Clearly, if the sponsoring bank fails to meets its obligations under the facility, the ABCP investors are not repaid in full, so

$$-\exp\left[-\xi\left(I + r_{cp,t}^i\right)A\right] > -\exp\left[-\xi\left(\theta_{t+1}^i + \frac{A}{n}\sum_{j=0}^{n-1} P_j^{u,i}\right)\right].$$

The second step in the analysis illustrates, that the sponsoring bank may incur a loss if it is forced to refinance its SIV under the facility. To ensure full repayment of the ABCP investors, the bank must pay I for the SIVs' assets if it refinances the SIV under the facility. The purchase price of each asset, is not set on market terms, but is set to ensure that the SIV can redeem the maturing ABCP. If bank i is the only bank to provide liquidity to its SIV, it can subsequently sell the assets for,

$$P_j^{u,i} = 1 - \xi\sigma_j^2\left(S - (N-1)\frac{A}{n}\right).$$

Since $P_j^{u,i} > P_j^I > P_j^B$ for all j, it is optimal for the bank to sell the risky assets.

Let L be bank i's profits from refinancing its SIV under the facility. Then,

$$
\begin{aligned}
L &= A\left[\frac{1}{n}\sum_{j=0}^{n-1} P_j^{u,i} - I\right] \\
&= \frac{A}{n}\sum_{j=0}^{n-1}\left(P_j^{u,i} - P_j^{cp}\right) + A\left[\frac{1}{n}\sum_{j=0}^{n-1} P_j^{cp} - I\right] \\
&= \frac{A}{n}\sum_{j=0}^{n-1}\left(P_j^{u,i} - P_j^{cp}\right) + \frac{A}{n}\left(P_0^{cp} - P_n^{cp}\right).
\end{aligned}
$$

The first term in this expression is bank i's loss from acquiring the risky assets from the SIV. The second term is the gain that accrues to the bank as a fee under the facility. This fee corresponds to the contraction in the risk premium that occurs over one period. Lemma 3 lists the condition under which the loss from the first term exceeds the gains from the second term. Under this condition, the refinancing of the ABCP program leads to a loss.

Lemma 3 *If bank i is the only bank to provide liquidity to its ABCP program and*

$$S < \frac{A}{n} \left(\sum_{j=0}^{n-1} j + N \right),$$

(5)

then bank i incurs a profit of L, where

$$L = A\xi r^2 \left[S - \frac{A}{n} \left(\sum_{j=0}^{n-1} \frac{j}{n} + N \right) \right] < 0.$$

Throughout the analysis, I assume that condition (5) is fulfilled.

The third step of the analysis illustrates, that under condition (5), the short-term investors' willingness to refinance the SIV at time t depends both on the sponsoring bank's capital, and on the expected behaviour of the short-term investors at time $t+1$. The state space can be partitioned into three sets. If $\theta_t^i \leq \underline{\theta} \equiv -\delta$ for some $\delta \to 0$, $\delta > 0$, the sponsoring bank is certain to violate the minimum capital requirement. This implies, that the sponsoring bank and the ABCP program are liquidated independent of the behaviour of the short-term investors at time $t + 1$. This leaves the ABCP investors with recourse to the risky assets. Condition (5) implies that $L < 0$, so

$$- \exp \left[-\xi \left(\frac{A}{n} \sum_{j=0}^{n-1} P_j^{u,i} \right) \right] < - \exp \left[-\xi I A \right].$$

Thus, for $\theta_t^i \leq \underline{\theta}$, the dominant action for short-term investors is to invest in the risk-free asset. Conversely, for $\theta_t \geq \overline{\theta} \equiv L + \delta$, the sponsoring bank has sufficient capital to meet its obligations under the facility, so ABCP investors are certain to receive repayment of at least their investment. Consequently, their dominant action is to refinance the SIV independent of the behaviour of the short-term investors at time $t + 1$.

For $\underline{\theta} < \theta_t^i < \overline{\theta}$, the short-term investors' dominant action varies as a function of their beliefs. This suggests, that the ABCP program exhibits multiple equilibria with a beliefs determined equilibrium selection. To see this, let p_t be the likelihood that short-term investors at time t attach to a refinancing of the SIV at time $t + 1$, i.e. p_t is the short-term investors' beliefs about the actions of the short-term investors in the subsequent period. Then, the expected utility from investing in ABCP is given by,

$$E_t \left[U \left(W_{t+1} \right) \right] = -p_t \exp \left[-\xi \left(I + r_{cp,t}^i \right) A \right] - (1 - p_t) E_t \left\{ \exp \left[-\xi \left(\theta_{t+1} + \frac{A}{n} \sum_{j=0}^{n-1} P_j^{u,i} \right) \right] \right\}.$$

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If $p_t = 1$, it is optimal for the short-term investors to refinance the SIV. Conversely if $p_t = 0$, it is optimal for short-term investors to refrain from refinancing the SIV. Although this suggests the occurrence of multiple equilibria, the game is a local game where the short-term investors' optimal behaviour is determined uniquely as a function of the sponsoring banks' equity.

Based on these observations, Lemma 4 lists the necessary conditions for short term investors to refinance the SIV.

Lemma 4 *There is a unique value of θ_t^i, $\theta^{i,*}$, such that short-term investors refinance the SIV sponsored by bank i only if $\theta_t^i \geq \theta^{i,*}$.*

The result in Lemma 4 is derived by iterated deletion of conditionally dominated strategies. The proof verifies, that if there is only one bank in the economy, there is only one strategy which survives this procedure, and therefore the model has a unique subgame perfect equilibrium. In this equilibrium, the short-term investors employ a trigger strategy and refinance the SIV if and only if the sponsoring bank's capital exceeds a given threshold. However, when there are multiple banks in the economy, the failure to refinance one SIV may lead to the failure to refinance other SIVs. Thus, Lemma 4 yields only the necessary conditions for short-term investors to refinance the SIV. The logic behind the switching strategy is driven by three features of the ABCP program:

1. **Strict dominance regions:** The existence of values for θ_t^i, $\underline{\theta}$ and $\overline{\theta}$, such that short-term investors have strictly dominant strategies for $\theta_t^i \notin \left(\underline{\theta}, \overline{\theta}\right)$,

2. **Strategic complementarity:** For $\theta_t^i \in \left(\underline{\theta}, \overline{\theta}\right)$, the return to refinancing the SIV at time t is strictly higher if short-term investors refinance the SIV at time $t + 1$ than if short-term investors refuse to refinance the SIV at time $t + 1$, and

3. **Strict monotonicity:** For $\theta_t^i \in \left(\underline{\theta}, \overline{\theta}\right)$, the expected utility from refinancing the SIV is strictly increasing in θ_t^i.

The first feature ensures the existence of ranges of fundamentals for which the short-term investors' optimal action is independent of the action of the short-term investors in the subsequent

period. These regions anchor the behaviour of the short-term investors when $\theta_t^i \in \left(\underline{\theta}, \overline{\theta} \right)$. The second feature ensures, that short-term investors, post observing a θ_t^i "sufficiently close" to $\overline{\theta}^i$ $(\underline{\theta}^i)$, maximize their expected utility by selecting the action which is dominant in the region above (below) $\overline{\theta}^i$ $(\underline{\theta}^i)$. The third feature ensures the existence of a unique value of θ_t^i, $\theta^{i,*}$, such that "sufficiently close" to $\overline{\theta}^i$ $(\underline{\theta}^i)$ implies $\theta_t^i \geq \theta^{i,*}$ $(\theta_t^i < \theta^{i,*})$.

One important insight of Lemma 4 is, that the ability to refinance the ABCP program depends on the sponsoring bank's stock of capital, and not on the quality of the assets held in the program. Thus, Lemma 4 illustrates, that a failure to refinance the SIV can occur without a deterioration in the credit quality of the assets held by the SIV. In the framework presented here, the quality of the risky assets is invariant over time, and the losses which lead to the failure of the ABCP program arise from the fire-sale of the SIV's assets.

In the following, I assume that all banks have the ability to launch an ABCP program at time 0, i.e. $\theta_0 \geq \theta^{i,*}$ for all i.

When the stock of capital varies across the banks, the threshold at which one ABCP program is liquidated differs from the threshold at which other ABCP programs are liquidated, i.e. $\theta^{i,*} \neq \theta^{l,*}$ for $i \neq l$. Lemma 5 shows that there is an important interconnectedness across the ABCP programs. The source of this interconnectedness is, that the ABCP programs are invested into the same risky assets. This implies, that the failure to refinance one ABCP program, in a contagious fashion, can trigger a failure to refinance other ABCP programs.

Lemma 5 *Short-term investors refinance the SIV sponsored by bank i only if they refinance the SIV sponsored by bank l for all i, l such that $\theta_0^i \leq \theta_0^l$.*

Lemma 5 contains two insights. First, it illustrates, that the resilience of the ABCP program is increasing in the sponsoring bank's stock of capital.[18] An increase in the sponsoring bank's stock of capital raises the repayment to the ABCP investor when the SIV is refinanced under the facility. Thus, for any given interest rate on the ABCP, a higher level of capital (weakly) raises the expected

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[18] The statement in the lemma refers to the banks' stock of capital at time 0. However, the shocks to the banks' capital are uniform across the banks. Thus, the ordering of the banks according to their stock of capital at time 0 is equivalent to the ordering of the banks according to their stock of capital at time t.

return on ABCP and enhances the investors' incentives to refinance the SIV.

Second, Lemma 5 reveals, that the ability to refinance the ABCP programs is linked across the programs. The interconnectedness arises since the ABCP programs are invested into the same risky assets. A failure to refinance one ABCP program creates an externality as it leads to a fire-sale of the assets held in that program. This fire-sale depresses the market price of the risky assets, and decreases (weakly) the expected return on ABCP issued by all other ABCP programs.[19] In turn, this reduces the investors' incentives to refinance other ABCP programs and may cause additional failures and fire-sales. In a contagious fashion, the failure of one ABCP program can start a chain reaction which leads to the failure of other ABCP programs and further fire-sales of the risky assets.

Given the simple structure of the risky assets and the returns on the banks' operations, expressions for $r_{cp}\left(\theta^{i,*}\right)$ and $\theta^{i,*}$ can be derived. These are listed in Lemma 6.

Lemma 6 *The lowest value of θ^i at which the short-term investors refinance the SIV sponsored by bank i is given by,*

$$\theta^{i,*} = \frac{1}{\xi} \ln \left(\frac{\exp\left(-\xi\left(-rA-\varepsilon\right)\right) + \exp\left(-\xi\left(-rA+\varepsilon\right)\right) + \exp\left(-\xi\left(rA-\varepsilon\right)\right)}{4\exp\left(-\xi IA\right) - \exp\left[-\xi\left(I+r_{cp}^*\right)A\right]} \right) - \frac{A}{n}\sum_{j=0}^{n-1} P_j^{u,i}, \quad (6)$$

where,

$$P_j^{u,i} = 1 - \xi\sigma_j^2\left[S - \left(1 - G\left(\theta_0^i\right)\right)N\frac{A}{n}\right], \tag{7}$$

and,

$$r_{cp}^* \equiv r_{cp}\left(\theta^{i,*}\right) = r + \frac{\varepsilon}{A}. \tag{8}$$

The results in Lemma 6 originates from Lemma 4 and 5 combined with the observation that the short-term investors refinance the SIV when they are indifferent between investing in ABCP and in the risk-free alternative.

Expression (7) captures the contagion effect. By Lemma 5, all banks with less capital than bank i liquidate their ABCP programs simultaneous with bank i. Thus, if bank i is the marginal bank to unwind its ABCP program, the price at which it can liquidate the risky assets reflects the liquidation of all the ABCP programs sponsored by banks with less capital than bank i.

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[19] Recall from the previous discussion that when the SIV is refinanced under the facility, the repayment to ABCP investors is increasing in the market price of the risky assets.

Let

$$T = \arg\min_i \theta_0^i - \theta^{i,*},$$

and let $T^- = \{i | \theta_0^i < \theta_0^T\}$. The shocks to the banks' capital are uniform, so bank T is the first bank to liquidate its ABCP program, and T^- is the set of banks which, by Lemma 5, liquidate their ABCP programs simultaneously with bank T. When $\theta_t^i > \theta^{i,*}$, the interest rate on the ABCP is set to maximize the payments to the bank under the swap agreement. Thus, $r_{cp,t}^i$ is the lowest interest rate which ensures that the short-term investors refinance the ABCP program. Lemma 7 exploits this indifference condition to derive $r_{cp,t}^i$.

Lemma 7 *At time t, the interest rate on the ABCP issued by the SIV sponsored by bank i is given by,*

$$r_{cp,t}^i = \frac{1}{\xi A} \ln\left(\Pr\left(\theta_t^k\right)\right) - \frac{1}{\xi A} \ln\left\{\exp\left(-\xi I A\right)\right.$$

$$\left. - \left[1 - \Pr\left(\theta_t^k\right)\right] \exp\left[-\xi\left(\theta_t^i + \frac{A}{n}\sum_{j=0}^{n-1} P_j^{u,k}\right)\right] E_t\left[\exp\left(-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right)|\theta_t^i, \theta_{t+1}^k < \theta^{k,*}\right]\right\} - I,$$

where $\Pr\left(\theta_t^k\right) \equiv \Pr\left(\theta_{t+1}^k \geq \theta^{k,*}\right)$ *and,*

$$k = \begin{cases} i \text{ for } i \notin T^- \\ T \text{ for } i \in T^- \end{cases}.$$

The expressions for $\Pr\left(\theta_t^k\right)$ and $E_t\left[\exp\left(-\xi\left(r_t A + \tilde{\varepsilon}_t\right)\right)|\theta_t^i, \theta_{t+1}^k < \theta^{k,*}\right]$ are unimportant for the model's qualitative conclusions and are listed in the appendix.

The contagion effect splits the set of banks into two. The first set of banks, $i \in T^-$, liquidate their ABCP programs when bank T breaches its capital threshold. The interest rate on these programs therefore depends on the sponsoring banks' capital and on the probability that bank T breaches its capital threshold. Note that the interest rate on these ABCP programs can exceed r_{cp}^*. This follows since the expected return on ABCP is increasing in θ_t^i. When $\theta_t^T = \theta^{T,*}$, the short-term investors are indifferent between refinancing the SIV sponsored by bank T or investing in the risk-free asset. Since $\theta_t^T > \theta_t^i$ for $i \in T^-$, banks in set T^- must offer a higher interest rate than bank T for any realisation of θ_t^T.

The banks outside T^- liquidate their ABCP programs when they breach their capital threshold. Consequently, the interest rate on these programs reflects the capital of the sponsoring bank and the probability that this capital falls short of the threshold.

Equipped with the insights of Lemma 4, 5 and 7, I present the main result of the paper. Proposition 8 characterises the short-term investors' equilibrium behaviour, and outlines the conditions under which the ABCP programs are refinanced. Proposition 8 combines the insights of the previous lemmas illustrates how a small shock to one banks stock of capital can trigger an unwind of the banks' ABCP program which, through the subsequent fire-sales, can be amplified and spread across the financial system.

Proposition 8 *Short-term investors refinance the SIV sponsored by bank i if and only if $\theta_t^i \geq \theta^{i,*}$ and $\theta_t^l \geq \theta^{l,*}$ and $r_{cp,t}^i \leq \theta_t^i - \theta^{i,*} + r + \frac{\varepsilon}{A}$ for all i, l such that $\theta_0^i \leq \theta_0^l$.*

Proposition 8 provides the necessary and sufficient conditions for short-term investors to refinance the ABCP programs. As in Lemma 5, Proposition 8 shows that contagion occurs across the ABCP programs, and that the resilience of the programs is increasing in the sponsoring bank's stock of capital. Further, as in Lemma 4, the key determinant of the viability of the ABCP program is the sponsoring bank's stock of capital. Thus, a failure to refinance the ABCP program can occur without a deterioration of the credit quality of the assets held in the program. The logic behind these insights is equivalent to the logic behind Lemma 4 and 5. The final condition of the proposition ensures, that when the sponsoring bank is not the marginal bank to liquidate its ABCP program, its stock of capital is sufficient for the SIV to pay an interest rate which renders short-term investors indifferent between investing in the ABCP and in the risk-free alternative.

Even though the risky assets are perfectly correlated, the binary structure of $\tilde{r}_t$ and $\tilde{\varepsilon}_t$ implies that there is a level of θ_t^i such that $r_{cp,t}^i = 0$.[20] This illustrates, that when the sponsoring bank's stock of capital is sufficiently high, the risk neutral bank completely absorbs the risk of the assets held by the SIV. By reducing the risk held by the risk averse investors, the ABCP program enhances risk sharing. Further, since the market price of the risky assets incorporates a risk premium, the

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[20]To see this, note that $\theta_t^T > \theta^{T,*} + rA + \varepsilon$ implies that $P\left(\theta_t^i\right) = 1$ for all i and therefore $r_{cp,t}^i = 0$.

risk neutral banks are able to acquire the risk of the assets at a discount to the expected return on the assets. Therefore, the banks obtain positive expected profits from sponsoring the ABCP programs. This observation is verified in Lemma 9, which illustrates why the ABCP programs arise endogenously in equilibrium.

Lemma 9 *Let $\pi^i_{cp,t}$ and π^i_t be bank i's profits at time t respectively with and without the ABCP program. Then,*

$$\sum_{s=1}^{\infty} E_t\left(\pi^i_{cp,t+s}\right) > \sum_{s=1}^{\infty} E_t\left(\pi^i_{t+s}\right) = 0.$$

The model has no bankruptcy costs, so, given that the banks' operations provide them with an expected return of zero, the banks are willing to launch ABCP programs when these yield positive expected profits. The ABCP programs increase the banks' probability of bankruptcy, $\theta^{i,*} > 0$, so when bankruptcy is costly, there is a lower limit on the profitability of the ABCP program below which the banks refrain from initiating the programs.

The crucial element of the ABCP program is, that the banks are not required to hold capital against the facilities. Thereby, the ABCP program allows the banks to take exposure to risky assets which they cannot profitably hold on their balance sheet. In the model, the term structure of interest rates is flat, so the profitability of the ABCP program does not benefit from the implicit maturity transformation of the assets held in the ABCP program. In fact, the maturity transformation, i.e. the finance of a long-term asset with short-term liabilities, is a tool the banks employ to reduce the risk of the ABCP.

5 Interbank market

The insights from the previous section has important implications for the interbank market. Banks which are forced to refinance their ABCP program under the facility are pushed into bankruptcy, so one should expect creditors in the interbank market to be wary about extending loans to banks with low levels of capital across ABCP roll dates, but less wary about extending short-term credit (over-night credit). This suggests, that when the banks' stock of capital is low, concerns about the

ability to refinance the ABCP programs may cause a seizure of the interbank market. This seizure prevails for loans which mature post the ABCP roll date, but it does not affect the market for short-term credit. Consequently, banks can be "awash" with liquidity and at the same time refuse to extend credit in the interbank market with a tenure significantly exceeding one day.[21]

To formalise this idea, I introduce an interbank market where financial institutions can lend and borrow unsecured. Generally, the existence of the interbank markets is motivated by the occurrence of liquidity shocks.[22] To keep the analysis simple, I refrain from modelling the origin of the liquidity shocks, but assume that banks with ABCP programs, at the mid–point of each period, can be hit by a liquidity shock which lasts either $\frac{1}{2}$ or 1 period.[23] The shocks are heterogeneous across the banks and observable to all agents. Shocks which last $\frac{1}{2}$ period are reversed prior to the refinancing of the SIVs. In addition to the banks with ABCP programs, I assume that there is a set of risk neutral financial intermediaries without ABCP programs which supply liquidity in the interbank market. If banks fail to raise liquidity in the interbank market, they can obtain liquidity from a lender of last resort. The lender of last resort provides liquidity only to banks which have failed to raise liquidity in the market, but which are solvent at the time when they apply for credit. Further, I assume that the banks observe $\tilde{r}_t$ simultaneously with the liquidity shock. This assumption leads to a tiering of the interbank market, as it allows creditors to distinguish the banks which are certain to be pushed into bankruptcy on the ABCP roll date from the banks which have a positive probability of being solvent post the ABCP roll date.

The interbank market is open every half period, i.e. at $t \in \left\{ \frac{1}{2}, 1, \frac{3}{2}, 2, ... \right\}$, and the tenure of the interbank loans match the tenure of the liquidity shocks. To keep the analysis simple, I assume that bank i's cost of borrowing in the interbank market is included as part of the random variable

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[21] One of the major British banks, Barclays, stated that it was "awash with cash" at the height of the seizure of the interbank markets. See Goodhart (2007).

[22] See for example Bhattacharya and Gale (1987) or Allen and Gale (2000) for a rationale for the existence of interbank markets.

[23] The liquidity shocks represents unforseen mismatches between the banks' cash flows. They have no effect on the banks' solvency, as the cash outflow at time $t - \frac{1}{2}$ is offset by a non-risky cash inflow at time t (or time $t + \frac{1}{2}$). If the bank is bankrupt at the time of the cash inflow, this accrues to the bank's creditors.

$\tilde{\varepsilon}_t.$[24] Consequently, the dynamics of the banks' equity remains as in (4). To introduce credit risk, I assume that the banks are subject to a bankruptcy cost of C which is incurred by the banks' creditors.

The liquidity shocks and the interbank market do not affect the dynamics of the banks' capital, so short-term investors' optimal behaviour is given by the trigger strategy outlined in Proposition 8.[25]

Banks which are hit by liquidity shocks apply for loans in the interbank market. In the following, I refer to loans (and liquidity shocks) with a tenure of $\frac{1}{2}$ period as short-term loans (shocks) and to loans (shocks) with a tenure of 1 period as long-term loans (shocks).

Lemma 10 *Following a shock at time* $t - \frac{1}{2}$, *banks which are exposed to short-term liquidity shocks obtain credit in the interbank market at the risk-free rate. Banks which are exposed to long-term liquidity shocks obtain credit in the interbank market if and only if,*

$$\theta_{t-1} > \theta^{i,*} - \left(r_t - r^i_{cp,t-1}\right) A - \varepsilon. \tag{9}$$

Banks which are exposed to long-term liquidity shocks, but which fail to meet condition (9) *cannot raise finance in the interbank market and obtain credit from the lender of last resort.*

Lemma 10 illustrates, that banks which realize short-term liquidity shocks obtain credit in the interbank market irrespective of their stock of capital. This follows, since the short-term liquidity shocks and the short-term loans mature prior to the refinancing of the SIVs, so short-term credit is risk-free.

Absence of arbitrage between short-term and long-term loan contracts ensures, that the banks which are exposed to long-term liquidity shocks apply for one period loans in the interbank market. These loans mature post the refinancing of the SIV, so the bank may be pushed into bankruptcy prior to the repayment of the loan. The interbank creditors can observe the realisation of the

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[24] The costs of borrowing in the interbank market are small when the liquidity shock is small. Thus, this assumption is equivalent to assuming that the liquidity shocks are small relative to the other shocks that affects the banks' operations.

[25] The bankruptcy cost affects the expression for the capital threshold, $\theta^{i,*}$, but it does not affect the structure of the short-term investors' equilibrium strategy.

variable $\tilde{r}_t$, and therefore they can single out loan applicants which are certain to be bankrupt given the realisation of $\tilde{r}_t$. Condition (9) separates the banks which are certain to be bankrupt at the maturity of the long-term loan from the banks which have a positive probability of being solvent at the maturity of the long-term loan. The bankruptcy cost exposes the interbank creditors to losses when the borrower is insolvent at the maturity of the loan, so banks which fail to meet condition (9) cannot obtain finance in the interbank market. At the time of the shock all banks have a positive stock of capital and therefore they comply with the minimum capital requirements.[26] Thus, banks which fail to raise finance in the interbank market are eligible for credit from the lender of last resort.

6   Policy responses

In this section, I use the model developed above to analyse the monetary authorities' and the private sector's responses to the unravelling of the ABCP market and the seizure of the interbank markets. To illustrate the different impact of the various responses, I initiate this section with a discussion of the role filled by the interbank markets and a brief outline of the responses of the different parties.

Traditionally, the monetary authorities use the discount rate and the open market operations to ensure that the aggregate amount of liquidity in the financial system is sufficient for financial intermediaries to settle their transactions and make payments. Only a limited number of banks have access to the central banks' open market operations (the "primary dealers"), and the central banks rely on a competitive market mechanism to ensure an efficient distribution of the liquidity across the financial system. This mechanism is the interbank market. Hence, when the interbank market freezes, the banks outside the primary dealers end up with too little liquidity to make payments and settle trades. This raises a systemic threat to the entire financial system. It is important to recognize, that a seizure of the interbank market is a problem of the distribution of liquidity, and

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[26] When the banks stock of capital is positive, they can always comply with the minimum capital requirements by reducing the scale of their operations and returning deposits to the depositors.

not a problem of amount of liquidity available in the financial system as a whole.[27]

The monetary authorities' responses to the seizure of the interbank markets can be broadly split into two categories. The first, traditional monetary policy, led to dramatic reductions in the policy rates and massive liquidity injections. From September 2007 to December 2008 the Federal Reserve Bank of New York reduced its policy rate by from 5.25% to 0%, and from September 2008 to December 2008, the size of the Federal Reserve Bank of New York's balance sheet doubled as a result of unsterilized intervention in the financial markets.[28]

The second category, "targeted liquidity measures", led to the introduction of a series of facilities and to a widening of the range of assets eligible as collateral under the open market operations. In the discussion below, I focus on the most important, the "Term Auction Facility" (TAF), the "Term Securities Lending Facility" (TSLF) and the "ABCP Money Market Mutual Fund Facility" (ABCPMMF). Lastly, the discussion touches briefly on the recapitalisation program, the Troubled Asset Relief Program (TARP), launched by the US Treasury.

In December 2007, the Federal Reserve Bank of New York opened the TAF under which commercial banks are allowed to repo securities in return for liquidity. Relative to the open market operations which have a short tenure (no more than 14 days), the repo transactions under the TAF have a tenure of 28 days.[29] The TAF distributes liquidity more widely than the open market operations, as the array of banks with access to liquidity under the TAF exceeds the group of primary dealers. The TAF is structured to affect the tenure of the liquidity provided by the central bank but not the aggregate amount of liquidity in the financial system. To meet this objective, the central bank takes the amount of liquidity distributed under the TAF into consideration when it fixes the amount of liquidity to be supplied under the open market operations.

In addition to the TAF, in March 2008 the Federal Reserve Bank of New York opened the

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[27] This does not rule out the co-existence of the two problems, i.e. too little aggregate liquidity and an inefficient distribution of the liquidity. However, the important point is, that since the two problems are distinct, the resolution the problems require different economic policies.

[28] Federal Reserve Bank of New York.

[29] On July 31, 2008, the tenure of the liquidity supplied under the TAF was increased as the central banks announced that 25% of loans were allowed to have a tenure of 84 days (Federal Reserve Bank of New York).

TSLF, under which commercial banks can repo structured and illiquid securities in exchange for government bonds. The TSLF is available to the primary dealers, and the tenure of the repo transactions is 28 days. The TSLF provides the largest banks with excess demand for liquidity with an alternative to a fire-sale of illiquid assets.

The central bank added the ABCPMMF facility to its arsenal of liquidity measures in September 2008. Under this facility, the central bank acquirers ABCP directly from the commercial banks. The price the central bank pays for the ABCP is equal to the price that the banks paid to acquire the ABCP from the SIV. The ABCPMMF facility is different to the other repo facilities, as the central bank underwrites the risk of the ABCP.[30]

Both the TAF, the TSLF and the ABCPMMF facilities were designed to be temporary, but the tenure of the TAF and the TSLF has been extended suggesting that they may become more permanent features of the financial architecture.[31]

Last, in October 2008 Congress approved the USD 700bn TARP program. The initial objective of the program was to purchase risky assets from the commercial banks at the market clearing price. As the program was put into effect however, the funds were employed to recapitalise the banking system.

The private sector's main initiative was the attempt to establish a "super fund" (or a "super SIV"). The idea behind the super fund was to create a SIV that could acquire the assets from the individual ABCP programs as these were forced into liquidation. The super fund was intended to limit the fire-sales of the risky assets in order to contain the externality through which the unwind of one ABCP program led to the liquidation of other ABCP programs. The proposed structure of the super fund was akin to the structure of the individual ABCP programs, with the important difference that the super fund was to be sponsored by a syndicate of Wall Street banks.[32] The

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[30] To circumvent regulation that prevents federal reserve banks from purchasing assets, the MMABCP facility is structured as a loan facility. The federal reserve bank's claim to repayment is limited to the ABCP pledged under the facility, so for all economic purposes the facility is akin to an outright purchase.

[31] See Taylor and Williams (2008) and Brunnermeier (2008) for further discussions of the TAF and the TSLF.

[32] The proposed size of the superfund was USD 400bn with Wall Street banks extending USD 100bn in credit lines (Financial Times 07/12/07).

super fund failed to materialize in early 2008 as the banks in the consortium one by one declined to provide the necessary credit and liquidity lines.

6.1 Monetary authorities' response

Casual empirics indicate, that traditional monetary policy has had a limited impact on the state of the interbank market, but that the targeted liquidity measures have been more succesful. In the model, the central banks can only alleviate the seizure of the interbank market by eliminating the cause of the seizure, that is by bringing the unravelling of the ABCP market to a halt. In the subsequent, I argue that traditional monetary policy is unlikely to achieve this objective, but that targeted liquidity measures, when structured correctly, can be successful.

The analysis in the previous section suggests that the bottleneck in the interbank market arises out of concern about counterparty risk and not due to liquidity shortages. In the model, liquidity is plentiful and all banks can obtain short-term credit through the interbank market. The liquidity shortage arises when the banks try to smooth liquidity shocks which stretch across the date at which their ABCP programs must be refinanced. The model predicts, that the interbank market is tiered such that banks with high levels of capital relative to the size of their ABCP program maintain access to the interbank market, and banks with low levels of capital relative to the size of their ABCP programs loose access to interbank finance.

In the model, traditional monetary policy affects only the amount of short-term liquidity, which is already abundant. Since it does not affect the dynamics of the ABCP market, it is futile in alleviating the seizure of the interbank market. One channel through which traditional monetary policy could affect the state of the interbank market, and which has been suppressed in the model, is if it affects the dynamics of the sponsoring banks' capital, i.e. (4). One can argue, that a change in the policy interest rates may affect the dynamics of the sponsoring banks' capital, however, it is questionable whether an increase in the aggregate amount of liquidity affects the dynamics of the banks' capital in a financial system where liquidity is already abundant.

The targeted liquidity measures go to the heart of the models friction. First, in contrast with

the open market operations, the TAF and the TSLF address the long-term liquidity shock which is the nub of the liquidity shortage. Second, and more important, under the TAF and the TSLF, the central banks accept a broader range of collateral. In the model, the banks' vulnerability arises because it is inefficient for them to hold the risky assets on their balance sheets. When the banks are forced to provide liquidity to their SIVs, this leads to a fire-sale of the risky assets and the subsequent price fall forces the banks into bankruptcy. By accepting a broader range of collateral, the central banks offer the commercial banks an alternative to the fire-sale. By pledging the risky assets to the central bank under the TAF or the TSLF, the sponsoring bank can obtain liquidity without selling the assets. To compensate the central banks for the counterparty risk, the banks are required to post collateral in excess of the amount of liquidity they obtain. If the amount of excess collateral is sufficiently low, the liquidity provided by the central bank is adequate for the banks to meet their obligations to the SIV and therefore the bankruptcy of the sponsoring bank can be avoided. In turn, this reduces the ABCP investors' incentives to withdraw from the SIV, and halts the unravelling of the ABCP market. Thus, when structured correctly, the mere announcement of the targeted liquidity measures is sufficient to alleviate the unravelling of the ABCP market, and it should therefore not be necessary for the commercial banks to make use of the facilities.[33],[34]

For the TAF and the TSLF to prevent the unravelling of the ABCP market, it is necessary that the banks obtain more liquidity by pledging the assets to the central bank than by selling them in the market.[35] If this condition is not fulfilled, the TAF and the TSLF fail to complement the banks' ability to raise liquidity, and therefore fail to prevent the unravelling of the ABCP market. Thus, for the TAF and the TSLF to be efficient, it is a prerequisite that the central bank is willing to accept a losses if it is forced to liquidate the collateral. Given the systemic threat of the unravelling of the ABCP market and the central bank's ability to carry the risky assets until maturity, the

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[33] Clearly, as new shocks hit the banks balance sheets, the stock of capital may deteriorate further and the central banks may be required to honour their commitments under the TAF and the TSLF.

[34] Although in theory the mere announcement of contingency policies may be enough to calm financial markets, the recent experiences with Fannie Mae and Freddie Mac prompts caution in overempahsizing the the importance of announcement effects.

[35] If the central bank supplies more liquidity against the risky assets than the banks could have raised in the market, the targeted liquidity measures are equivelent to an increase of $P_j^{u,i}$ in the model. This reduces $\theta^{i,*}$ and lead to greater resilience of the ABCP programs.

central bank may prefer the collateral risk to the systemic risk.[36]

The ABCPMMF facility is a more forceful tool to stop the unravelling of the ABCP market. In essence, under this facility the central bank undertakes the role of the ABCP investor. By becoming the "ABCP investor of last resort", the central bank prevents the unwinding of the ABCP programs and halts the fire-sale of the risky assets.

Finally, the implementation of targeted liquidity measures which expose the central bank to the risk of the collateral raises important moral hazard questions. In particular, the central bank's willingness to accept collateral risk creates incentives for the sponsoring banks to increase the size of their ABCP programs. In the model, the size of the ABCP programs is fixed exogenously, so a detailed discussion of this question falls outside the scope of this paper.

In both its initial and its modified form, the TARP can halt the unravelling of the ABCP market. In its initial form, the TARP reduces the stock of risky assets held by the risk averse investors. This reduces the risk premium, and thereby the losses incurred by the banks under the unwind of the ABCP program. Consequently, the TARP raises the expected return on ABCP and reduces the trigger threshold, $\theta^{i,*}$.[37] In the shape of a recapitalisation, the TARP corresponds to an exogeneous increase of θ_t^i. With a sufficient amount of funds available under the TARP, and with an appropriate distribution of the funds, the capital of banks which are under pressure to unwind their ABCP programs could be pushed above the unwind threshold. Whether the initial version of the TARP or the modified version is more efficient depends on the parameters of the model. From expression (6), it follows that the TARP is more efficient in its initial format if,

$$\frac{A}{n}\xi r^2 \sum_{j=1}^{n-1} j \geq 1.$$

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[36] Recall, that the risky assets are priced at a discount to their expected return, so the central banks' expected profits are positive if they carry the risky assets until maturity. Whether it is optimal for the central bank to hold the risky assets until maturity depends on their disutility of systemic risk. Indeed, the more permanent nature of the TAF and the TSLF suggests, that the central banks disutility of a systemic risk exceeds the disutility of financing the risky assets.

[37] The economic effect of the TARP in its initial format corresponds to an exogenous reduction of S in expression (6).

6.2 Super fund - one SIV to rule them all...

The objective of the super fund was to acquire the assets from the ABCP programs as these were pushed into liquidation. To evaluate the super fund, consider a version of the model where one SIV owns all the risky assets from the individual ABCP programs, and where the sponsoring bank owns all the capital of the individual banks, i.e. one bank and one ABCP program. By the logic of Lemma 4, as the sponsoring bank's capital breaches a predetermined threshold, the short-term investors switch from financing the SIV to investing in the risk-free assets. Let the sponsoring bank's stock of capital be given by θ_t^{sf}, then

$$\theta_t^{sf} = \sum_{i=1}^{N} \theta_t^i. \tag{10}$$

Substituting θ_t^{sf} for θ_t^i and $P_j^{u,sf}$ for $P_j^{u,i}$ in the proof of Lemma 7, it follows that the threshold value of the sponsoring bank's capital is given by $\theta^{sf,*}$, where

$$\theta^{sf,*} = -\frac{1}{\xi} \ln\left[4 \exp\left(-\xi NIA\right) - \exp\left(\left(I + r_{cp}^*\right) NA\right)\right]$$
$$+ \frac{1}{\xi} \ln\left[\exp\left(-\xi N\left(-rA - \varepsilon\right)\right) + \exp\left(-\xi N\left(rA - \varepsilon\right)\right) + \exp\left(-\xi N\left(-rA + \varepsilon\right)\right)\right]$$
$$- N\frac{A}{n}\sum_{j=0}^{n-1} P_j^{u,sf}, \tag{11}$$

and,

$$P_j^{u,sf} = 1 - \xi\sigma_j^2 S. \tag{12}$$

Expression (12) illustrates, that the price changes following a liquidation of the super SIV are more erratic than the price changes following a liquidation of a subset of the individual SIVs, i.e. $P_{t,j}^{u,sf} \leq P_{t,j}^{u,i}$ for all i. The intuition for this is straight forward. A liquidation of the super SIV forces the risk averse long-term investors to absorb a larger stock of the risky assets than a liquidation of a subset of the individual SIVs. The unwind of the super SIV therefore causes a greater expansion of the risk premium and a more erratic price change.

For the super fund to prevent the liquidation of the ABCP programs, it is necessary that,

$$\theta_t^{sf} \geq \theta^{sf,*}. \tag{13}$$

Inserting (10) and (11) into (13) yields,

$$\frac{\sum_{i=1}^{N} \theta_t^i}{N} \geq -\frac{A}{n} \sum_{j=0}^{n-1} P_j^{u,sf}$$

$$-\frac{1}{\xi} \ln \left[4 \exp\left(-\xi NIA\right) - \exp\left(\left(I + r_{cp}^*\right) NA\right) \right]^{\frac{1}{N}}$$

$$+\frac{1}{\xi} \ln \left[\exp\left(-\xi N \left(-rA - \varepsilon\right)\right) + \exp\left(-\xi N \left(rA - \varepsilon\right)\right) + \exp\left(-\xi N \left(-rA + \varepsilon\right)\right) \right]^{\frac{1}{N}}. \quad (14)$$

Expression (14) shows, that the super fund can prevent an unravelling of the ABCP market when the banks' average stock capital is sufficient to compensate the short-term investors for both the expected losses under the ABCP program (the sum of the first and second term), and for the risk premium they require to accept exposure to the banks' stock of capital (the third term).

If a set of banks are under pressure to liquidate their ABCP programs, the super fund can prevent the liquidations only if a subset of the banks which are not under pressure to liquidate their ABCP programs participate in the syndicate supporting the super SIV. Thus, for the super fund to halt the unravelling of the ABCP market, the banks with excess capital must be willing to cross pledge their capital to support the banks with a capital deficit. Under an appropriate distribution of the fee for the support of the super SIV, banks with surplus capital may be willing to participate in the syndicate.

The mechanics of the super SIV closely resembles the mechanics of an insurance mechanism. By pooling their resources, the ABCP programs of banks with a capital deficit can be supported under more adverse market conditions. Conversely, the cross pledging of capital from banks with surplus capital to banks with a capital deficit increases the vulnerability of banks with surplus capital.

Market forces caused the super fund initiative to collapse. The model suggests two potential interpretations of this event. Either the banks' aggregate capital was inadequate to prevent the unwind of the ABCP programs already under pressure, or the fees offered to the banks with surplus capital were insufficient to compensate the them for the increased vulnerability.

7 Contagion

Only a couple of papers provide micro foundations for financial contagion (Smith (1991), Allen and Gale (2000) and Diamond and Rajan (2005)). The mechanism explored in this paper is inherently different to Smith (1991) and Allen and Gale (2000), but shares many of the features of Diamond and Rajan (2005). Based on the model in Diamond and Dybvig (1983), Diamond and Rajan illustrate, that when a banks' assets are illiquid, a shock which creates a maturity mismatch between the banks' assets and liabilities can cause a systemic failure of the banking system. This failure is not driven by panic based bank runs, and it prevails even when the aggregate amount of liqudity that the banks can create by restructuring their assets is sufficient to mitigatge the liquidity shock. In Diamond and Rajan's model, ex ante there are no links between the banks, and shocks spill from one bank to the other through a common market for liquidity. When one bank is hit by a liquidity shock, it attempts to raise liquidity in the interbank market. The increased demand for liquidity raises the interest rate that the banks' creditors use to value the banks' assets and liabilities. The tenure of the banks' assets exceeds the tenure of their liabilities so a rise in the interest rates has an adverse impact on the banks' balance sheet. When the scramble for liquidity is sufficiently acute, the rise in the interest rate pushes the bank with the greatest asset-liability mismatch into bankruptcy, i.e. the present value of its liabilities exceeds the present value of its asset. Thus, the initial liquidity shortage is transformed into insolvency. The structure of Diamond and Rajan's model ensures, that the aggregate demand for liquidity rises when a banks fails. Thus, a bank failure leads to higher interest rates and a further deterioration of the remaining banks' balance sheets. In this fahsion, a liquidity shock which pushes one bank into bankruptcy can, via the interbank market, be transmitted to other banks and cause further insovencies.

In the model presented in this paper, ex ante there are no links between the banks. Shocks are transmitted between banks through a common market, not for liquidity, but for the risky assets. Rather than having an adverse impact on the asset side of the other banks' balance sheet, a bank failure has an adverse impact on the other banks' *off balance sheet liabilities*. The net effect however is the same; a failure of one bank can push other banks into insolvency.

Both models suggest that the interbank markets can seize when the aggregate amount of liquidity is plentiful, albeit for different reasons. In Diamond and Rajan's model, the interbank market seizes because banks with excess liquidity obtain higher returns from employing the liquidity internally than from lending it in the interbank market. In the model I have presented, the interbank market seizes because the lenders are concerned about counterparty risk. The policy implications of the two models are quite similar. First, Diamond and Rajan's paper presents a real model, and therefore traditional monetary policy is absent from their model. Their analysis suggests, that to mitigage the systemic risk and to eliminate contagion, the central authority can impose a tax on consumers and use the proceeds from the tax to inject liquidity into the interbank markets. In their model, this would force the interest rates down and impair the mechanism through which shocks are transmitted from one financial intermediary to another. In the model I have presented, the central (monetary) authority can lend against the risky assets. If the collateral requirements are sufficiently lenient, this will halt the unravelling of the ABCP market and stop the fire-sales of the risky assets. Thus, a liquidity injection can elminate the externality that transmits shocks across the financial system. One notable difference between the policy implications is, that in Diamond and Rajan's model the liquidity injection does not expose the central authority to risk, whereas in the model I have presented, and integral element of the liquidity injection is that the central bank must take risk.

Diamond and Rajan consider a recapitalisation as a tool to alleviate the contagion. Given the real nature of Diamond and Rajan's model, the recapitalisation is essentially a transfer of capital from solvent to insolvent banks. By increasing the capital of the insolvent banks, this mechanism can prevent bank failures and contagion. In the model I have presented, this type of recapitalisation is equivalent to the mechanism behind the super fund. When the aggregate capital in the financial system is sufficient to support the aggregate amount of ABCP outstanding, a pooling of the banks' ressources can halt the unravelling of the ABCP market and eliminate contagion.

Last, a crucial ingredient for the contagion mechanism in Diamond and Rajan's model is that it is optimal for the depositors to run a bank when the present value of its assets exceeds its liabilities.

This feature requires the absence of a deposit insurance scheme. In the model I have presented, deposits are insured but the run on the bank is by ABCP investors which are not entitled to compensation if the bank defaults on its claims.

8   Conclusion

The past decades have seen sweeping changes of banks' business model. Banks have moved from being simple entities that take deposits and give loans to become vehicles for origination and transformation of risk. In parallel, capital markets have become increasingly heterogeneous as a wide range of players with different investment objectives have entered the markets (hedge funds, pension and insurance funds, private equity funds etc.). The developments in information technology has increased computational power, and allowed the implementation of ever more sophisticated derivative programs and risk management models. This paper has provided one rationale for the rise of capital market banks; banks which exploit derivative programs to take advantage of inefficiencies arising from the regulatory framework, the heterogeneity of the agents in the financial markets and the pooling of risks inherent in financial securities.

Motivated by the seizure of the interbank markets during 2007 and 2008, and the simultaneous unravelling of the ABCP market, this paper has illustrated how banks can exploit complex derivative programs to overcome inefficiencies arising from financial regulation. In particular, I have argued that ABCP programs have emerged to overcome inefficient risk sharing created by the capital adequacy requirements. The model has highlighted how the risk transformation of the derivative programs can amplify small shocks to the banks capital and create systemic risks for the financial system.

Modern banks' business model create novel challenges for the financial regulator, as the risk from the derivative programs is frequently moved off the banks balance sheets and appear only as a couple of seemingly simple derivative contracts. In the case of the ABCP program, the simple short-term derivative contracts cover a complex structure where the effective maturity of the contracts exceed the stated maturity. The "arbitrage" in the ABCP program exploits the rules based nature

of financial regulation, as the program leans heavily on the one year rule for undrawn committed credit and liquidity lines.

Although the current regulatory regime allows financial intermediaries to accumulate off balance sheet exposures without a regulatory capital requirement, the theoretical analysis does not conclude that the regulatory structure is inefficient. Indeed, it may well be that the current financial regulation is constrained efficient. As illustrated in the model, the ABCP programs arise in response to inefficient risk sharing. Evaluation of the desirability of off balance sheet vehicles requires a careful analysis of the trade off between systemic risk and efficient risk sharing. The framework I have presented does not a allow for this analysis, since it does not quantify the private and social cost of bankruptcies of financial intermediaries.

The theoretical analysis, has underscored the importance of tracking the financial intermediaries' off balance sheet exposures. The crisis of 2007 and 2008 has revealed several examples, most prominently among the German landesbanks, of banks whose outstanding ABCP programs were multiples times the size of their balance sheet. Further, the model suggests that the regulator must pay close attention to the banks' stock of capital relative to their off balance sheet exposures. Small shocks to the banks' capital, such as the deterioration in the conditions of US subprime mortgage market, can have a disproportionate effect on the banks ability to support their off balance sheet vehicles. The subsequent consolidation of the off balance sheet exposures can magnify the impact of the initial shock.

The analysis has contributed to the discussion about the importance of capital and liquidity for the seizure of the interbank market. The model presented here emphasizes that the two concepts are fundamentally intertwined.[38] Banks with abundant capital maintains access to liquidity in the interbank market whereas banks with insufficient capital fall victim to worries about counterparty risk and loose access to interbank credit. Based on this insight, it is clear that the monetary authorities' early attempts to alleviate the seizure of the interbank markets through injection of liquidity and a reduction in policy interest rates were destined to fail.

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[38]See Goodhart (2007) for a related argument.

The model presented in this paper attempts to provide a motivation for the change in the banks' business models, and to illustrate how these changes affect the systemic risk of the financial markets. The model ignores many issues which have been at the forefront of the financial turmoil during 2007 and 2008. The most prominent of these is the information imperfections created by the off balance sheet vehicles. This is a serious shortcoming of the theoretical framework, but the model highlights that even without this friction, the rise of capital market banks creates important new challenges for the financial system.

An interesting topic for future research is to develop further the understanding the banks' role as financial intermediaries in a capital market with heterogeneous agents. Given banks' increasing reliance on derivative programs, it appears that modern banks to a greater extent exploit the ability to transform risk and redistribute it, than their ability to maintain large static loan portfolios. This development presents new and non-trivial challenges for the financial regulator and the monetary authorities. Further, research into how the capital market banks affects the monetary transmission mechanism could provide important insights into how monetary shocks affect the modern financial system.

Last, the model presented in this paper takes a reduced form approach to the banks' balance sheet. Important new insights could be obtained from a more careful modelling of the tools the banks' use to manage their balance sheets.

9 Appendix

Proof. Lemma 1. Consider an investor with a remaining life of n periods. If the investor invests $1 in the risky asset with n periods to maturity, and holds investment until the maturity of the asset, he obtains a return of,

$$1 + \sum_{\tau=1}^{n} \tilde{r}_{t+\tau} = 1 + n \frac{\sum_{\tau=1}^{n} \tilde{r}_{t+\tau}}{n}$$

$$\equiv \tilde{R}_n.$$

From the central limit theorem,

$$\tilde{R}_n \sim_a N\left(1, nr^2\right).$$

Let $\bar{P}_n^I$ be the price of the risky asset with n periods until maturity if the investor is required to hold the asset until maturity. Let X_n be the investors' demand for the risky asset with n periods if he is required to hold the asset until maturity. Since $W_t = 0$ and $r_I = 0$,

$$W_{t+n} = \left[\tilde{R}_n - \bar{P}_j^I\right] X_n,$$

and therefore,

$$W_{t+n} \sim_a N\left(X_n\left(1 - \bar{P}_j^I\right), n\left(X_n\right)^2 r^2\right).$$

The investor maximizes expected utility, so his optimization problem is,

$$\max_{X_n} \quad -\exp\left[-\xi\left(X_n\left(1 - \bar{P}_n^I\right) - \frac{1}{2}n\left(X_n\right)^2 r^2\right)\right]$$

$$= \max_{X_n} \ X_n\left(1 - \bar{P}_n^I\right) - \frac{1}{2}n\left(X_n\right)^2 r^2.$$

The first order condition is

$$X_n = \frac{1 - \bar{P}_n^I}{\xi n r^2},$$

and by market clearing,

$$\frac{1 - \bar{P}_n^I}{\xi n r^2} = S,$$

so

$$\bar{P}_n^I = 1 - \sigma_n^2 S,$$

where $\sigma_j^2 = jr^2$. Thus, if the investor has the option to sell the asset prior to maturity, $P_n^I \geq \bar{P}_n^I$. A parallel argument illustrates that the investor is required to hold his position in the asset until maturity, he will short the asset if $P_n^I \leq \bar{P}_n^I$. Thus, equilibrium requires $P_t^I = \bar{P}_t^I$. n is large, so a similar argument implies that,

$$P_{n-1}^I = 1 - \xi\sigma_{n-1}^2 S.$$

To price the asset with one period to maturity, P_1^I, consider the strategy of purchasing the asset with one period to maturity at time t, and the asset with $n-1$ periods to maturity at time $t+1$. This strategy yields the cash flows,

$$1 + \tilde{r}_1 + 1 + \sum_{t=2}^{n} \tilde{r}_\tau = 1 + \tilde{R}_n.$$

The investment opportunity set is constant, so the price of an asset with j periods to maturity has the same price independently of whether it is purchased at time t or time $t+1$. Thus, absence of arbitrage requires,

$$P_1^I + P_{n-1}^I = 1 + P_n^I,$$

so,

$$P_1^I = 1 + P_n^I - P_{n-1}^I = 1 - \xi r^2 S.$$

To price the asset with two periods to maturity, note that the strategy of investing in the asset with two periods to maturity at time t, and the asset with $n-1$ periods to maturity at time $t+2$ yields the cash flows,

$$1 + \tilde{r}_1 + \tilde{r}_2 + \sum_{\tau=3}^{n+1} \tilde{r}_\tau = \tilde{R}_n + \tilde{r}_{n+1}.$$

Due to the constant investment opportunity set, absence of arbitrage requires,

$$P_2^I + P_{n-1}^I = P_n^I + P_1^I - 1,$$

so,

$$P_2^I = P_n^I + P_1^I - 1 - P_{n-1} = 1 - \xi 2r^2 S.$$

Iteration of the absence of arbitrage argument for all securities with less than $n-1$ periods to maturity yields,

$$P_j^I = 1 - \sigma_j^2 \xi S.$$

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This verifies the claim in the lemma. Note, that from the expression for P_j^I and market clearing it follows that,

$$
\begin{aligned}
X_j &= S \Leftrightarrow \\
X_j &= \frac{1 - P_j^I}{\sigma_j^2 \xi S}.
\end{aligned}
$$

∎

Proof. Lemma 3. Let $P_j^{u,i}$ be the market price of the risky asset with j periods until maturity if bank i is the only bank to liquidate its ABCP program. Then,

$$
P_j^{u,i} = 1 - \xi \sigma_j^2 \left(S - (N-1)\frac{A}{n} \right).
$$

Inserting the expression for $P_j^{u,i}$ and P_j^{cp} into the expression for L yields,

$$
\begin{aligned}
L &= \frac{A}{n} \sum_{j=0}^{n-1} \left(P_j^{u,i} - P_j^{cp} \right) + \frac{A}{n} \left(P_0^{cp} - P_n^{cp} \right) \\
&= \frac{A}{n} \left[-\sum_{j=0}^{n-1} \xi \sigma_j^2 \frac{A}{n} + n \xi r^2 \left(S - \frac{A}{n} N \right) \right] \\
&= \frac{A}{n} \xi r^2 \left[nS - \frac{A}{n} \left(\sum_{j=0}^{n-1} j + nN \right) \right],
\end{aligned}
$$

where third equation follows since $\sigma_j^2 = jr^2$. Thus, $L < 0$ requires

$$
S < \frac{A}{n} \left(\sum_{j=0}^{n-1} j + N \right).
$$

Thus, liquidation of the ABCP program leads to a profit of,

$$
L = A \xi r^2 \left[S - \frac{A}{n} \left(\sum_{j=0}^{n-1} \frac{j}{n} + N \right) \right] < 0.
$$

This verifies the claim in the lemma. ∎

Proof. Lemma 4. Assume that the short-term investors have refinanced the ABCP programs of $N - 1$ banks and are deciding whether to refinance the ABCP program of bank i (the superscript is suppressed everywhere in the proof). The short-term investors' equilibrium action is derived by iterated deletion of conditionally dominated strategies. Short-term investors' action at time t is given by $a_t \in \{CP, RF\}$, where CP indicates an investment in ABCP and RF indicates an

investment in the risk-free asset. Define $R_{cp,t} \equiv (1 + r_{cp,t})$. At time t, short-term investors choose a_t to maximize expected utility, $E_t [U (\theta_t, r_{cp,t}, a_t, a_{t+1}) | \theta_t]$, where

$$
\begin{aligned}
&E_t [U (\theta_t, r_{cp,t}, CP, a_{t+1}) | \theta_t] \\
&= \begin{cases}
-\exp(-\xi R_{cp,t} A) \text{ for } \theta_t \geq \overline{\theta} \\
-\Pr(a_{t+1} = CP | \theta_t) \exp(-\xi R_{cp,t} A) \\
-\Pr(a_{t+1} = RF | \theta_t) E_t \left\{ \exp\left[-\xi \left(\theta_{t+1} + \frac{A}{n} \sum_{j=0}^{n-1} P_j^{u,i} \right) \right] | \theta_t, a_{t+1} = RF \right\} \text{ for } \theta_t \in \left(\underline{\theta}, \overline{\theta} \right) \\
-\exp\left(-\xi \frac{A}{n} \sum_{j=1}^{n} p_j^{u,i} \right) \text{ for } \theta_t^i \leq \underline{\theta}
\end{cases}
\end{aligned}
\tag{15}
$$

and,

$$
E_t [U (\theta_t, r_{cp,t}, CP, a_{t+1}) | \theta_t] = U (RF) = -\exp(-\xi I A) .
$$

$R_{cp,t} \geq I$, so if θ_t is sufficiently high, $a_t = CP$ is the dominant action. Define $\overline{\theta}^0$ to be the lowest value of θ_t such that, given that $a_{t+1} = RF$ for all θ_{t+1}, $a_t = CP$ for all $\theta_t \geq \overline{\theta}^0$. That is,

$$
\overline{\theta}^0 \equiv \inf \left\{ \theta_t | E_t [U (\theta_t, r_{cp,t}, CP, RF)] \geq U (RF) \ \forall \theta_t \geq \overline{\theta}^0 \right\} .
$$

Clearly, $\overline{\theta}^0 = \overline{\theta}$. The short-term investors' problem is symmetric across time, so the observation that $a_t = CP$ is a dominant action for all $r_{cp,t}$ when $\theta_t \geq \overline{\theta}^0$ implies that $a_{t+1} = CP$ is a dominant action for all $r_{cp,t+1}$ when $\theta_{t+1} \geq \overline{\theta}^0$. Let $\bar{a}_t^0$ be the strategy under which $a_t = CP$ if and only if $\theta_t \geq \overline{\theta}^0$, that is

$$
\bar{a}_t^0 \equiv \begin{cases} CP \text{ if } \theta_t \geq \overline{\theta}^0 \\ RF \text{ otherwise} \end{cases} .
$$

Let $\overline{\theta}^1$ be the smallest value of θ_t such that, given $\bar{a}_{t+1}^0$, $a_t = CP$ for all $\theta_t \geq \overline{\theta}^1$. That is,

$$
\overline{\theta}^1 \equiv \inf \left\{ \theta_t | E_t \left[U (\theta_t, r_{cp,t}, CP, \bar{a}_{t+1}^0) \right] \geq U (RF) \ \forall \theta_t \geq \overline{\theta}^1 \right\} .
$$

Recall that $r_{cp,t} \equiv r_{cp} (\theta_t)$, so the full characterisation of $\overline{\theta}^1$ requires determination of $r_{cp} \left(\overline{\theta}^1 \right)$. To this end, note the SIV is sponsored by the bank and therefore $r_{cp,t}$ is set to maximize the return

on the bank subject to short-term investors refinancing the SIV. Thus, $r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right)$ solves

$$- \Pr\left(\bar{a}_{t+1}^0 = CP | \theta_t\right) \exp\left(-\xi R_{cp,t} A\right)$$

$$- \Pr\left(\bar{a}_{t+1}^0 = RF | \theta_t\right) E_t \left\{ \exp\left[-\xi \left(\theta_{t+1} + \frac{A}{n} \sum_{j=0}^{n-1} P_j^{u,i} \right) \right] | \theta_t, \bar{a}_{t+1}^0 = RF \right\} \geq$$

$$- \exp\left(-\xi I A\right) \quad (16)$$

Note that $r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right) = 0$ for $\theta_t \geq \bar{\theta}^0$, so there are values of θ_t such that $r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right)$ is non-empty.

Let θ and θ' be two such values of θ_t where $\theta > \theta'$, then $r_{cp}\left(\theta', \bar{a}_{t+1}^0\right) \geq r_{cp}\left(\theta, \bar{a}_{t+1}^0\right)$. To see this, as-

sume to the contrary that $r_{cp}\left(\theta', \bar{a}_{t+1}^0\right) < r_{cp}\left(\theta, \bar{a}_{t+1}^0\right)$ and that θ' and $r_{cp}\left(\theta', \bar{a}_{t+1}^0\right)$ fulfils (16), i.e.

$E_t\left[U\left(\theta', r_{cp}\left(\theta', \bar{a}_{t+1}^0\right), CP, \bar{a}_{t+1}^0\right)\right] \geq U\left(RF\right)$. Since $E_t\left[U\left(\theta', r_{cp}\left(\theta', \bar{a}_{t+1}^0\right), CP, \bar{a}_{t+1}^0\right)\right]$ is strictly

increasing in θ_t, it follows that $E_t\left[U\left(\theta, r_{cp}\left(\theta', \bar{a}_{t+1}^0\right), CP, \bar{a}_{t+1}^0\right)\right] > E_t\left[U\left(\theta', r_{cp}\left(\theta', \bar{a}_{t+1}^0\right), CP, \bar{a}_{t+1}^0\right)\right] \geq$

$U\left(RF\right)$. But if $r_{cp}\left(\theta', \bar{a}_{t+1}^0\right) < r_{cp}\left(\theta, \bar{a}_{t+1}^0\right)$ this contradicts that $r_{cp}\left(\theta, \bar{a}_{t+1}^0\right)$ is the lowest interest

rate which fulfils (16) for $\theta_t = \theta$.

Note that the two point distribution of $\tilde{r}_t$ and $\tilde{\varepsilon}_t$ implies that $r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right)$ is discontinuous,

but that $\Pr\left(\bar{a}_{t+1}^0 = CP | \theta_t\right) = \Pr\left(\theta_{t+1} \geq \bar{\theta}^0 | \theta\right)$ implies that $r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right)$ is right continuous.

The highest interest rate that the SIV can credibly promise short-term investors is given by

$r_{cp}^{\max}\left(\theta_t\right)$, where $r_{cp}^{\max}\left(\theta_t\right) = r + \frac{\theta_t + \varepsilon}{A}$. This follows since $r_{cp}\left(\theta_t\right) > r_{cp}^{\max}\left(\theta_t\right)$ implies that $\theta_{t+1} = \underline{\theta}$

and therefore, that the SIV is liquidated in the subsequent period. Thus, since $r_{cp}\left(\theta_t\right)$ is decreasing

in θ_t, $\bar{\theta}^1$ is the value of θ_t which solves,

$$\bar{\theta}^1 = \arg\max_{\theta_t} \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right)$$

$$s.t. \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^0\right) \leq r_{cp}^{\max}\left(\theta_t\right).$$

Note, that by construction of $r_{cp}\left(\theta_t\right)$, $\bar{\theta}^1$ complies with the definition,

$$\bar{\theta}^1 \equiv \inf\left\{\theta_t | E_t\left[U\left(\theta_t, r_{cp,t}, CP, \bar{a}_{t+1}^0\right)\right] \geq U\left(RF\right) \; \forall \theta_t \geq \bar{\theta}^1\right\}.$$

Existence of $\bar{\theta}^1$ follows since $r_{cp}\left(\theta_t\right)$ is strictly decreasing and right continuous.

Given $\bar{a}_{t+1}^0$, the dominant strategy of short-term investors at time t is given by $\bar{a}_t^1$, where

$$\bar{a}_t^1 \equiv \begin{cases} CP \text{ if } \theta_t \geq \bar{\theta}^1 \\ RF \text{ otherwise} \end{cases}.$$

Thus, the symmetry of the investors' problem implies that the short-term investors' dominant action at time $t + 1$ is given by $\bar{a}_{t+1}^1$. Analogous to the procedure above, $\bar{\theta}^2$ is constructed such that, given $\bar{a}_{t+1}^1$, $a_t = CP$ when $\theta_t \geq \bar{\theta}^2$, that is

$$\bar{\theta}^2 \equiv \inf \left\{ \theta_t | E_t \left[U \left(\theta_t, r_{cp,t}, CP, \bar{a}_{t+1}^1 \right) \right] \geq U\left(RF \right) \; \forall \theta_t \geq \bar{\theta}^2 \right\}.$$

Note that $r_{cp}\left(\theta_t, \bar{a}_{t+1}^1 \right) \leq r_{cp}\left(\theta_t, \bar{a}_{t+1}^0 \right)$. This implies that

$$\arg\max_{\theta_t} \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^0 \right)$$

$$s.t. \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^0 \right) \leq r_{cp}^{\max}\left(\theta_t \right),$$

is no greater than

$$\arg\max_{\theta_t} \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^1 \right)$$

$$s.t. \; r_{cp}\left(\theta_t, \bar{a}_{t+1}^1 \right) \leq r_{cp}^{\max}\left(\theta_t \right).$$

Consequently, $\bar{\theta}^2 \leq \bar{\theta}^1 \leq \bar{\theta}^0$. By reiterating this procedure, a sequence can be constructed where $\bar{\theta}^0 \geq \bar{\theta}^1 \geq ... \geq \bar{\theta}^\infty$.

In a similar fashion, a sequence $\underline{\theta}^0, \underline{\theta}^1, ..., \underline{\theta}^\infty$ can be constructed which starts from the region where $a_t = RF$ is the dominant action irrespective of $r_{cp,t}$ and θ_t. In this sequence,

$$\underline{\theta}^k \equiv \sup \left\{ \theta_t | E_t \left[U \left(RF, \bar{a}_{t+1}^{k-1} \right) \right] > U\left(r_{cp,t} \right) \; \forall \theta_t < \underline{\theta}^k \right\},$$

and,

$$\underline{a}_t^k \equiv \left\{ \begin{array}{l} RF \text{ if } \theta_t < \underline{\theta}^k \\ CP \text{ otherwise} \end{array} \right..$$

By the logic above,

$$\underline{\theta}^k = \arg\min_{\theta_t} \; r_{cp}\left(\theta_t, \underline{a}_{t+1}^{k-1} \right)$$

$$s.t. \; r_{cp}\left(\theta_t, \underline{a}_{t+1}^{k-1} \right) \leq r_{cp}^{\max}\left(\theta_t \right).$$

Existence of $\underline{\theta}^k$ follows since $r_{cp}\left(\theta \right)$ is decreasing and right continuous. Since $r_{cp}\left(\theta_t, \underline{a}_{t+1}^{k-1} \right) \leq r_{cp}\left(\theta_t, \underline{a}_{t+1}^k \right)$, it follows that $\underline{\theta}^0 \leq \underline{\theta}^1 \leq ... \leq \underline{\theta}^\infty$.

The proof is concluded by noting that the limit of the two sequences coincides, so only one strategy survives iterated deletion of conditionally dominated strategies. Let the limit of the two

sequences be given by respectively $\overline{\theta}^{\infty}$ and $\underline{\theta}^{\infty}$. By construction of $\underline{\theta}^{\infty}$, for $\theta = \underline{\theta}^{\infty}$, there exists an r_{cp} such that,

$$r_{cp} = \arg \min r_{cp}(\theta_t),$$

$$s.t.\ r_{cp}(\theta_t) \leq r_{cp}^{\max}(\underline{\theta}^{\infty}).$$

Thus, for $\theta = \underline{\theta}^{\infty}$, there exists an r_{cp} such that,

$$r_{cp} = \arg \max r_{cp}(\theta_t),$$

$$s.t.\ r_{cp}(\theta_t) \leq \overline{r}(\underline{\theta}^{\infty}).$$

Since $\overline{\theta}^0 \geq \overline{\theta}^1 \geq ... \geq \overline{\theta}^{\infty}$, this implies that $\underline{\theta}^{\infty} \geq \overline{\theta}^{\infty}$.

By construction of the sequences however, it follows that,

$$\underline{\theta}^{\infty} \leq \overline{\theta}^{\infty},$$

since,

$$\overline{\theta}^k \equiv \inf \left\{ \theta_t | E_t \left[U\left(\theta_t, r_{cp,t}, CP, \overline{a}_{t+1}^{k-1}\right) \right] \geq U(RF)\ \forall \theta_t \geq \overline{\theta}^k \right\},$$

and,

$$\underline{\theta}^k \equiv \sup \left\{ \theta_t | U(RF) > E_t \left[U\left(\theta_t, r_{cp,t}, CP, \underline{a}_{t+1}^{k-1}\right) \right]\ \forall \theta_t < \underline{\theta}^k \right\}.$$

Therefore,

$$\underline{\theta}^{\infty} = \overline{\theta}^{\infty} \equiv \theta^*.$$

This proves, that the only strategy that survives iterated deletion of strictly dominated strategies, is the switching strategy under which investors finance the SIV sponsored by bank i if and only if $\theta_t^i \geq \theta^{i,*}$. Thus, irrespective of whether the short-term investors refinance the other SIVs, a requirement for the SIV sponsored by bank i to be refinanced is $\theta_t^i \geq \theta^{i,*}$. ∎

Proof. Lemma 5. Contrary to the claim in the lemma, assume that the short-term investors refinance the SIV sponsored by bank i but not the SIV sponsored by bank l for $\theta_0^i < \theta_0^l$. Lemma 4 implies, that the SIV sponsored by bank l fails to be refinanced at time t if $\theta_t^l < \theta^{l,*}$. By construction of the switching strategy in Lemma 4, when $\theta_t^k = \theta^{k,*}$ the short-term investors are

indifferent between investing in the SIV sponsored by bank k or in the risk-free alternative. That is,

$$-\Pr\left(\theta_{t+1}^k \geq \theta^{k,*}|\theta_t^k = \theta^{k,*}\right)\exp\left[-\xi\left(I + r_{cp}\left(\theta^{k,*}\right)\right)A\right]$$

$$-\Pr\left(\theta_{t+1}^k < \theta^{k,*}|\theta_t^k = \theta^{k,*}\right)E_t\left\{\exp\left[-\xi\left(\theta_{t+1}^k + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,k}\right)\right]|\theta_t^k = \theta^{k,*}, \theta_{t+1}^k < \theta_{t+1}^{k,*}\right\}$$

$$= -\exp\left(-\xi IA\right). \quad (17)$$

Conjecture that $r_{cp}\left(\theta^{k,*}\right)$ is constant across k, and let $r_{cp}^* \equiv r_{cp}\left(\theta^{k,*}\right)$ for all k. Lemma 6 verifies that indeed this is the case. If $\theta_t^k = \theta^{k,*}$ and $\theta_{t+1}^k < \theta^{k,*}$, then the bank defaults prior to making its payments under the swap, so $\theta_{t+1}^k = \theta_t^k + \tilde{r}_t A + \tilde{\varepsilon}_t$. Inserting this into (17) implies,

$$-\Pr\left(\theta_{t+1}^l \geq \theta^{l,*}|\theta_t^l = \theta^{l,*}\right)\exp\left[-\xi\left(I + r_{cp}^*\right)A\right]$$

$$-\Pr\left(\theta_{t+1}^i < \theta^{l,*}|\theta_t^l = \theta^{l,*}\right)\exp\left(\theta^{l,*} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,l}\right)E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^l = \theta^{l,*}, \theta_{t+1}^l < \theta_{t+1}^{l,*}\right\}$$

$$= -\Pr\left(\theta_{t+1}^l \geq \theta^{i,*}|\theta_t^i = \theta^{i,*}\right)\exp\left[-\xi\left(I + r_{cp}^*\right)A\right]$$

$$-\Pr\left(\theta_{t+1}^l < \theta^{i,*}|\theta_t^i = \theta^{i,*}\right)\exp\left(\theta^{i,*} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i}\right)E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^i = \theta^{i,*}, \theta_{t+1}^i < \theta_{t+1}^{i,*}\right\}.$$

and therefore,

$$\theta^{i,*} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i} = \theta^{l,*} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,l}. \quad (18)$$

Under the assumption that short-term investors refinance the SIV sponsored by bank i but not the SIV sponsored by bank l, $P_j^{u,i} < P_j^{u,l}$. Thus, (18) implies that that $\theta^{i,*} > \theta^{l,*}$. The shocks to the banks capital are uniform, so $\theta_0^i < \theta_0^l$ implies that $\theta_t^i < \theta_t^l$. Thus, $\theta_t^i < \theta_t^l < \theta^{l,*} < \theta^{i,*}$, which by Lemma 4 contradicts that the short-term investors refinance the SIV sponsored by bank i but not the SIV sponsored by bank l. ∎

Proof. Lemma 6. First note that when $\theta_t^i = \theta^{i,*}$, the highest interest rate that the SIV sponsored by bank i can credibly promise to pay on ABCP is $r_{cp}^* = r + \frac{\varepsilon}{A}$. To see this, recall that

$$\theta_{t+1}^i = \theta_t^i + \left[\tilde{r}_t - r_{cp}\left(\theta_t^i\right)\right]A + \tilde{\varepsilon}_t, \quad (19)$$

so,

$$\Pr\left(\theta_{t+1}^i < \theta^{i,*}|\theta_t^i = \theta^{i,*}\right) = 1 \Leftrightarrow$$

$$r_{cp}^* > r + \frac{\varepsilon}{A}.$$

To see that the SIV pays r_{cp}^* to the investors, assume contrary to the claim in the lemma that $r_{cp}\left(\theta^{i,*}\right) < r_{cp}^*$. Then, there exists a $\gamma > 0$ such that

$$\Pr\left(\theta^{i,*} + \left(\tilde{r}_t - r_{cp}^* - \gamma\right)A + \tilde{\varepsilon}_t \geq \theta^{i,*}\right) = \Pr\left(\theta^{i,*} + \left(\tilde{r}_t - r_{cp}^*\right)A + \tilde{\varepsilon}_t \geq \theta^{i,*}\right).$$

Let $\Pr\left(y\right) \equiv \Pr\left(\theta_{t+1}^i \geq \theta^{i,*} | \theta_t^i = y\right)$. Then,

$$- \Pr\left(\theta_t^{i,*}\right)\exp\left(-\xi\left(I + r_{cp}\left(\theta^{i,*}\right) + \gamma\right)A\right)$$
$$- \left[1 - \Pr\left(\theta_t^{i,*}\right)\right]\exp\left(\theta^{i,*} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i}\right)E_t\left\{\exp\left[-\xi\left(\tilde{r}_t + \tilde{\varepsilon}\right)\right]|\theta_t^i = \theta^{i,*}, \theta_{t+1}^i < \theta_{t+1}^{i,*}\right\}$$
$$> -\exp\left(-\xi I A\right).$$

Thus, since the expected utility of refinancing the SIV is strictly increasing in θ, there exists a θ_t^i, $\theta^{i,**}$, such that $\theta_t^{i,**} < \theta^{i,*}$ and

$$- \Pr\left(\theta_{t+1}^i \geq \theta^{i,**} | \theta_t^i = \theta^{i,**}\right)\exp\left[-\xi\left(I + r_{cp}\left(\theta^{i,*}\right) + \gamma\right)A\right]$$
$$- \Pr\left(\theta_{t+1}^i < \theta^{i,**} | \theta_t^i = \theta^{i,**}\right)\exp\left(\theta^{i,**} + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i}\right) \times$$
$$E_t\left\{\exp\left[-\xi\left(\tilde{r}_t + \tilde{\varepsilon}\right)\right]|\theta_t^i = \theta^{i,**}, \theta_{t+1}^i < \theta_{t+1}^{i,**}\right\} = -\exp\left(-\xi I A\right).$$

Consequently, short-term investors refinance the SIV sponsored by bank i for $\theta^{i,**} \leq \theta_t^i < \theta^{i,*}$. This contradicts Lemma 4. Thus, $r_{cp}\left(\theta^{i,*}\right) \geq r_{cp}^*$.

Assume that $r_{cp}\left(\theta^{i,*}\right) > r_{cp}^*$. Then by construction of r_{cp}^*, $\Pr\left(\theta_{t+1}^i \geq \theta^{i,*} | \theta_t^i = \theta^{i,*}\right) = 0$ and investors therefore refuse to refinance the SIV sponsored by bank i. This verifies that $r_{cp}\left(\theta^{i,*}\right) = r_{cp}^* = r + \frac{\varepsilon}{A}$.

To determine $\theta^{i,*}$, exploit that when $\theta_t^i = \theta^{i,*}$, short-term investors are indifferent between refinancing the SIV sponsored by bank i and investing in the risk-free alternative. Thus, $\theta^{i,*}$ solves,

$$- \Pr\left(\theta_t^i\right)\exp\left[-\xi\left(I + r_{cp}^*\right)A\right]$$
$$- \left[1 - \Pr\left(\theta_t^i\right)\right]E_t\left\{\exp\left[-\xi\left(\theta_{t+1}^i + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i}\right)\right]|\theta_t^i = \theta^{i,*}, \theta_{t+1}^i < \theta^{i,*}\right\}$$
$$= -\exp\left(-\xi I A\right). \quad (20)$$

By construction of r_{cp}^*, it follows from (19) that when $\theta_t = \theta^{i,*}$, the event $\theta_{t+1} < \theta^{*,i}$ occurs if $\tilde{r}_t \neq r$ and $\tilde{\varepsilon}_t \neq \varepsilon$. Therefore, $\Pr\left(\theta^{i,*}\right) = \frac{1}{4}$ and

$$E_t\left\{\exp\left[-\xi\theta_{t+1}^i\right]|\theta_t^i = \theta^{i,*}, \theta_{t+1}^i < \theta^{i,*}\right\}$$
$$= \frac{1}{3}\exp\left(-\xi\theta^{i,*}\right)\left[\exp\left(-\xi\left(-rA-\varepsilon\right)\right) + \exp\left(-\xi\left(rA-\varepsilon\right)\right) + \exp\left(-\xi\left(-rA+\varepsilon\right)\right)\right]. \quad (21)$$

Inserting expression (21) and r_{cp}^* into (20) and rearranging terms yields,

$$\theta^{i,*} = \frac{1}{\xi}\ln\left(\frac{\exp\left(-\xi\left(-rA-\varepsilon\right)\right) + \exp\left(-\xi\left(-rA+\varepsilon\right)\right) + \exp\left(-\xi\left(rA-\varepsilon\right)\right)}{4\exp\left(-\xi IA\right) - \exp\left[-\xi\left(I + r_{cp}^*\right)A\right]}\right) - \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,i},$$

where $P_j^{u,i}$ is given by (7). This completes the proof of the lemma. ∎

Proof. Lemma 7. Let $\Pr\left(y\right) \equiv \Pr\left(\theta_{t+1}^i \geq \theta^{i,*}|\theta_t^i = y\right)$ and let $r_{cp,t}^i \equiv r_{cp}\left(\theta_t^i\right)$. $r_{cp,t}^i$ is set to maximize the sponsoring bank's return from the ABCP program, subject to the constraint that the short-term investors must be willing to refinance the SIV. Let

$$k = \left\{\begin{array}{l} i \text{ for } i \notin T^- \\ T \text{ for } i \in T^- \end{array}\right. .$$

Then, $r_{cp,t}^i$ is the lowest rate which solves,

$$-\Pr\left(\theta_t^k\right)\exp\left[-\xi\left(I + r_{cp,t}^i\right)A\right]$$
$$-\left[1 - \Pr\left(\theta_t^k\right)\right]E_t\left\{\exp\left[-\xi\left(\theta_{t+1}^i + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,k}\right)\right]|\theta_t^i, \theta_t^k, \theta_{t+1}^k < \theta^{k,*}\right\}$$
$$\geq -\exp\left(-\xi IA\right),$$

so is the lowest value such that,

$$r_{cp,t}^i \geq \frac{1}{\xi A}\ln\left(\Pr\left(\theta_t^k\right)\right) - \frac{1}{\xi A}\ln\left\{\exp\left(-\xi IA\right)\right.$$
$$\left. -\left[1 - \Pr\left(\theta_t^k\right)\right]\exp\left[-\xi\left(\theta_t^i + \frac{A}{n}\sum_{j=0}^{n-1}P_j^{u,k}\right)\right]E_t\left[\exp\left(-\xi\left(\tilde{r}_tA + \tilde{\varepsilon}\right)\right)|\theta_t^i, \theta_t^k, \theta_{t+1}^k < \theta^{k,*}\right]\right\} - I.$$

Given the binary distribution of $\tilde{r}_t$ and $\tilde{\varepsilon}_t$, there are five different values of $\Pr\left(\theta_t^i\right)$.

$$\Pr\left(\theta_t^i\right) = 1 \text{ for } \theta_t^k \geq \theta^{T,*} + rA + \varepsilon,$$

$$\Pr\left(\theta_t^i\right) = \frac{3}{4} \text{ for } \theta^{k,*} + rA + \varepsilon > \theta_t^k \geq \theta^{k,*} - \left(r - r_{cp,t}^i\right)A + \varepsilon,$$

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$$\Pr\left(\theta_t^i\right) = \frac{1}{2} \text{ for } \theta^{k,*} - \left(r - r_{cp,t}^i\right) A + \varepsilon > \theta_t^k \geq \theta^{k,*} + \left(r + r_{cp,t}^i\right) A - \varepsilon,$$

$$\Pr\left(\theta_t^i\right) = \frac{1}{4} \text{for } \theta^{k,*} + \left(r + r_{cp}^i\right) A - \varepsilon > \theta_t^k \geq \theta^{k,*} \forall i \in T^-,$$

$$\Pr\left(\theta_t^i\right) = 0 \text{ for } \theta_t^k < \theta^{k,*}.$$

$r_{cp,t}^i$ is a non-linear function of θ_t^i, so a closed form solution for the thresholds which the value of $\Pr\left(\theta_t^i\right)$ changes is not available.

Given the discrete structure of $\Pr\left(\theta_t^i\right)$, there are three values of $E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^i, \theta_{t+1} < \theta^{i,*}\right\}$.

$$\Pr\left(\theta_t^i\right) = \frac{3}{4} \Rightarrow E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^i, \theta_{t+1} < \theta^{i,*}\right\} = \exp\left[-\xi\left(-rA - \varepsilon\right)\right],$$

$$\Pr\left(\theta_t^i\right) = \frac{1}{2} \Rightarrow E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^i, \theta_{t+1} < \theta^{i,*}\right\} = \frac{1}{2}\left\{\exp\left[-\xi\left(-rA - \varepsilon\right)\right] + \exp\left[-\xi\left(rA - \varepsilon\right)\right]\right\},$$

$$\begin{aligned}\Pr\left(\theta_t^i\right) &= \frac{1}{4} \Rightarrow E_t\left\{\exp\left[-\xi\left(\tilde{r}_t A + \tilde{\varepsilon}_t\right)\right]|\theta_t^i, \theta_{t+1} < \theta^{i,*}\right\} \\ &= \frac{1}{3}\left\{\exp\left[-\xi\left(-rA - \varepsilon\right)\right] + \exp\left[-\xi\left(rA - \varepsilon\right)\right] + \exp\left[-\xi\left(-rA + \varepsilon\right)\right]\right\}.\end{aligned}$$

This completes the characterisation of the interest rate on the ABCP. ∎

Proof. Proposition 8. The proof follows directly from the proof of Lemma 4 and Lemma 5. Note that Lemma 4 indicates, that there is only one strategy which survives iterated deletion of conditionally dominated strategies. Thus, subject to the caveat in Lemma 5, in equilibrium, the short-term investors employ the trigger strategy outlined in Lemma 5. Last, the banks which are not the marginal bank to liquidate their ABCP program is charged an interest rate above the interest rate of the marginal bank. Thus, to ensure that it is credible for the SIV to offer this interest rate on the ABCP, it must be the case that $\Pr\left(\theta_{t+1}^l \geq \theta^{l,*}\right) \geq 0$. This requires that $\theta_t^l + \left(r - r_{cp,t}\right) A + \varepsilon \geq \theta^{l,*}$, which yields the condition on the interest rate listed in the proposition. ∎

Proof. Lemma 9. Let $\pi_{cp,t}^i$ be bank i's profits at time t post the launch of the ABCP program,

then, for all $i \in T^-$,

$$\sum_{s=1}^{\infty} E_t \left(\pi_{cp,t+s}^T | \theta_t^T \right)$$

$$= \sum_{s=1}^{\infty} \Pr \left(\theta_{t+s}^T \geq \theta^{T,*} | \theta_t^T, \{ \theta_t \geq \theta^{T,*}, .., \theta_{t+s-1}^T \geq \theta^{T,*} \} \right) \times$$

$$\left[\frac{A}{n} \sum_j \left(P_{j-1}^{u,T} - P_j^{u,T} \right) + E_t \left((\tilde{r}_{t+s} - r_{cp,t+s}) A + \tilde{\varepsilon}_{t+s} | \theta_{t+s}^T \geq \theta^{T,*} \right) \right]$$

$$> \left[\frac{A}{n} \sum_{j=1}^n \left(P_{j-1}^{u,T} - P_j^{u,T} \right) \right] \sum_{s=1}^{\infty} \Pr \left(\theta_{t+s}^T \geq \theta^{T,*} + rA + \sigma \varepsilon | \theta_t^T, \{ \theta_t \geq \theta^{T,*}, .., \theta_{t+s-1}^T \geq \theta^{T,*} \} \right)$$

$$= A \xi r^2 \left(S - N \frac{A}{n} \right) \sum_{s=1}^{\infty} \Pr \left(\theta_{t+1}^T \geq \theta^{T,*} + rA + \sigma \varepsilon | \theta_t^T, \{ \theta_t \geq \theta^{T,*}, .., \theta_{t+s-1}^T \geq \theta^{T,*} \} \right)$$

$$> 0,$$

where the inequality follows since $r_{cp,t} = 0$ for $\Pr \left(\theta_t^i \right) = 1$. Since $\pi_{cp,t}^i > \pi_{cp,t}^T$ for all $i \notin T^-$, it follows that all banks derive positive expected profits from the ABCP program. ∎

Proof. Lemma 10. It is risk-free to lend to banks which are exposed to a short-term liquidity shocks because the loans and the liquidity shocks mature prior to the refinancing of the SIV.

Banks which are hit by long-term liquidity shocks at time $t - \frac{1}{2}$ can apply for a one period loan or two consecutive short-term loans. Thus, following the occurrence of a long-term liquidity shock, the bank can obtain credit in the interbank market if,

$$\Pr \left(\theta_t^i \geq \theta^{i,*} | \theta_{t-1}, r_t \right) > 0 \Leftrightarrow$$

$$\Pr \left(\tilde{\varepsilon}_t \geq \theta^{i,*} - \theta_{t-1}^i - (r_t - r_{cp,t-1}) A \right) > 0.$$

This condition fails if,

$$\theta^{i,*} - \theta_{t-1}^i - (r_t - r_{cp,t-1}) A > \varepsilon \Leftrightarrow$$

$$\theta_{t-1}^i > \theta^{i,*} - (r_t - r_{cp,t-1}) A - \varepsilon.$$

This is the condition listed in the lemma.

To show that the tenure of the interbank loans match the tenure of the banks liquidity shocks, I show below that the banks are indifferent between two consecutive short-term loan, or one long-term loan. Let $r_{Ib,j,t}^i$ be the interest rate bank i pays for an interbank loan with a tenure of j

periods at time t. The (gross) return on a short-term loan at time $t - \frac{1}{2}$ is

$$\left(1 + r^i_{Ib, \frac{1}{2}, t-\frac{1}{2}}\right).$$

Short-term interbank loans mature and must be refinanced prior to the short-term investors' decision to refinance the SIV. Thus, the expected (gross) return from the loan credit at time t is,

$$\Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, \tilde{r}_t\right)\left(1 + r^i_{Ib, \frac{1}{2}, t}\right) + \left[1 - \Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, \tilde{r}_t\right)\right](1 - C).$$

The second term in this expression captures that the shock is a pure liquidity shock, and that the losses to the interbank creditors derive solely from the bankruptcy cost. Lenders in the interbank market are risk neutral, so

$$r_{Ib, \frac{1}{2}, t-\frac{1}{2}} = 0,$$

and

$$r^i_{Ib, \frac{1}{2}, t} = \frac{1 - \Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)}{\Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)} C.$$

The return from extending a long-term loan at time $t - \frac{1}{2}$ is

$$\Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)\left(1 + r^i_{Ib, 1, t-\frac{1}{2}}\right) + \left[1 - \Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)\right](1 - C),$$

and therefore

$$r^i_{Ib, 1, t-\frac{1}{2}} = \frac{\left[1 - \Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)\right]}{\Pr\left(\theta^i_t \geq \theta^{i,*} | \theta_{t-1}, r_t\right)} C.$$

The costs of a one period loan and two consecutive short-term loans are equivalent so the borrower is indifferent between the two strategies. Banks which fail to meet condition (9) are denied credit in the interbank market. ∎

10 Literature

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