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Liquidity Shortages and Banking Crises

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Abstract

We examine the effects of shortages of liquid assets on a banking system. We characterize the kinds of problems that can arise, and the kinds of interventions that might be appropriate. We also point out the dangers of the wrong kind of intervention, such as infusing capital when the need is for liquidity, as well as the practical difficulty of telling what is needed in some situations.

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What causes banking crises? Usually, "illiquidity" seems at the center of such crises but what does this term mean? How is it related to "insolvency" -- a shortfall in a bank's collateralizable asset values relative to its liabilities? What role do banks play in crises? What are the kinds of interventions that can help avert an incipient crisis? What are the ones that will hurt?

To answer these questions, we start with a simple model of a bank that we have developed in earlier work (Diamond and Rajan (2000, 2001a, 2001b), summarized in Diamond and Rajan (2001c)). In the model, we attempt to understand why the functions a bank performs – primarily of lending to difficult credits and providing demandable liquid claims – should be under the same roof. We argue that an important reason that assets cannot be sold for the present value of the future surplus that can generate is that specific skills are typically needed to generate that surplus. Since the owner's specific skills cannot typically be committed to financial or real assets when these assets are sold, specificity makes these assets illiquid.

For example, an entrepreneur cannot borrow against the full value of cash flows a project can generate because only he can generate those flows. Even if he promises to make future payments, he can always renegotiate them down if they are very high by threatening to withhold his specific skills. Similarly, a financial asset like a loan may not fetch as much in sale as the initial lender can extract from the borrower because the initial lender, perhaps through his relationship with the borrower, has developed a greater skill in collecting repayment than anyone else has. Since he cannot commit to applying these skills in the future on behalf of a current buyer or a lender, the loan will sell at a discount, or he will be able to borrow only a fraction of the amount he can collect on the loan.

A bank, however, can tie its collection skills to the loans it has made, and thus transform these typically illiquid assets into a more valuable base against which to borrow. The way it does this is by financing with demand deposits, which suffer from a collective action problem that makes them hard to renegotiate. The threat of a destructive run by trigger-happy depositors if the banker reneges on his promised payment to depositors, commits the banker to use his collection skills on behalf of depositors. As a result, if a bank finances solely through demand deposits, it can promise to pass through all it collects to depositors, thus essentially "selling" its illiquid financial assets for their full value. Because depositors need not have any special skills to collect from the bank, the bank creates liquid, readily transferable, claims even though its loans are illiquid. Because banks leave themselves committed to payment at any time, this links financial assets that are illiquid due to lender specificity to another notion of liquidity: immediacy. Short-term (demand) deposits are the best way to finance illiquid loans.

In practice, however, banks are not fully financed by demand deposits; they also issue "softer" financial claims such as equity or long-term debt. We argue in Diamond and Rajan (2000) that a mix of capital and demandable deposits may be the optimal capital structure for banks if they face sufficient uncertainty, since all-deposit financing subjects the bank to an unreasonable risk of a destructive run any time there is a minor dip in the value of bank assets. Thus even without an externally imposed capital requirement, the market will require banks to include some capital among its liabilities. In addition, banks face Basel minimum capital requirements. We simplify the exposition of our ideas by assuming banks have to finance with a certain minimum amount of capital. This can be interpreted as either the market or a regulator imposing a minimum level of capital.

Our focus then is to explore what happens to a bank's functioning if there is an aggregate shortage of liquidity – if the supply of liquid assets is small relative to aggregate demand for them. To model this, we assume that there are two broad kinds of assets. First, there are liquid consumable goods owned by potential investors. Second, there are projects owned by potential entrepreneurs. Projects require an investment of consumable goods up front, and will pay off a larger amount of consumable goods, either quickly or after considerable delay.[1] Projects are thus

[1] This could be thought of as a model of delays in harvest, or crop failure, that so plagued banking systems in the 19th century.

risky, but only in that the timing of when they pay off is uncertain. Projects also are illiquid in the earlier sense that we used the word – only a specific entrepreneur can produce consumable goods from a specific project, and only the initial lender may have the specific collection skills to extract a sizeable fraction of it from the entrepreneur.

Now suppose entrepreneurs, who have no endowments of consumable goods, borrow from investors indirectly through a bank. The bank will have to issue these investors a sizeable amount of demand deposits so that they can feel confident they will get repaid even though the bank loans to entrepreneurs are illiquid. What happens now if a number of projects are delayed and investors want to consume immediately?

If the number of delayed projects is not too large, the investors will be able to consume more than if they did not use the banks. The reason is that not only can the bank pass along the repayments from entrepreneurs whose projects are timely; it can also raise new financing against delayed projects and pass that along also to those who want to consume. The new financing will be available from entrepreneurs whose projects are timely, and who have spare cash after repaying their debts. By contrast, if an investor financed directly, he would have an extremely illiquid loan to the project if the project were delayed, and have little ability to convert it into a consumable good (since no one would lend to him against it, or buy it from him). Thus the bank's ability to commit to repay enables it to pass along to depositors more than they could get financing directly.

Problems arise if too many projects are delayed. In that case, not only does the bank get paid less immediately, its capital requirement ensures it can only borrow a fraction of the future value of delayed projects. As a result, the funds the bank can raise today against future earnings may be smaller than its immediate net liabilities – what we term a "solvency problem". At the same time, because few entrepreneurs are timely, there may also be a shortage of consumable goods in the economy with which to pay hungry investors. This is a "liquidity problem". A solvency problem or a liquidity problem alone can bring down the bank. The problems can also interact. With consumable goods in short supply, banks can be forced to find inefficient ways of coming up with liquid assets to meet the demands of depositors, which may make the banks insolvent. The interactions can also be good. When banks have limited solvency, they may be more constrained in the rate they pay, and a liquidity shortage can be less dissipative of bank value.

The problem for a bank is that liquidity shortages are exacerbated by the demandable nature of its liabilities. Anticipating a liquidity shortage, depositors are liable to run, forcing the bank to raise liquidity in inefficient ways, and forcing depositors to settle for much less in consumable goods. Thus the putative collective action problem inherent in deposits, which is so useful in adding to the liquidity that flows to depositors when there is plenty of liquidity around, subtracts from the liquidity flowing to depositors when there is an aggregate liquidity shortage. Depending on circumstance, the nature of a bank can help it create, or force it to destroy, liquidity!

Not only do bank runs force consumable goods to be produced in inefficient ways, they also may leave the consumable goods in the wrong hands. Thus there might be room for intervention by a central authority to prevent runs. We examine different kinds of interventions, taking into account the central authority's need to finance the intervention. We find situations where seemingly benign interventions, such as recapitalizing banks, can actually precipitate more runs. In other situations, aggressive interventions, such as pumping liquidity into the system at a low interest rate, can actually increase the private market interest rate. We therefore develop a taxonomy of crises situations, and the most appropriate intervention for each one.

Although we assume that fluctuations in the supply of liquid date 1 goods comes from variation in production or cash receipts by entrepreneurs, our results also apply when banks face other quantity constraints on their funding, and in particular when the quantity constraint is due to a panic.

We characterize the ex-post situations where liquidity and solvency interact to cause problems for the financial system. It is possible to use this to study ex-ante decisions of banks to fund short-term investments (storage) versus long-term (projects). We will report these results in a revision, but they are not very surprising. A shortage of liquidity creates a shadow value for liquidity that may be quite high, and eventually this may make liquid storage a lucrative prospect, even if its expected return is dominated by lending. Thus anticipated future illiquidity can curtail lending today. However, unless the ex-ante probability of aggregate date-1 cash flow delay is very high, banks will choose to lend to projects in sufficient quantity to lead to a chance of ex-post liquidity problems. As a result, the ex-post problems analyzed here will occur with positive probability.

Our work is related to a number of important recent papers. In particular, while Caballero and Krishnamurthy (1999, 2000) and Holmstrom and Tirole (1997,1998, 2000), also focus on crises, the notion that banks create liquidity for depositors is less central to their argument. Moreover, by liquidity they typically mean collateral value or wealth, while we introduce an additional notion of immediacy in this paper. Our paper also relates to Allen and Gale (2000), Diamond (1999), Diamond and Dybvig (1983), and Donaldson (1992, 1993) in its focus on the consequences of an aggregate shortage of liquidity. The notion of loans as illiquid due to specific lending skill combined with limited commitment is also present in Kiyotaki and Moore (2000), although they do not focus on the structure of bank contracts or on banking crises. These links will be made more clear in future revisions.

The rest of the paper is as follows. We lay out the framework in section I, examine date-1 outcomes in section II, and consider interventions in section III. Section IV is yet to be written, and will focus on the ex ante decision between storage and credit by the banks, and how the prospect of intervention will affect it. Section V examines issues of robustness. We conclude in section VI.

I. Framework

In what follows, we describe the economy, entrepreneurs, investors, and why banks are special in intermediating finance. This section will rely heavily on Diamond and Rajan (2000, 2001a, 2001b). In the next section, we describe lending and deposit taking, where we will account for competition between banks, which was not the focus of our earlier work. This section provides a microfoundation for the results in the balance of the paper, adapting the models from our previous research.

1.1. Agents and Projects.

Consider an economy with entrepreneurs and investors. The economy lasts for two periods and three dates -- date 0 to date 2. All agents are risk neutral and the discount rate is zero. There are two kinds of goods in the economy – consumption goods and machinery. Each entrepreneur has a project idea. The project requires $1 of consumption goods at date 0, which the entrepreneur then converts to machinery. Machinery then produces consumption goods, but since the process of fine-tuning the machinery to produce is complicated, it is uncertain when it will be ready to produce. The project may be completed "early," in which case it will produce consumption goods C at date 1 or it may be completed "late" and produce C only at date 2. Once a machine produces consumption goods, it becomes worthless.

There are only two aggregate states on the world. In the "healthy" state, denoted whenever necessary by superscript "H", all projects are early. In the "late" state, denoted by "L", which occurs with probability p^L, the probability that any project will be early is only α where $\alpha<1$.Thus there is both idiosyncratic risk (that a project may be late) and aggregate risk (that the state may be "Late"). While no one knows at date 0 what the state will be and whether a particular project will be early or late, everyone knows the probabilities. We will assume initially that uncertainty about the state and project maturity is revealed at date ½. This is interpreted as the effects of an anticipated future liquidity or solvency shortage. We will then explore what happens if it is revealed at date 1 instead, a current liquidity or solvency shortage. It turns out that they have somewhat different implications. We will assume the state is not verifiable (see the discussion later) so that contracts cannot be made contingent directly on the state.

In order to produce consumption goods worth C at any date, the entrepreneur has to work with the machinery. In other words, production requires his specific human capital skills. There are two other ways to make use of the machinery. The first is to *restructure* the project to focus on the near-term production of consumption goods. This can be done at any time until date 1 by the entrepreneur himself, or by any other entrepreneur with help (we will explain this shortly). Restructuring may involve salvaging the consumption goods that have not yet been converted to machinery or abandoning the uncertain technology in favor of tried and tested technologies that can produce goods quickly and with certainty. A project, when restructured, produces c_1 immediately, and c_2 at date 2. Thus a restructured project will produce more goods before date 2 than a project that is known to be late.

A second alternative is to produce with the machinery in a way that is not as dependent on the entrepreneur. This may involve finding an entrepreneur who has similar skills to those possessed by the original entrepreneur, or abandoning some aspects of the original project that were particularly dependent on the original entrepreneur's skills. Let us call this alternative "*replacement*," even though the range of possible actions may be broader than simply replacing the entrepreneur. What is important is that this involves retaining much of the original strategy so that the timing of cash flows is unchanged. Specifically, when the original entrepreneur is replaced, the project produces γC on the date it would have produced with the original entrepreneur, where $\gamma<1$.

In summary, there are two differences between restructuring the project to squeeze more out of it in the short run and replacing the entrepreneur. First, though both are costly because

$$c_1 + c_2 < 1 < \gamma C < C \qquad (1.1)$$

replacing the entrepreneur generates more goods in expectation since it preserves the original intent of the investment. Second, restructuring produces some goods immediately if the project is known to be late, while replacement produces none. There is also a similarity. While an entrepreneur can restructure his own project, special skills are needed for another entrepreneur to restructure the project, or to find a replacement for the entrepreneur while continuing the original project. We now describe investors, and also who may have skills to help restructure or replace.

1.2. Endowments.

Entrepreneurs do not have money to finance their projects. There are a large number of investors at date 0, each with a fraction of a unit of endowment of the consumption good, who can finance entrepreneurs. Investors can potentially finance entrepreneurs directly (our assumptions will rule this out) or finance via banks, an institution that we will describe shortly. The aggregate endowment of investors at date 0 is less than the total number of potential projects, so the economy is short of investment capital.

We assume initially that all date-0 investors only value consumption at date 1. In addition to investment in a project, investors have access to a storage technology that generates $1 at date t+1 for every dollar stored at date t.

As in Diamond and Rajan (2000, 2001a), the initial financier of a project has seen the project strategy from an early stage and knows how best to help another entrepreneur restructure the project, or whom to replace the original entrepreneur with. Restructuring requires less of the specific expertise of the original entrepreneur, so an entrepreneur who is helped by the initial financier can obtain as much by restructuring the project as the initial entrepreneur, i.e., $c_1 + c_2$. But since the original entrepreneur is particularly suited for the originally planned strategy, the initial financier can get only gC by replacing the entrepreneur. Financiers who come in later cannot get anything if they restructure the project or replace the entrepreneur. This is only for simplicity, and our results hold qualitatively if later financiers get something, but not as much as the initial relationship financier.

Since educating the initial relationship financier takes time and effort, we assume that there can be just one such financier for each entrepreneur. We assume that the relationship financier needs constant close contact with the entrepreneur to maintain his skills so that if he sells the financial claim or it is seized from him, he loses his specific skills next period. This assumption simplifies the analysis but is not necessary. In Diamond-Rajan (2001a) we get similar results when the financier retains relationship lending skills no matter what happens to the ownership of the financial claim.

1.3. Contracting.

We consider financial contracts that specify that the entrepreneur owns the machinery and has to make a payment to the financier, failing which the financier will get possession of the machinery and the right to use it as he pleases. So a contract specifies repayments P_t the entrepreneur is required to make at date *t*, as well as the assets the financier gets if the entrepreneur defaults. If $P_t<\infty$, this is a debt contract with promised payment P_t. If $P_t=\infty$ this is an equity contract where the outside investor is free to liquidate or replace the entrepreneur (as in Hart-Moore (1994)). Henceforth, we will refer to the financier as the lender.

1.4. Firm's Liabilities and Bargaining.

Any agent can commit explicitly to contributing his human capital to a specific venture only in the spot market. As a result, just before production the entrepreneur may attempt to renegotiate the terms of the loan he agreed to in the past, using the threat of withholding human capital. We assume bargaining at date *2* takes the following form; the entrepreneur offers an alternative payment from the one contracted in the past and commits to contribute his human capital if the offer is accepted. The lender can (1) accept the offer, or (2) reject the offer and replace the entrepreneur immediately (or wait till the next date to do so) (3) reject the offer and restructure the project. The game gives all the bargaining power to the entrepreneur, apart from the lender's ability to exercise control rights over the way the machinery is used going forward, i.e., whether the project is restructured, or the entrepreneur replaced and the control over machinery given to a new entrepreneur.[2] If the entrepreneur's offer is accepted, the entrepreneur contributes his human capital, and the offered payment is made. The sequence is summarized in figure 1.

[2] This is for simplicity only, and modified versions of our results hold when there is more equal bargaining power. What is important is that the amount a lender can collect is increasing in the value he can get from

Example 1: Suppose that it is date 1, the project turns out to be early, and at date 0, the entrepreneur promised to pay P_1=C at date 1. The entrepreneur knows the relationship lender can obtain γC by replacing him. As a result, he offers to pay only γC and the lender accepts since he cannot do any better by refusing. Note that lenders other than the relationship lender would have no ability to replace the entrepreneur or restructure the project. As a result, they would not be able to enforce any repayment. The relationship lender's specific skills enable him to collect more, so we will refer to these skills as *collection skills*.

1.5. Intermediation.

With the assumption that one individual's endowment is not enough to fund the project, that at most one lender can acquire collection skills vis a vis a borrower, and that collection skills are necessary for lending to be profitable, investors have no option but to delegate the acquisition of specific collection skills to an intermediary at date 0. Another (equivalent) motivation for an intermediary is that investors need liquidity at date 1. In this case (see Diamond and Rajan (2001a)), an intermediary provides continuity and reduces the need to sell illiquid assets at fire-sale prices. Regardless of the motivation for intermediation, it will turn out the intermediary must use demand deposits to commit not to renegotiate with investors. Let us now understand why.

1.6. Intermediary and its Liabilities.

Consider an intermediary who has borrowed from other investors, lent initially to the entrepreneur, and now possesses collection skills. Assume that these investors, unlike depositors (see later), do not suffer from collective action problems, and bargain as one with the intermediary. In the same way that the entrepreneur can negotiate his repayment obligations down by threatening not to contribute his human capital, the intermediary can threaten to not contribute his collection skills. By virtue of his ownership of the loan, the intermediary can earn a rent equal to some fraction of the value of his collection skill. As in Diamond and Rajan (2000), this will be an important but undesirable source of power for the intermediary.

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restructuring the project – the results would hold qualitatively if the entrepreneur obtained only a fraction

The intermediary will negotiate first with outside investors before concluding any deal with the entrepreneur (else his threat to withhold his collection skills is without bite). So he will open negotiations with investors by offering a different schedule of repayments. The negotiations between an intermediary and investor(s) take much the same form as the negotiations between the entrepreneur and a lender (see Figure 2). The investor can either (1) accept the proposed schedule (2) reject it and bargain directly with the entrepreneur as in figure 1 (this is equivalent to the investor seizing the "asset" -- the loan to the entrepreneur -- from the intermediary), or (3) bargain with the intermediary over who will bargain with the entrepreneur.

Because of his irreplaceable collection skills, the intermediary will capture a rent from investors (see Diamond and Rajan (2000, 2001a) and will not be able to pass through all it collects from the entrepreneur. In particular, in our example, the intermediary will keep a rent of $\frac{gC}{2}$ from the early project at date 1 (or the late project at date 2), and pass through only $\frac{gC}{2}$ to investors. The prospect of paying this rent to the intermediary can limit the amount the intermediary can raise from investors up front, and limit the entrepreneur's ability to get financing. Note that unlike the bargaining between the entrepreneur and the intermediary where the latter has no bargaining power, we allow the investor here to have some bargaining power. In practice, we would typically have interior amounts of bargaining power in both situations. We assume the entrepreneur has all the bargaining power in negotiations with the intermediary only to simplify notation.

1.6.1. Depositors as Investors.

The intermediary can commit to collect loans on behalf of outsider investors if it is a bank financed by demand deposits. The sequential service nature of demand deposits creates a collective action problem that prevents the banker from negotiating depositors down. As a result (see Diamond and Rajan (2001) for a detailed proof), with the appropriate level of outstanding deposits, the bank can commit to pass on whatever it collects to depositors.

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of the surplus from co-operation with the lender.

To sketch why, we have to first specify the terms of the deposit contract. The deposit contract allows the investor to withdraw at any time. He forms a line with other depositors who decide to withdraw at that time. If the banker does not pay him the full promised nominal repayment *d*, the depositor has the right to seize bank assets (cash + loans) equal in market value (as determined by what the assets would fetch in a sale by the intermediary -- see above) to *d*. Depositors get paid or seize assets based on their place in line.[3] Therefore if bank assets are insufficient to pay all depositors, the first one in line gets paid in full while the last one gets nothing.

Suppose the banker announces that he intends to renegotiate and makes an initial offer. Depositors can (1) accept the new terms, or (2) join a line, with positions allocated randomly, to seize the bank's assets of loans and cash based on what is due to them in the original contract– we call this a *run*, (3) refuse the offer but negotiate without seizing bank assets. All depositors choose between these alternatives simultaneously. At the end of this stage, either the banker or the depositor will be in possession of the loan to the entrepreneur. If depositors have seized the loan, the banker is disintermediated, and the entrepreneur can directly initiate negotiations with depositors by making an offer. The subsequent steps follow the sequence that we have already documented above, and in figure 1.

There is an essential difference between an intermediary bargaining with investors who have ordinary debt or equity claims on the intermediary, and the bank bargaining with demand depositors. If the bank attempts to renegotiate, or takes any other action that would impair the value of deposits, depositors will choose to run in an attempt to grab a share of the bank's assets to come out whole. As we will argue shortly, the run, by disintermediating the banker, will destroy his rents even though he continues to have specific skills in the short run. Fearing disintermediation, the banker will not attempt to renegotiate and will pass through the entire

[3] An equivalent assumption to depositors seizing loans is that they demand cash and the bank is forced to sell loans at their market value to third parties to meet cash demands. The net effect is the same -- unskilled parties are in possession of the loans after the run.

amount collected from the entrepreneur to depositors. Thus the bank is unlike more conservatively financed intermediaries who will, as we saw earlier, absorb a rent for their collection services.

Example 1 Continued

Suppose the bank wants to raise money at date 1 against a loan to a later entrepreneur. At date 1, how much can the banker commit to pay out at date 2 from the amounts collected on the loan with face value $P_2=\gamma C$? Let the banker issue demand deposits at date 1 with face value $d=\gamma C$ in total, raising the money from many depositors. A depositor with claim d' is permitted to take cash, or loans with market value, equal to d' (or to force this amount of loans to be sold to finance the payment of the deposit). As argued earlier, the market value of the loans at date 2 is only $\gamma C/2$ (the amount loan buyers expect to get after paying the banker to collect on their behalf). As a result, not all the depositors will be paid in full if they run. Therefore, if the banker should offer depositors less than $d=\gamma C$ at date 2, then each depositor has the unilateral incentive to run to the bank to get paid in full, whenever other depositors have not done so first. Therefore, when other depositors have not run on the bank, a given depositor will not make any concessions, preferring to run instead.

Finally, once a run has fully disintermediated the bank's assets, the banker's rents are driven to zero despite his specific skills. To see why, the entrepreneur and depositors (or loan buyers) who now hold the loan to the entrepreneur, can negotiate without the banker intervening. Depositors can threaten to hire the banker to collect the full γC less the rent they will have to pay the banker for his specific skills. Knowing this, the entrepreneur will offer to pay this net amount directly to the depositors who hold the bank's loans and thus save on the banker's fee. Depositors will accept and the banker will receive zero. Consequently, a bank run drives the banker's rents to zero. Disciplined by the threat of a complete loss in rents, the banker can commit at date 1 to pay the depositors at date 2 the entire amount $P_2 = \gamma C$ extracted from the firm.

1.6.2. Financing through a mix of deposits and other claims.

We have seen that investors holding non-deposit claims typically have to give a rent to the intermediary, while depositors do not. What if both kinds of investors simultaneously hold claims on the intermediary? It turns out, as might be expected, that the intermediary can now capture some rent but not as much as when there are no deposits. Call the non-deposit claims *capital*. Capital gets the residual value after deposits *d* are paid out. Capital can seize the intermediary's assets (cash and loans) if the intermediary does not make an acceptable offer, but it then becomes responsible for paying depositors. In effect, this assumption that capital can always seize assets is tantamount to assuming that capital is outside equity. Let the banker threaten not to collect the loan at date 2. We have already argued that he will be unsuccessful in negotiating depositors down. Hence this threat must be directed at capital.

Example 1 Continued Without the banker, capital will be able to collect nothing from the entrepreneur. So capital will not be able to avoid a run if the banker quits, and will get zero. The net amount available to capital and the banker if the bank does use its skills in collecting the loan is $\gamma C - d$. Since neither can get any of the surplus without the other's co-operation, they split the surplus, and each gets $\frac{1}{2}(\gamma C - d)$.

The problem with capital is that it does not provide the banker as hard a budget constraint as demand deposits. As a result, of the amount recovered from the entrepreneur, $\frac{1}{2}(\gamma C - d)$ will be absorbed by the banker as rent. The higher the capital to deposit ratio, the higher the rent the banker gets.

In Diamond-Rajan (2000), we show that when there is uncertainty, the banker's rent cannot generally be driven to zero. The reason is simple, a zero capital bank would experience frequent runs and failure, and so the optimal level of capital is positive. Based on these results, we could introduce residual uncertainty at date 1 to prevent banks from eliminating rents at date 1. For simplicity, and with identical results, we introduce a minimum capital requirement.

1.6. 3. Capital Requirement.

To see what rent will go to the banker, let capital be required to be a fraction k of the bank's pledgeable assets at date t. Since deposits make up the rest of the bank's liabilities, they will amount to (1-k) of the bank's pledgeable assets in value.

Example 1 Continued

If the only assets the bank has continuing into date 2 are loans to late projects from which it can collect γC, and if the capital requirement is just met, it must be that $k = \frac{\frac{1}{2}(gC - d)}{\frac{1}{2}(gC + d)}$ where the numerator on the right hand side is the date-2 value of capital, and the denominator is the value of capital plus deposits. Therefore, the total amount that can be pledged to investors at date 1 out of the amount the bank collects from borrowers at date 2 is the denominator which, on substituting for d, works out to $\frac{gC}{1+k}$. Since the total amount paid by the entrepreneur is γC, the bank absorbs $\frac{kgC}{1+k}$ in rent, an amount increasing in k. Deposits are $\frac{(1-k)}{1+k}gC$. More generally, only a fraction $1/(1+k)$ of the total date-t value of the bank can be pledged to outsiders at date t-1. The banker absorbs the remaining amount as rent.

Why might the banker issue capital instead of deposits? The problem is that deposits are a very rigid form of financing. This is good in that it disciplines the banker and enables him to commit to pay out. It is bad if there is any uncertainty in bank asset values because a drop in bank asset values will precipitate a run, disintermediating the banker, and further reducing their value. Capital can act as a buffer in such cases because, unlike deposits, its value adjusts to underlying asset values. Specifically, when there is uncertainty, Diamond and Rajan (2000) show that the optimal capital structure for the bank may involve some capital in addition to demand deposits. In the rest of the paper, we will assume there is a capital requirement of k for banks, either specified by regulatory authorities or chosen to deal with uncertainty about asset values.

1.7. Storage by banks.

Thus far, we have admitted no intrinsic differences between the investors and the banker. We now allow for such a difference. While investors can use a storage technology for consumption goods that returns 1, banks have access to a storage technology that pays out r_S at date1 when *$1* is stored at date 0. We assume

$$gC > r_S > 1 \qquad (1.2)$$

so that uninterrupted lending creates more total surplus than storage by the bank.

1.8. Bank Actions.

We assume the actions of how much to store (and hence how much is lent) as well as which loans are sold for restructuring, and which are continued, cannot be pre-specified by investors. However, investors will finance with rational expectations of bank actions, and with the knowledge that they can exercise some control rights.

We assume that there are a large number of completely symmetric banks in this economy so no bank has a significant influence on prices or quantities. Since there is a capital shortage in the economy at date 0, we normalize the total amount that each bank can raise at date 0, by offering investors the competitive rate, to $1 (assuming, of course, the bank can meet investors' opportunity rate of storage). Each bank has a large number of loans so that it is fully diversified across borrower types. Let us now determine how much each bank charges entrepreneurs and how much it pays depositors, and then what happens at date 1 as a function of date-0 decisions.

II. Date–1 Outcomes.

Since there is a capital shortage in the economy at date 0, banks will charge entrepreneurs the maximum for a loan, and offer investors the maximum value consistent with the constraints on pledgeability imposed by the capital requirement. Also, since all initial investors will want to consume at date 1, the bank should be able to raise enough at date 1 to pay them back what was promised earlier, modulo any date-1 renegotiation. Let us start by determining what rate a bank will charge entrepreneurs at date 0, then how much it can raise at date 1 to repay date-0 investors.

2.1. Lending.

The bank will charge the maximum possible on each loan it makes. Entrepreneurs can pledge to pay, at maximum, γC when they produce. So at date 0, the bank will ask entrepreneurs to pay $P_1 = \gamma C$. The entrepreneurs with early projects will repay the bank at date 1, while entrepreneurs with late projects will default and have to renegotiate their debt. The bank will then have the maximum leeway to decide how to deal with the late project – whether to restructure or preserve long run value by keeping the project as a going concern.

In order to repay all date-0 investors, the bank has available the inflow from repayments by early entrepreneurs, the amount it can raise against the loans to the late projects it keeps as going concerns, the amount it can raise by selling late projects for restructuring, and finally, the amount it can raise against storage between date 1 and date 2. Let us now see what it does in each state.

2.2. Bank Actions in Healthy State at date 1.

Let s_0 be the amount the banker stores at date 0. In the healthy state, all projects pay off early. From our earlier analysis, it follows that if d_0 is the amount depositors can claim at date 1, the amount the bank will pay out to investors at date 1, provided $s_0 r_S + (1-s_0) gC \geq d_0$ is

$$\frac{s_0 r_S + (1-s_0) gC - d_0}{2} + d_0 \qquad (1.3)$$

After paying investors, the banker keeps whatever remains of the cash inflows as rent, and consumes or reinvests it at rate 1 between dates 1 and 2.

2.2. Bank Actions in Late State at Date 1.

When the state is "Late", and some of the entrepreneurs are late, it is possible that the bank may not have enough value, or there may not be enough aggregate liquidity per bank, to pay off investors. If so, depositors will run. Let us check the conditions at date 1 to see if this happens. Let *r* be the prevailing gross interest rate between date 1 and date 2.

The α early entrepreneurs will repay γC to the bank. If the banker continues financing a late entrepreneur, he expects to collect γC at date 2 from the entrepreneur by forgiving the date-1 default, and rescheduling the date-1 payment to date 2. He can raise $\frac{\gamma C}{(1+k)r}$ in deposits and capital at date 1 against the prospective payment from late entrepreneurs. Since banks are symmetric, and since early entrepreneurs, who are the only ones at date 1 with liquid funds to invest, have limited supplies of it, we assume that if all banks offer the same rate, each bank captures a share of total funds available for deposits in proportion to the total loans it has made.[4]

The bank can also sell late projects for $c_1 + \frac{c_2}{r}$ to a suitable, cash rich, early entrepreneur. Note that this is more than the original entrepreneur can pay to retain his late project, since he can generate, at most, c_1, and he has no additional funds to pay with.[5]

If *m* is the fraction of late projects that are restructured, then the realizable value of the bank's assets at date 1 is

$$V(m,r) = r_s s_0^i + (1-s_0^i)\left[\alpha\gamma C + m(1-\alpha)(c_1 + \frac{c_2}{r}) + (1-m)(1-\alpha)\frac{\gamma C}{(1+k)r}\right] \qquad (1.4)$$

The bank can raise more in deposits against a late project than it can get by restructuring it if

$$r < R = \frac{\frac{\gamma C}{(1+k)} - c_2}{c_1} \qquad (1.5),$$

which is why the realizable value of the bank's assets fall with *m* when interest rates are less than *R*. Since the bank gets a rent from projects that are continued to date 2, it always prefers

[4] Intuitively, early entrepreneurs, when faced with a common deposit rate across banks, break ties by re-depositing their excess cash in the bank they borrowed from.
[5] The cash flow at date 2 cannot be pledged since outsiders have no way to extract it. So the cash rich early entrepreneur can pay more for the late project than the original entrepreneur can.

continuing to restructuring when r<R. The aggregate per-bank supply of the consumption good (liquidity) available to repay date-0 investors is

$$L(m) = r_s s_0^i + (1 - s_0^i)\left[a\, C + m\,(1 - a\,)c_1\right] \qquad (1.6).$$

This increases in m because restructuring creates consumption goods, while refinancing a loan does not.

At any given interest rate between date 1 and date 2, the bank's ability to raise money to repay date-0 investors and continue late projects is constrained by either its date-1 realizable value (solvency) or aggregate liquidity. Define $\overline{m}(r)$ to be $\arg\max\{Min[V(m,r), L(m)]\}$. Then $\overline{m}(r)$ is the level of restructuring that maximizes the amount the bank can raise at the interest rate r. Let us now examine how the interest rate and the amount of restructuring are jointly determined. The cases are ranked by decreasing degrees of solvency followed by decreasing degrees of illiquidity.

Case 1: Banking System is Solvent and Liquid.

First, if there is enough liquidity and solvency at date 1 for the bank to meet its claims without restructuring, the interest rate will be 1, which is the marginal return on storage between date 1 and date 2. The necessary conditions for this are that the highest realizable value of the bank's assets given liquidity conditions in the market are sufficient to pay deposits,

$$Min[V(\overline{m},1), L(\overline{m})] \geq d_0 \qquad (1.7)$$

and there is enough liquidity per bank, even without restructuring, to pay date-0 investors

$$L(0) \geq \frac{Min[V(\overline{m},1), L(\overline{m})] + d_0}{2} \qquad (1.8)$$

where the left hand side of (1.8) is the aggregate (per bank) liquidity without any restructuring, and the right hand side is the amount date-0 investors (depositors and capital) get.

Case 2: Solvent but Moderately Illiquid.

It may turn out that banks are solvent but there is not enough liquidity in the system to make the payments that date-0 investors can extract without some restructuring. The bank prefers continuing a late project to restructuring it if r<R (where R is the rate that equates the value from restructuring to the amount that can be raised against the continued project – see (1.5)).

It is straightforward to show that when there is an aggregate shortage of liquidity, the rate r goes up to R. The intuition is as follows. The bank will increase the rate r it will pay on deposits if by doing so it can continue more projects. But the bank cannot continue more projects by paying a higher rate than R: At such a rate, the amount it can raise against a continued project will be lower than the amount it can get by restructuring it, forcing the bank to restructure more, rather than fewer, projects. On the other hand, if the cost of funding is less than R, the bank can raise more by continuing a project than by restructuring it, and since this also results in more rents for the banker, he will be happy to push the rate up a little to attract more funds. Hence R is the competitive rate when there is an aggregate liquidity shortfall, if banks are solvent at this rate. From (1.5), the more illiquid the projects (the lower is c_1 compared to γC) the higher is R.

Interestingly, the liquidity shortage forces the banker to sell something that is worth $\frac{g C}{R}$ for $c_1 + \frac{c_2}{R}$. Since we know the latter term equals $\frac{g C}{(1+k)R}$, this implies in a situation of liquidity shortage, the private return to the banker of having extra liquidity is (1+k), exactly the rate at which his future revenues are discounted by outsiders. The date-1 interest rate equates the outside value of continuing to the value of restructuring, leaving the additional inside value of continuing as a foregone private return.

The necessary conditions for this case are

$$Min[V(\overline{m},R), L(\overline{m})] \geq d_0 \qquad (1.9)$$

and there is not enough liquidity per bank without restructuring to pay date-0 investors

$$L(0) < \frac{Min[V(\overline{m},R), L(\overline{m})] + d_0}{2} \qquad (1.10)$$

The equilibrium amount of restructuring is then the minimum needed; m^* that solves

$L(m) = \frac{Min[V(\bar{m}, R), L(\bar{m})] + d_0}{2}$. The banker keeps $V(m^*, R) - L(m^*)$ as rent at date 1 and enjoys an additional rent from late projects continued till date 2.

Case 3: Solvent but Severely Illiquid.

It may turn out that most projects are late. If so the banking system may be solvent (in the sense that at the highest rate R that a solvent bank would pay, it may have enough value to pay off deposits) but so illiquid that even when all projects are restructured, there is not enough consumable good to pay depositors. Specifically, if $V(1, R) \geq d_0 > L(1)$, depositors will know that there is insufficient liquidity for them to all get paid at date 1. Since they cannot be renegotiated down, and since the first one to the window will get paid in full, they will run.

As depositors come to take their money out, banks will be desperate for liquidity and will sell projects for restructuring for whatever they will fetch. Banks will try to swap their long dated assets – the date-2 cash flows on the restructured project – for the consumable goods early entrepreneurs possess after repaying their loans. Given that many projects are restructured, the price (the discount rate) of long dated assets will have to fall tremendously (rise) to clear the market. The precise consequences depend on whether depositors learn about the state at date ½ or date 1.

Run at date ½ caused by an anticipated liquidity shortage*:* Anticipating a liquidity shortfall at date 1, all depositors will run on the bank at date ½. All projects will be restructured, even the early ones, because they do not produce cash flows until date 1. Moreover, since no one has spare liquidity, banks will get just c_1 from selling the project. The interest rate going forward will effectively be infinite since date-2 cash flows from the restructured project will fetch nothing.

Banks will therefore be forced to scramble for liquidity at date ½ because they have issued demandable claims, and not just because depositors want to consume at date 1. In fact, depositors collectively would be better off waiting till date 1, because they could allow early projects to mature, and would have access to L(1) of liquidity rather than just c_1. Instead, they will be forced to join the run if there is a severe anticipated liquidity shortfall, thus forcing an unnecessary additional demand for liquidity, which will result in inefficient restructuring. In this way, the capital structure of banks, which we argue creates liquidity in times when there is adequate aggregate liquidity (by giving depositors a cast iron demandable claim to a consumable good even if there are only illiquid long dated assets backing it), absorbs liquidity when there is an aggregate shortage. Entrepreneurs, capital, and the banker will get nothing, and depositors will get a small fraction of what they are owed, or even of what they could get if their nominal claims were not so large as to make them run.

Run at date 1 caused by a current liquidity shortage: If depositors learn about the state only at date 1, they will run then. Early projects will have generated cash to pay off the bank. Moreover, early entrepreneurs will have residual cash left over (=(1-γ)C) to buy the late projects that are sold for restructuring. So there will be a finite interest rate. The rate that clears the market will equate the value of the fully restructured bank to the amount of available liquidity so that $r_S s_0 + (1-s_0)\left[agC + (1-a)[C_1 + \frac{C_2}{r}]\right] = r_S s_0 + (1-s_0)\left[aC + (1-a)C_1\right]$. Solving, the interest rate will go above R to $\frac{(1-a)C_2}{a(1-g)C_1}$.[6] Even safe long dated assets will sell at a huge discount as banks give all their value away in an attempt to garner any liquidity there is.

Even though all late projects are restructured as a result of the run, this is not inefficient since restructuring feeds the consumption needs of depositors. As a result of the run, capital, the banker, and entrepreneurs with late projects get nothing. Depositors will get a fraction of what they are owed, and all the rents will go to early entrepreneurs who are the only ones who possess the scarce liquidity.

Case 4: Conditionally Solvent and Moderately Illiquid

The next case is when there is insufficient liquidity in the system to pay off deposits without restructuring, and at the high resulting interest rate that would prevail as banks bid for liquidity to avoid restructuring, banks would become insolvent. Therefore, banks are constrained to bid lower interest rates for liquidity, even though they want to go higher, since they simply do not have the purchasing power to bid more. The conditions for this case to obtain are that an interior amount of restructuring is needed to raise enough liquidity to pay depositors

$$L(m') = d_0 \quad \text{where } 0 < m' \le 1 \qquad (1.11)$$

and that at this level of restructuring, the bank is insolvent at rate R but not at rate 1.

$$V(m',1) \ge d_0 > V(m',R) \qquad (1.12)$$

The competitive banks would therefore offer to raise new deposits to refinance continued late projects, and discount long dated portions of restructured late projects that are sold, at the highest rate that still leaves them solvent, i.e., rate r' such that

$$V(m',r') = d_0 \qquad (1.13)$$

Interestingly, in this case the moderate capitalization of banks helps them ex post, because it constrains their bidding in a situation of liquidity shortage. By constraining the rate they can offer, they limit the rents that go to those who possess liquidity. Note that in this case, the internal return to the bank of possessing an extra dollar of liquidity at date 1 is even higher than 1+k (more precisely, $\frac{gC/r'}{c_1 + c_2/r'} > \frac{gC/R}{c_1 + c_2/R} = 1+k$) because continued projects are worth even more at rate r'. On the other hand, the value to early entrepreneurs of possessing spare liquidity is limited, because interest rates are constrained by bank solvency.[7]

The banker gets no rent at date 1, but gets a rent at date 2 from continued late projects. Some entrepreneurs with late projects will be restructured, while others will survive.

The interesting point here is that the banks would not be better off with more capital – they would simply bid up the interest rate, passing more value to the liquidity-flush early entrepreneurs and reducing the total amount investors get. Note the difference from the previous

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[6] This can be shown to exceed R if the bank is solvent at the rate R.

case. When banks have no hope of attracting enough liquidity to survive, they will offer all their value in an attempt to get whatever liquidity there is. When there is enough liquidity but limited capital, saner counsel will prevail, and they will bid for the liquidity in a manner that does not render them insolvent.

Case 5: Moderate Illiquidity Leading to Insolvency

As in the previous case, liquidity is insufficient for the bank to meet deposits without some restructuring. But the restructuring drives down the value of the bank so that it is insolvent, even at the storage rate of 1. The conditions are

$$L(m') = d_0 \quad \text{where } 0 < m' \leq 1 \qquad (1.14)$$

and at this level of restructuring, the bank is insolvent at rate 1

$$V(m',1) < d_0 \leq V(0,1) \qquad (1.15)$$

Date-0 depositors will run. Depending on whether depositors learn the state at date ½ or at date 1, the run will either force all projects to be inefficiently restructured, or only force late projects to be restructured. But there is now a sense in which the run is inefficient even at date 1. The reason is that the bank serves as a kind of purchasing agent for liquidity which it then passes on to depositors. When the bank restructures more late projects as a result of the run, its purchasing power decreases even further, so there is some liquidity in the hands of early entrepreneurs that is "trapped" (see Holmstrom and Tirole (2000)) in the sense that it does not get passed on to the depositors who could best use it. Allocations after a run may be inefficient, and there typically exists a reallocation that would make everyone better off.

Case 6: Insolvent but liquid

Finally, enough projects may be late, and the capital requirement so high, that the banking system may not be able to raise enough at date 1 to pay maturing deposits even if there is plenty of liquidity around. The conditions are $L(0) \geq d_0$ and $V(0,1) < d_0$. There will be a run, the interest

[7] Because of the low reward to possessing spare liquidity in such situations, Caballero and Krishnamurthy (1999) argue that this would reduce the incentive, ex ante, to store liquidity.

rate will be 1, all late projects will be restructured, and capital and the banker will be left with nothing.

2.3. Discussion: The Sources of Inefficiency in Runs.

Deposits (optimally) suffer from a collective action problem, which helps the bank commit to pay even in good times. However, this may cause an inefficient run in bad times (the "Late" state). A run in this circumstance is inefficient for several reasons. The first, of course, is that when information about an anticipated shortage of liquidity or solvency at date 1 is revealed at date ½, all projects will be restructured, to the detriment of everyone. The anticipated shortfall at date 1 causes a rush for liquidity at date ½, forcing it to be produced in inefficient ways.

Second, a run forces all depositors to grab the liquid asset even if they do not need it immediately. The liquid claim (the deposit) is extinguished, and substituted with a lower amount of the consumable good. Thus there are fewer liquid assets in the economy after the run as liquid financial assets get exchanged for fewer liquid real assets. Also, the run allocates these fewer liquid assets not on the basis of need, but on the basis of random position in line. A slight change in the model would highlight the inefficiency of this allocation. If, for example, depositors were heterogeneous, and some were willing to consume later, a run would give even late consumers precious liquidity that they would have no immediate use for, and if no banks survived, they would have no way of infusing it back into the system.

Finally, a run destroys banks, and hence their ability to extract more from borrowers. Since the bank's "purchasing power" or "collateral value", which is normally passed through to its depositors, is extinguished, it can no longer perform its role of drawing liquid assets from early entrepreneurs and passing them on to depositors. Thus, after a run, early entrepreneurs may have spare liquidity that they cannot lend to depositors because the latter have no purchasing power.

III. Intervention at date 1

3.1. Objectives and Forms of Ex-post Interventions.

Since runs can be inefficient, the central authority (e.g., government or central bank) may intervene to prevent an incipient run. There are essentially two ways the central authority can intervene.

It can *provide liquidity* by lending consumption goods to the banks at date 1. The central authority is then the lender of last resort. A pure liquidity infusion, if large enough, need not be targeted at specific banks. It can simply be the central authority making bank deposits at random in the market. The market will then equilibrate by shifting the consumption goods where needed.

The central authority can also *provide capital* by gifting consumption goods to the bank at date 2. Recapitalizations have to be targeted since they assure the solvency of specific banks, and an infusion of capital into one part of the banking system will not spread through the system (in fact, as we will see, it can cause the reverse).

Clearly, we also have to specify where the central authority gets the goods to intervene. In order to lend as a last resort to, or recapitalize, the banking system, the central authority (or its agent) must have the ability to tax, or have wealth of its own (perhaps raised from past taxes).

In order to make a real infusion of liquidity into the system, the central authority must be able to impose current taxes. In principle, any date-1 holdings of consumption goods can be taxed, but since early entrepreneurs already infuse all their consumable goods into the system (provided there is no solvency problem), the taxes have to fall on depositors or capital. The taxes must be raised at date 1, and the future interest paid to the central authority will allow a reduction in future taxes. Note that simply raising future taxes, and assigning them to the bank in the form of a bond will not solve a liquidity crisis. Thus we want to distinguish liquidity from wealth or capital (in contrast, say to Holmstrom and Tirole (1998)).

A recapitalization can be provided either through a tax on current or future goods. The central authority can recapitalize the banking system by offering it bonds. Furthermore, the taxes needed to recapitalize can fall on any agents with wealth, be they the entrepreneurs or investors.

3.2. Why do we care what causes the crisis?

Why is it important to identify the source of the crisis and then make the right intervention in the right magnitude? The reason is that an inappropriate intervention may precipitate a worse crisis.

For example, recapitalizing a portion of the banking system when there is a moderate liquidity shortage may actually precipitate runs, which destroy much more.

For example, let us assume the system is in Case 4 of the previous section, and this information is revealed at date ½. As argued earlier, this is a situation of liquidity shortage and banks would be insolvent at the rate R that would make them indifferent between taking deposits and selling loans (the rate they want to bid for deposits). So a lower rate r' equilibrates the market. Bank capital is driven to zero, but there are no runs; Banks restructure and raise enough to just meet deposits. Now consider what would happen if, instead of infusing liquidity, the central authority saw that banks had no capital and infused capital to a segment of the banks.

These recapitalized banks would have the ability to pay higher interest rates. Since interest rates were constrained by the banks' lack of solvency to be below what banks were willing to pay to attract liquidity, interest rates will be bid up by the recapitalized banks as they try to attract all the available liquidity. If the recapitalization is small, these banks will be "just solvent" as they bid out all their wealth in order to attract liquidity. So a selective and small recapitalization will not increase the capitalization of banks that are targeted, it will merely be a transfer to those with liquidity for sale (the early entrepreneurs). More pernicious, the banks that were not recapitalized and were just solvent at the old interest rate will be insolvent at the new interest rate. They will not be able to attract enough liquidity to pay depositors at date 1, and in anticipation they will be run at date ½ with all the attendant inefficiencies. The net effect will be that the recapitalization precipitates a crisis. In fact, over a range, the more a portion of the banking system is recapitalized, the worse the crisis for the rest of the system.[8]

3.3. The Base Case: State-contingent deposits.

In general, a liquidity crisis will be resolved by an infusion of liquidity and a solvency crisis by an infusion of capital. Sometimes, however, a combination of either intervention might work (e.g., Case 5). The least cost intervention depends on whose utility the central authority maximizes. For example, consider a central authority that wants to maximize the utility of date-0 depositors and which can tax only date-0 depositors. It turns out that an intervention by an authority with such intent replicates the payout from state-contingent deposits that, ex ante, seek to pay out the maximum in expectation.

A run is caused by an excessive amount of maturing deposits (relative to available solvency or liquidity), and this is also almost always the reason for liquidation of late projects.[9] If deposits could be made state contingent, runs could be eliminated. We have assumed that the promised payment on deposits cannot be made state contingent because of the difficulty of verifying the state. So a potential objective of interventions could be to restore effective state-contingency to the level of outstanding deposits. We postpone for now the question of whether the central authority's willingness to intervene may reduce the disciplinary effect of deposits on the banker.

Intervention could reduce the effective level of deposits in the "Late" state in a number of ways. The amount withdrawn by depositors could be taxed and transferred back to the banks. Alternatively, the tax could be imposed before date 1 on deposits to allow the bank to reduce its deposits to an acceptable level. In a monetary economy there could be an inflation tax that reduces the real value of nominal deposits. It should be noted that whenever deposits are reduced without the bank incurring an offsetting future obligation, it is as if the bank obtains both liquidity and solvency with a fixed quantity of deposits.

Because there is a date 0 capital shortage, the equilibrium state contingent deposits will maximize the expected date-1 (state contingent) payments to initial depositors and capital holders given the capital requirement. An intervention that mimics the payment date-0 investors would get with equilibrium state contingent deposits, is also the least costly (ex-post) intervention financed by a tax on depositors, because it minimizes the need to tax.

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[8] Once those who are recapitalized can credibly pay out R, further recapitalization will not push the rate higher.

[9] It is possible for some parameter values that even with no deposits, capital will force some liquidation in order to get repaid.

Recall $\overline{m}^s(r) = \text{argmax}\{Min[V^s(m,r), L^s(m)]\}$ is the level of restructuring that maximizes the amount the bank can raise at the interest rate r in state s, given the level of storage at date 0. Then we have

Lemma 1: If $L^s(1) \geq V^s(1,1)$ then the maximum amount that can be paid to investors at date 1 is $\overline{d}^s = Min[V^s(\overline{m}^s(1),1), L^s(\overline{m}^s(1))]$, else the maximum amount that can be paid to investors at date 1 is $\overline{d}^s = L^s(1)$.

Proof: Omitted.

The intuition behind this lemma is that initial depositors get the maximum if early entrepreneurs get the smallest payment for their liquidity at date 1, i.e., r=1. Thus the fraction of late projects restructured that maximizes the payment to depositors is $\overline{m}^s(r=1)$, and the maximum payment to deposits plus capital is constrained to be less than or equal to $Min[V^s(\overline{m}^s(1),1), L^s(\overline{m}^s(1))]$. The problem when $L^s(1) < V^s(1,1)$ is that even when maximum liquidity is squeezed out of the banking system with all projects being restructured, there is too little available liquidity relative to what banks can raise at an interest rate of 1 by selling off all restructured projects. The interest rate will therefore rise so that the demand for liquidity (what banks can raise) will equal the supply. This higher interest rate will transfer some value to early entrepreneurs, but given the limited liquidity, there is no way of capturing that for date-0 investors.

This then implies that if payments to depositors could be state contingent, the payment in the "Late" state would be set at the amount given by Lemma 1, $\overline{d}^L$. The payment in the "Healthy" state would be set at the highest level that ensures capital requirements are just met in expectation at date 0.

As a result, if deposits cannot be made state contingent as we have assumed, they will be initially set at the high level consistent with the "Healthy" state, and if the "Late" state is realized, the central authority will intervene to make the net payment effectively $\overline{d}^L$. This will be the least cost intervention funded solely by depositors.

3.4. Other Objectives for Intervention.

Note that interventions can be justified on welfare grounds (making everyone weakly better off) if they prevent any run occurring at date ½, or if they prevent a run at date 1 due to inadequate solvency. However, intervention at date 1 merely to stop the liquidation of late entrepreneur projects will not unambiguously enhance welfare since it can reduce the amount going to date-0 investors. Of course, this could change if the central authority cared about agents other than date-0 investors. For example, the central authority might be concerned about the welfare of late entrepreneurs. In that case the authority might choose to intervene to stop the liquidation of late projects and not just intervene to stop incipient runs.

3.4. More Precise Tools for Intervention.

Thus far, we have looked only at interventions that reduce the effective level of date-0 deposits due at date 1. Unless the central authority takes a deposit claim payable after date 1 in compensation, this will be akin to a combination of a liquidity and capital infusion. Let us now look at more targeted interventions – those that provide only liquidity or only capital. We will look at a specific case; one where a liquidity shortage leads to a shortfall of solvency.

Consider Case 5 when moderate illiquidity leads to insolvency. Liquidity is insufficient for the bank to meet deposits without some restructuring. But the restructuring drives down the value of the bank so that it is insolvent, even at the storage rate of 1. The conditions are $L(m') = d_0$ where $0 < m' \leq 1$ and the bank is insolvent at rate 1 so that

$V(m',1) < d_0 \leq V(0,1)$.

Figure 3 indicates the possible interventions. Consider first a pure liquidity infusion that does not affect solvency. Let $V(m'',1) = d_0$ where $m'' < m'$. Then a loan of $L(m') - L(m'')$ of consumable goods at an interest rate of 1, financed by a tax on deposits would avert the run. In this case, however, a capital infusion that does not affect liquidity will also work. A promised infusion at date 2 of $d_0 - V(m',1)$ would give the bank enough solvency to attract the liquidity it needs at rate 1. This infusion would be financed by a tax on entrepreneurs at date 2.

Of course, the incidence of the tax depends on the precise intervention, as does the identity of the beneficiary. With a pure liquidity infusion, assuming as we do that the central authority has no hidden resource of liquidity it can call upon, the tax is borne by the date-0 investors who get a lower net payment.[10] Late entrepreneurs are particularly helped because more of their projects are continued relative to status quo.

By contrast, a pure capital infusion would help date-0 investors because there is no reduction in the fraction of late projects restructured, and all the resulting liquidity from restructuring is passed on to them. Entrepreneurs bear all the cost. Also, we can see in the graph that the most liquidity that can be paid out by the banks without a capital infusion from entrepreneurs is when $m = \overline{m}$. This can be achieved by lowering deposits to $\overline{d}$. Thus reducing deposits to the level given by lemma 1 is akin to a simultaneous capital infusion of $d_0 - V(\overline{m},1)$ and a liquidity infusion of $L(m') - L(\overline{m})$, both implicitly financed by date-0 depositors.

It is also useful to see what might go wrong with interventions, even well directed ones. Consider, for example, a capital infusion that exceeds the required amount without any accompanying liquidity infusion. Initially, the only effect this will have is to increase the banks' ability to pay for liquidity. So interest rates will go up from 1. When, however, enough capital has been infused so that the rate goes up to R, further capital infusion will not automatically leak out of the bank through higher offered interest rates. But now, the bank will have value over and above the value of deposits, so some value will have to go to pay capital. But this implies additional liquidity will have to be found, which can come only by liquidating more late projects. So an excess infusion of capital will initially push up interest rates without increasing interest rates, and will eventually result in more liquidation – an unintended consequence.

[10] Somewhat confusingly, a liquidity infusion into the banks means less overall restructuring and will mean less liquidity in the entire system.

Finally, let us consider a pure liquidity infusion intended to reduce liquidation. Consider Case 4, where the liquidity shortage does not lead to a run, but leads to some projects being restructured so $L(m') = d_0$ where $0 < m' \leq 1$. Also, at this level of restructuring, the bank is insolvent at rate R but not at rate 1, so the solvency constrained banks are forced to pay an artificially low rate r' such that $V(m', r') = d_0$. Now suppose the authority wants to intervene with an infusion of liquidity to reduce the fraction of late projects that are restructured. What interest rate should it charge if its objective is to minimize liquidation?

The answer is that it should charge an interest rate higher than r', reminiscent of Bagehot's dictum to the central bank to "lend freely but at a penal interest rate". Bagehot probably suggested the penal rate to discourage too frequent visits to the discount window. It turns out in our model that if the central authority lends at r' (though not an unlimited amount), not only will the market rate go up, but also eventually banks may have to restructure more than if a penal rate were charged.

The intuition is that if the central authority wants to stop liquidation, it will have to lend at least $d_0 - L(0)$. But if it lends at rate r', we know $V(0, r') > V(m', r') = d_0$. So at rate r', the banks will have value over and above the value of deposits. They will clearly use this to bid up the interest rate for private sources of liquidity, since it makes more sense to continue, rather than restructure, late projects at any rate below R. So the interest rate for private liquidity (that held by early entrepreneurs) will be pushed up. If $V(0, R) > d_0$, it will be pushed up to R. But since the bank's value exceeds the value of deposits at this maximum rate R, and since capital can always ask the bank to restructure projects to find the liquidity to pay it, the bank will now have to start paying out to capital in addition to depositors. If the amount of liquidity the central authority infuses is fixed, this will imply more restructuring than if it charged a penal rate $r'' > r'$ such that $V(0, r'') = d_0$.

IV. Credit vs Storage

This section is to be written. We will show that the aggregate liquidity shortages create a shadow value for the liquidity generated from storage at date 1, so that if the anticipated probability of the shortage is high, less credit will be offered. If the probability is sufficiently high, lending will be limited to make sure that banks are ex-post solvent and liquid in all states of nature. We will examine how anticipated interventions (that we may eventually be able to map into central bank policy) will affect credit creation and will provide good or bad incentives to banks.

V. Robustness

5.1. Why can't state contingent contracts pre-specify private "interventions?"

If contracts could be written contingent on observable and verifiable indicators of the state of nature, then the bank need not suffer from ex-post solvency or liquidity problems. The optimal state-contingent level of deposits provides the best outcomes of full contingent contracting between initial depositors, the banker, and entrepreneurs. If these are the only parties that a central authority could tax in a contingent way, ex-post interventions can do no better than this, and will generally not even do this well. But what prevents the full state-contingent contracts? It is important to note that some of the same factors that make it difficult to implement state contingent contacts also make it difficult to implement optimal ex-post intervention. We have nothing particularly new to say, and have not designed the model to illustrate these limits, but it is worthwhile to describe how the traditional constraints are relevant in this context.

The contracts that benefit from contingency are the demand "deposit" contracts. Non-demand contracts do not commit the bank. To discipline and commit the bank, it is important that depositors will run on the bank when the banker threatens to take (or takes) an action that imposes losses on them, even though the run collectively hurts depositors. However, without state contingent deposits, losses might be anticipated due to the state of nature and not improper actions or threats of the banker. One reason, therefore, for why contracts cannot be made state contingent is that it is hard to tell apart a deliberate action reducing the value of deposits, and an outcome beyond the banker's control.

An important point is that the relevant state variables may not be verifiable (and thus not be legally enforceable), even though they may be ex-post observable to some. In addition, each depositor must be able to verify the state at the instant he withdraws to determine if the contract has been fulfilled, which further limits the set of available contracts with small depositors. As a result, it may not be possible to avoid situations where there is an ex-post incentive to run or to restructure all entrepreneur's projects, when it is not in depositor's interests. There may be no available indicators of the exogenous state of nature.

Particularly problematic may be the use of endogenous variables that depend on the state of nature. In particular, one promising variable would be the price of the equity in a bank (or of other banks). However, this variable has two problems. First, it reflects the actions of the banker so the state of nature cannot unambiguously be inferred from the equity price. Banker holdup that reduces value and late states of nature that reduce solvency could have identical effects on equity prices. In this case, reducing the value of deposits when bank equity is low would eliminate the commitment value of deposits.

Similar problems occur when some of the information is private and cannot be used to condition contracts immediately (before any deposits are withdrawn). Runs or aborted runs would then be needed to make other depositors aware of the private information, and intervention could be ex-post desirable.

We have only sketched the constraints on contingent contracts and risk management. Once there are any such constraints there will be circumstances where particular interventions are ex-post desirable, while others are undesirable. There is room for ex-post improvement if the central authority can determine the desirable intervention at a given time. We discuss this next.

5.2. How to determine the nature of the crisis

Just as it can be difficult to describe precisely the exogenous cause of a crisis (for use in a state contingent contract), it can be very difficult for a central authority to determine the precise cause of a crisis, which is needed to figure out how to intervene.

Banks will always be insolvent at the market clearing prices that result from a crisis. In the literal context of our model, it is quite possible to determine the cause of a crisis—real returns will increase when there is a liquidity crisis, but will not when there is a solvency crisis (returns will actually fall in this case although promised return will go to infinity). Since risk free long-term real interest rates will increase in a liquidity crisis, the precise source of the shock can be identified in a closed economy. However more generally in an open economy or with nominal interest rates, or only observations of promised rates of interest, the identification is imperfect. Other factors may increase the required rate of return of investors and it may not be possible to link the increase in real rates solely to illiquidity.

One idea outside our model is that liquidity problems are system wide, but solvency can be bank specific. However, when solvency problems are system wide (as in our model), all banks will offer high promised rates of return, without stopping disintermediation. It is imperfect to use pervasiveness as an indicator of illiquidity.

When the central authority has sufficient information about the bank's balance sheet to determine its solvency at "normal" interest rates, then it should use our results to determine the best possible policy response. When it cannot, our results suggest that providing capital is potentially more dangerous. Liquidity provided when solvency is the problem will not stop a run, but it will not make it worse, and may help banks other than those who receive the liquidity. Capital provided during a liquidity-induced crisis will hurt banks that do not receive it. Even if there is imperfect information about the source of a crisis, it is important for the central authority to understand the potentially hazardous effects of solving the wrong problem.

VI. Conclusions.

When banks create liquidity by issuing demand deposits to finance illiquid lender-specific loans, any ex-post anticipated loss to depositors leads them to run. Anticipated losses can be caused by shortages of solvency or liquidity. If there is no intervention, a banking system that is unable to able to fully refinance itself will appear to be both insolvent and illiquid as the run continues. The appropriate policy response to problems in the banking system depends on cause of the problems, and potential solvency and liquidity problems interact.

Our view of liquidity creation implies that banks optimally choose deposit contracts that commit depositors to ex-post runs that may not be in the depositors collective interest. This leads to ex-post undesirable outcomes. If banks could write state contingent deposit contracts, the ex-ante desirable properties of demand deposit contracts could be obtained without ex-post undesirable outcomes. A central authority such as a central bank might want to intervene to attempt to replicate the ex-ante optimal state contingent contracts (but also might find that this requires information and commitment ability that it does not have).

The optimal intervention depends on the source of the problem, and it can be very difficult to determine the source. In circumstances when there is a liquidity shortage, lending at the equilibrium market interest rate, providing liquidity to the system, is the best intervention, but this may be ineffective when solvency is the problem. When solvency is the problem, the optimal intervention is to recapitalize banks by providing them with a future subsidy. However, recapitalization will make matters worse when solvency is not the source of banking problems.

Only in cases where a liquidity shortage in the system is the source of problems is the advice in Baghot (1873), Friedman and Schwartz (1963) or Goodfriend and King (1988) correct. Our results provide a more complete framework to analyze the best response to problems in the banking system. By examining the problem in a context where the specific lending skill role of banks, we learn about the interactions between solvency and liquidity problems and the effects on borrowers and depositors. Problems are caused both by bank failures and by banks' attempts to avoid failing. In this draft, all banks face the same ex-post shock. In a revision, we will show that when banks are ex-post heterogeneous, there is even greater scope for the wrong intervention to make matters worse than none.

References

Allen, F, and D. Gale, "Optimal Financial Crises," *Journal of Finance* 55.

Baghot, W. (1873) *Lombard Street*.

Bernanke, Benjamin, 1983, Non-monetary effects of the financial crisis in the propagation of the great depression, *American Economic Review* 73, 257-276.

Bhattacharya, S. and D. Gale [1987], "Preference Shocks, liquidity and Central Bank Policy", in *New approaches to monetary economics,* edited by W. Barnett and K. Singleton, Cambridge University Press: Cambridge.

Boyd, John and Edward Prescott [1986], "Financial Intermediary Coalitions," *Journal of Economic Theory*.

Bryan, Lowell [1988]. *Breaking Up The Bank : Rethinking an Industry Under Siege* , Dow Jones-Irwin, Homewood, IL.

Bryant, John [1980], "A Model of Reserves, Bank Runs, and Deposit Insurance," *Journal of Banking and Finance*, 4: 335-344.

Caballero, R, and A. Krishnamurthy [1999], "Emerging Market Crises: An Asset s Market Perspective," MIT Mimeo.

Caballero, R, and A. Krishnamurthy [2000], "International Liquidity Management: Sterilization Policy in Illiquid Financial Markets", mimeo, MIT.

Calomiris, Charles W. and Charles M. Kahn [1991], "The Role of Demandable Debt in Structuring Optimal Banking Arrangements" *The American Economic Review*, Vol. 81, No. 3. (Jun., 1991), pp. 497-513.

Diamond, D. W. [1984], "Financial Intermediation and Delegated Monitoring," *Review of Economic Studies* 51 (July): 393-414.

Diamond, D. W. [1991], "Debt Maturity Structure and Liquidity Risk," *Quarterly Journal of Economics*, (August).

Diamond, D. W. [1997], "Liquidity, Banks, and Markets," *Journal of Political Econom*y, 105 (October): 928-956.

Diamond, D. W. [1999], "Should Japanese Banks Be Recapitalized?" University of Chicago working paper.

Diamond, D. W. and P. H. Dybvig [1983], "Bank Runs, Deposit Insurance, and Liquidity," *Journal of Political Economy* 91, 401-419.

Diamond, D. W. and R. G. Rajan [2000], "A Theory of Bank Capital," *Journal of Finance* 55 (December): 2431-2465.

Diamond, D. W. and R. G. Rajan [2001a], "Liquidity Risk Liquidity Creation and Financial Fragility: A Theory of Banking," forthcoming *Journal of Political Economy* 109 (April).

Diamond, D. W. and R. G. Rajan [2001b], "Banks, Short Term Debt, and Financial Crises: Theory, Policy Implications, and Applications", forthcoming, *Journal of Monetary Economics: Carnegie Rochester Conference on Public Policy,* 54 (Summer).

Diamond D. W. and R. G. Rajan [2001c], "Banks and Liquidity," forthcoming, *American Economic Review, Papers and Proceedings, 2001.*

Donaldson, Glen [1992], "Costly Liquidation, Interbank Trade, Bank Runs and Panics", Journal of Financial Intermediation, 2, 1, 59-82.

Friedman, M and A. Schwartz [1963], *A Monetary History of the United States 1867-1960*. Princeton: Princeton Univ Press.

Goodfriend, Marvin, and Robert G. King (1988) “Financial Deregulation, Monetary Policy, and Central Banking,” Federal Reserve Bank of Richmond *Economic Review*, vol. 74 (May/June 1988), pp. 3–22.

Gorton, Gary, and George Pennacchi [1990]"Financial Intermediaries and Liquidity Creation", *Journal of Finance* 45: 49-71.

Hart, Oliver and John Moore, “A Theory of Debt Based on the Inalienability of Human Capital,” *Quarterly Journal of Economics*, v109 n4 (November 1994), pp. 841-79.

Hart, Oliver, *Firms, contracts, and financial structure,* Oxford and New York: Oxford University Press, Clarendon Press, 1995.

Hellwig, Martin [1994], Liquidity Provision, Banking, and the Allocation of Interest Rate Risk, *European Economic Review* v38, n7 (August 1994): 1363-89.

Holmström, B. and J. Tirole [1997], “Financial Intermediation, Loanable Funds, and the Real Sector,” *Quarterly Journal of Economics*, 52 (August): 663-692.

Holmström, B. and J. Tirole [1998], “Private and Public Supply of Liquidity,” *Journal of Political Economy* 106 (February): 1-40.

Holmstrom, B. and J.Tirole [1999], Presentation notes, Conference on Liquidity at the LSE.

Jacklin, C. J. [1987], “Demand Deposits, Trading Restrictions, and Risk Sharing,” in: E. C. Prescott, N. Wallace (eds.), *Contractual Arrangements for Intertemporal Trade*, Minneapolis: University of Minnesota Press, 26-47

Jacklin, C. and S. Bhattacharya [1988], "Distinguishing Panics and Information-based Bank Runs: Welfare and Policy Implications", Journal of Political Economy, 96 (3) 568-592.

Kashyap, A., R. Rajan, and J. Stein [1999], “Banks as Liquidity Providers: An Explanation for the Co-Existence of Lending and Deposit Taking”, mimeo, University of Chicago.

Kaufman, G. (1994), “Bank Contagion: A Review of the Theory and Evidence,” *Journal of Financial Services Research*: 8 (April): 123-50.

Kiyotaki, N. and J. Moore (2000), “Inside Money and Liquidity,” working paper, LSE.

Myers, Stewart and Raghuram Rajan (1998), “The Paradox of Liquidity”, *Quarterly Journal of Economics*, August 1998, vol 113: (3), pp 733-771.

Qi, Jianping (1998), “Deposit Liquidity and Bank Monitoring”, forthcoming, *Journal of Financial Intermediation*.

Rajan, R. [1992], “Insiders and outsiders: the choice between informed and arm's length debt”, *Journal of Finance* 47, 1367-1400.

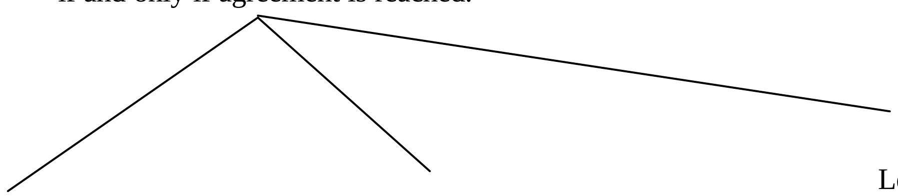
Simons, Henry [1948]. *Economic Policy for a Free Society* , University of Chicago Press Chicago, IL.

Figure 1

Bargaining at date 1 or 2 between a lender and entrepreneur

At date 2 there is no future output or future liquidation right remaining.

Entrepreneur offers an alternative current and future financial contract. Entrepreneur will supply current human capital and make the alternative current payment if and only if agreement is reached.



Lender accepts, cash produced, current payment made

Lender rejects the offer and current cash is not produced. If t=1, lender retains liquidation rights to liquidate for γC at date 2 if project is late (for 0 if not the relationship lender).

Lender rejects the offer, liquidates for γC if the project is early (or for 0 if not the relationship lender). This destroys all future output.

Figure 2

Bargaining at date 1 or 2 between a relationship lender and her creditor

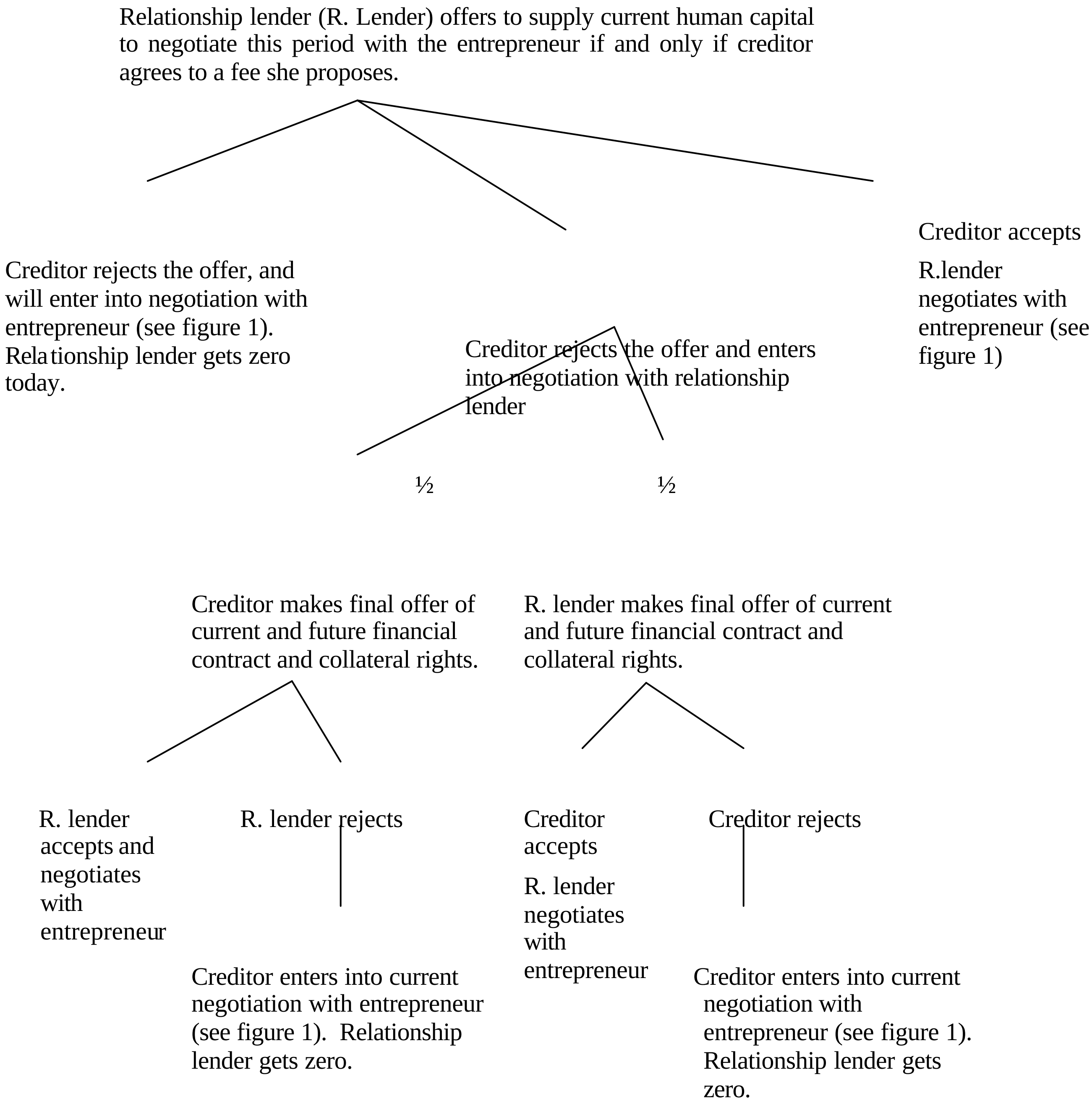


Figure 3: Case 5 and possible interventions.