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SYSTEMIC RISK refers to the propagation of an agent's economic distress to other agents linked to that agent through financial transactions. Systemic risk is a serious concern in manufacturing, where trade credit links producers through a chain of obligations,[1] and in the insurance industry through the institution of reinsurance. The anxiety about systemic risk is perhaps strongest among bank executives and regulators. For, banks' mutual claims, which, by abuse of terminology, we will gather under the generic name of "interbank loans" or "interbank transactions," have grown substantially in recent years. These include intraday debits on payment systems, overnight and term interbank lending in the Fed funds market or its equivalents, and contingent claims such as interest rate and exchange rate derivatives in OTC markets. To the extent that interbank loans are neither collateralized nor insured against, a bank's failure may trigger a chain of subsequent failures and therefore force the central bank to intervene to nip the contagion process in the bud. Indeed, it is widely believed by banking experts (and by interbank markets!) that industrialized countries adhere to a "Too-Big-to-Fail" (TBTF) policy of protecting uninsured depositors of large insolvent banks, whose

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1. Trade credit has some specificities relative to, say, interbank lending. In particular, the value of collateral (the wares in trade credit) is usually much larger for the creditor (the supplier) than for other parties. Kiyotaki and Moore (1995) develop an interesting model of decentralized trade credit and study propagation in a chain of supplier-buyer relationships. The mechanics of their model (which is not based on peer monitoring) are different from those presented here. Also, Kiyotaki and Moore focus on propagation while, from our interbank lending slant, we are particularly concerned with the impact of interbank lending on liquidity ratios and on the compatibility between decentralized trading and centralized prudential control, and with the Too Big To Fail policy.

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failure could propagate through the financial system, although authorities (rationally) refuse to corroborate this belief and like to refer to a policy of "constructive ambiguity" when discussing their willingness to intervene.[2] Interbank transactions also reduce the transparency of a bank's balance and off-balance sheet data and complicate the measurement of a bank's actual liquidity and solvency ratios for prudential purposes.

Systemic risk is a concern only in a decentralized environment in which banks incur credit risk in their mutual transactions. Banking regulators have various means at their disposal to prevent systemic risk. Traditionally, governments have implicitly *insured* most of the interbank claims by rescuing distressed banks through discount loans, the facilitation of purchase-and-assumptions, nationalizations, and so forth. It is, however, widely recognized that such policies do not provide proper incentives for interbank monitoring and may lead to substantial cross-subsidies from healthy banks to frail ones through a government-mediated mechanism. This concern about moral hazard has recently led regulators and politicians to consider ways of reducing the government's exposure to bank failures.

An alternative method of prevention of systemic risk would consist in *centralizing banks' liquidity management*. A case in point is a payment system in which the central bank acts as a counterparty and guarantees the finality of payments. To the extent that the central bank bears the credit risk if the sending bank defaults, the default cannot propagate to the receiving bank through the payment system. Similarly, the Fed funds market could be organized as an anonymous double auction (to which the central bank could participate to manage global liquidity), in which each bank would trade with the central bank rather than with other banks. The central bank would then have better control over interbank positions and would further prevent systemic risk on the interbank market. Last, bank transactions on derivative markets could be protected through sufficient collateral so that, again, banks would not grant each other credit. Whether the government is affected by a bank failure in a centralized system depends on the constraints it puts on banks, but, in any case, centralization, like insurance, eliminates systemic risk. Unsurprisingly, reformers tend to respond to the current concerns about systemic risk and moral hazard with projects emphasizing a reduction in interbank linkages, such as strict collateral requirements in settlement systems, qualitative reductions in the volume of interbank lending, and restrictions on banks' participation in derivative markets.

Unfortunately, reforms cannot currently be guided by a clear conceptual framework. Economic theorists have devoted little attention to systemic risk.[3] The purpose of this paper is to provide a stylized framework in which some of the issues

2. While this work emphasizes contagion in the banking system through interbank transactions, financial distress may alternatively propagate through an informational channel. Namely, in a situation in which financial markets are imperfectly informed about the central bank's willingness to bail out failing banks, the central bank's refusal to support a troubled bank may signal that other banks may not be supported either in the future and may thus precipitate their collapse (although the collapse is likely to occur in practice through runs in the interbank market, the existence of interbank lending is not required for this argument).

3. The bank run literature initiated by Bryant (1980) and Diamond-Dybvig (1983) mostly focuses on the solvency of individual banks and leaves systemic risk aside for future research (in fact, both articles

surrounding systemic risk can start being analyzed.[4] Our goal is to analyze whether one can build an articulate story for why the TBTF policy may exist in the first place, and to study how one might protect central banks while preserving the flexibility of the current interbank market.

The premise of our work is that the current system of interbank linkages suffers from its hybrid nature: On one hand, banks engage in largely decentralized mutual lending. On the other hand, government intervention, voluntary or involuntary, destroys the very benefit of a decentralized system, namely, peer monitoring among banks. Consistency between goals and incentives could be restored in one of two ways. If one does not believe that the fine information that banks have or may acquire about each other can be used fruitfully, or else that similar information can be acquired and utilized efficiently by regulatory authorities, then there is no particular reason to encourage decentralized interactions among banks.[5] Alternatively, one may argue that this reformist view of cutting interbank linkages amounts to throwing the baby out with the bathwater, and that one should preserve the current flexibility while improving banks' incentive to cross-monitor. This policy, to be successful, requires not only keeping banks formally responsible for their losses in interbank transactions, but also restoring the central bank's credible commitment not to intervene in most cases of bank distress. As we will see, this credibility cannot be taken for granted, and must build on a specific regulatory treatment of interbank transactions.

To stress the point that a decentralized operation of interbank lending must be motivated by peer monitoring,[6] let us consider the following (alternative) plausible explanation of interbank lending: Some banks, perhaps due to their regional implantation, are good at collecting deposits, but have poor investment opportunities. In contrast, some other banks, such as the money center banks, have plenty of such opportunities or else are sufficiently large to afford the large fixed costs associated with complex derivative and other high-tech financial markets. It then seems natural

consider a single "representative" bank). Recently, several papers have analyzed the incentive constraints imposed by the possibility open to depositors to fake liquidity needs to take advantage of favorable reinvestment opportunities (Hellwig 1994, von Thadden 1994a, b) or to ex ante invest in profitable illiquid assets (Bhattacharya-Fulghieri 1994). The Bhattacharya-Fulghieri paper looks at an insurance mechanism among banks facing idiosyncratic shocks. As in Hellwig and von Thadden, private information about the realized idiosyncratic liquidity needs prevents the achievement of the optimal insurance allocation. While Bhattacharya and Fulghieri derive interbank contracting, they have no peer monitoring and thus the optimal private contract can be implemented through a centralized liquidity arrangement, in which the central bank acts as a counterparty to all transactions. So, systemic risk cannot arise. There is also a literature on peer monitoring in LDC credit relationships (see, for example, Armendariz 1995 and Stiglitz 1990). This literature does not study prudential regulation and systemic risk.

4. Our model is in many respects a general model of systemic risk, and could be applied to other types of firms that lend to each other and need to monitor one another.

5. There might be "political economy" considerations for why the centralization of liquidity management might be undesirable. We are, however, not aware of any explicit model along these lines.

6. There is ample evidence on the existence and relevance of peer monitoring in the banking industry. For example, in their study of the Suffolk system, Calomiris and Kahn (1996) show that this cooperative arrangement between New England banks to exchange each other's notes worked in effect as a disciplining device. For instance (p. 10): "The effectiveness of cooperative bank arrangements in preventing malfeasance by individual banks was enhanced by the collective banks' being able to "blow the whistle" on an individual even before formal legal procedures could be initiated."

for the former banks to lend to the latter. Yet, that a deposit-collecting bank should incur a loss when the borrowing bank defaults, as is implied by interbank lending, is not a foregone conclusion. If the relationship between the two banks involves a transfer of funds but no monitoring, the operation described above could be implemented in a more centralized, and probably better for prudential control, way. Namely, the deposit-collecting bank could pass the deposits on to the borrowing bank, while continuing to service them (in the same way a bank may continue to service mortgage loans it has securitized without recourse to other banks). The key difference with the interbank-loan institution is that the deposits made at the originating bank would, except to the eyes of the depositors, become deposits of the receiving bank. So, if the latter defaulted, losses would be borne by the deposit insurance fund, and not by the originating bank. We conclude that a mere specialization of banks into deposit-taking banks and actively investing banks by itself does not predict the existence of decentralized interbank lending.

Interbank loans are also subject to a debate in the prudential arena. International regulations currently require little capital for interbank lending. An interbank loan receives one fifth of the weight of an industrial loan. Because capital requirements impose an eight percent ratio of equity to risk weighted assets, only 1.6 c of capital is required per $1 of interbank loan. Some observers would argue that this capital requirement is excessive in view of the track record of interbank loan reimbursements. This position, however, misses the point that this fine historical record has been purchased at the price of government exposure and bank moral hazard. Indeed, in an improved system, in which banks would be made responsible for losses they incur on interbank transactions, the latter would be riskier than they currently are and might be affected a higher weight in the capital adequacy requirement. It might also be the case that formal quantitative restrictions (caps) would be imposed on interbank lending (as suggested by the reformers' position to limit interbank linkages).

The flip side of the coin is that, under effective interbank monitoring, debtors on the interbank market(s) are certified by their peers. The beneficiaries of (medium- or long-term) interbank loans might therefore be allowed lower capital ratios than banks that rely primarily on uninformed deposits for funds. Thus, with better incentives for monitoring, a fraction of (medium- and long-term) interbank borrowing could conceivably be included in the borrowing bank's regulatory capital, while this inclusion would make little sense in the current system. A peer monitoring approach also explains why short-term loans, even uninsured, are poor substitutes for bank capital, as they allow lenders to escape responsibility for poor monitoring by liquidating their position.

A last policy issue is the question of the credibility of limited central bank involvement.[7] Interbank lending creates a "soft budget constraint" (SBC) when the borrowing bank is in distress and the lending bank is solvent provided one ignores

7. For simplicity, this paper does not make a distinction between the deposit insurance fund, banking supervisors and the several departments of the central bank.

its interbank activities.[8] For interbank loans to play their certification role, the lending bank must be held partly accountable for the borrowing bank's distress. This may, as we will see, imply closing the lending bank when it itself is solvent but near insolvency. In such cases, however, it is not "ex post optimal" for the central bank to adhere to the stated resolution method. The solvency of the lending bank leads to a rescue, that in turn conflicts with its ex ante incentives to monitor.

One of the key issues addressed in this paper is whether the rescue of the lending bank operates through a bail-out of the borrowing bank, a move that we take to be the hallmark of the Too-Big-to-Fail (TBTF) policy. Note that, despite its name, we deemphasize the concept of size in TBTF by simply viewing TBTF as a policy in which a borrowing bank bail-out substitutes for direct assistance to its lenders. Because our viewpoint may surprise some readers, we ought to make some comments in this respect. First, it is clear that size per se cannot be the cause of TBTF; Drexel and the BCCI (which were allowed to fail) were large institutions whose failure created little risk of contagion as they were somewhat disconnected from the rest of the system. Second, even if one accepts our position, TBTF may not be a misnomer. As discussed above, large banks often borrow from smaller deposit-collecting banks, and thus there is a correlation between size and rescue operations. Third, the latter correlation may have alternative explanations; for instance, a political economy explanation may be that the failure of a large bank makes national headlines while that of small banks goes almost unnoticed in the media.

The paper is organized as follows: Section 1 sets up the benchmark situation of "autarky," in which banks do not monitor each other. That is, there is no interbank lending and liquidity markets might as well be centralized. The three-period autarky model is drawn from Holmström-Tirole (1995). Each bank must at date 0 hold liquid reserves in order to finance liquidity shocks at date 1. Once the liquidity shock is realized, there is still moral hazard in the bank. Returns accrue at date 2. The need for reserves is not obviated by the possibility of going to depositors or to the capital market to obtain more funds when the liquidity need occurs. So, banks must complement the possibility of diluting external claims by hoarding liquid securities or must count on credit facilities at the central bank. As we will see, in the optimal financial contract linking each bank and its lenders, the bank is subject to a liquidity requirement, proportional to the value of a bank's risky assets.

Section 2 considers optimal contracting in the presence of peer monitoring. To

8. Interbank loans might conceivably impose another externality on the central bank: Increased indebtedness impairs incentives for good or prudent behavior and thus reduces the value of deposits, or, equivalently, increases the deposit insurance fund's liabilities. As usual, a lender (here, the lending bank) does not internalize the loss its loan inflicts on any other lender (here, the deposit insurance fund); this standard "multiprincipal externality" has been extensively studied in economics. [See for example, Bernheim and Whinston (1986), Stole (1992), Martimort (1992), and, in a banking context, Bizer and DeMarzo (1992).] This externality, however, is limited by the existing regulatory regime. For, in the computation of the Cooke ratio, an increase in interbank borrowing does not affect the measurement of capital and risk weighted assets, and therefore, ceteris paribus, does not allow the borrowing bank to acquire assets other than Treasury and assimilated securities. [To be certain, current measures of capital do not continuously monitor interbank transactions (although, as we argue in Rochet and Tirole (1996), there is a case for keeping track of bank's mutual net claims). There thus remains some "multiprincipal externality" of the lending bank on the deposit insurance fund.]

focus on the basic mechanics, it looks at the two-bank case in which one bank monitors the other. This generalization of the Holmström-Tirole model allows us to study how the borrowing bank's liquidity requirement should be affected by interbank lending and whether the borrowing bank's distress should propagate to the lending bank, possibly forcing the latter to shut down.

Section 2 focuses on (date-0) peer monitoring of date-1 performance. Concretely, this means that monitoring is aimed at encouraging the commercial activities of banks that will suffer low liquidity shocks. We show that the monitoree's survival decision and return are independent of the liquidity shock facing its monitor. This result implies that the decision of whether to close bank 1 is independent of whether this decision jeopardizes the survival of its monitor, bank 2. More concretely, the cost of rescuing bank 1 is independent of the existence of a monitor, as a bailout of bank 1 can be replaced by an equal-cost assistance loan to bank 2. So "Too Big to Fail" is by no means a foregone conclusion.

Section 3 studies the robustness of the latter conclusion by looking at date-1 peer monitoring. There, the monitoring is aimed at encouraging the commercial activities of banks that will have low probabilities of poor returns (at date 2). We show that the banks' closure decisions are now interlinked because of the existence of economies of scope between monitoring and commercial activities. A bank is less likely to be allowed to fail if its failure jeopardizes the profitability of its lenders. We also show that even in an optimal prudential arrangement, propagation can occur. For example, starting from a situation in which no bank fails, a small increase in a bank's liquidity shock can trigger the closure of all banks. Section 4 summarizes the main insights and discusses alleys for research.

1. BENCHMARK: NO INTERBANK LENDING

1.1 The Model

The benchmark model is adapted from Holmström-Tirole (1995), to which we refer for more detail. There are n banks, and three periods, $t = 0, 1, 2$. Banks and investors (depositors, consumers) are risk neutral with a time separable utility. That is, an agent with random consumption stream (c_0, c_1, c_2) has expected utility $E(c_0 + c_1 + c_2)$. Thus, the interest rate demanded by depositors is equal to zero.

A bank $i \in \{1, \dots, n\}$ has access to a stochastic decreasing-returns-to-scale technology, which for an initial investment of size I_i (which can be interpreted as a portfolio of commercial loans, which we call a "project") costs $C(I_i)$ and returns RI_i if the "project" succeeds and 0 if it fails.[9] The cost function $C(\cdot)$ is increasing, strictly convex and differentiable. (Equivalently the cost could be linear and the re-

9. The "project" stands for the bank's investments in loans or other illiquid assets. Our formulation implies that the bank is not perfectly diversified; otherwise, there would be no moral hazard: see Diamond (1984).

turn in case of success increasing and concave in investment.) The size of the investment I_i can be varied freely, subject only to financial constraints. The investment is made at date 0. At date 1, an additional, uncertain amount $\rho_i I_i > 0$ of cash is needed to carry on with the project. The *liquidity shock* ρ_i is distributed according to the cumulative distribution F, with a density function f. If $\rho_i I_i$ is not paid, the project terminates and yields nothing. If $\rho_i I_i$ is paid, the project continues and its payoff is realized at date 2.

Investment is subject to moral hazard in that the bank (a banking entrepreneur) privately chooses the probability p that the project succeeds. The bank can either "behave" or "shirk." One interpretation of this "effort choice" might be the intensity of the bank's monitoring of its commercial loans. If the bank behaves, the probability of success is p_H (high). If the bank shirks, the probability of success is p_L (low), where $p_H - p_L \equiv \Delta p > 0$, and it enjoys a private benefit, $BI_i > 0$, proportional to the level of its investment I_i. The private benefit to shirking might stand for insider lending or for the reduced monitoring effort. The firm makes the decision on p after the liquidity shock has been paid. If the project is abandoned, no decision on p needs to be made. We assume that it is optimal to provide incentives for the bank to behave.[10]

The timing of events is described in Figure 1.

Bank i has a date-0 endowment of cash, A_i, and no endowments at dates 1 and 2. A_i is the bank's date-0 equity.[11] If the bank wants to invest $C(I_i) > A_i$, it will need to raise $C(I_i) - A_i$ from outside investors. For the moment, we assume that the initial investment level, the project outcome and the liquidity shock are all verifiable (as we will see, nothing would change if only the banking entrepreneur observed the liquidity shock).

Together with the scale I_i of the project, an allocation is characterized by a continuation rule at date 1 and a sharing rule for the proceeds of the investment. Because preferences are linear, the only relevant variables are the (interim) expected utility of bank i and of outside investors, conditionally on the realized liquidity shock ρ_i.[12] We denote these interim expected utilities by $U_i(\rho_i)$ and $V_i(\rho_i)$, respectively. The continuation rule is a function $\rho_i \rightarrow x_i(\rho_i) \in \{0, 1\}$, with the interpretation that the project is continued when $x_i(\rho_i) = 1$ and stopped when $x_i(\rho_i) = 0$.

Feasibility requires that the sum of expected utilities not exceed expected investment proceeds, net of the liquidity shock:

$$U_i(\rho_i) + V_i(\rho_i) \leq x_i(\rho_i)[p_H R - \rho_i]I_i . \quad (1)$$

10. This is the case for example if $B < (\Delta p)^2 R / p_H$. This condition guarantees that it is cheaper for outside claimholders to provide the banking entrepreneur with monetary incentives not to shirk.

11. The identification of cash and equity is not a real restriction at date 0. Of course, these two notions differ after date 0.

12. In the absence of interbank transactions, bank i's continuation decision, incentives, and utility should not depend on the other banks' liquidity shocks.

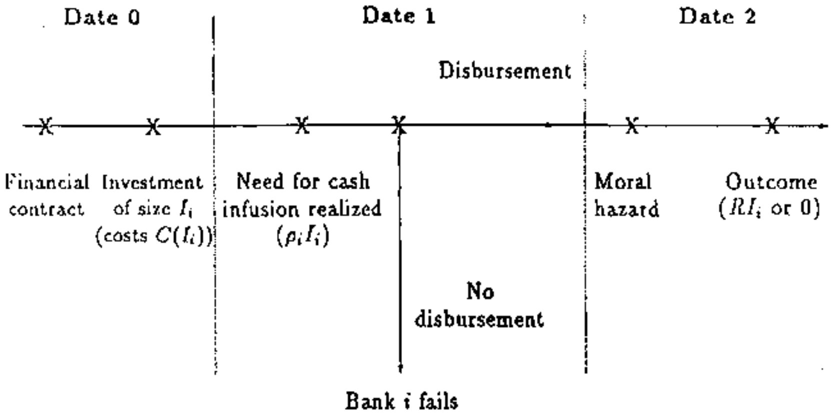

FIG. 1. The Timing of Events in the Model

This constraint is binding in any optimal allocation (one could for example give more money to outside investors if it were not binding), therefore we have

$$V_i(\rho_i) \equiv x_i(\rho_i)[p_H R - \rho_i]I_i - U_i(\rho_i) .$$

An allocation must also satisfy the following constraints:

$$(\Delta p)U_i(\rho_i) \geq x_i(\rho_i)[p_H B I_i] \qquad (IC_i),\ i = 1, \ldots, n$$

(incentive compatibility constraint for bank i).

When $x_i(\rho_i) = 0$, constraint (IC_i) simply means that $U_i(\rho_i)$ cannot be negative (limited liability of the bank). When $x_i(\rho_i) = 1$, it means that the expected gain obtained by the bank by shirking is smaller than the increase in expected utility obtained by behaving (which increases the probability of success by Δp). Under risk neutrality, bank i receives R_i in case of success and 0 otherwise. The moral hazard constraint in case of continuation is $(\Delta p)R_i \geq BI_i$. Using $U_i(\rho_i) = p_H R_i$ then yields (IC_i).

An allocation is Pareto optimal if it maximizes a weighted sum of banks' and depositors' utilities under the constraints (1) and (IC_i) for $i = 1, \ldots, n$.[13] For simplicity, we take the weights, ν_i for bank i and λ for depositors, as exogenous. Note also that we give the same weight λ to all depositors. Thus Pareto optima are obtained by maximizing

$$L = \sum_i E[(\nu_i - \lambda)U_i(\rho_i) + \lambda x_i(\rho_i)I_i(p_H R - \rho_i) + \lambda(A_i - C(I_i))]$$

13. We could also have introduced participation constraints as in the original model of Holmström-Tirole (1995). In effect, we would obtain similar formulas with endogenous welfare weights. To simplify the comparison with the case of interbank monitoring, we have taken exogenous weights.

under the moral hazard constraints (IC_i). Notice that λ has to exceed ν_i for all i, otherwise the problem would have no solution (economically, a mere redistribution of wealth from depositors to bankers raises social welfare). Therefore, L is maximized for the smallest interim utilities satisfying (IC_i). Thus constraint (IC_i) is always binding:

$$U_i(\rho_i) = p_H \frac{BI_i}{\Delta p} \quad \text{if} \quad x_i(\rho_i) = 1$$
$$= 0 \quad \text{if} \quad x_i(\rho_i) = 0 \,. \tag{2}$$

If we now replace $U_i(\rho_i)$ by the value given by (2), the optimal $x_i(\cdot)$ and I_i can be obtained by maximizing:

$$\frac{L}{\lambda} = \sum_i I_i E\left[\left\{\left(\frac{\nu_i}{\lambda} - 1\right)\frac{p_H B}{\Delta p} + (p_H R - \rho_i)\right\}x_i(\rho_i)\right] - \sum_i [C(I_i) - A_i] \,.$$

Given ρ_i, the net present value (per unit of investment) of continuation thus equals the difference between $[p_H R - \rho_i]$ (the net return on investment) and $(1 - \nu_i/\lambda)p_H B/\Delta p$ (the net incentive cost). Therefore, the optimal continuation policy is characterized by a threshold liquidity shock ρ_i^A (where the superscript A stands for "autarky"), which is also independent of the level of equity:

$$\begin{cases} x_i(\rho_i) = 1 & \text{if} \quad \rho_i \le \rho_i^A \\ = 0 & \text{if} \quad \rho_i > \rho_i^A \,, \end{cases}$$

where

$$\rho_i^A \equiv p_H\left(R - \frac{B}{\Delta p}\right) + \frac{\nu_i}{\lambda}\frac{p_H B}{\Delta p} \,. \tag{3}$$

This threshold represents the (interim) expected return on investment, net of incentive costs. Using this optimal continuation rule, the expression to be maximized becomes

$$\frac{L}{\lambda} = \sum_i \left\{I_i \int_0^{\rho_i^A} (\rho_i^A - \rho_i) f(\rho_i) d\rho_i - C(I_i) + A_i\right\} .$$

Finally, maximization with respect to I_i gives the optimal investment level I_i^A:

$$C'(I_i^A) = \int_0^{\rho_i^A} (\rho_i^A - \rho_i) f(\rho_i) d\rho_i = \int_0^{\rho_i^A} F(\rho_i) d\rho_i \,. \tag{4}$$

The integral in (4) can be interpreted as the (ex ante) expected return on investment net of the incentive cost and the liquidity shock.

Note from (3) that the optimal threshold satisfies $\rho_i^A < p_H R$, so that positive net present value reinvestments may not be optimal; that is, the logic of credit rationing and solvency requirements applies not only to the initial investment, but also to the reinvestment decision. More interestingly, let

$$\rho_0 \equiv p_H \left(R - \frac{B}{\Delta p} \right)$$

denote the expected per unit pledgeable income, that is, the maximal income that can be pledged to outsiders given the insiders' incompressible share. Note that the total value of the investors' claims on the bank is equal to $\rho_0 I_i$ (in case of continuation). Condition (3) yields

$$\rho_i^A > \rho_0 \,. \tag{5}$$

Condition (5) implies that the bank cannot withstand all shocks for which it should continue by just diluting its existing claims, that is by leveraging itself up. This explains the need for hoarding liquid reserves.

1.2 Implementation

From the transposition of Holmström-Tirole (1995) to the banking sector, we know that the optimal allocation can be implemented in one of two ways, given that the bank needs to hoard at date 0 reserves in order to be able to withstand date-1 shocks above $\rho_0 I_i^A$.

a. *Liquidity requirement:* The bank can at date 0 borrow more than $C(I_i^A) - A_i$ and invest the residual amount in liquid assets such as Treasury bills, that it will be able to sell at date 1 in order to pay for the liquidity shock. For example, bank i can borrow $C(I_i^A) - A_i + \rho_i^A I_i^A$, agree to invest $\rho_i^A I_i^A$ in Treasury bills (or other liquid securities) and commit not to dilute existing claims at date 1. Alternatively, the bank can borrow only $C(I_i^A) - A_i + (\rho_i^A - \rho_0) I_i^A$, invest $(\rho_i^A - \rho_0) I_i^A$ in Treasury bills, but keep the option of leveraging itself up at date 1. Either way, it is important that the liquidity requirement be monitored by the investors [see Holmström-Tirole (1995) for details].

b. *Credit line:* Alternatively, the bank can borrow $C(I_i^A) - A_i$, but obtain a credit line (corresponding to the level of liquidity hoarding $(\rho_i^A - \rho_0) I_i^A$, assuming that dilution is allowed) from the central bank in exchange of an appropriate amount of equity or debt.

1.3 Positive NPV, Liquidity, and Solvency

We can now define the notions of (date-1) positive NPV, liquidity, and solvency. Bank i has *positive NPV* at date 1 if the expected return exceeds the liquidity shock it faces, that is, if and only if $p_H R \geq \rho_i$. To define a notion of liquidity, let $\mathcal{L}_i$ denote the bank's reserves, which are hoarded at date 0 and can be mobilized at date 1. $\mathcal{L}_i$ can represent for example the date-1 value of Treasury notes held by bank i plus the level of a credit line that bank i can draw upon at date 1. Bank i is *liquid* if its reserves exceed its liquidity shock, that is if and only if $\mathcal{L}_i \geq \rho_i I_i$. It then does not need to contract new external financing in order to continue.

Last, we come to the notion of solvency. One possible definition is that bank i is solvent if, after efficient bargaining among the various stakeholders, the bank does not fail. As we will see, this definition can be given several interpretations depending on the control rights conferred upon the various stakeholders. We will, first, remark that bank i is *solvent* if $\rho_i \leq \rho_0$, that is, if the value of outside claims on the bank exceeds the bank's liquidity shock. After efficient bargaining among the various stakeholders, a solvent bank is always rescued even if it has hoarded no liquidity. Note also that in the absence of moral hazard ($B = 0$), $\rho_0 = p_H R$ and thus solvency coincides with positive NPV; but in general the agency cost introduces a wedge between the two concepts and a positive NPV bank need not be solvent.

Second, suppose that $\rho_0 < \rho_i < p_H R$ (for $\rho_i > p_H R$, bank i is always closed after efficient bargaining among the claimholders). Suppose that the bank has hoarded reserves $\mathcal{L}_i$ and that the banking entrepreneur has been previously given the right to use those reserves and to dilute a fraction $\alpha (0 \leq \alpha \leq 1)$ of outside claims to withstand liquidity shocks. Because $\rho_0 < \rho_i$, the community of outside claimholders would prefer to let the bank fail and therefore will not provide further credit. However, the banking entrepreneur is able to withstand the liquidity shock if $(\rho_i - \alpha\rho_0)I_i \leq \mathcal{L}_i$. We can talk about *solvency sustained by reserves and dilution rights* if this condition and $\rho_0 < \rho_i < p_H R$ are both satisfied. We see that whether the bank fails when $\rho_0 < \rho_i < p_H R$ depends on the control rights which have been conferred upon the bank.

REMARK: In this paper we do not investigate whether the private sector is "liquidity self-sufficient," in that the aggregate liquidity needs can be covered by the holding of private securities (in which case Treasury securities provide no extra liquidity service and must be sold at par). The analysis in Holmström-Tirole (1995) implies that (i) in the absence of macroeconomic shock (there is a large number of banks facing independent liquidity shocks), the private sector is liquidity self-sufficient. However, banks' crossholdings of securities "dispatches" liquidity in an inefficient way, while a "liquidity bank" (such as the German Likobank) is able to achieve the social optimum; and (ii) in the presence of macroeconomic shocks, the government has a role in creating and managing liquidity in the economy.

1.4 The Role of Banking Regulation in our Framework

The optimal allocation described in sections 1.1 and 1.2 can be implemented through a contract between the bank and its investors specifying a liquidity requirement. In practice, however, depositors have very small individual incentives to participate in the design of the contract and to verify that the bank complies with its covenants. This free-rider problem creates a need for representation. In this paper, we follow Dewatripont-Tirole (1994) in viewing the role of (public or private) banking regulators as solving the depositors' collective action problem, and thus as writing and enforcing the banking contract that the bank would have signed with a rational representative depositor who would verify that her investments in the bank yield the market rate of interest. We will adhere to this view of regulation throughout the paper, even though we will allow regulatory authorities to face commitment problems in their role of protectors of depositors.

1.5 Modeling Interbank Monitoring

As we discussed, decentralized interbank transactions can be justified only on the ground that they contain privy information that banks hold about each other. Since the current incentives for mutual monitoring are poor, we must partly conjecture what monitoring would look like in a more incentive compatible world. Following the literatures on moral hazard and adverse selection, there are two ways in which bank 2, say, can monitor bank 1. In the *moral hazard version,* bank 2 studies bank 1's activities and discloses information to the authorities, or else insists on an improved management, use of derivatives or asset portfolio by bank 1 in order to grant an interbank loan. That is, bank 2 rules out some dimensions of potential mismanagement by bank 1 (this does not necessarily mean that all moral hazard in bank 1 is eradicated). In the *adverse selection version,* monitoring by bank 2 consists in acquiring information about bank 1's managerial ability or about the riskiness of its existing assets.

Anecdotal evidence suggests that the adverse selection version is a better description of the *current* state of interbank monitoring. But there is no reason why the peer monitoring would not take the alternative form in a system in which banks would issue long-term, uninsured loans to each other.

As usual, the moral hazard and adverse selection description of monitoring give very similar results. We will here content ourselves with an exposition of the simpler moral hazard version. We have studied the adverse selection version in the case of two possible values for the liquidity shock of the borrowing bank. It is expositionally more complex since, under adverse selection, regulators may "screen" banks by offering menus of solvency and liquidity requirements, besides relying on peer monitoring to learn bank quality.

Monitoring will be described as in Holmström-Tirole (1994). It consists in identifying certain forms of misbehavior and therefore reducing the scope for moral hazard by the monitoree. More concretely, we will assume that monitoring shrinks the private benefit that the monitoree can enjoy by "shirking."

Section 2 studies "date-0 monitoring" while section 3 focuses on "date-1 monitoring". Date-0 monitoring will consist in reducing (actually eliminating) the monitoree's incentive to mismanage in the short run (for instance, the monitor may check the monitoree's risk management system). In section 1 we assumed that the liquidity shocks were exogenous. We will in section 2 posit that the borrowing bank's liquidity shock follows some distribution and the bank enjoys no date-0 private benefit if the bank is monitored. If it is not monitored, the bank may be tempted to enjoy a private benefit between dates 0 and 1, which stochastically raises the liquidity shock. Last, date-1 monitoring will be described in section 3 as resulting in a reduction in the monitoree's private benefit of shirking between dates 1 and 2. The key distinction between date-0 and date-1 monitoring is that one takes place before, and the other after the (date-1) closure decisions. Under date-0 monitoring interbank linkages impact on the closure decisions in a *retrospective* way; namely, their object is to punish or reward monitors for their monitoring performance. As we will see, this implies that a bank's closure decision should not be influenced by the fragility of its lenders. However, "soft budget constraint" problems may appear. In contrast, the impact of date-1 monitoring should be *prospective*, and therefore a bank's closure decision may reflect the health of its monitors.

2. DATE-0 MONITORING AND OPTIMAL INTERBANK LOANS

2.1 The Two-Bank Case: Optimal Allocation with Peer Monitoring

In this section, we analyze in detail the simplest example of peer monitoring, that involving a borrowing bank (bank 1) and a lending bank (bank 2). In this situation, only one bank (bank 2) has an incentive to monitor the other bank.[14]

We formalize monitoring in the following way: At private and unobservable cost cI_1 (proportional to the size I_1 of the investment of bank 1), bank 2 can reduce bank 1's private benefit of "shirking" on short-term management. Namely, if bank 2 incurs cI_1, bank 1 is unable to enjoy any private benefit by engaging in short-term mismanagement. The situation is then the same as that described in section 1 since we assumed there that the distribution of liquidity shocks was not subject to moral hazard. Let $F_1(\rho_1)$ denote the cumulative distribution of bank 1's liquidity shock when it is monitored, and let $f_1(\rho_1)$ denote the associated density (on $[0, \infty)$). On the other hand, if bank 2 does not monitor, that is, does not incur cI_1, bank 1's liquidity shock is distributed according to cumulative distribution $\tilde{F}_1(\rho_1)$ with density $\tilde{f}_1(\rho_1)$, where $F_1(\cdot)$ dominates $\tilde{F}_1(\cdot)$ in the sense of first-order stochastic dominance: $F_1(\rho_1) > \tilde{F}_1(\rho_1)$ for all $\rho_1 > 0$. The interpretation of this (stochastic) increase in the liquidity shock is that bank 1 is left free to engage in poor short-term management and enjoys a private benefit from this, that exceeds the loss in its monetary stake it incurs by generating higher liquidity shocks. We assume that the unit cost of monitoring, c, is small relative to the monitoree's private benefit of misbehaving, so that inducing monitoring by bank 2 is more efficient than not having monitoring and directly inducing bank 1 to behave. This assumption is natural given our goal of formalizing interbank monitoring. Last, we assume that bank 2 faces an exogenous

14. In this section (and the next) we assume that the two banks do not interact on the product market. A bank meant to monitor a close competitor might want to shirk on its monitoring duties solely to increase the probability of failure of the monitoree and thus to raise its market power.

liquidity shock ρ_2 distributed according to cumulative distribution function $F_2(\rho_2)$ with density $f_2(\rho_2)$ on $[0, \infty)$.

Let $\rho = (\rho_1, \rho_2)$ denote the vector of liquidity shocks encountered by the two banks at date 1. We maximize the same weighted sum of the welfares of banks 1 and 2 and their depositors as in the autarkic case,[15] subject to (i) the interim incentive constraints guaranteeing that the banks are diligent when they are not liquidated, and (ii) bank 2's ex ante incentive constraint, reflecting the fact that bank 2 chooses a privately optimal level of monitoring. We delay the discussion of the implementation of the optimum until section 2.2.

Let $E\{\cdot\}$ denote the expectation operator for the joint density $f_1(\rho_1)f_2(\rho_2)$, and let

$$\ell(\rho_1) \equiv \frac{f_1(\rho_1) - \tilde{f}_1(\rho_1)}{f_1(\rho_1)}$$

denote the likelihood ratio. As is usual, we assume that a lower liquidity shock "signals" a higher monitoring effort. That is, the likelihood ratio is decreasing in ρ_1 (this property implies the previously stated first-order stochastic dominance property).

The optimum is a tuple described by $\{U_1(\rho), U_2(\rho), x_1(\rho), x_2(\rho)\}$ for each realization of ρ (where U_i and x_i denote, as in section 1, the interim utilities and the continuation probabilities), and investment levels I_1 and I_2, that solve program $(\mathcal{P})$, given by

$$\max L = \sum_{i=1}^{2} E[(\nu_i - \lambda)U_i(\rho) + \lambda x_i(\rho_i)I_i(p_H R - \rho_i) + \lambda(A_i - C(I_i))] - \nu_2 c I_1 \tag{6}$$

s.t.

$$U_i(\rho) \geq x_i(\rho) p_H \frac{BI_i}{\Delta p} \text{ for all } (i, \rho)\ , \tag{IC_i}$$

and

$$E\{U_2(\rho)\ell(\rho_1)\} \geq cI_1\ . \tag{IC'_2}$$

(IC'_2) is the incentive compatibility condition ensuring that bank 2 monitors bank 1.[16]

One must also require that

$$x_i(\rho) = 1 \text{ for } \rho_i < \rho_0\ . \tag{7}$$

For, when bank i's liquidity shock is lower than the per-unit value ρ_0 of the bank, the bank is solvent (although perhaps illiquid, as we will see), and its liquidation is not

15. As before, we put the same weight on the welfare of depositors in both banks.

16. To see this, note that the left-hand side of (IC'_2) represents the gain in expected utility that bank 2 obtains by monitoring bank 1:

$$E\left\{U_2(\rho)\ell(\rho_1)\right\} = \int U_2(\rho_1, \rho_2)(f_1(\rho_1) - \tilde{f}_1(\rho_1))f_2(\rho_2)d\rho_1 d\rho_2\ .$$

credible. Investors have an incentive to dilute their claims on bank i in order to raise the cash needed to withstand the liquidity shock.

We did not explicitly impose the credibility constraint (7) in section 1 because it is redundant under autarky (recall that $\rho_i^A > \rho_0$). As we saw, it is then never ex ante optimal to commit to shut down ex post a solvent bank. In contrast, under interbank monitoring one may want to "punish" bank 2 for a poor monitoring of bank 1 by liquidating bank 2 even when the latter is solvent. Such a liquidation policy is, however, not ex post optimal, and we assume that a financial reorganization then lets the bank continue. Imposing constraint (7) does not affect the qualitative results in this section, but will play an important role in our study of the soft budget constraint in section 2.3.

Maximizing program (6) subject to constraints (IC_i), (IC_2'), and (7) yields the following results, proved in the appendix:

- Bank 1's closure rule is the same as under autarky:

$$x_1(\rho) = 1 \Leftrightarrow \rho_1 \leq \rho_1^* = \rho_1^A .$$

- The optimal investment level of bank 1 is determined by the equality between the net expected return on investment and its total marginal cost (direct cost + monitoring cost + incentive cost):

$$\int_0^{\rho_1^*} F_1(\rho_1)d\rho_1 = C'(I_1^*) + c\left(\frac{\nu_2 + \mu}{\lambda}\right),$$

where μ denotes the multiplier associated to constraint (IC_2').

- Bank 2's closure rule depends on the performance of bank 1. More specifically, we have

$$x_2(\rho) = 1 \Leftrightarrow \rho_2 \leq \rho_2^*(\rho_1) = \rho_0 + \frac{\max(0,\, \nu_2 + \mu\ell(\rho_1))}{\lambda}\,\frac{p_H B}{\Delta p} .$$ [17]

- Finally, the investment level of bank 2 is determined by a similar condition as under autarky, except that the closure rule for bank 2 is now stochastic:

$$E\left[\int_0^{\rho_2^*(\rho_1)} F_2(\rho_2)d\rho_2\right] = C'(I_2^*) .$$

Let us describe now the consequences of these results, first for the borrowing bank and then for the lending bank.

- *Borrowing bank:* As one would expect, the study on the borrowing bank side is

17. To be complete, we actually need to assume $\rho_2^*(0) \leq p_H R$. This corresponds to an assumption of "restricted impact of interbank lending" that we discuss below.

similar to that of the autarky case, for distribution $F_1(\rho_1)$. The following proposition and the next are proved in the appendix:

PROPOSITION 1 *(borrowing bank).*
Under optimal interbank lending:
(a) The continuation decision and the welfare of the borrowing bank do not depend on the liquidity shock facing the lending bank.
(b) The borrowing bank is closed less often than under autarky.
(c) When the unit cost of monitoring c is small, the borrowing bank invests more than under autarky.

Part (a) of Proposition 1 is highly reminiscent of the sufficient statistic theorem of Holmström (1979) and Shavell (1979). Its simple implications will be drawn in section 2.2.

Part (b) of Proposition 1 comes from the fact that the liquidity threshold of the borrowing bank is the same as under autarky. Since the borrowing bank is now monitored, the distribution of liquidity shocks becomes F_1 instead of $\hat{F}_1$, and the probability of closure decreases. The impact on investment [part (c)] is less obvious, since the total cost of monitoring (direct cost + incentive cost) is proportional to I_1. However, in the limit case where $c = 0$ (costless monitoring) the incentive cost is also zero and bank 1 is clearly allowed to invest more than under autarky. Therefore by continuity, this is also true for c small enough.

• *Lending bank:* To provide incentives for monitoring, the lending bank's stake must be linked to the borrowing bank's outcome, namely ρ_1. This linkage can be provided through two channels: bank 2's continuation decision, and bank 2's reward. We will here restrict our attention to the case, which we will label "restricted impact of interbank monitoring," in which the linkage from the borrowing bank's liquidity shock to the lender's outcome operates solely through the continuation decision. That is, as in the autarky case, bank 2 never receives more than what is needed to preserve incentives (in a sense this means that bank 2 never has excess capital at date 1). The generalization of condition (3) of the autarky case for the lending bank then defines a contingent threshold $\rho_2^*(\rho_1)$ by

$$\rho_2^*(\rho_1) = p_H\left(R - \frac{B}{\Delta p}\right) + \frac{\max(0, \nu_2 + \mu\ell(\rho_1))}{\lambda}\frac{p_H B}{\Delta p}\,, \tag{8}$$

where μ is the shadow price of (IC_2'). "Restricted impact of interbank monitoring" is equivalent to the continuation decision for bank 2 never being ex post inefficient: $\rho_2^*(0) \leq p_H R$.[18]

REMARK: When monitoring has a large impact on bank 1's shock or when the cost of monitoring is high, it becomes inefficient to reward bank 2 for low shocks solely through the continuation decision (the threshold defined in (8) then implies ex post

18. This is satisfied, for instance, if the unit cost of monitoring, c, is small (in which case μ is small) or if the likelihood ratio l (which is decreasing and equal to zero in expectation) does not vary much with ρ_1; this corresponds to the case in which monitoring is useful but does not affect drastically bank 1.

inefficient continuation in some states of nature). It then is more efficient to reward bank 2 through direct monetary rewards as well (meaning, technically, that (IC_2) is not binding).[19]

Suppose that there is no SBC ($\rho_2^*(\rho_1) \geq \rho_0$ for all ρ_1. We will later discuss the SBC); let us rewrite bank 2's continuation decision as follows:

$$\rho_2 \geq \rho_2^*(\rho_1) \Leftrightarrow \rho_2 + \rho_{21}(\rho_1) \geq \rho_2^A$$

where

$$\rho_{21}(\rho_1) = -\frac{\mu}{\lambda}\ell(\rho_1)\frac{p_H B}{\Delta p}, \qquad \rho_2^A = \rho_0 + \frac{\nu_2}{\lambda}\frac{p_H B}{\Delta p}.$$

Notice that ρ_2^A is nothing but the autarky threshold [see equation (3)]. But now this threshold is applied to the *overall liquidity shock* of bank 2, computed as the sum of ρ_2 and the "interbank liquidity shock" ρ_{21}. By construction, ρ_{21} has zero expectation (this is one possible normalization of the interbank liquidity shock. We will provide another normalization in the next section). $\rho_{21} > 0$ (which occurs for low ρ_1) can be interpreted as a realized profit generated by the interbank loan while $\rho_{21} < 0$ (which stems from a high ρ_1) corresponds to a loss on the interbank loan.

PROPOSITION 2 *(lending bank).*

(a) At the optimal allocation (and when the credibility constraint is not binding), the lending bank is liquidated whenever its overall liquidity shock $\rho_2 + \rho_{21}(\rho_1)$ *exceeds the autarky threshold* ρ_2^A. *The interbank liquidity shock* $\rho_{21}(\rho_1)$ *is proportional to (minus) the likelihood ratio* $\ell(\rho_1)$, *and is therefore decreasing with* ρ_1.

(b) When the credibility constraint is not binding, the lending bank invests more than under autarky.

It may seem strange that the lending bank is allowed to invest more in its own commercial activities. This is true only when the credibility constraint does not bind, and comes from a pure "option value." The interbank liquidity shock ρ_{21} amounts to adding a pure noise to the own liquidity shock ρ_2 of bank 2. Since the closure decision is made after the realization of these two shocks, the expected net return on investment increases and the optimum investment level also increases. Another reason why part (b) of Proposition 2 is unlikely to be a robust conclusion (and therefore is interesting only because of its identifying an "option value" effect) is that the type of monitoring envisioned in this section does not embody a "reinforcement of moral hazard effect," that is, a deterioration of the moral hazard problem on commercial activities due to the presence of interbank activities. The

19. An awkward feature of the risk-neutrality-continuous-liquidity-shock model is that the monetary reward should take the form of a spike at $\rho_1 = 0$ in this case. As is well known there are various ways of obtaining smoother reward structures, for instance, by introducing risk aversion, or a constant likelihood ratio for small shocks, or else a "manipulability constraint" that the reward does not change discontinuously with the performance. As this is mainly a technical point, we will not pursue the analysis further.

outcome of monitoring is revealed *before* bank 2's moral hazard decision on its commercial loans. This limits the efficacy for bank 2 of shirking in both tasks, as shirking in the first is partly detected before the second can be undertaken (in *simultaneous* multitask finance problems with risk neutrality and limited liability, the binding moral hazard constraint is that the bank do not select to shirk on *all* tasks). In other words, the sequential timing implies that the moral hazard problem on interbank lending does not directly aggravate the moral hazard problem on commercial loans. Suppose by contrast that (i) the monitoring of commercial and interbank loans takes place simultaneously and (ii) that the outcomes for the two activities are correlated, say, due to macroeconomic reasons (this is to avoid diversification effects à la Diamond (1984), by which the widening of banking activities need not raise the need for regulatory capital). Then a minor reinterpretation of Holmström-Tirole (1994) shows that interbank loans *crowd out* commercial loans, that is interbank loans require their own regulatory capital which must be subtracted from the capital available to sustain commercial loans.

2.2 *Intuition and Implementation*

The lending bank's closure decision should be linked with the performance of the borrowing bank. Bank 2's closure is more likely, the higher the liquidity shock faced by bank 1. The natural vehicle for this linkage is the credit risk on the interbank loan. We defined bank 2's *overall liquidity shock* (per unit of illiquid asset) as the sum of ρ_2 and the "interbank liquidity shock" ρ_{21}, which must correspond to the credit loss incurred at date 1 on the interbank market:

$$\hat{\rho}_2 \equiv \rho_2 + \rho_{21} \, .$$

The harder the liquidity shock hitting bank 1, the lower the value of the interbank loan and the higher the overall liquidity shock of bank 2.

While the qualitative features of the implementation of the optimum are clear, the exact details of this implementation depend on a number of institutional features.[20] In particular, one may entertain different assumptions as to how small liquidity shocks are met by bank 1 (are its liquid assets sold or are claims on the bank diluted through issues of shares or increased leverage?), and as to the roles of priority on bank 1's second-period profit. So, we content ourselves with an example.

EXAMPLE: Let us make the following assumptions:

(a) Each bank's liabilities are composed of inside equity (which cannot be diluted), outside equity, and debt claims (all debt claims are senior).

(b) Bank i holds at date 0 liquid assets $\mathcal{L}_i$. Think of these assets as being interest-free Treasury bills (recall that the consumers' rate of time preference is normalized to be zero). These liquid assets are sold first to meet the liquidity shock; claims on the bank start being diluted when liquid assets no longer suffice to meet the shock. The dilution is then proportional to the claims' payoffs in case of success.

20. Only a richer model could tell apart the various ways of implementing the optimum.

To be able to withstand shocks up to $\rho_1^A I_1$, bank 1 must hold $\mathcal{L}_1 = (\rho_1^A - \rho_0)I_1$ in liquid assets. Let us next consider bank 2's holding of liquid assets. Let bank 2 hold $\mathcal{L}_2$ interest free Treasury bills (with face value 1), as well as a nominal debt claim equal to $\beta\rho_0 I_1$ on bank 1. That is, the interbank loan entitles bank 2 to receive a fraction β of bank 1's second-period profit if bank 1 succeeds. When $\rho_1 \leq \rho_1^A$, the date -1 value of this interbank loan, V_{21}, is given by

$$V_{21}(\rho_1) = \beta\rho_0 I_1 \qquad \text{if} \qquad \mathcal{L}_1 \geq \rho_1 I_1,$$[21] and

$$V_{21}(\rho_1) = \beta[\rho_0 I_1 - (\rho_1 I_1 - \mathcal{L}_1)]$$
$$= \beta(\rho_1^A - \rho_1)I_1 \qquad \text{if} \qquad \mathcal{L}_1 \leq \rho_1 I_1 ,$$

where we make use of the proportional-dilution-of-claims assumption. When bank 1 has liquidity problems ($\mathcal{L}_1 \leq \rho_1 I_1$), then bank 2 incurs what we have called above an interbank liquidity shock:

$$\rho_{21} I_2 \equiv \beta\rho_0 I_1 - V_{21}(\rho_1) = \beta(\rho_1 I_1 - \mathcal{L}_1) .$$

For $\rho_1 > \rho_1^A$, bank 1 fails at date 1 and $V_{21}(\rho_1) = 0$. Note that we adopt a normalization of ρ_{21} different from that in section 2.1. Here, the interbank liquidity shock is either zero or positive.

Bank 2 can securitize at date 1 its loan to bank 1 and obtain $V_{21}(\rho_1)$ if it needs to meet its own liquidity shock. So, bank 2's total reserves are equal to $\mathcal{L}_2 + V_{21}(\rho_1)$, and are nonincreasing in ρ_1. The interbank loan just defined implements the optimum defined in Proposition 2 if and only if

$$\mathcal{L}_2 + V_{21}(\rho_1) = [\rho_2^*(\rho_1) - \rho_0]I_2 .$$

Thus, it implements the optimum if and only if the likelihood ratio (which recall defines $\rho_2^*(\cdot)$) satisfies this equality. Conversely, starting from a given likelihood ratio, one can build interbank claims that yield the optimum. Although the resulting interbank claim need not be a simple senior, unsecured debt claim as in this example, its qualitative features are similar to those of the example.

2.3 Soft Budget Constraints Do Not Imply Too Big to Fail

Conventional wisdom dictates that banks with large amounts of uninsured deposits cannot be allowed to fail when their failure would trigger a chain of bankruptcies (for example, sixty-six banks had uninsured deposits at Continental Illinois in excess of their capital when the latter was in distress in 1984). It is widely accepted that interbank lending puts the central bank in an awkward position of having to step in when a bank with large amounts of uninsured deposits is about to fail.

21. The excess liquidity, $\mathcal{L}_1 - \rho_1 I_1$, is then distributed at date 1 to outside shareholders, say.

Our analysis of the soft budget constraint shows that it arises exactly in the circumstances that are perceived to create the TBTF conundrum, namely when the borrowing bank is in trouble (ρ_1 high) and the lending bank(s) are themselves fragile (ρ_2 less than ρ_0, but high). One can also note that TBTF is itself an expression of a SBC, that is, of a policy that the central bank would like, but is unable, to commit to in order to create proper incentives. Indeed, TBTF depicts the case in which the undesirable rescue takes the specific form of bailing out the borrowing bank in order to save the lending banks, as opposed to letting the borrowing bank fail and rescuing the lending banks in other ways. The analysis of date-0 monitoring does not support the view that the borrowing bank should be kept alive.

Indeed, with date-0 monitoring, there is a compelling logic for why the closure decision should not necessarily be linked with the sake of the uninsured creditors. For, the central bank can let the borrowing bank fail while issuing emergency loans, guaranteeing uninsured deposits, exerting forbearance, or taking any other measure that prevents the contagion. Thus the central bank can opt for the cheapest of the two broad approaches (bail out versus closure and assistance to uninsured depositors), and not systematically rule out liquidation.

To stress this point, note that the key feature of monitoring as described here is that it is exerted *before* rescue decisions are made. If the monitor-monitoree relationship at that point of time is bygone (except for the resulting financial flows), then an unprofitable rescue cannot be undertaken: If it involves a net cost $X > 0$ to the outside claimholders altogether, a rescue that creates benefit $Y > 0$ for bank 2 costs $X + Y$ to the other holders of claims on bank 1. The latter are then better off offering Y to bank 2 and saving X by shutting bank 1 down.

Our second observation is that the presence of the credibility constraint (7) reduces the value of program $\mathcal{P}$. Because the optimal policy is time consistent, and therefore the credibility constraint has no bite in the absence of interbank lending, interbank lending becomes less desirable when the central bank cannot commit not to bail out bank 2. Thus, it may be the case that the SBC leads banks to forgo interbank lending; equivalently, in the interpretation in which the central bank represents the interests of dispersed, free-riding depositors, the SBC may lead the central bank to prohibit interbank lending, when it would allow it if it could commit not to bail out bank 2. Conversely, it is never the case that the SBC makes interbank lending more desirable.

We summarize the observations made in this section in:

PROPOSITION 3 *(central bank bailouts).*

(a) The central bank's inability to commit not to rescue a bank that incurs losses on the interbank market but is otherwise solvent may lead to the prohibition of interbank lending in cases where it would be allowed if the central bank's commitment were credible.

(b) The SBC differs from TBTF, as the borrowing bank's closure decision is unrelated to the fragility of the lending bank. Central bank assistance to a solvent but failing lending bank operates through a direct assistance to that bank rather than through a bail out of the borrowing bank.

3. DATE-1 MONITORING, TOO BIG TO FAIL, AND BANK FAILURE PROPAGATIONS

Section 2 pointed out that TBTF is by no means a foregone conclusion. This section shows that TBTF policies resurface in the presence of economies of scope (à la Diamond (1984)) between monitoring and commercial activities. Such economies of scope exist when monitoring takes place at date 1 instead of date 0. The section also analyzes the possibility of propagation of bank failures.

3.1 A Symmetric Model of Date-1 Monitoring

So far, we have considered date-0 monitoring, which affects the monitoree's short-term performance, namely, the liquidity shock. We now modify slightly our set-up by ignoring date-0 monitoring and by assuming instead that monitoring reduces the private benefit of date-1 shirking from BI to bI. The cost of monitoring is c per unit of investment; so the cost for the monitor is cI if the monitoree's investment is of size I. If the monitor does not incur cI, the monitoree shirks as long as his monetary incentive does not exceed BI; in contrast, in the presence of monitoring, the minimal monetary incentive that induces the monitoree to manage his commercial loans is only bI.

For simplicity, we consider a symmetric model with n equally endowed banks ($i = 1, \ldots, n$) located on a circle, where bank i is supposed to monitor bank $i - 1$ (with the convention that $0 = n$). We assume that B is large enough so that it is never optimal to leave one bank unmonitored. "Closing" bank i at the interim date $t = 1$ (which will occur if its liquidity shock ρ_i is large enough) means in fact a liquidation of its investment (commercial activity), but monitoring of bank $i - 1$ can still be performed. (One can then think of bank i as a deposit-taking bank which must monitor whom it lends to in the money market.) When such a *downsizing* occurs (or when both banks' commercial activities are shut down), we denote it by $x_i = 0$. When $x_i = 1$, on the contrary, bank i is allowed to continue its commercial activities (that is, withstand liquidity shock ρ_i and operate I_i). Denoting (as before) by $U_i(\rho)$ the interim payoff of bank i (as a function of the vector $\rho = (\rho_1, \ldots, \rho_n)$ of all liquidity shocks), we can write the incentive compatibility constraints as follows:

$$(p_H - p_L)U_i(\rho) \geq p_H cI_{i-1} \tag{9}$$

when $x_i = 0$ and $x_{i-1} = 1$,

$$(p_H - p_L)U_i(\rho) \geq p_H bI_i \tag{10}$$

when $x_i = 1$ and $x_{i-1} = 0$, and finally

$$(p_H^2 - p_L^2)U_i(\rho) \geq p_H^2(bI_i + cI_{i-1}) \tag{11}$$

when $x_i = x_{i-1} = 1$. Indeed, when both bank i and bank $i - 1$ are allowed to maintain their commercial activities, risk neutrality implies that the most efficient way to provide bank i with the correct incentives is to punish it when either its investment or the investment of bank $i - 1$ is unsuccessful (in which case bank i gets a zero return). It is only when both investments are successful that bank i receives a positive return. Therefore, condition (11) expresses the fact that the expected utility gain of bank i exceeds the private benefit of misbehaving in commercial activities (bI_i) plus the cost of monitoring bank $i - 1$ (cI_{i-1}).

3.2 The Nature of the Economies of Scope between Interbank and Commercial Activities

The economies of scope are easily detected by comparing (11) with (9) and (10): if we denote $p_H - p_L$ by Δp and $p_H/(p_H + p_L)$ by γ (which is therefore less than 1), the minimum rent to be given to bank i to behave in both activities is

$$U_i(\rho) = \frac{p_H^2}{p_H^2 - p_L^2}(bI_i + cI_{i-1}) = \frac{\gamma p_H}{\Delta p}(bI_i + cI_{i-1}) \ . \tag{11'}$$

Therefore, the minimum rent that induces bank i to monitor both its commercial activities and bank $i - 1$ is less than the sum of the minimum rents that correspond to separate activities:

$$U_i(\rho) = \frac{p_H}{\Delta p}(bI_i) \ , \tag{10'}$$

for commercial activities alone, and

$$U_i(\rho) = \frac{p_H}{\Delta p}(cI_{i-1}) \ , \tag{9'}$$

for interbank monitoring alone. Multiplying these three expressions by the relevant probabilities of continuation and combining them, we obtain a condition on the minimum ex ante utility of bank i, which depends on the probabilities x_i and x_{i-1} that the commercial activities of banks i and $i - 1$ are maintained at $t = 1$:

$$E[U_i] \gtrsim \frac{p_H}{\Delta p} E[\gamma(bI_i + cI_{i-1})x_i x_{i-1} + cI_{i-1}x_{i-1}(1 - x_i) + bI_i x_i(1 - x_{i-1})] \ ,$$

which can also be written

$$E[U_i] \gtrsim \frac{p_H}{\Delta p} \{bI_i E(x_i - (1 - \gamma)x_i x_{i-1}) + cI_{i-1}E(x_{i-1} - (1 - \gamma)x_i x_{i-1})\} \ . \tag{12}$$

Note that $1 - \gamma = p_L/(p_H + p_L)$ is a simple measure of the economies of scope.[22]

22. See Cerasi-Daltung (1994) for a richer study of the costs and benefits of the diversification of a bank's monitoring activities.

3.3 Characterization of Pareto-Optima

Pareto-Optima allocations can be obtained by maximizing a weighted sum of the banks' and depositors' utilities, under the incentive compatibility constraints:[23]

$$\max L = \sum_{i=1}^{n} (\nu_i - \lambda)E[U_i] + \lambda \sum_{i=1}^{n} (E[x_i(p_H R - \rho_i)]\, I_i - C(I_i)) + \lambda \sum_{i=1}^{n} A_i$$

subject to, for all i,

$$E[U_i] \geq \frac{p_H}{\Delta p}\{bI_i E[x_i - (1-\gamma)x_i x_{i-1}] + cI_{i-1}E[x_{i+1} - (1-\gamma)x_i x_{i-1}]\}\,. \qquad (IC_i)$$

The welfare weight of the depositors, λ, strictly exceeds ν_i for all i (otherwise, the utility of at least one bank would be infinite), and so (IC_i) is binding. Therefore, we can replace $E[U_i]$ by the right-hand side of (IC_i) and obtain a simpler expression of the Lagrangian:

$$L = \sum_{i=1}^{n} (\nu_i - \lambda)\frac{p_H}{\Delta p}\{bI_i E[x_i - (1-\gamma)x_i x_{i-1}] + cI_{i-1}E[x_{i-1} - (1-\gamma)x_i x_{i-1}]\} + \lambda \sum_{i=1}^{n} (E[x_i(p_H R - \rho_i)]I_i - C(I_i)) + \lambda \sum_{i=1}^{n} A_i\,.$$

In contrast with the case of date-0 monitoring, the Lagrangian is no longer separable in the x_is. The closure decisions for the n banks are now intertwined. More specifically, for a given realization $\rho = (\rho_1, \ldots, \rho_n)$ of liquidity shocks, the optimal $x = (x_1, \ldots, x_n)$ is obtained by maximizing the following expression:

$$H(x, \rho) = \sum_{i=1}^{n} (\nu_i - \lambda)\frac{p_H}{\Delta p}\{bI_i(x_i - (1-\gamma)x_i x_{i-1}) + cI_{i-1}(x_{i-1} - (1-\gamma)x_i x_{i-1})\} + \sum_{i=1}^{n} \lambda I_i x_i(p_H R - \rho_i)\,,$$

23. Because there is no date-0 incentive problem in this section, it is not optimal to contract at date 0 on inefficient date-1 closure decisions, and therefore we need not add the credibility constraint (7).

which can also be written in a more compact form as

$$H(x, \rho) = \sum_{i=1}^{n} u_i x_i + \sum_{i=1}^{n} v_i x_i x_{i-1} \ , \tag{13}$$

with:

$$u_i \equiv I_i \left\{ \lambda(p_H R - \rho_i) - (\lambda - \nu_i) \frac{p_H b}{\Delta p} - (\lambda - \nu_{i+1}) \frac{p_H c}{\Delta p} \right\} ,$$

and

$$v_i \equiv (1 - \gamma) \frac{p_H}{\Delta p} (\lambda - \nu_i)\{bI_i + cI_{i-1}\} > 0 \ .$$

Therefore, bank i's commercial activities are shut down at the optimum if and only if:

$$\frac{\partial H}{\partial x_i} = u_i + v_i x_{i-1} + v_{i+1} x_{i+1} \leq 0 \ . \tag{14}$$

Since v_i is positive for all i, this is less likely (other things being equal) when $x_{i+1} = 1$ or $x_{i-1} = 1$:

PROPOSITION 4 *(local interdependency).*
A bank's commercial activities are less likely to be liquidated if its "neighbors"'s are not.

Note that H satisfies the single crossing property in (x_i, ρ_i):

$$\frac{\partial^2 H}{\partial x_i \partial \rho_i} = -\lambda I_i < 0, \qquad \text{for all } i \ .$$

Also, H is supermodular in the vector of control variables x:

$$\frac{\partial^2 H}{\partial x_i \partial x_j} \geq 0 \qquad \text{for all } i, j \text{ (with equality if } |i - j| \neq 1) \ .$$

Therefore we can apply the monotone comparative statics result of Milgrom-Shannon (1994, Theorem 4) and obtain the following:

PROPOSITION 5 *(global interdependency).*
For all i *and* j, *bank* i *is more likely to be liquidated* ($x_i = 0$) *if the liquidity shock* ρ_j *facing bank* j *increases.*

3.4 Too Big to Fail and Systemic Risk

An interesting consequence of the global interdependency (Proposition 5) is that it can lead to some (efficient) propagation of bank failures. We content ourselves with a simple example. Let us recall the expression of H:

$$H(x, \rho) = \sum_{i=1}^{n} u_i x_i + \sum_{i=1}^{n} v_i x_i x_{i-1} .$$

We demonstrate the existence of situations (that is, particular realizations of ρ) in which H has (exactly) two maxima: $x^* = (0, \ldots, 0)$ and $x^{**} = (1, \ldots, 1)$. In such situations, by the comparative statics results obtained above, a slightly higher liquidity shock for any of the banks will imply a complete breakdown of the banking system ($x^* = (0, \ldots, 0)$) whereas a slightly lower liquidity shock for any of the banks would on the contrary entail no failure at all ($x^* = (1, \ldots, 1)$). We interpret this as showing the existence of unstable situations where the failure of a single bank can propagate to the entire banking system.

PROPOSITION 6 *(propagation).*
For some values of ρ, H *has exactly two maxima* $x^* = (0, \ldots, 0)$, *and* $x^{**} = (1, \ldots, 1)$. *Thus a small increase in a bank's liquidity shock may imply the closure of the entire banking system.*

PROOF: *We only give an example for* $n = 3$. *Recall that* v_1, v_2, v_3 *are given positive numbers, while* u_i *depends linearly on* ρ_i. *Therefore we have to find* u_1, u_2, u_3 *such that*

$$0 = u_1 + u_2 + u_3 + v_1 + v_2 + v_3 , \tag{15}$$

and

$$0 \geq \max (u_1, u_2, u_3, u_1 + u_2 + v_2, u_2 + u_3 + v_3, u_1 + u_3 + v_1) . \tag{16}$$

Now (15) implies in particular

$$u_1 + u_2 + v_2 = -[u_3 + v_1 + v_3] ,$$

which has be nonpositive by (16). Therefore:

$$-(v_1 + v_3) \leq u_3 \leq 0 .$$

Similarly, the conditions on u_1 and u_2 are:

$$-(v_1 + v_2) \leq u_1 \leq 0, -(v_2 + v_3) \leq u_2 \leq 0 .$$

It is obvious that these constraints are jointly compatible with (15).□

4. CONCLUSION

We have investigated whether the flexibility afforded by decentralized interbank transactions can be made consistent with protecting the central bank against undesired rescue operations. We first argued that the flexibility must correspond to effective peer monitoring; otherwise, centralizing the payment system, the Fed funds market, and other markets in which banks currently have bilateral exposures would result in an equally efficient allocation of liquidity among banks and would facilitate prudential control.

Our preliminary insights for capital adequacy requirements are as follows: 1) Provided lenders can be made accountable for poor monitoring, interbank lending certifies the borrowing banks, which may in some circumstances be able to count some of their interbank liabilities as regulatory capital. 2) Lender accountability requires interbank loans to be medium- or long-term loans, so lenders cannot fly by night and escape their monitoring obligations. Accountability is weakened when the central bank cannot commit not to rescue an otherwise solvent bank whose survival is jeopardized by bad interbank loans.

We also established a distinction between soft budget constraint and Too Big to Fail. The SBC takes the form of TBTF when central bank assistance to a solvent but failing lending bank operates through a bail out of the borrowing bank rather than through a direct assistance to the lending bank. Perhaps surprisingly, we found that TBTF never occurs in the absence of returns to scope between commercial and interbank activities. On the other hand, if such returns to scope exist, the fates of banks are inexorably linked; so, a bank's trouble may permeate the entire banking system even though, in an optimal regulatory framework, domino effects can be nipped in the bud by guarantees and sufficient collateral.

Some readers may not view economies of scope as the only, or even the main cause of TBTF. Alternative, although more complex, theories of TBTF are worth exploring. In fact, the logic emphasized in the paper of comparing the costs of alternative failure resolution methods, as compelling as it is, may well overstate the likelihood of direct lending-bank assistance relative to borrowing-bank bailout. Suppose a bank is about to fail and thereby create difficulties for some of the banks which loaned to it. Our model predicts that, in this situation, the central bank will assist only those lenders who are solvent but about to fail because of their interbank shortfall, and this at the smallest possible level of assistance. This reasoning, however, ignores transaction costs. To operate the selective rescue, the central bank must have a clear picture of (i) mutual positions, (ii) priority rules in bankruptcy (which, incidentally, are still somewhat ill-defined in netting systems), and (iii) solvent banks' needed cash infusion. While computers have substantially improved information about these dimensions of the rescue decision, the central bank still must exercise difficult judgment in a short time span in order to operate this selective rescue properly. It might then be simpler for the central bank to bail out the failing bank.

This and many other fascinating questions lie outside the scope of this paper, whose main objectives have been to build a formal framework in which analysis of interbank lending and systemic risk can begin, and to derive some first insights.

APPENDIX: SOLUTION OF PROGRAM ($\mathcal{P}$)

The Lagrangian of program ($\mathcal{P}$) can be written:

$$L_1 = E[U_1(\rho)(\nu_1 - \lambda + \mu_1(\rho))] + E[U_2(\rho)(\nu_2 - \lambda + \mu_2(\rho) + \mu\ell(\rho_1))]$$

$$+ \sum_i \left\{ I_i\, E\left(x_i(\rho)\left[\lambda(p_H R - \rho_i) - \mu_i(\rho)\, \frac{p_H B}{\Delta p} \right]\right) - \lambda C(I_i) - (\nu_2 + \mu)cI_1 \right\},$$

where $\mu_i(\rho)$ and μ denote, respectively, the multipliers associated to constraints (IC_i) and (IC_2'). $x_i(\rho)$ is also required to satisfy condition (7). The differentiation of L_1 with respect to $U_1(\rho)$ and $U_2(\rho)$ gives

$$\begin{cases} \mu_1(\rho) = \lambda - \nu_1 \geq 0 \\ \mu_2(\rho) = \lambda - \nu_2 - \mu\ell(\rho_1) \geq 0\ . \end{cases}$$

This implies that (IC_i) is binding for all i and ρ, except maybe when $\ell(\rho_1)$ is maximum. In other words, the incentive compatibility constraints (IC_i) are always binding, except for low values of ρ_1, where $U_2(\rho)$ may be strictly above $x_2(\rho)p_H BI_2/\Delta p$. When the likelihood ratio ℓ does not vary too much with ρ_1, on the contrary, (IC_2) binds everywhere: This corresponds to the case of "restricted impact of interbank monitoring", on which we focus. Maximizing L_1 with respect to $x_i(\rho)$ gives:

$$x_i(\rho) = 1 \Leftrightarrow \rho_i \leq p_H R - \frac{\mu_i(\rho)}{\lambda}\frac{p_H B}{\Delta p} \equiv \rho_i^*(\rho)\ , \tag{A1}$$

as long as $\rho_i^*(\rho) \geq \rho_0$.

Replacing $\mu_i(\rho)$ by its value for $i = 1,2$, we obtain that ρ_i^* is constant (the same as in autarky) and that ρ_2^* only depends on ρ_1:

$$\begin{cases} \rho_1^* = \rho_0 + \dfrac{\nu_1}{\lambda}\dfrac{p_H B}{\Delta p} = \rho_1^A\ , & \text{(A2)} \\[2ex] \rho_2^*(\rho_1) = \rho_0 + \dfrac{\nu_2 + \mu\ell(\rho_1)}{\lambda}\dfrac{p_H B}{\Delta p}\ . & \text{(A3)} \end{cases}$$

Maximizing L_1 with respect to I_1 yields

$$\frac{\partial L_1}{\partial I_1} = 0 = \lambda\{E[x_1(\rho)(\rho_1^* - \rho_1)] - (\nu_2 + \mu)c - C'(I_1^*)\}\ .$$

Now (A2) implies that the credibility constraint never binds for bank 1; therefore the above condition can be simplified:

$$\int_0^{\rho_1^*} F_1(\rho_1)d\rho_1 = E[(\rho_1^* - \rho_1)_+] = C'(I_1^*) + c\,\frac{(\nu_2 + \mu)}{\lambda} \,. \qquad (A4)$$

Finally, maximizing L with respect to I_2 gives:

$$\frac{\partial L}{\partial I_2} = 0 = \lambda\{E[x_2(\rho)(\rho_2^*(\rho_1) - \rho_2)] - C'(I_2^*)\} \,. \qquad (A5)$$

For large values of ρ_1, the credibility constraint may be binding:

$$x_2(\rho) = 1 \Leftrightarrow \rho_2 \leq \max(\rho_0, \rho_2^*(\rho_1)) \,.$$

Therefore condition (A5) becomes:

$$\int_0^{+\infty}\left(\int_0^{\max(\rho_0,\rho_2^*(\rho_1))}(\rho_2^*(\rho_1) - \rho_2)f_2(\rho_2)d\rho_2\right)f_1(\rho_1)d\rho_1 = C'(I_2^*) \,. \qquad (A6)$$

PROOF OF PROPOSITION 1

By (A2), the optimal threshold ρ_1^* is the same as under autarky (this is because the welfare weights ν_i and λ are exogenous):

$$\rho_1^* = \rho_1^A = \rho_0 + \frac{\nu_1}{\lambda}\frac{p_H B}{\Delta p} \,.$$

Now, since $\tilde{F}_1$ dominates F_1 in the sense of first-order stochastic dominance, we have

$$F_1(\rho_1^*) \gtrsim \tilde{F}_1(\rho_1^A) \,,$$

which means that the borrowing bank is indeed closed less often than under autarky.

As far as investment is concerned, we start by examining the limit case $c = 0$. In that case the autarkic closure rule is feasible, since by the independence of liquidity shocks:

$$E[U_2^A(\rho_2)\ell(\rho_1)] = E[U_2^A(\rho_2)]E[\ell(\rho_1)] = 0 \,.$$

This implies that $\mu = 0$ and that the investment under peer monitoring, given by

$$C'(I_1^*) = \int_0^{\rho_1^*} F_1(\rho_1)d\rho_1$$

is larger than the investment under autarky, given by

$$C'(I_1^A) = \int_0^{\rho_1^A} \hat{F}_1(\rho_1)d\rho_1 .$$

By continuity, this remains true for c small.

PROOF OF PROPOSITION 2

Part (a) has already been proved in the text. For proving (b), let us define an auxiliary function:

$$V(\hat{\rho}) = \int_0^{\hat{\rho}} (\hat{\rho} - \rho)dF_2(\rho) = \int_0^{\hat{\rho}} F_2(\rho)d\rho .$$

This function is convex, therefore by Jensen's lemma,

$$E[V(\rho_2^*(\rho_1))] \geq V(\rho_2^A) \qquad \text{(A7)}$$

where we have used the fact that

$$E(\ell(\rho_1)) = 0 ,$$

which implies that $E[\rho_2^*(\rho_1)] = \rho_2^A$.

Now the left-hand side of (A7) is equal to $C'(I_2^*)$ (when the credibility constraint does not bind), whereas its right-hand side is just $C'(I_2^A)$. Since C' is an increasing function we have established:

$$I_2^* \geq I_2^A . \qquad \square$$

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