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Regulation of Systemic Liquidity Risk

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Abstract

The paper provides a baseline model for regulatory analysis of systemic liquidity shocks. We show that banks may have an incentive to invest excessively in illiquid long term projects. In the prevailing mixed strategy equilibrium the allocation is inferior from the investor's point of view since some banks free-ride on the liquidity provision as a result of limited liability. The paper compares different regulatory mechanisms to cope with the externalities. It is shown that the combination of liquidity regulation ex ante and lender of last resort policy ex post is able to implement the outcome maximizing investor's payoff. In contrast, both "narrow banking" and imposing equity requirements as buffer are inferior mechanisms for coping with systemic liquidity risk.

JEL classification: E5, G21, G28

Key words: Liquidity Regulation, Systemic risk, Lender of last resort, Financial Stability

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There is no single big remedy for the banks' flaws. But better rules – and more capital – could help.

– "Three trillion dollars later…". The Economist, May 14th, 2009

1. Introduction

Inevitably, severe financial crises are echoed by a resonance of draconian re-regulation. The world wide crisis triggered in 2007 will be no exception. After the meltdown of financial markets in September 2008, politicians and voters from Washington to Warsaw, from Berlin to Beijing, joined in a unanimous call for drastic regulation of greedy financial institutions that stole jobs and held the entire global economy to ransom. Old fashioned proposals such as narrow banking and banning of short selling, which for a long time have been intentionally desecrated, deliberately forgotten, or cautiously disguised in the regulators' reports, regained reputation and momentum.

Regulatory rules should, however, be based on sound economic analysis. First, regulators need to fully understand the driving forces behind misallocations in the market economy before designing adequate rules. Second, the benefit and cost of various regulatory regimes need to be quantified so that the optimal one can be picked up. Third, regulators have to go beyond current crisis measures in order not to run the risk of fighting the last war but rather to be able to design robust policies, addressing market's incentives to circumvent latest regulation.

A key lesson from the current crisis has been that a sound regulatory and supervisory framework requires a system-wide approach: the macroeconomic impact of risk exposure across financial institutions needs to be taken into account. Regulation based purely on the soundness of individual institutions misses a crucial dimension of financial stability - the fact that risky activities undertaken by individual institutions may get amplified on the aggregate level. Among academics, this "macro-prudential" perspective has been the focus of intensive research for quite some time, stressing the need to cope with the pro-cyclicality of capital regulation (see Danielsson et. al. (2001) and Borio (2003)). Several recent studies surveyed in the following section provide a deeper understanding of the nature of externalities creating a tendency for financial intermediaries to lean towards excessive correlation, resulting in exposure to systemic risk. Most of these studies concentrate on solvency issues and capital adequacy regulation. As emphasised by Acharya (2009), externalities creating incentives to raise systemic risk justify charging a higher capital requirement against exposure to general risk factors: Capital adequacy requirements should be increasing not just in individual risks, but also in the correlation of risks across banks.

Surprisingly, however, there are hardly any studies of the systemic impact of liquidity regulation. Given the recent massive unprecedented scale of central bank intervention in the market for liquidity, a careful analysis of incentives for private and public liquidity provision seems to be warranted. Presumably, one of the reasons for neglecting this issue is the notion that central bank intervention is the perfect instrument to cope with problems of systemic liquidity crises. Following several studies (in particular, Holmström/Tirole (1998) and Allen/Gale (1998)), the public provision of emergency liquidity is frequently considered to be an efficient response to aggregate liquidity shocks. Central bank's lender of last resort policy is seen as optimal insurance mechanism against these shocks. In this view, private provision of the public good of emergency liquidity would be costly and wasteful.

But as we will show, this notion is no longer correct if the exposure of financial institutions to systemic shocks is affected by decisions of these institutions themselves. In Holmström/Tirole (1998), aggregate liquidity shocks are assumed to be exogenous. We show, however, that incentives affect endogenously the exposure of financial institutions to systemic liquidity shocks. Based on Cao/ Illing (2008, 2009), we demonstrate that externalities result in excessive investment in illiquid assets (maturity mismatch), creating systemic liquidity risk. These externalities may be reinforced by central bank intervention. Ex ante liquidity regulation (the requirements to reduce maturity mismatch) can raise depositor's payoff.

Section 2 discusses related literature. The framework of our analysis is introduced in section 3. In order to focus purely on liquidity issues, we deliberately abstract from solvency problems. We analyze aggregate real illiquidity in a banking model with deposit contracts. Depositors are impatient (they want to consume early), but financial intermediaries may have an incentive to invest excessively in illiquid long term projects. Systemic liquidity risk (the notion that too many projects will be realized too late from the investor's point of view) is derived endogenously out of free-riding incentives of financial institutions. In Section 4 we extend the baseline model by introducing nominal contracts in order to allow for central bank policy. We show that unconditional liquidity support by the central bank destroys incentives for prudent financial intermediation. Liquidity requirements need to be imposed ex ante as a way to cope with the underlying externalities. In Section 5 we allow for equity finance and narrow banking in a tractable way. Both are shown to be inferior relative to liquidity requirements when illiquidity is the driving force for systemic risk. Our analysis also calls for skepticism about recent changes in the way public deposit insurance schemes have been re-designed. Extending unlimited deposit insurance is likely to destroy an important disciplinary mechanism and may result in excessive rents in the banking industry. Section 6 concludes.

2. Related Literature

The need for banking regulation is based on the inherent fragility of financial intermediation. Whereas traditional models focus on coordination failures of a representative bank triggered by runs (Diamond/Dybvig (1983)), recent research analyzes endogenous incentives for systemic risk arising from correlation of asset returns held by different banks. As shown by Acharya (2009), risk-shifting incentives for banks may result in over-investment in correlated risk activities, thereby increasing economy-wide aggregate risk. In Acharya (2009), these incentives arise from limited liability of banks and the presence of a negative externality of one bank's failure on the health of other banks. If this effect dominates the strategic benefit of surviving banks from the failure of other banks (expansion and increase in scale), banks find it optimal to increase the probability of surviving and failing together. Thus, capital adequacy requirements should be increasing not just in individual risks, but also in the correlation of risks across banks.

The correlation of portfolio selection is also explored by Acharya/Yorulmazer (2005). Here, incentives to correlate arise from informational spillovers. Starting from a two-bank economy, when the returns of bank's investments have a systemic factor, the failure of one bank conveys negative information about this factor which makes market participants skeptical about the health of the banking industry, inflating the borrowing cost of the surviving bank and increasing the probability to fail. Since such informational spillover is costly for banks, they herd ex ante (i.e. they choose perfectly correlated portfolio) to boost the likelihood of joint survival, given that bank's limited liability mitigates concerns about their joint failure. Again, systemic risk arises out of excessive correlations.

Wagner (2009) considers a financial market with a continuum of banks, all offering fixed deposit contracts, their portfolios being invested in two types of assets. A bank is run when it cannot meet the contract. Liquidation costs increases with the number of the banks run. However, since each bank is atomistic in this economy, the *marginal* liquidation cost when one more bank fails is zero. Therefore, when deciding about its investment portfolio, each single bank never internalizes its impact on the social cost of bank runs, imposing a negative externality on the banking industry. As a result, the bank's equilibrium portfolios correlate in an inefficient way. Therefore, small banking failures may ripple to a large amount of banks with similar investment strategies. Optimal banking regulation should take correlation of the banks assets into account, encouraging heterogeneous investment.

In Korinek (2008), endogenous systemic risk arises from the feedback between incomplete financial markets and the real economy. Adverse shocks tighten individuals' credit constraints, contracting economic activity. This depresses the prices of productive assets, hence the net worth of their owners, and worsens their credit constraints. The financial accelerator amplifies negative shocks to the economy, giving rise to externalities: Atomistic agents take the level of asset prices in the economy as given. In their demand for productive assets, they do not internalize the externalities that arise when aggregate shocks lead to aggregate fluctuations. So decentralized agents undervalue social benefits of having stronger buffers when financial constraints are binding, taking on too much systemic risk in their investment strategies. Again, capital requirements need to address the externality so as to implement the constrained efficient allocation.

All studies surveyed look at endogenous incentives to create systemic *solvency* risk, arising from excessive correlation of assets invested. In contrast, our paper analyzes endogenous incentives to create systemic *liquidity* risk. Our model attempts to capture the unease many market participants felt for a long time about abundant liquidity being available, before liquidity suddenly dried up world-wide in August 2007. We characterize incentives of financial intermediaries to rely on liquidity provided by other intermediaries and the central bank. Traditional models of liquidity shortages claim that provision of liquidity by the central bank is the optimal response to systemic shocks. We argue, however, that this view neglects the endogenous nature of liquidity provision. As we will show, incentives to rely on liquidity provided by the market may result in excessively illiquid investment. Enforcing strict liquidity requirements ex ante can tackle the externalites involved.

The classic paper about private and public provision of liquidity is Holmström/Tirole (1998). In their model, liquidity shortages arise when financial institutions and industrial companies scramble for, and cannot find the cash required to meet their most urgent needs or undertake their most valuable projects. They show that credit lines from financial intermediaries are sufficient for implementing the socially optimal (second-best) allocation, as long as there is no aggregate uncertainty. In the case of aggregate uncertainty, however, the private sector cannot cope with its own liquidity needs. In that case, according to Holmström/Tirole (1998), the government needs to inject liquidity. The government can provide (outside) liquidity (additional resources) by committing future lump sum tax revenue to back up the reimbursements. In their model, public provision of liquidity is a pure public good in the presence of aggregate shocks, causing no moral hazard effects. The reason is that aggregate liquidity shocks are modeled as exogenous events. The aggregate amount of liquidity available is not determined endogenously by the investment choice of financial intermediaries. Furthermore, according to Holmström/Tirole (1998) and also Fahri/Tirole (2009), the lender of last resort can redirect resources ex post at not cost via lump sum taxation. Allowing for lump sum taxation ex post, however, amounts to liquidity constraints becoming effectively irrelevant ex ante.

Allen/Gale (1998) analyze a quite different mechanism for public provision of liquidity, closer to current central bank practice. They allow for nominal deposit contracts. The injection of public liquidity works via adjusting the price level in an economy with nominal contracts: The more public liquidity the central bank injects, the lower the real value of nominal deposits. Diamond/Rajan (2006) adopt this mechanism to characterize post crisis intervention in an elegant framework of financial intermediation with bank deposits and bank runs triggered by real illiquidity. Similar to Holmström/Tirole (1998), however, shocks to real liquidity (an increase in the share of projects realized late) are again assumed to be exogenous.

Any ex post intervention, however, usually has profound impact on the industry players' ex ante incentives. Financial intermediaries relying on being bailed out by the central bank in case of illiquidity may be encouraged to cut down on investing in liquid assets. If so, taking liquidity shocks as exogenously given and concentrating on crisis intervention misses a decisive part of the problem: Ex post effective intervention may exacerbate the problems ex ante that lead to the turmoil. So policy implications from models based on exogenous liquidity shocks may be seriously misleading.

Following Cao/Illing (2008, 2009), we therefore modify the setup of Diamond/Rajan (2006) to allow for endogenous exposure to systemic liquidity risk. In our model, financial intermediaries can choose ex ante the share of projects invested in liquid projects. If they would invest all funds in (lower yielding) liquid projects, a systemic crisis would never occur. In order to focus on liquidity problems, we abstract from solvency issues: All illiquid projects are assumed to be realized at some stage, but possibly too late from the investor's point of view. Not surprisingly, endogenizing liquidity risk affects policy conclusions significantly: Since private provision of liquidity affects the likelihood of an aggregate (systemic) shock, there is no longer a free lunch for central bank intervention.

Our paper contributes to the existing research for the following two aspects. First, we endogenize systemic liquidity risk in an intuitive and tractable way. We provide a baseline model for regulatory analysis of pure liquidity shocks. We show that even with rational financial market participants, no asymmetric information and pure illiquidity risk the free-riding incentive on liquidity provision may be large enough to generate bank's excessive appetite for risks, at a cost of the stability of the financial market. Our framework captures two major sources of inefficiency: (a) competitive forces encourage banks with limited liability to take on more risk, resulting in an inferior mixed strategy equilibrium and (b) bank runs forcing inefficient liquidation impose social costs. The mix of both externalities creates a role for liquidity regulation.

Second, following Diamond/Rajan (2006), we extend the baseline model in section 4 by allowing for nominal deposit contracts. This captures the popular notion that central banks can ease nominal liquidity constraints using the stroke of a pen. Doing so, central banks don't produce real wealth. Instead, their intervention works via redistribution of real wealth. Flooding the market with nominal liquidity in times of crisis may help to prevent ex post inefficient bank runs; at the same time, however, it encourages financial intermediaries to invest excessively on high yielding, but illiquid projects, lowering liquid resources available for investors. We show that with unconditional liquidity support by central banks, all banks will free-ride on liquidity in equilibrium, reducing the expected payoff for investors substantially. In contrast, ex ante liquidity regulation combined with ex post lender of last resort policy can implement the constrained second-best outcome from the investor's point of view.

Finally, section 5 discusses alternative ways to regulate financial markets within our baseline model. We compare the performance of "narrow banking" and equity requirements relative the mix between ex ante liquidity regulation and ex post lender of last resort policy. Both alternatives turn out to be inferior. We also briefly discuss problems with recent proposals for (private) insurance against systemic risk.

3. A framework for the analysis: Free-riding on liquidity

There are three types of agents: investors, banks (run by bank managers) and entrepreneurs. All agents are assumed to be risk neutral. The economy extends over 3 periods. We assume that there is a continuum of investors each initially (at $t = 0$) endowed with one unit of resources. The resource can be either stored (with a gross return equal to 1) or invested in the form of bank equity or bank deposits. Using these funds, banks as financial intermediaries can fund projects of entrepreneurs. There are two types i of entrepreneurs ($i = 1$ or 2), characterized by their project's return R_i. Projects of type 1 are liquid in the sense that they are realized early at period $t = 1$ with a safe return $R_1 > 1$. Projects of type 2 give a higher return $R_2 > R_1 > 1$. With probability p, these projects will also be realized early at $t = 1$, but they may be delayed (with probability 1-p) until $t = 2$. In the aggregate, the share p of type 2 projects will be realized early. The aggregate share p, however is not known at $t = 0$. It will be revealed between 0 and 1 at some intermediate period $t=1/2$. Investors are impatient: They want to consume early (at $t = 1$). In contrast, both entrepreneurs and bank managers are indifferent between consuming early ($t = 1$) or late ($t = 2$).

Resources of investors are assumed to be scarce in the sense that there are more projects of each type available than the aggregate endowment of investors. Thus, in the absence of commitment problems, total surplus would go to investors. They would simply put all their funds in early projects and capture the full return. We take this frictionless market outcome as reference point and analyze those equilibria coming closest to implement that market outcome. Since there is a market demand for liquidity only if investor's funds are the limiting factor, we concentrate on deviations from this frictionless market outcome and take investor's payoff as the relevant criterion.

Due to a hold up problem as modeled in Hart/Moore (1994), entrepreneurs can only commit to pay back a fraction $\gamma<1$ of their return with $\gamma R_i>1$. Banks as financial intermediaries can pool investment; they have superior collection skills (a higher γ). The specific skills of the bank managers pose another potential hold up problem. But as shown by Diamond/Rajan (2001), deposit contracts with a fixed payment d_0 payable at any time after $t = 0$ can serve as credible commitment device for banks not to abuse their collection skills. The threat of a bank run disciplines bank managers to fully pay out all available resources pledged in the form of bank deposits. In contrast, with equity finance (not being subject to costly runs), bank managers are able to capture part of the rent out of their specific skills. So, from the investor's point of view, equity finance is more costly than deposits. At the same time, however, equity can serve as a buffer reducing the risk of costly bank runs. In equilibrium, investors' expected return both from equity funding and deposits have to be equal.

There are a finite number of active banks engaged in Bertrand competition. Banks compete by choosing the share α of deposits invested in type 1 projects, taking their competitors choice as given. Investors have rational expectations about each banks default probability; they are able to monitor all banks investment. So if, in a mixed strategy equilibrium, banks differ with respect to their investment strategy, the expected return from deposits must be the same across all banks. Due to Bertrand competition, all banks will earn zero profit in equilibrium. In the absence of aggregate risk, financial intermediation via bank deposits can implement a second best allocation, given the hold up problem posed by entrepreneurs.

Note that because of the hold up problem, entrepreneurs retain a rent — their share $(1-\gamma)R_i$. Since early entrepreneurs are indifferent between consuming at $t = 1$ or $t = 2$, they are happy to provide liquidity at $t = 1$ (they use their rent both to buy equity shares from investors and to deposit at banks at $t = 1$ at the market rate r). Banks use the liquidity provided to pay out depositors. This way, impatient investors can profit indirectly from investment in high yielding long term projects. So banking allows transformation between liquid claims and illiquid projects.

At date 0, banks competing for funds offer deposit contracts with payment d_0 and equity claims which maximize expected consumption of investors at the given expected interest rates. Investors put their funds into those assets promising the highest expected return among all assets offered. So in equilibrium, expected return from deposits and equity must be equal across all active banks. At date $t = 1$, banks and early entrepreneurs trade at a perfect market for liquidity, clearing at interest rate r. As long as banks are liquid, the payoff per investor at $t=1$ is equal to available aggregate resources from early projects: $\alpha\ R_1 + p\ [1- \alpha]\ R_2$. The return $(1-p)\ [1-\alpha]\ R_2$ of those projects realized late in period $t=2$ will accrue to entrepreneurs and bank managers.

Deposit contracts, however, introduce a fragile structure into the economy: Whenever depositors have doubts about their bank's liquidity (the ability to pay depositors the promised amount d_0 at $t=1$), they run the bank early. As a result of the first come, first serve rule, they will run already at the intermediate date $t = 1/2$), forcing the bank to liquidate all its projects (even those funding safe early entrepreneurs) at high costs: Early liquidation of projects gives only the inferior return $c<1$. We do not consider pure sunspot bank runs of the

Diamond/Dybvig type. Instead we concentrate on runs happening if liquid funds (given the interest rate r) are not sufficient to payout depositors.

If the share p of type 2 projects realized early is known at t = 0, there is no aggregate uncertainty. Banks invest such that — on aggregate — they are able to fulfill depositors' claims in period 1, so there will be no run. But when the share p is unknown at the time t=0, low realizations of p may result in sufficiently low aggregate liquidity, triggering bank runs. We model aggregate shocks in the simplest way: the aggregate share of type 2 projects realized early can take on just two values: either p_H or p_L with $p_H>p_L$. The "good" state with a high share of early type 2 projects (the state with plenty of liquidity) will be realized with probability π. Note that the aggregate liquidity available depends on the total share of funds invested in liquid type 1 projects. Let α be this share. If α is so low that banks cannot honor deposits when p_L occurs, depositors will run at t = 1/2. Investors get paid the inferior payoff $c<1$ in that case; there are no funds left for entrepreneurs and bank managers.

Given this structure, a bank seems to have just two options available: It may either invest so much in safe type 1 projects that it will be able to pay out its depositors all the time ("ready for all rainy days", i.e. always get prepared even if the bad state occurs). Let us call this share α (p_L). Alternatively, it may invest just enough, α (p_H), so as to pay out depositors in the good state (i.e. only "work for sunny days"). If so, the bank will be run in the bad state. Obviously, the optimal share depends on what other banks will do (since that determines aggregate liquidity available at t = 1 and so the interest rate for liquid funds between period 1 and 2), but also on the probability π for the good state.

To gain some intuition, let us first assume that all banks behave the same — just as a representative bank. If so, it will not pay to get prepared for the rainy days if the likelihood for the bad state is very low. In that case, the representative bank will choose a small share α (p_H). In contrast, if π is very low and the likelihood for the bad state is very high, the representative bank will invest a high share $\alpha (p_L) > \alpha (p_H)$ to be always prepared for the worst case since the cost of bank run is too high to be neglected. Since α (p_s) ($s \in \{L,H\}$) is the share invested in safe projects with return R_1, in the absence of a bank run the total payoff out of investment strategy α (p_s) is: $E[R_s] = \alpha (p_s) R_1 + [1- \alpha (p_s)] R_2$ with $E[R_H] > E[R_L]$.

With α (p_H) there will be a bank run in the bad state, giving just the bankruptcy payoff c with probability $1- \pi$. So strategy α (p_H) gives just $\pi \gamma E[R_H]+(1-\pi)c$, which is increasing in π. Depositors prefer α (p_H) to α (p_L), if $\pi \gamma E[R_H]+(1-\pi)c > \gamma E[R_L]$, or

$$\pi > \bar{\pi}_2 = \frac{\gamma E[R_L] - c}{\gamma E[R_H] - c}.$$

Up to now, we simply restricted all banks to follow the same strategy. For $\pi > \bar{\pi}_2$ there will indeed be a unique symmetric equilibrium with all banks choosing α (p_H). But with $\pi < \bar{\pi}_2$, when all banks choose strategy α (p_L), there is excess liquidity available at t = 1 in case the good state occurs (with a large share of type 2 projects realized early). A deviating bank anticipating this event has a strong incentive to gamble by investing all funds in type 2 projects, reaping the benefit of excess liquidity in the good state. Having invested only in high yielding projects, the deviating bank can always credibly extract entrepreneur's excess liquidity at t = 1, promising to pay back at t = 2 out of highly profitable projects. After all, at that stage, this bank, free-riding on the liquidity provided by prudent banks, can offer a capital cushion with expected returns well above what prudent banks are able to promise. Of course, if the bad state happens, there is no excess liquidity. The deviating banks would just bid up the interest rates, urgently trying to get funds. Rational depositors, anticipating that these banks won't succeed, will already trigger a bank run on these banks at t = 1/2.

When the bad state is realized, free-riding banks are run and driven out of the market, leaving their depositors just the return c. Nevertheless, those banks free-riding on liquidity in the good state can on average offer the attractive return $\pi\gamma R_2+(1-\pi)c$ as expected payoff for depositors. Thus, a free-riding bank will always be able to outbid a prudent bank as long as the probability π for the good state is not too low. The condition is

$$\pi > \bar{\pi}_1 = \frac{\gamma E[R_L] - c}{\gamma R_2 - c}.$$

Since $R_2 > E[R_H]$, it pays to free-ride within the range $\bar{\pi}_1 < \pi < \bar{\pi}_2$.

Obviously, there cannot be equilibrium in pure strategies within that range. The intuition is as following: If all banks try to free-ride, there will be no excess liquidity available; but if all banks choose to be prudent, it pays off to free-ride. Therefore, in the resulting mixed strategy equilibrium, a proportion of banks behave prudent, investing some amount $\alpha_s < \alpha$ (p_L) in liquid assets, whereas the rest free-rides on liquidity in the good state, choosing α=0 to maximize their yields. Prudent banks reduce α_s in comparison to α (p_L) in order to cut down the opportunity cost of investing in safe projects. Interest rates and α_s adjust such that depositors are indifferent between both types of banks. At t = 0, both prudent and free-riding banks offer the same expected return to depositors. The proportion of free-riding banks is determined by aggregate market clearing conditions in both states. These banks are known to be run for sure in the bad state, but the high return R_2 in good times compensates depositors for that risk.

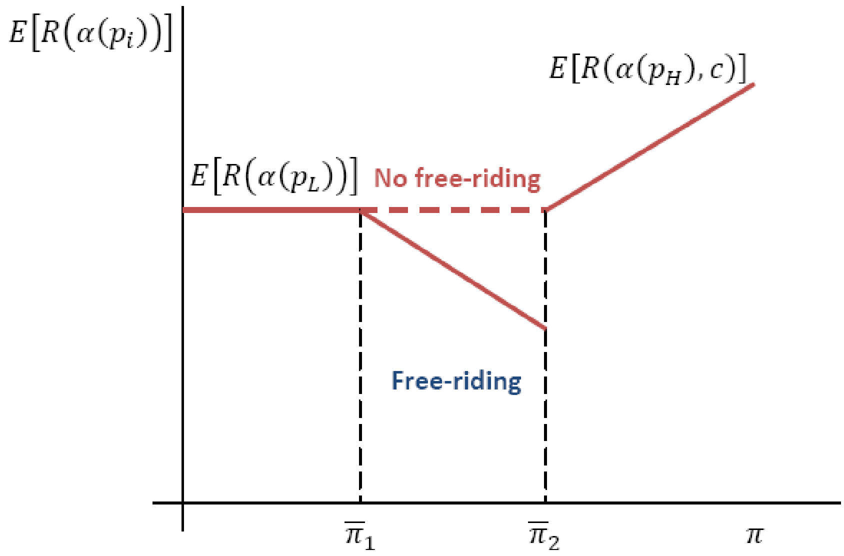

Figure 1 Depositors' expected return

Since competitive pressure forces prudent banks to reduce investment in liquid projects, too, free-riding drives down expected return for depositors (see Figure 1). They are definitely worse off than if all banks would coordinate on the prudent strategy α (p_L). As illustrated in figure 1, the effective return on deposits for investors deteriorates in the range $\overline{\pi}_1 < \pi < \overline{\pi}_2$ as a result of free-riding behaviour. These results are summarized in Proposition 1.

Proposition 1 *Given p_H and p_L, and suppose that α 's are observable to all investors:*

a) There is a unique symmetric equilibrium of pure strategy such that all the banks set $\alpha^* = \alpha\left(p_H\right)$ *as soon as* $\pi > \overline{\pi}_2 = \dfrac{\gamma \cdot E\left[R_L\right] - c}{\gamma \cdot E\left[R_H\right] - c}$ *;*

b) There exists a unique symmetric equilibrium of pure strategy such that all the banks set $\alpha^* = \alpha\left(p_L\right)$ *when* $0 \le \pi < \dfrac{\gamma \cdot E\left[R_L\right] - c}{\gamma \cdot R_2 - c} = \overline{\pi}_1$ *;*

c) When $\overline{\pi}_1 < \pi < \overline{\pi}_2$, there exists no symmetric equilibrium of pure strategies. There exists a unique equilibrium of mixed strategies consisting of prudent banks (with $\alpha_s < \alpha\ (p_L)$) and free-riding banks (with $\alpha_r = 0$). Investors are worse off than if all banks would coordinate on the prudent strategy α (p_L).

Proof: See Cao/Illing (2008).

4. Lender of last resort policy and ex ante liquidity requirements

In section 3, we have demonstrated that free-riding incentives encourage excessive risk taking, lowering investor's return even in the case of a pure illiquidity problem. Therefore sound regulation is needed to implement the constrained second-best allocation from the investor's point of view. In this section, we discuss two options (lender of last resort policy and imposing ex ante liquidity requirements) and show that a mix of both is needed to implement this allocation.

4.1 Lender of last resort policy: Ex post liquidity injection

Consider first the case $\pi > \overline{\pi}_2$ in figure 1. In that range, the probability for the good state is so high that it would be inefficient for any bank to invest more in type 1 projects than the share α (p_H) needed to be able to payout if the good state occurs. Bad systemic shocks are so rare that it does not pay to self-insure against this event. Therefore, in that range it is optimal to allow for exposure to systemic risk. If, however, the bad state is realized, all banks will be run, forcing early liquidation of all projects. Evidently, these costly runs are inefficient. A central bank acting as lender of last resort could intervene at time t=1/2 in order to prevent such runs.

Obviously, neither the central bank nor the government are able to provide additional real resources. With banks offering nominal deposits, promising a fixed nominal payment d_0 in the future, the central bank can, however, inject additional nominal liquidity at the stroke of a pen. Following Allen/Gale (1998), [see also Diamond/Rajan (2006)], we assume that the price level is then determined by the ratio of amount of liquidity (the sum of money and real resources) in the market relative to the amount of real resources available. If the central bank injects additional liquidity at time t=1/2 so as to enable banks to honour their nominal deposit contracts, the price level will adjust such that the real value of deposit equals the available resources $b = \alpha(p_H)R_1 + [1-\alpha(p_H)]\, p_L R_2 > 1$ available at t=1. This way, lender of last resort policy prevents a bank run, raising the real return of deposits in the bad state above the liquidation value: b>1>c. So central bank intervention can raise expected return of depositors in the range $\pi > \bar{\pi}_2$ (see figure 2). It even allows to expand the range of parameter values for which $\alpha(p_H) < \alpha(p_L)$ (low investment in liquid type 1 projects) is efficient from the investor's point of view: With lender of last resort activity, this range is expanded to $\pi > \pi'_2$ (figure 2). Obviously, depositors will favour such a rescue policy. Public insurance against rare systemic events encourages risk taking, but nevertheless it raises investor's payoff in that range of parameter values.

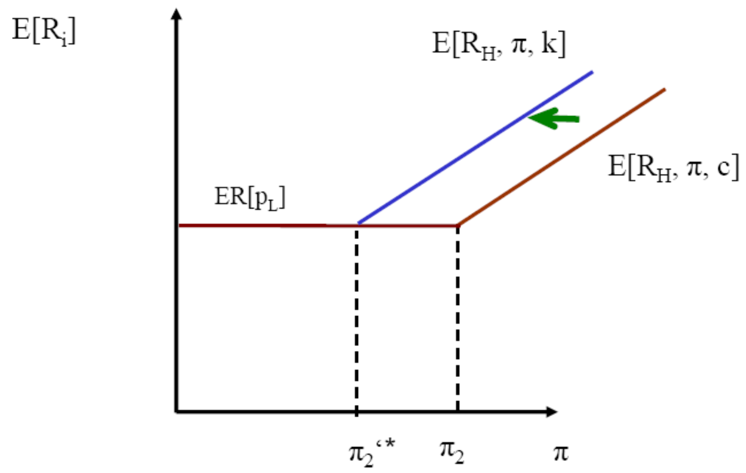

Figure 2 Depositors' return under liquidity regulation combined with lender of last resort policy

Unfortunately, it turns out that, anticipating the rescue policy there will be strong incentives for banks to free-ride on liquidity provision. Those banks, investing all their funds only in risky projects ($\alpha = 0$), can always afford to offer early entrepreneurs a higher rate of return as long as central bank intervention helps to prevent bankruptcy. The problem is that free-riding banks have a higher average return than prudent banks, provided that they will be bailed out by central bank intervention. Because these banks are absolutely better off than prudent banks when central bank money is provided, the incentive to free-ride will be aggravated! In the end, with unlimited central bank support, all banks will free-ride in equilibrium, choosing $\alpha = 0$. Since there will no longer be sufficient investment in liquid assets, the expected payoff for depositors is reduced substantially. In the end, all investors will be seriously damaged from such a policy of unconditional liquidity support.

A simple solution for central banks might seem to provide targeted liquidity support only to those banks behaving prudently. Liquidity support might be made conditional on banks having invested sufficiently in liquid assets. But as shown in Cao/Illing (2008), such a commitment is not credible. There is a serious problem of dynamic consistency. Since all banks face a pure illiquidity problem (all projects are known to be realized at some stage), it is always welfare improving for the central bank to prevent costly bank runs ex post. Obviously, anticipating this behaviour ex ante encourages incentives for free-riding.

4.2 Liquidity injection combined with ex ante liquidity requirements

Rather than relying on an implausible commitment mechanism, the obvious solution is a mix between two instruments: comprehensive ex ante liquidity regulation combined with ex post lender of last resort policy. Whereas perceived wisdom argues that central banks can pursue their objectives [both price stability and financial stability] using just one tool, interest rate policy, sensible lender of last resort policy cannot work without support of liquidity regulation. The second best outcome from the investor's point of view can be implemented by the following mix of policies: In a first step, a banking regulator imposes ex ante liquidity requirements as a function of the probability π for the good state. For the range $\pi < \pi_2$' the required minimum investment in liquid type 1 assets should be at least $\alpha(p_L)$. In that range, playing safe gives investors the highest payoff yielding $E[R(p_L)]$ (see figure 2). If all banks are required to hold ex ante $\alpha(p_L)$. No bank is allowed to deviate as free-rider, ruling out the inferior range $\pi_1 < \pi < \pi_2$ as in figure 1.

For $\pi > \pi_2$', however, it would be inefficient for banks to play safe all the time. The risky strategy $\alpha(p_H) < \alpha(p_L)$ allows investors a higher expected payoff. In that range, the payoff increases in π as characterised in figure 2. For the range $\pi > \pi_2$' investors are better off if banks invest only a minimum share as low as $\alpha(p_H)$ in liquid assets so as to be able to survive just in the good state,. In the bad state, the central bank as lender of last resort has to inject enough liquidity to prevent runs. Liquidity regulation, preventing banks ex ante from operating with insufficient liquidity holdings, kills the incentives for free-riding. Given that the ex ante imposed liquidity requirements have been fulfilled, the central bank can ex post safely play its role as lender of last resort in the range $\pi > \pi_2$' whenever the bad state is realised.

5. Discussion: Alternative ways to regulate banks

As shown in the last section, imposing comprehensive liquidity requirements ex ante combined with lender of last resort policy ex post is able to implement the constrained second-best outcome from the investor's point of view for the case of pure liquidity risk. In our model, α represents the share of investment in liquid type 1 projects. A higher share α reduces the risk arising from maturity mismatch. The liquidity requirements imposed, should, however, respond to the economic environment: When the probability for the good state p_H is high enough (that is, beyond the threshold $\pi > \pi'_2$), liquidity requirements should be cut down from $\alpha(p_L)$ to $\alpha(p_H)$.

Our baseline model provides a tractable framework for regulatory analysis of pure liquidity shocks. It is straightforward to extend out analysis to discuss alternative institutional designs for regulatory reform. In this section, we analyze narrow banking, equity (capital adequacy) requirements and private insurance against systemic risk.

5.1 Narrow banking

Narrow banking imposes a perfect maturity match for those institutions issuing deposit contracts. Financial intermediaries offering deposits would be restricted to invest only in the most liquid assets so as to be always able to meet any deposit withdrawal by selling its assets. The idea of narrow banking is to reduce the inherent fragility of the financial system in a drastic way. Evidently, narrow banking can be extremely costly. In our model, if banks are required to hold sufficient liquid funds to pay out in all contingencies, they are restricted to hold $\alpha \geq \alpha(p_L)$, giving the payoff $E[R(p_L)]$ irrespective of probability π. As can be seen immediately in figure 2, under narrow banking investor's payoff would be much lower for high π compared to the mix of ex ante liquidity regulation combined with ex post lender of last resort policy. Narrow banking can be quite inferior: If the bad state is a rare probability event, it imposes enormous costs to dispense with the efficiency gains out of investing in high yielding illiquid assets, despite its impact on systemic risk.

5.2 Equity as buffer

An alternative way to reduce financial fragility is to dispense with deposit contracts (offering fixed nominal claims irrespective of the realization of risk), and instead impose state contingent payoffs. Investing in money market mutual funds rather than in deposits was supposed to make the financial sector more resilient. But again, that comes at a potentially high cost. As evidence from the turmoil in September 2008 illustrates, fears about "breaking the buck" can trigger runs on markets just like runs on banks. Obviously, there is a demand for fixed deposit contracts as insurance against liquidity risk (compare Diamond/ Dybvig (1983)). Furthermore, as argued in section 3, deposit contracts can be an efficient way to cope with incentive problems in the banking industry: The threat of a bank run disciplines bank managers to fully pay out all available resources pledged in the form of bank deposits. In contrast, when finance is not subject to costly runs, bank managers are able to capture at least part of the rent out of their specific skills. In this section, we compare variable payments (equity finance) with deposit contracts. In our model, equity finance is more costly than deposits for incentive reasons. At the same time, equity can serve as a buffer reducing the risk of costly bank runs. So it might be optimal to impose some equity (capital) requirements in order to reduce the fragility arising from deposit contracts. It turns out, however, that imposing liquidity requirements dominates equity in the case of pure liquidity shocks.

Equity can be introduced in a straightforward way into our baseline model. Instead of pure fixed deposit contracts, the banks issue a mixture of deposit contract and equity shares held by investors. In contrast to deposit contracts, equity is a claim that can be renegotiated ex post. So bank manager and equity holders (the investors) will split the residual surplus $\gamma E[R_s]- d_0$ after deposit contracts have been paid out. Equity holders get only a share ζ from the surplus; the share $(1- \zeta)$ will be captured by the bank manager, not accounted for in the banks balance sheet. We assume that $\zeta<1$. Suppose that all banks have to meet some minimum equity requirement k imposed by regulatory rules. Liabilities and equity in the banks balance sheet amount to $d_{0,i} + \zeta \left[\gamma\, E(R_{s,i}) - d_{0,i}\right]$. Thus, as long as bank i is not run, k is defined as

$$k = \frac{\zeta \left[\gamma\, E(R_{s,i}) - d_{0,i}\right]}{d_{0,i} + \zeta \left[\gamma\, E(R_{s,i}) - d_{0,i}\right]}$$

with $R_{s,i}$ as bank i's return under state s. Solving for d_0, we get $d_0 = \frac{1-k}{1+k\,(1-\zeta)/\zeta}\,\gamma\, E[R_{s,i}]$.

Evidently, due to the incentive costs involved in equity finance, it cannot be efficient to strictly impose pure equity finance (k=1). The incentive cost of equity finance has to be weighted against the benefit of equity – its role as buffer, preventing costly bank runs. In our baseline model, it is straightforward to calculate the equity share k needed to prevent bank runs. All equity held will be wiped out completely in the bad state, leaving just enough resources to honor deposit claims: In order not to be run, a bank having invested $\alpha(p_H)$ in liquid assets must be able to pay out depositors' claims even in the bad state. This is feasible as long as deposit claims do not exceed the funds available in that state, that is if $d_0 \le \alpha(p_H)R_1 + [1-\alpha(p_H)]\, p_L R_2$. Thus, as a regulatory rule, k would need to be so high that equity is sufficient to cushion the bad state. From $d_0 = \frac{1-k}{1+k(1-\zeta)/\zeta}\,\gamma\, E[R_{s,i}]$, we get:

$$d_0 = \frac{1-k}{1+k((1-\zeta)/\zeta}\gamma\, E[R_H] \leq \alpha(p_H)R_1 + [1-\alpha(p_H)]p_L R_2 .$$

The equation holding as equality defines the minimum requirement k for equity holding. It's easily seen that k is decreasing in p_L: if the bad state is not too bad, banks don't need much equity to stay solvent in the bad state. In contrast, if the bad state is really bad (in the sense that the share p_L of type 2 projects realized early is very small) or quite likely to happen (that is, π is low) banks need more equity to absorb losses, imposing higher cost to investors.

Just as with narrow banking, equity requirements (imposing the requirement that banks hold sufficient equity so as to be able to pay out demand deposits in all states of the world) can be quite inferior: Issuing equity is costly compared to deposit contracts, since it allows the bank manager to extract rents. Cao/ Illing (2009) provide a numerical simulation to quantify the impact of equity requirements for $\zeta = 1/2$. They show that a policy of ex ante liquidity regulation combined with ex post lender of last resort policy is always dominating equity requirements in the case of pure liquidity risk. The intuition behind this result is as follows: The return for investors under pure deposit contracts with efficient liquidity regulation is drawn in figure 2 as a function of π. In the range $\pi > \pi'_2$, depositor's real return will be γ E[R_H] in the good state (when p_H is realized) and $\alpha(p_H)R_1 + [1-\alpha(p_H)]\, p_L R_2$ in the bad state (p_L) [with the lender of last resort preventing costly bank runs]. If equity holding replaces the lender of last resort as risk buffer, investors need to invest part of their funds in the initial period in form of bank equity. Deposit claims need to be restricted to the amount $d_0 = \alpha(p_H)R_1 + [1-\alpha(p_H)]\, p_L R_2$. Evidently, the return in the bad state is the same as in the liquidity regulation regime. Equity holding, however, is costly for investors, allowing the bank manager to capture the part 1-ζ>0 of the surplus γE[R_H]- d_0 in the good state. So if the good state is realized, the payoff for investors from holding both deposits and equity will be just $d_{0,i} + \zeta\, [\gamma\, E(R_{s,i}) - d_{0,i}]$. As long as the share accruing to the manager is positive (ζ<1), the payoff with equity as buffer is less than γE[R_H].

Obviously, liquidity regulation dominates equity holding as buffer in the case of pure liquidity risk. Of course, in reality, banks are exposed to both solvency and liquidity problems. In that case, a mix between equity and liquidity requirements may result in superior outcomes. To analyze that case is left for future research.

5.3 Private Insurance against systemic risk

Our model suggests that the regulator needs to impose comprehensive liquidity requirements ex ante to all financial institutions in order to prevent the incentive to free-ride on liquidity in good states. The extent of liquidity requirement depends on the probability π of the good state. In our model, π is known to all agents. The regulator does not need to be better informed than other market participants. Out of distrust for regulator's abilities and incentives, however, economists usually favor private market arrangements. Kashyap, Rajan and Stein (2008) recently proposed the idea of private insurance against systemic risk (forcing banks to hold some type of contingent capital). One of their proposals was to require that systemically important, and leveraged, financial firms buy fully collateralized insurance policies (from unleveraged firms, foreigners, or the government) that will capitalize these institutions when the system is in trouble. In that case, instead of the regulator defining some liquidity threshold α, he would impose the need to buy insurance against systemic liquidity risk. As insurance premium, the shadow value which gives banks incentives to hold the required minimum level α would need to be charged.

In our model, such a private insurance scheme would not work for the following reason: For the range $\pi>\pi_2$', the efficient amount of real resources paid out to depositors is less than the nominal value of deposits in case the bad state occurs. In our general equilibrium setting, forcing external insurers to pay out more is simply not feasible. Such a systemic insurance scheme would strain the aggregate insurance capacity of the market (see also Gersbach (2009)). Imposing strictly the requirement of full insurance against systemic risk would restrict banks to always hold $\alpha\geq\alpha(p_L)$ [which is equivalent to the narrow banking solution]. More generally, with limited liability, the problem of dynamic consistency is likely to haunt also the market for private insurance: Insurance companies will have a strong incentive to rely on government bailout, distorting insurance premiums against systemic risk.

Our analysis calls also for skepticism about recent changes in the way public deposit insurance schemes have been re-designed. As a result of the turmoil in financial markets, many governments quite generously extended public schemes for deposit insurance since September 2008. Before the crisis, in many countries only some share (usually 90%) of deposits up to some maximum amount had been publicly insured. This cap has been removed in most countries. In addition, the amount of insurance coverage for deposits has been raised significantly. Our model, however, suggests that these popular changes may end up in unpleasant surprises from the investor's point of view. As emphasized, fragile deposit contracts work as an incentive device to limit the rents bank managers are able to extract from their specific skills. As Diamond & Rajan (2001) show, banks, having superior collection skills, always have the incentive to negotiate with depositors *ex post* and seize all the rent. The fragile deposit contracts, which allow depositors to run the bank whenever contracts are not met, can serve as a credible commitment device for the banks not to abuse their expertise. An insurance threshold (such as insuring only 90% of deposit up to some maximum amount) can thus serve as such an important incentive device, while at the same time protecting depositors. Extended perfect deposit insurance risks to destroy this fragility mechanism and may result in excessive rents in the banking industry, eventually making the investors rather worse off.

6. Conclusion

The "macro-prudential" perspective of regulation, focusing on system wide financial stability, has become an intensive research agenda recently. Most current studies concentrate on solvency issues and capital adequacy regulation. They emphasize a variety of externalities creating a tendency for financial intermediaries to lean towards excessive correlation, resulting in exposure to systemic risk. We extend this analysis to the case of liquidity risk, providing a baseline model for regulatory analysis of pure liquidity shocks. Usually, lender of last resort policy is assumed to cope efficiently with liquidity risk. But we show that, contrary to perceived wisdom, there is also a strong case for systemic liquidity regulation.

We derive systemic liquidity risk (the notion that too many projects will be realized too late from the investor's point of view) endogenously out of free-riding incentives of financial institution. In our model, financial intermediaries can choose ex ante the share of projects invested in liquid projects. We show that they may have an incentive to invest excessively in illiquid long term projects, exposing them to systemic risk. In the prevailing mixed strategy equilibrium the allocation is inferior from the investor's point of view since some banks are encouraged to free-ride on the liquidity provision from the other banks due to bankers' limited liability.

We focus on an economy with a limited number of the banks. One bank's failure may have global impact on the financial market. In this way, we try to capture both a feature of modern finance where the banking industry is highly leveraged, and the fact that banking failure needs to be large enough to kick out a full-fledged financial crisis.

We go beyond modeling the feedback mechanism between financial market and the real economy and explicitly take the role of the central bank as lender of last resort into account. Perceived wisdom suggests that lender of last resort policy is an efficient response to systemic liquidity shocks. We argue, however, that policy implications from models based on exogenous liquidity shocks may be seriously misleading. According to our analysis, time inconsistency problems give the lender of last resort strong incentives for ex post bailing out policies in the absence of binding ex ante liquidity regulation. We show that unconditional liquidity support by the central bank destroys incentives for prudent financial intermediation.

As shown in the paper, the combination of comprehensive liquidity regulation ex ante and lender of last resort policy ex post is able to implement the outcome maximizing investor's payoff. Analyzing the case of pure liquidity risk, we also show that regulations enforcing either "narrow banking" or equity requirements as buffer are inferior for coping with systemic liquidity risk compared to the mix between ex ante liquidity regulation and ex post lender of last resort policy.

How to implement liquidity regulation in practice is a complicated issue, subject to controversies. As this paper shows, liquidity requirements should be designed such as to reduce the banks' reliance on short-term refinancing. A crucial insight of the paper is that, in order to prevent systemic crises, there is a need to shorten the maturity mismatch between assets and liabilities, without going to the extreme of narrow banking. Recently, new liquidity standards issued by the FSA in UK seek to cut bank's reliance on short-term funding, by imposing liquidity buffers as a "prescribed share of the easily saleable assets an institution would need to survive catastrophes, such as an inability to refinance short-term debt and a run on deposits[1]". According to the FSA's rules, only cash and high-quality government bonds will count toward the requirements. These newly designed rules are a straightforward way to implement the reduction in maturity mismatch suggested by our model.

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