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Incomplete Solvency Information as a Trigger for Systemwide Bank Runs

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ABSTRACT

This paper presents a model of bank runs and evaluates relevant policy tools. The model is founded on the historical pattern of banking panics, involving an economic boom, an adverse shock, prominent bank failures, and runs on both insolvent and solvent banks. The model analyzes various ways in which solvency information affects the likelihood of systemwide bank runs. An interesting result is that partial bank-specific information can be worse than no bank-specific information. The model can also explain runs driven by liquidity concern based on incomplete solvency information. The main policy implication derived from the model and the evaluation of policy tools is that policy actions to contain a financial crisis should incorporate weeding out insolvent institutions and assuring the solvency of remaining institutions.

KEYWORDS

Bank Runs; Financial Crisis; Financial Contagion; Lender of Last Resort; Solvency Information

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1. Introduction

In a competitive market, good businesses thrive, and bad businesses fail. Through this process, economic efficiency improves. Thus, business failures do not harm the economy if only bad businesses fail. Oftentimes, however, bank failures raise public concern for two main reasons; fundamentally solvent banks can fail, and failures of many banks can seriously disrupt overall economic activities.

Bank runs are the main mechanism that distinguishes bank failures from failures of other businesses; bank runs can force solvent banks into liquidation, and widespread bank failures can paralyze the economy. To prevent or contain bank runs effectively, policymakers need to know the root cause, but there is no consensus on it.

In a seminal paper by Diamond and Dyvig (1983), it is optimal for depositors to withdraw their deposits when they expect other depositors to withdraw. Runs would force the bank into liquidation, and the liquidation value of the bank would be less than the face value of deposits. Within this framework, their logic is indisputable. The paper, however, leaves some fundamental questions unanswered. What makes depositors expect other depositors to withdraw? Shouldn't depositors care about the solvency of their banks? According to them, a shift in expectation could depend on almost anything, including a bad earnings report, a commonly observed run at some other bank, a negative government forecast, or even sunspots. It need not be anything fundamental about the bank's condition.

The literature on bank runs flourished in the 1980s and the 1990s, inspired by massive failures of savings and loan associations in the U.S. Some studies (e.g., Waldo (1985) and Postlewaite and Vives (1987)) continued to focus on the liquidity aspect of bank runs, while some others (e.g., Gorton (1985), Chari and Jagannathan (1988), and Park (1991)) shifted the focus to the solvency of banks. Later studies look at more specific propagation mechanisms. Furfine (2003) and Ladley (2013), for example, analyze interbank risk exposure. Duarte and Eisenbach (2021) and Liu (2023) examine the effects of fire sales and asset prices on financial crises. See Gorton (2018) for a review of the literature.

At the conceptual level, one can hardly rule out any of these possibilities or choose one as the most compelling case. Each possibility is backed by a solid logic. Depositors have good reasons to worry about both liquidity and solvency. They lose money if bank runs force their bank into liquidation. They also lose money if their bank turns out to be insolvent. If two banks are financially connected, the failure of one bank can make the other bank insolvent. Fire sales depress asset prices which in turn puts many banks under water at least temporarily. These debates must be settled at the empirical level.

This paper builds on Park (1991) which singles out the lack of information about the conditions of individual banks (bank-specific information) as the main cause of systemwide bank runs. He provides a brief verbal explanation that a large number of bank failures can lead to systemwide bank runs by signaling a high proportion of insolvent banks. This paper presents an analytical model in which both bank-specific information and information about the condition of the banking system (system information) play critical roles. The model focuses on the transition from failures of some insolvent banks to widespread bank runs which is the most critical stage of banking panics. Without the transition, bank failures would not be much different from failures of other businesses; failures would be confined to insolvent banks, and bank failures would not significantly disrupt the overall economy. The crisis may be over before other problems become serious. Until many banks fail or become severely distressed, interbank risk exposure or fire sales may not produce systemwide effects.

In the model, the crisis period begins upon the occurrence of an adverse shock. Throughout the crisis period, depositors make their withdrawal decisions based on the probability that their bank is insolvent (insolvency probability). System information is important when bank-specific information is incomplete. When there is no bank-specific information, depositors update the estimate of the insolvency probability based on the number of failures in each subperiod. The likelihood of systemwide bank runs depends on the magnitude of the shock, depositors' confidence in system information, and the frequency of estimation for the insolvency probability. An interesting result is that partial bank-specific information can be worse than no bank-specific information at all. The model is also capable of linking the liquidity concern to the solvency concern; when depositors are uncertain about other depositors' estimates of the insolvency probability, they may decide to run in fear of the withdrawals by other depositors.

Historical episodes support the importance of solvency information. Park (1991), who examines policy tools used before the establishment of the Federal Deposit Insurance Corporation (FDIC), shows that the effectiveness of policy tools in containing bank runs derived largely from the provision of solvency information. The provision of liquidity was of secondary importance. Jaremski, Richardson, and Vossmeyer. (2025) analyze deposit flows after the banking holiday of 1933. During the banking holiday, the U.S. government declared that it would permit only solvent banks to reopen. After the reopening, deposits flew into those banks that were permitted to reopen early. The explanation is that earlier reopening permissions signaled stronger financial standings. This finding also suggests that depositors are primarily concerned about the solvency of banks.

The main contributions of this paper are to presents an analytical model that details the process of updating the insolvency probability and to apply the model's findings to policy evaluations. By incorporating adaptive expectations and looking at both system information and bank-specific information in a novel way, the model produces many interesting results, including the one that partial bank-specific information can be worse than no bank-specific information. With an extension, the model can also link runs driven by the liquidity concern to incomplete solvency information. Based on the key results of the model, this paper evaluates policy options in a rigorous and systematic manner. The main policy implication is that containing a financial crisis requires weeding out insolvent institutions and assuring the solvency of remaining institutions. It is also important to make solvency information widely available.

The rest of this paper is organized as follows. The next section describes the pattern of banking panics in U.S. history to match the structure of the model with the historical pattern. Section 3 presents a model showing how incomplete solvency information can lead to systemwide bank runs. Section 4 evaluates the effectiveness of policy tools used before the establishment of the FDIC and discusses the implications of their effectiveness for current policy tools. Section 5 concludes.

2. Pattern of Banking Panics

In the U.S., banking panics were recurrent before the establishment of the FDIC in 1934. Major banking panics occurred in 1837, 1857, 1873, 1984, 1890, 1907, and 1933. Banking panics are a complex phenomenon involving multiple causes. Although the main cause may vary across panics, there is a noticeable pattern. See Park (2014), Sobel (1968), and Sprague (1910) for detailed descriptions of banking panics in the U.S., and Kindleberger (1977) for the description of financial crises in other countries.

Banking panics were typically preceded by a period of economic boom, characterized by a high level of investment in the production sector and a high level of speculative activities in the financial sector. Banks accommodated the money demand arising from those activities by expanding loans. As a result, the financial position of banks became riskier (high leverage ratios and high-risk portfolios). As always, such a boom would end.

In the next phase, economic and financial excesses produced an adverse shock that could impair the financial condition of many banks. The cotton market collapsed in 1837. Overinvestment in railroads led to failures of railroad companies in 1857 and in 1873. The disclosures of fraud and embezzlement at large financial institutions shocked the financial market in 1984. The Sherman Silver Purchase Act of 1890 drained the Treasury's gold reserves and resulted in monetary disturbances that were prolonged until 1895. In 1907, some financial institutions suffered large losses from unsuccessful cornering of the copper market. The economy was in the Great Depression in 1933.

An adverse shock caused failures of some financial institutions that were insolvent and/or heavily exposed to the shock. The panic of 1837 was an exception; bank runs spread quickly after the collapse of cotton houses in New Orleans. In all other cases, failures of some prominent financial institutions were present between the adverse shock and widespread bank runs. The list of the failures that preceded a banking panic includes the Ohio Life Insurance & Trust Company which had made imprudent advances to Western Railroads (the 1857 panic), Messrs. Kenyon, Cox & Co. that had endorsed Canada Southern Railway paper (the 1873 panic), the Marine National Bank that was financially connected with an insolvent brokerage firm, Grant & Ward (the 1884 panic), National Cordage Company which was a trust company (the 1893 panic), the Mercantile National Bank that attempted to corner the stock of the United Copper company and Knickerbocker Trust Company that was financially connected with the Mercantile National Bank (the 1907 panic), and the Bank of the United States in New York City which some people mistakenly thought had a tie with the U.S. government (the 1933 panic).

The failures of some insolvent banks developed into a banking panic when depositors started running on both insolvent and solvent banks. A reasonable explanation is that depositors panicked because they became suspicious about the soundness of the banking system as a whole. Kane (1923), who served in the Bureau of Currency for 36 years, states, "Every panic that has occurred during the existence of the national banking system has found its precipitating cause in some bank or business failure occurring at a time when conditions throughout the country were favorable to disturbances." This statement suggests that a panic occurred when depositors had a reason to be suspicious about the soundness of the banking system.

Why would rational depositors, whose main concern is the solvency of banks, run on solvent banks upon observing failures of insolvent ones? It should be because they don't have sufficient information to distinguish between solvent banks and insolvent ones.

3. Withdrawal Decisions Based on Incomplete Solvency Information

This section models an economy in which depositors make withdrawal decisions to maximize their expected consumption. To maximize the expected consumption, depositors should keep their deposits at their bank until they consume if the bank is solvent and withdraw their deposits early if the bank is insolvent. Thus, depositors withdraw early if they estimate the probability of insolvency to be higher than a critical level. Depositors estimate the insolvency probability with limited information.

3.1. The Economy

The economy has three periods and only one good which can be consumed, stored costlessly (zero net return), or invested in a risky project of which the expected return per unit ($E(R)$) is greater than 1. (See Appendix 1 for variable definitions.) All agents are risk-neutral. There are ordinary individuals (to be referred to as individuals) and bankers. In the first period, individuals are identical and endowed with 1 unit of the good each. Bankers have K ($K > 1$) units of the good each and a production project. Individuals and bankers consume only in the last period of their lives. In the second period, individuals learn whether they are type 1 individuals who have one period left (live two periods) or type 2 individuals who have two periods left (live three periods). This information is private and cannot be verified to others. All bankers live three periods.

Production projects are indivisible and illiquid. Each project requires an investment of L ($L >> K$) units and takes two full periods for completion. In terms of the risk-return profile, all projects are identical in the first period. If a project succeeds, it yields R_G in the third period. In the second period, a shock can occur, and the projects affected by the shock fail. The probability of being affected by a shock (q) is the same for all project; whether or not a project is to be affected by a particular shock depends on the nature of the shock which is unknown in the first period. Failed projects are liquidated, and all liquidated projects yield R_B ($R_B < 1$) in the second period. Since $E(R) > 1$, $R_G >$

$(1 - qR_B) / (1 - q)$.

3.2. The Banking sector

Bankers open banks which take deposits from individuals and undertake their projects. In the first period, there are N banks of the same size and financial strength. Every bank invests L units of the assets (A) in its project and store the rest (S) to meet withdrawal demand in the second period. The investment and self-storage are financed with deposits (D) and the banker's endowment (K): $A = L + S = D + K$. If a shock occurs, the financial conditions of banks diverge in the second period. Affected banks become insolvent, and unaffected ones remain solvent. With these assumptions, I abstract away from the maximization behavior of banks which involves moral hazard and other complex issues. For the purpose of analyzing the role of solvency information in triggering bank runs, it does not matter how some banks become insolvent. It is enough to have a mixture of solvent banks and insolvent banks.

All deposits are demandable. Although banks cannot distinguish between type 1 and type 2 depositors, they know the probability distribution of the number of type 1 depositors and keep a sufficient portion of their assets in self-storage to cover withdrawals by type 1 depositors.

If a bank is forced to liquidate its project by either the effect of the shock or withdrawals by type 2 depositors, the liquidation value is smaller than the face value of deposits.

3.3. The Deposit contract

This paper employs a simplified version of the deposit contract in Diamond and Dyvig (1983). Their paper pays considerable attention to the consistency of the deposit contract with optimal consumption smoothing. I abstract away from this issue. For the purpose of analyzing the withdrawal decisions of depositors, I only need three key features of the deposit contract: Deposits are demandable, the liquidation value of the bank's assets is smaller than the face value of deposits, and the face value is higher in the third period than in the second period.

In the first period, all individuals deposit their endowments in a bank. Provided that their bank is solvent and liquid, depositors can withdraw the principal (1 unit) in the second period, or the principal plus interest ($1+r$ units) in the third period. If the bank becomes insolvent or illiquid in the second period, first S depositors withdraw 1 unit, and all others receive the pro rata share of the liquidation value of the bank's assets (v), which is less than 1.

Type 1 depositors consume either the principal or the liquidation value in the second period. The type 2 depositors who withdraw the principal or receive the liquidation value in the second period store the good in their self-storage to consume it in the third period. Other type 2 depositors consume $1+r$ units in the third period.

3.4. Withdrawal decisions

Type 1 depositors have no decision to make. They want to withdraw and consume the good in the second period. Type 2 depositors make withdrawal decisions in the second period to maximize the expected value of third-period consumption. In this paper, the focus is on the solvency of banks. The expected value of third-period consumption:

$$\begin{aligned} E(C) &= (1 - p_E)(1 + r) + p_E v \equiv E(C)_{wait} \qquad for\ waiters \\ &= 1 \equiv E(C)_{withdraw} \qquad for\ withdrawers \end{aligned} \tag{1}$$

where p_E is the estimated probability that the bank is insolvent.

Depositors withdraw if they estimate that $E(C)_{wait}$ is smaller than $E(C)_{\text{withdraw}}$. Setting $E(C)_{wait} < E(C)_{\text{withdraw}}$ and solving for p_E,

$$p_E > \frac{r}{1+r-v} \equiv p^*, \qquad \frac{\partial p^*}{\partial r} = \frac{1+v}{(1+r-v)^2} > 0 \; and \; \frac{\partial p^*}{\partial v} = \frac{r}{(1+r-v)^2} > 0 \tag{2}$$

A higher interest rate boosts the upside of waiting, and a higher liquidation value limits the downside of waiting. Thus, a higher interest rate and a higher liquidation value make depositors more tolerant to a higher insolvency probability.

3.5. Estimation of the insolvency probability

To analyze the contagion of bank runs, this section divides the second period into *T* sub periods: SP_1, SP_2, ⋯ and SP_T. At the beginning of SP_1, a shock can occur to make some banks insolvent. All insolvent banks fail in one of the subperiods. The number of banks affected by the shock depends on the magnitude of the shock. Upon observing the occurrence of a shock, depositors estimate the proportion of insolvent banks (insolvency ratio or system information) based on the magnitude of the shock and the likelihood of their banks having been affected (bank-specific information) based on the connection between the nature of the shock and the nature of their bank's project. The estimates are subject to large errors because assessing the effects of the shock is difficult.

When either bank-specific information or system information is complete, the outcome is obvious.

Proposition 1. When bank-specific information is complete, systemwide bank runs do not occur. Depositors run only on insolvent banks, and system information is irrelevant.

The actual probability of insolvency (p_A) is 0 for solvent banks and 1 for solvent banks. From (2), $0 < p^* < 1$. Thus, when bank-specific information is complete, $p_E = p_A = 0 < p^*$ for solvent banks and $p_E = p_A = 1 > p^*$ for insolvent banks.

Proposition 2. When system information is complete and bank-specific information is unavailable, systemwide bank runs either occur right after the shock or do not occur at all.

When there is no bank-specific information, the estimated insolvency probability for every bank is the estimated insolvency ratio. If depositors know that a large shock has made the insolvency ratio greater than p^*, they run on all banks immediately after the shock. If depositors know that the shock is not large enough to make the insolvency ratio greater than p^*, depositors do not run on any bank. Depositors with complete system information do not infer the solvency ratio from the number of failures.

Now suppose that depositors have incomplete system information and no bank-specific information. In this case, depositors update their initial estimate of the insolvency ratio each subperiod based on the number of failures in the previous subperiod (adaptive expectation). Failures of insolvent banks are stochastic, and the expected number of failures is assumed to be the same for all subperiods. That is, the unconditional probability that an insolvent bank fails in SP_t is one over the total number of *SP*s (*T*). This is the case when the conditional probability (conditional on that an insolvent bank did not fail in previous *SP*s) is one over the number of remaining *SP*s (T-t+1). For clarification, see the numerical example in section 3.6. This assumption is to make the raw number of failures a key variable, for analytical convenience. The essential feature of the model is that depositors revise the estimated insolvency probability upward (downward) when the actual number of failures turns out to be larger (smaller) than the expected number of failures. Assumptions about the expected number of failures do not affect qualitative results.

Needless to say, the revision is much more likely to entail systemwide runs when the actual insolvency ratio is higher than p^*. Given that the number of failures is stochastic, however, the actual insolvency ratio does not necessarily determine the final outcome.

At the beginning of SP_t, the estimated number of insolvent banks (bad banks) that remain,

$$NBE_t = NBE_{t-1} - NF_{t-1} + \beta\big(NF_{t-1}SPR_t - (NBE_{t-1} - NF_{t-1})\big) \tag{3}$$

where NF_{t-1} is the number of failures during SP_{t-1}, β ($0 \leq \beta \leq 1$) is the weight given to new information (adaptive expectation coefficient), and SPR_t is the number of remaining *SP*s at the beginning of SP_t which is T-t+1.

At the beginning of SP_{t-1}, depositors estimated the following: the number of remaining insolvent banks was NBE_{t-1}; $(1/SPR_{t-1})\ NBE_{t-1}$ of those would fail during SP_{t-1}; and there would remain $((SPR_{t-1}-1)/SPR_{t-1})\ NBE_{t-1}$ insolvent banks at the beginning of SP_t. Solely based on the number of failures during SP_{t-1}, the estimated number of insolvent banks remaining at the beginning of SP_t is NF_{t-1} times SPR_t. If NF_{t-1} turned out to be $(1/SPR_{t-1})\ NBE_{t-1}$, as expected, $NF_{t-1}SPR_t$ equals $NBE_{t-1} - NF_{t-1}$, and NBE_t equals NBE_{t-1} - NF_t. If NF_{t-1} deviates from $(1/SPR_{t-1})\ NBE_{t-1}$, depositors weigh the two pieces of information. The adaptive expectation coefficient (β) reflects the depositors' confidence in the previous estimate. Complete confidence means β=0, while no confidence at all means β=1.

To clarify equation (3), let's assume the following numerical values: There are 10 *SP*s (T = 10); the estimation takes place at the beginning of SP_4 (t = 4); the estimated number of remaining insolvent banks at the beginning of SP_3 is 80 (NBE_3 = 80); the adaptive expectation coefficient is 0.7 (β = 0.7), and the number of failures during SP_{t-1} is 15 (NF_{t-1} = 15). Under these assumptions, the remaining number of subperiods is 8 (3 to 10) at the beginning of SP_3 (SPR_3 = 8) and 7 (4 to 10) at the beginning of SP_4 (SPR_4 = 7). At the beginning of SP_3, depositors estimated that one eighth of the 80 banks (10 banks) would fail during SP_3 and seven eighths (70 banks) would remain at the beginning of SP_4. The actual number of failures, however, turned out to be 15, indicating that 120 banks (15 × 8) were insolvent at the beginning of SP_3 and 105 of them (15 × 7) remain at the beginning of SR_4. Depositors weigh the two pieces of information to arrive at the estimated number of insolvent banks at the beginning of SP_4 (NBE_t). When the adaptive expectation coefficient is 0.7 (β = 0.7), NBE_t is 93 (65 + 0.7(105 – 65)).

With no bank-specific information, the insolvency probability for every bank is the insolvency ratio. Algebraically, the estimated insolvency probability at the beginning of SP_t,

$$p_{Et} = \frac{NBE_t}{NR_t} = \frac{NBE_{t-1} - NF_{t-1} + \beta\big(NF_{t-1}SPR_t - (NBE_{t-1} - NF_{t-1})\big)}{NR_{t-1} - NF_{t-1}} \tag{4}$$

where NR_t is the number of remaining banks at the beginning of SP_t.

Differentiating p_{Et} with respect to NF_{t-1},

$$\frac{\partial p_{Et}}{\partial NF_{t-1}} = \frac{(1-\beta)NBE_{t-1} + (\beta SPR_t + \beta - 1)NR_{t-1}}{(NR_{t-1} - NF_{t-1})^2} \tag{5}$$

The sign of equation (5) is indeterminate. For example, $\frac{\partial p_{Et}}{\partial NF_{t-1}} < 0$ if β = 0 and $\frac{\partial p_{Et}}{\partial NF_{t-1}} > 0$ if β = 1. Note that $NRB_{t-1} < NR_{t-1}$ because not all banks are insolvent. An additional bank failure in SP_{t-1} means that there is one less insolvent bank in SP_t (elimination effect). On the other hand, a large number of failures prompts depositors to revise up the estimated number of insolvent banks (signaling effect). The relative magnitudes of the two effects depend on β and SPR_t.

Proposition 3. With no bank-specific information and incomplete system information, the likelihood of systemwide bank runs is higher when depositors have lower confidence in system information.

When depositors have lower confidence in system information (larger β), the estimate of the insolvency probability is more sensitive to the number of failures and hence more volatile. When the estimate is more volatile, it can easily exceed the critical level of the insolvency probability.

Differentiating $\frac{\partial p_{Et}}{\partial NF_{t-1}}$ with respect to β,

$$\frac{\partial^2 p_{Et}}{\partial NF_{t-1}\partial\beta} = \frac{SPR_t NR_{t-1} + NR_{t-1} - NBE_{t-1}}{(NR_{t-1} - NF_{t-1})^2} > 0. \tag{6}$$

The effect of bank failures on the estimated probability of insolvency increases with the adaptive expectation coefficient. When depositors have complete confidence in the previous estimate of the insolvency ratio (β = 0), a larger number of failures is good news to depositors of surviving banks; there remain fewer insolvent banks. With no confidence in the previous estimate (β = 1), a large number of failures fully translates into a high estimate of the insolvency ratio. Thus, the signaling effect is more likely to dominate the elimination effect when β is larger, and the opposite is the case when β is smaller.

Proposition 4. With no bank-specific information and incomplete system information, systemwide bank runs are much more likely to occur soon after the shock than with a delay.

Obviously, depositors run on all banks right after a shock if the initial estimate of the insolvency probability (p_{E1}) is higher than p^*. This possibility can explain the panic of 1837 which was preceded by the collapse of the cotton market, but not by major bank failures. Since the cotton industry was very important at that time, the collapse of the cotton market was a huge shock.

Holding the pace of failures constant, the estimated number of remaining insolvent banks decreases over time. Thus, provided that p_{E1} is below p^*, the likelihood of p_E exceeding p^* is higher in earlier periods. Within the context of this model, the effect of bank failures on the estimated probability of insolvency increases with the number of remaining subperiods, which decreases as t nears T.

Differentiating $\frac{\partial p_t}{\partial NF_{t-1}}$ with respect to SPR_t,

$$\frac{\partial^2 p_{Et}}{\partial NF_{t-1} \partial SPR_t} = \frac{\beta NR_{t-1}}{(NR_{t-1} - NF_{t-1})^2} > 0. \tag{7}$$

A large number of failures increases the estimate of per-*SP* failures. When *SPR* is small, an increase in per-*SP* failures does not translate into a large increase in the total number of remaining insolvent banks. On the other hand, the elimination effect accumulates over time. As time progresses, therefore, the signaling effect becomes weaker, and the elimination effect becomes stronger. Thus, the signaling effect has a much better chance to dominate the elimination effect in early *SP*s.

Proposition 5. With no bank-specific information and incomplete system information, the likelihood of systemwide bank runs increases with the frequency of the revision to the estimated insolvency probability.

More frequent revisions mean a larger number of *SP*s and shorter duration of each *SP*. When the duration of each *SP* is shorter, the expected number of per-*SP* failures is smaller, and the probability of a large percentage deviation from the expected number is higher. Thus, in each *SP*, the elimination effect is likely to be smaller, and the signaling effect is likely to be larger. The frequency of the revision may depend on the nature of the shock. The effects of some shocks are more uncertain than those of others. When depositors face greater uncertainty, they may revise their estimate more frequently. Rumors and panicky moods may also prompt depositors to revise the insolvency probability more frequently.

Proposition 6. The likelihood of systemwide bank runs can be higher with partial bank-specific information than with no bank-specific information.

I consider two types of partial bank-specific information. In the first case, the solvency of each bank is known to a fraction of its depositors. In the second case, depositors of some banks know the solvency of their bank, while depositors of other banks do not know the solvency of their bank. In both cases, informed depositors at insolvent banks run immediately after the shock, sharply increasing the number of failures in SP_1. The large number of failures can easily push p_{E2} above p^*. Systemwide runs occur if the partial bank-specific information is extensive enough to force many insolvent banks into liquidation immediately, but not extensive enough to prevent runs on solvent banks.

Let M_{ALL} be the total number of depositors at each bank, M_{IFM} be the number of depositors with bank-specific information (informed depositors), M_{TY1} be the number of type 1 depositors, M_{TY2} be the number of type 2 depositors, and M_{WD2} be the number of type 2 depositors who want to withdraw early.

A bank is forced into liquidation if its reserve runs out (M_{TY1} + M_{WD2} > S). If a bank is insolvent, informed depositors withdraw immediately after the shock. Thus, for an insolvent bank, M_{WD2} is the proportion of informed depositors ($M_{IFM}/M_{ALL} \equiv m_{IFM}$) times M_{TY2}. Solving for m_{IFM}, an insolvent bank fails in *SP1* if:

$$m_{IFM} > \frac{M_{STR} - M_{TY1}}{M_{TY2}} \equiv m_{IFM}{}^{*}. \tag{8}$$

For an insolvent bank, the proportion of type 2 depositors who withdraw early is equal to the proportion of informed depositors. Thus, an insolvent bank fails if the proportion of informed depositors exceeds the reserve ratio for type 2 deposits (reserves remaining after type 1 withdrawals divided by type 2 deposits). Based on this analysis, the availability of bank-specific information causes insolvent banks to fail early. By Proposition 4, a large number of failures in *SP1* makes it more likely that p_{E2} becomes higher than p^*.

Once p_{E2} becomes higher than p^*, depositors of solvent banks run on their banks. For a solvent bank, M_{WD2} is the proportion of uninformed depositors (1 – m_{IFM}) times M_{TY2}. A solvent bank is forced into liquidation if:

$$1 - m_{IFM} > \frac{M_{STR} - M_{TY1}}{M_{TY2}} \equiv 1 - m_{iFM}{}^{*}. \tag{9}$$

If m_{IFM} is the same for all banks, from equations (8) and (9), systemwide bank runs are more likely when:

$$m_{IFM}{}^{*} < m_{IFM} \frac{M_{STR} - M_{TYD1}}{M_{TY2}} < 1 - m_{IFM}{}^{*}. \tag{10}$$

It is not necessary that m_{IFM} be the same for all banks to make bank runs more likely. The basic conditions are that the share of informed depositors at many insolvent banks is large enough to force those banks into liquidation immediately after the shock and that the share of informed depositors at many solvent banks is not large enough to keep those bank liquid.

Now suppose that depositors of some banks (transparent banks) have bank-specific information on their banks, while depositors of other banks (opaque banks) do not have bank-specific information. This partial bank-specific information prompts depositors to run on transparent insolvent banks immediately. Thus, in SP_1, there are failures caused by bank-specific information, as well as stochastic failures. A large number of bank failures in SP_1 leads to a high p_{E2} by signaling a high insolvency ratio. If p_{E2} exceeds $p_E{}^*$, depositors run on opaque solvent banks in SP_2. Obviously, runs will be widespread in SP_2 if many solvent banks are opaque. Even a moderate proportion of opaque banks can make runs widespread later through interconnectedness and fire sales, which are not modeled in this paper.

An assumption in this case is that bank-specific information is available only to the depositors of each bank. If all depositors knew that some banks were insolvent, the failures of those banks in SP_1 would have no signaling effect, and the partial bank-specific information would decrease the likelihood of systemwide bank runs. The key point of Proposition 6 is that partial bank-specific information has complex effects on the likelihood of systemwide runs.

3.6. Numerical example

Let's assume the following numerical values: r = 0.03; v = 0.5; the number of *SP*s = 10; N = 2,000; the number of insolvent banks at the beginning of SP_1 = 100. From (2), p^* = 0.03/ (1+0.03-0.5) = 0.0566, and the actual insolvency ratio is 100/2000 = 0.05.

With no bank-specific information and complete system information, systemwide bank runs do not occur because the actual insolvency ratio is lower than p^*. If the number of insolvent banks is 120 to make the actual insolvency ratio 0.06, however, systemwide bank runs occur in SP_1.

Provided that an insolvent bank did not fail in previous *SP*s, its failure probability in SP_t is 1/10 for t=1, 1/9 for t=2, ---, 1/2 for t=9, and 1 for t=10 because the number of remaining *SP*s is 10 at the beginning of SP_1, 9 at the beginning of SP_2, and so on. The unconditional probability that an insolvent bank fails in SP_t is 1/10 for all *t*'s. The probability for SP_5, for example, is (9/10) (8/9) (7/8) (6/7) (1/6) = 1/10.

Suppose that the initial estimate of the insolvency ratio is the same as the actual insolvency ratio. That is, NBE_1 = 100, and p_{E1} = 100/2000 =0.05. Then systemwide runs do not occur in SP_1. From (4),

$$p_{E2} = \frac{100 - NF_1 + \beta\big(NF_1 \times 9 - (100 - NF_1)\big)}{2000 - NF_1} \tag{11}$$

Illustration of Proposition 3. The NF_1 that makes P_{E2} greater than p^* is 13 when β = 1, 14 when β = 0.7, 16 when β = .05, 22 when β = 0.3. Assuming that stochastic failures are independent events, the number of failures is binomially distributed. The probability that $NF_1 = X$:

$$P(NF_1 = X) = \frac{100!}{X!\,(100 - X)!}\big(0.1^X 0.9^{(100-X)}\big) \tag{12}$$

Under these assumptions, P($NF_1 \geq 13$) = 0.1982, P($NF_1 \geq 14$) = 0.1239, P($NF_1 \geq 16$) = 0.0399, P($NF_1 \geq 22$) = 0.0003. Thus, the probability of systemwide bank runs is 0.1982 when β = 1, 0.1289 when β = 0.7, 0.0399 when β = 0.5, 0.0003 when β = 0.3.

Illustration of Proposition 4. Let's assume that β = 1 and NF_1 = 10 as expected. Then:

$$p_{E3} = \frac{90 - NF_2 + \big(NF_2 \times 8 - (90 - NF_2)\big)}{1990 - NF_2} \tag{13}$$

In this case, $p_{E3} > p^*$ when $NF_2 \geq 14$. For 90 trials with a probability of 1/9, $P(NF_2 \geq 14)$ = 0.1225. Assuming that β = 1, NF_1 = 10, and NF_2 = 10, $p_{E4} > p^*$ when $NF_3 \geq 16$. For 80 trials with a probability of 1/8, $P(NF_3 \geq 16)$ = 0.0376. Assuming that β = 1, NF_1 = 10, NF_2 = 10, NF_3 = 10, $p_{E5} > p^*$ when $NF_4 \geq 19$. For 70 trials with a probability of 1/7, $P(NF_4 \geq 19)$ = 0.0036. In this example, the probability of systemwide runs is 0.1982 in SP_2, 0.1225 in SP_3, 0.0376 in SP_4, and 0.0036 in SP_5.

Illustration of Proposition 5. Let's assume that β = 1, the number of *SP*s is 20, and the probability that an insolvent bank fails in SP_t is 1/20 for all *t*'s. Then:

$$p_{E2} = \frac{100 - NF_1 + \big(NF_1 \times 19 - (100 - NF_1)\big)}{2000 - NF_1} \tag{14}$$

In this case, $p_{E2} > p^*$ when $NF_1 \geq 6$. For 100 trials with a probability of 1/20, P($NF_1 \geq 6$) = 0.3840. Thus, the probability of systemwide runs occurring in SP_2 is much higher when the number of *SP*s is 20 (0.3840) than when it is 10 (0.1982). The difference would be even larger if the comparison were based on calendar time. Two *SP*s of 20 *SP*s is the same calendar time as one *SP* of 10 *SP*s.

Illustration of Proposition 6. Suppose that M_{ALL} = 100, M_{TY1} = 2, M_{TY2} = 98, S = 10, and m_{IFM} is the same for all banks. Then the bank runs out of reserves if M_{WD2} > 10 – 2 = 8. All insolvent banks fail in SP_1 if more than 8 of 98 type 2 depositors are informed (m_{IFM} > 0.0816). Obviously, p_{E2} is highly likely to exceed p^* when NF_1 = 100; p_{E2} is 0.4737 when β = 1 and NBE_1 = 100, and it is 0.0474 when β = 0.1 and NBE_1 = 100. Once p_{E2} exceed p^*, uninformed depositors at solvent banks run on their banks. All solvent banks are forced into liquidation if more than 8 of 98 type 2 depositors are uninformed (1 – m_{IFM} > 0.0816 or m_{IFM} < 0.9184). Accordingly, systemwide runs are much more likely when m_{IFM} is between 0.0816 and 0.9184.

Now suppose that β = 1, NBE_1 = 100, and depositors have bank-specific information on 10 percent of banks (10 insolvent banks and 190 solvent banks). Depositors run on the 10 insolvent banks, forcing them into liquidation in SP_1. If bank-specific information is available only to depositors of each bank, depositors of other banks count the 10 failures as stochastic failures. Since $p_{E2} > p^*$ when $NF_1 \geq 13$, three or more stochastic failures in SP_1 will prompt depositors to run on all but 190 banks known to be solvent to their depositors. For 90 trials with a probability of 1/10, P ($NF_1 \geq 3$) = 0.9954.

If all depositors have the same bank-specific information, depositors exclude the 10 insolvent banks from the failure count and infer the insolvency ratio from the stochastic failures among other 90 banks. Then:

$$p_{E2} = \frac{90 - (NF_1 - 10) + ((NF_1 - 10) \times 9 - (90 - (NF_1 - 10)))}{2000 - NF_1} \tag{15}$$

In this case, $p_{E2} > p^*$ when $NF_1 \geq 23$ or the number of stochastic failures is greater than or equal to 13. For 90 trials with a probability of 1/10, P ((NF_1-10 ≥ 13) is 0.1126.

In this example, the probability of systemwide runs in SP_1 is 0.1982 when no bank-specific information is available, 0.9954 when bank-specific information is available only to the depositors of each bank, and 0.1126 when bank-specific information is available to all depositors.

3.7. Guessing games and multiple equilibria

The basic assumption in the model above is that all depositors identically process given information so that depositors with the same information come up with the same estimate of the insolvency probability. Under this assumption, depositors make withdrawal decisions based on their estimates of the insolvency probability without considering what other depositors may do. They do not play a game, so game theoretical equilibrium concepts do not apply to the model.

With the assumption relaxed, the model can combine the solvency concern and the liquidity concern to produce multiple equilibria a la Diamond and Dybvig (1983). Suppose that the estimate of the solvency probability varies across depositors; some depositors may update their estimate more frequently and/or weight new information more heavily. In this case, it is not optimal for depositors to make withdrawal decisions solely based on their own estimates of the insolvency probability.

For simplicity, let's divide type 2 depositors into two groups: Group A and Group B. Each group estimates the insolvency probability that turns out to be either higher than p^* (high insolvency probability) or lower than p^* (low insolvency probability). Withdrawals by either group force a bank into liquidation. Any group estimating a high insolvency probability withdraws deposits (RUN), forcing the bank into liquidation. When both groups estimate a low insolvency probability, however, the outcome is not necessarily waiting until the third period (WAIT).

A guessing game akin to the Keynesian beauty contest can kick in. Group A depositors choose RUN if they believe that Group B depositors estimate a high insolvency probability or if they believe that Group B depositors believe that Group A depositors estimate a high insolvency probability. Group B depositors do the same. The outcome of this guessing game is uncertain; both (WAIT, WAIT) and (RUN, RUN) qualify as a Nash equilibrium. Given that the selection of RUN by either group forces the bank into liquidation, unilaterally switching from either (WAIT, WAIT) or (RUN, RUN) lowers the payoff.

Partial bank-specific information can also trigger a guessing game when informed depositors are uncertain about the proportion of uninformed depositors. Upon observing a large number of failures, uninformed depositors at a solvent bank estimate a high insolvency probability and withdraw their deposits. Their withdrawals force the bank into liquidation if the proportion of uninformed depositors is high (higher than the critical level that can be covered by reserves). The actual share of uninformed depositors does not have to be high to force a solvent bank into liquidation.

There is no game between informed depositors and uninformed depositors because uninformed depositors withdraw regardless of what informed depositors do. However, there can be a guessing game among informed depositors leading to multiple equilibria. Divide informed depositors into two groups (Group C and Group D) and suppose the following: The proportion of uninformed depositors is low; both groups know the low proportion of uninformed depositors; and each group is not sure whether the other group knows it. In these circumstances, Group C runs on the bank if it believes that Group D does not know the low proportion of uninformed depositors or if it believes that Group D believes that Group C does not know the low proportion of uninformed depositors. Thus, both (WAIT, WAIT) and (RUN, RUN) are possible. Each group may believe that the other group will choose WAIT, or each group may believe that the other group will choose RUN.

The trigger for these guessing games is incomplete solvency information. Thus, the model focusing on incomplete solvency information can explain liquidity-driven bank runs, as well as solvency-driven runs. The model's capability to encompass both the solvency concern and the liquidity concern bolsters the importance of incomplete solvency information as the main trigger for systemwide bank runs.

4. Policy Evaluations and Implications

This section evaluates the effectiveness of policy tools employed to contain bank runs before the establishment of the FDIC and draws implications for current policy tools. A good policy tool should effectively contain bank runs, restrain moral hazard, and limit the cost to taxpayers.

4.1. Suspension of payments

Before the establishment of the FDIC, virtually all banking panics led to suspension of payments for some or all banks. When banks reopened after the suspension, runs on those banks did not recur in most cases (Friedman and Schwartz, 1963, p.329). It is not obvious why depositors would not run again.

Diamond and Dyvig (1983) claim that their model can explain why suspension of payments has been effective in containing bank runs. Since the suspension assures that the bank will not run out of reserves, type 2 depositors do not withdraw. Based on this explanation, the suspension should be more effective in preventing runs than in containing runs. If type 2 depositors expected that the bank would suspend payments before it runs out of reserves, they should not run in the first place. They limit the scope of their model by ruling out the possibility of insolvency.

Park (1991) offers an alternative explanation. According to him, the suspension served as a process of verifying solvency information. The suspension was always followed by thorough examinations conducted by banking authorities. Depending on the examination results, insolvent banks were placed in the hands of receivers for liquidation, and other banks were permitted to reopen after their solvency was confirmed. In its Annual Report of 1893, the Comptroller of the Currency made it clear that its policy was to allow only solvent banks to reopen (Park, 2014, p.74). In the model above, weeding out insolvent banks during the suspension would decrease the insolvency ratio (elimination effect) with little signaling effect. Since those closures were not stochastic outcomes, they shouldn't signal a high insolvency ratio. Thus, the estimate of the insolvency probability would be much lower when banks reopened their doors.

Weeding out insolvent banks during the suspension would not encourage moral hazard or increase the cost to taxpayers. A main problem with the suspension is that it makes the deposit contract suboptimal by disallowing type 1 depositors to withdraw on time. Unless the suspension lasts very long, however, the harm to type 1 depositors may not be large. All in all, suspension of payments appears to have been a good policy tool.

4.2. Clearing house loan certificates

Clearing house loan certificates were an interbank settlement device which were used frequently before the establishment of the Federal Reserve System. During a crisis, banks acquired the certificates by depositing qualifying assets with the Clearing House Association. Then they used the certificates in lieu of legal reserves for interbank settlements. This arrangement enabled banks to meet increased withdrawal demand without liquidating their assets. Clearly, the certificates improved the liquidity position of banks.

In addition to enhancing liquidity, the certificates conveyed information about the financial condition of banks. The Association required banks acquiring the certificates to deposit securities which would be easily marketable under normal circumstances. Furthermore, the Association considered the overall financial condition of the bank, as well as the quality of the assets deposited when it issued the certificates (Park, 2014, p.65); the Association consisted of profit-maximizing banks which had strong incentive to protect themselves. Given this nature, the certificates certified that the holder of the certificates was experiencing not a solvency problem but merely a liquidity problem; insolvent banks were not allowed to obtain the loan certificates, so the banks having the loan certificates were fundamentally solvent. In the model above, the certificates would improve bank-specific information and make system information less relevant.

The certificates were fairly effective with few side effects. Given that the certificates were issued against high-quality assets, their effects on moral hazard and the cost to taxpayers should be small, if any. Thus, the certificates were a good policy tool. At the conceptual level, one cannot assert whether it was the liquidity enhancement or the information provision that made the certificates effective. A comparison between the certificates and equalization of reserves can shed light on this issue.

4.3. Equalization of reserves

The New York Clearing House Association adopted equalization of reserves only once in 1873. It was a practice of centrally pooling all legal reserves of member banks in an emergency and granting member banks equal access to the centralized reserve pool. With the arrangement, the legal tender belonging to the member banks became a common fund.

Apparently, equalization of reserves should relieve the banks with insufficient reserves from difficulties of settling balances with other banks. In addition, it should reduce stochastic withdrawal risks; the aggregate risk is lower when independent risks are pooled. Thus, for the purpose of enhancing liquidity, equalization of reserves may be superior to clearing house loan certificates. It does not improve solvency information, however. In the model above, it would not change system information, and it would obscure bank-specific information.

Soon after the adoption of equalization of reserves, depositors ceased running on the particular banks targeted previously. However, they started withdrawing deposits from banks in general (Sprague, 1910, 51-52). Unable to withstand the withdrawals, member banks collectively suspended payments and discontinued the reserve pooling. Apparently, equalization of reserves was ineffective. Furthermore, it might encourage moral hazard by allowing weak banks to ride on the strength of other banks. Equalization of reserves deserved a failing grade. The poor outcome of equalization of reserves suggests that information provision is the main factor making policy tools effective.

4.4. Lender of last resort

A key role of central banks is a lender of last resort (LOLR). Central banks lend against eligible collateral to ensure smooth functioning of the financial market and the economy. Bagehot (1873) offers sound principles for the LOLR which are widely respected by scholars and policymakers. His explanations are lengthy and somewhat vague (part 2 of chapter 7), requiring summarization and interpretation. Although the exact wordings vary across summaries, the interpretation is basically the same: "To avert panic, central banks should lend early and freely (i.e. without limit), to solvent firms, against good collateral, and at 'high rates'" (Tucker, 2009).

The LOLR following these principles (Bagehot LOLR) can contain a financial crisis with minimal side effects. Lending without limit would address the liquidity problem. Restricting lending to solvent institutions would verify solvency information and discourage moral hazard. Securing good collateral would lighten, if not eliminate, the potential burden on taxpayers. Bagehot wanted "a very high rate of interest" to discourage borrowings by banks that did not have an urgent need. Charging a high interest rate might also discourage moral hazard by penalizing low-liquidity institutions. With early intervention, central banks could contain a crisis more easily and minimize economic disturbances. It is also consistent with Proposition 4 above.

With the Bagehot LOLR, bank runs would not force solvent banks into liquidation because solvent banks could turn illiquid assets into cash. Thus, if depositors were concerned only about the liquidity of banks, the Bagehot LOLR would make it unnecessary for depositors to worry about whether or not other depositors would withdraw. It would even make deposit insurance redundant.

Solvency must matter. If depositors are suspicious about the solvency of their bank, they should still worry about their money. The Bagehot LOLR would not lend to insolvent banks. Even if it did, insolvent banks would run out of good collateral. Thus, solvency information plays a critical role. To prevent systemwide runs, the LOLR should effectively convey solvency information to depositors.

The LOLR should combine lending with the provision of solvency information. For example, it may set a threshold level of lending as a percentage of assets which should be sufficient to meet liquidity needs in normal circumstances. If a shock occurs and some banks request credit that exceeds the threshold level, the LOLR may grant it and conduct a special examination at the same time. Based on the examination results, the LOLR may pledge unlimited lending to solvent banks and stop lending to insolvent ones. The LOLR should make the examination results and its intention public for two purposes: The failures of insolvent banks later would not signal a high insolvency ratio among remaining banks; and depositors would view the acquisition of LOLR loans not as a sign of weakness but as a sigh of strength. The failures of insolvent banks should not harm the banking system much. Bagehot (1873, p.97) opines: "No advances indeed need be made by which the Bank will ultimately lose. The amount of bad business in commercial countries is infinitesimally small fraction of the whole business. ---. The great majority, the majority to be protected, are the 'sound' people, the people who have good security to offer."

An important issue is how heavily the LOLR should penalize low-liquidity banks through high interest rates. Not so heavily, I argue. The interest rate should only be moderately higher than the equilibrium interest rate that would prevail in normal circumstances. The LOLR would be useless if it charged such a high interest rate that borrowings from the LOLR would be as bad as fire sales of assets. Maintaining a large amount of liquidity during normal times may not improve economic efficiency. Rather, it can be a waste of resources. A valuable function of the LOLR is to allow banks to economize liquidity holdings by pooling reserves. At the individual level, the liquidity need can fluctuate significantly. Economywide, however, the liquidity need may be fairly stable, except in crisis periods, which may be considered as disequilibria. It is a misconception that all institutions should maintain sufficient liquidity to protect themselves or that the market price of liquidity should determine the optimal amount liquidity for each entity. The optimal amount of liquidity may depend on institutional arrangements which typically involve the public sector. Bagehot did not mention about penalizing low-liquidity banks. He proposed a very high rate of interest to conserve the reserves at the Bank of England by discouraging precautionary borrowings by banks with no urgent need. At that time, England was not under the fiat money system, so the Bank of England could not just print money.

4.5. Deposit insurance

Deposit insurance is a blatant way to prevent bank runs. If government fully insures deposits, bank runs should not occur, regardless of the underlying cause of bank runs (liquidity or solvency). Deposit insurance, however, would encourage moral hazard and increase the potential cost to taxpayers. Because of the side effects, some studies suggest that the net benefit of deposit insurance may be negative (e.g., Anginer, Demirgüç-Kunt, and Zhu (2014) and Calomiris and Jaremski (2016)).

Although quantifying the net benefit of deposit insurance is beyond the scope of this paper, the analyses above offer valuable insights into the necessity of deposit insurance. It is not really critical to protect the depositors of insolvent banks because failures of insolvent banks should not be much different from failures of other businesses. Some policy tools that provide solvency information can effectively prevent bank runs from spreading from insolvent banks to solvent ones. Provided that it is not necessary to prevent bank runs completely and that deposit insurance as a tool to prevent bank runs is substitutable to a reasonable extent, other policy tools involving much smaller side effects may produce larger net benefits.

There is a potentially large benefit of deposit insurance that deserves more attention, however. Market discipline is beneficial, but it is not costless. Suppose that without deposit insurance, all depositors, small and large, would have to evaluate the solvency of their bank once a month. The aggregate cost of decentralized information processing by a huge number of depositors could be very large. It could be like an economywide increase in transaction costs. Avoiding this cost can be considered as a main benefit of deposit insurance. Quantifying the cost of information processing might be a valuable contribution.

4.6. Modern Financial Markets

Needless to say, financial markets today are different from those in the 19th century. Modern facial markets have more safeguards against old problems, but face some new challenges. Central banks provide liquidity more reliably, and deposit insurance protects most depositors. On the other hand, the complexity of financial markets and technological advances make it more difficult to prevent and contain bank runs.

With central banking and deposit insurance, the risk of bank runs is much lower, but it persists. The presence of a central bank makes the LOLR more formal and reliable, but the LOLR is not a new device. Deposit insurance does not eliminate bank runs because it has coverage limits.

In developed financial markets, nonbank financial institutions (nonbanks) have prominent market shares. Many nonbanks are large and susceptible to shocks because they hold and trade complex financial products that are highly risky. The failures of large nonbanks can destabilize the entire financial market. It is very difficult to insulate banks from financial market turmoil. Formally extending the Bagehot LOLR to nonbanks would be a good policy. The Bagehot LOLR has not much to lose and very much to gain from formally serving non-bank financial institutions based on transparent rules. As discussed above, the Bagehot LOLR would not encourage moral hazard or increase the cost to taxpayers much. At minimal costs, it could protect banks, the overall financial market, and the economy much more effectively.

With advanced technologies, bank runs can occur and spread superfast. Information/misinformation disseminates through social media within seconds, and withdrawals take only a few minutes online. In these circumstances, banks and banking authorities have little time to take appropriate actions. These are technical issues that can be resolved, however. Park (2023), for example, proposes a deposit insurance scheme that can contain superfast runs. Under the scheme, deposit insurance has modest coinsurance; banks have the authority to invoke deposit insurance, forcing withdrawers to pay their coinsurance portion; and if a bank is verified to be solvent after an examination, the bank uses the coinsurance money to reward those depositors who have patiently waited for the examination result. This scheme should discourage reactionary runs and allow banking authorities to secure time to verify solvency information.

In sum, although circumstances have changed, the basic principles remain the same.

5. Conclusion

This paper has presented a model consistent with the historical pattern of banking panics. Banking panics were typically preceded by a period of economic boom and credit expansion. Resulting economic and financial excesses were followed by an adverse shock that made many banks insolvent. Some of the insolvent banks failed. A banking panic occurred when depositors started running on solvent banks, as well as insolvent ones. This pattern suggests that initially, the main concern of depositors is the solvency of banks, as opposed to liquidity, and hence that the solvency concern is the main trigger for systemwide runs.

The model analyzes the roles of both bank-specific information and system information. When there is no bank-specific information, the proportion of insolvent banks is the insolvency probability for every bank. Upon observing a shock, depositors estimate the insolvency probability initially based on the perceived magnitude of the shock and update the estimate based on the number of failures throughout the crisis period. The likelihood of systemwide bank runs is higher when depositors have lower confidence in system information, higher soon after the shock than later, and higher if depositors revise their estimate of the insolvency probability more frequently. Another key result is that partial bank-specific information can increase the likelihood of systemwide runs by shifting the failures of insolvent banks to the early stage of crises. It is also possible that uncertainty about other depositors' estimates of the insolvency probability raises the liquidity concern leading to systemwide runs.

Historically, a policy action to contain bank runs was highly effective when it involved weeding out insolvent banks and assuring the solvency of remaining banks. Providing liquidity was of secondary importance. These findings suggest that any policy action to prevent or contain bank runs should focus primarily on providing solvency information. Lending against good collateral only to solvent institutions, as suggested by Bagehot (1873), is a good policy because such lending may signal the solvency of borrowing institutions. The lending policy may become even more effective if it is accompanied by a formal solvency examination and a public disclosure of the examination result.

This paper adds to the literature in several respects. By detailing the process of updating the insolvency probability, this paper clarifies the propagation mechanism of banking panics. The model is realistic and comprehensive. It is realistic in that it is based on the historical pattern. It comprehensively looks at both system information and bank-specific information to present many interesting possibilities, including the one that partial bank-specific information can be worse than no bank-specific information. Another contribution is the evaluation of policy options in a rigorous and systematic manner.

This paper also discusses a way to link the solvency concern and the liquidity concern. For future research, it can be fruitful to derive rigorously the conditions under which the solvency concern arising from incomplete information leads to the liquidity concern involving an expectations game. Another important topic is protecting banks and the financial market effectively and efficiently from turmoil caused by distressed nonbank financial institutions.

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Conflict of interest

The author claims that the manuscript is completely original. The author also declares no conflict of interest.

Appendix

A1. Variable Definitions.

A	amount assets per bank ($A = L + S = D + K$)
C	consumption per individual
D	amount of deposits per bank
K	banker's endowment and bank's equity capital ($K > 1$)
L	required amount of investment per project ($L >> K$)
m_{IFM}	proportion of informed depositors (M_{IFM}/M_{ALL})
M_{ALL}	number of depositors per bank,
M_{IFM}	number of informed depositors at each bank
M_{TY1}	number of type 1 depositors at each bank
M_{TY2}	number of type 2 depositors at each bank
M_{WD2}	number of type 2 depositors who want to withdraw early
N	initial number of banks
NBE_t	estimated number of insolvent banks at the beginning of subperiod t
NF_t	number of failures during subperiod t.
NR_t	number of remaining banks at the beginning of subperiod t
p^*	critical level of the insolvency probability (withdraw if $p_E > p^*$)
p_A	true probability that a bank is insolvent
p_E	estimated probability that a bank is insolvent.
q	ex ante probability that a project is affected by a shock
r	interest rate on deposits
R	gross rate of return from the investment project
R_B	gross rate of return from a failed or liquidated investment project
R_G	gross rate of return from a successful investment project
S	amount of liquid assets (reserves) per bank
SP	subperiods within the second period (decision period)
SP_t	subperiod t
SPR_t	number of remaining subperiods at the beginning of subperiod t
T	number of subperiods
type 1	depositors who need to withdraw early
type 2	depositors who do not need to withdraw early
v	per-depositor share of the liquidation value of the bank's assets
β	weight given to new information ($0 \leq \beta \leq 1$)

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