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Banks, Payments, and Coordination

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Banks are modeled as Bryant/Diamond–Dybvig "insurers" against the risk of early consumption. Consumption claims must be verified by clearing and settlement. A clearinghouse does this efficiently as long as banks are sufficiently liquid. If liquidity requirements cannot be enforced against all banks, then the threat of panics is necessary to induce banks to hold sufficient liquidity. If the clearinghouse can issue emergency currency, then banks can coexist with less liquid institutions. However, if banks' return to holding reserves is low during "normal times," then there must be times when the return to liquidity is abnormally high. We associate these episodes with the panics of the National Banking Era. *Journal of Economic Literature* Classification Numbers: 042, 311, 314.

I. INTRODUCTION

In the National Banking period from 1864 to 1913 the American banking system was subject to recurrent widespread runs known as panics. Following Bryant (1980) and Diamond and Dybvig (1983), numerous papers have theorized about bank panics (for a survey see Bhattacharya and Thakor, 1993). While there is no shortage of viable theories of runs on individual

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banks, a less-developed aspect of the recent bank-panic literature is the propagation mechanism that leads from a run on one bank to a bank panic. The proximate goal of this paper is a better understanding of such a mechanism.

Our analytical innovation is to allow depositors to be "mobile" across banks, and thus to allow for a nontrivial role for the clearing and settlement of interbank payments. Reserves are required to settle payments in our model, and it is the scramble for reserves in times of high reserve demand, combined with the incentive to free ride on others' holdings of reserves, that can lead to a panic. A well-enforced reserve requirement, in conjunction with the sure knowledge that other banks are not experiencing a run, can alleviate the uncertainty regarding the sufficiency of reserves and eliminate panics.

Our analysis follows Bryant (1980), Diamond and Dybvig (1983), and Chari (1989). In the Bryant/Diamond–Dybvig models, runs arise even in the absence of payoff risk in banks' assets. If some of the banks' assets are illiquid, then runs can occur if too many people believe that too many other people are withdrawing their bank deposits. Both Bryant (1980) and Diamond–Dybvig (1983) envision deposit insurance as an appropriate remedy for this problem, while Chari finds that a suspension of convertibility rule, combined with a reserve requirement and an interbank market for reserves, can eliminate the problem of runs and panics (system-wide runs) in a community of banks.

An obvious implication of analyses such as Chari's is that the governmental banking safety net put in place by the creation of the Federal Reserve System and the Federal Deposit Insurance Corporation may have been unnecessary. These studies suggest that cooperative agreements between private parties could have protected at least as well. This argument is supported by the historical responses of private banks to the problem of panics. For example, Timberlake (1984), Gorton (1985), and Gorton and Mullineaux (1987) discuss the quasi-regulatory role of bank clearinghouse associations during the period 1864–1913. Through a combination of devices such as capital and reserve requirements, frequent examinations to guarantee the quality of members' assets, and the issuance of emergency currency in the form of "loan certificates," clearinghouses were able to lessen the effects of panic-induced liquidity strains on their member banks and the banks' customers.

However, Donaldson's (1992a, 1993) studies reject the benign view of bank panics implicit in the recent literature on clearinghouses. Donaldson presents evidence in favor of a monopolistic model of the market for bank reserves during the pre-1914 bank panics. He argues that during the panics, large banks, and particularly members of the New York Clearing House Association, were able to earn excess risk-adjusted rates of return. This argument implies that, while pre-1914 banking arrangements may have represented something close to Pareto-efficiency, such arrangements could be less than desirable now because of their associated distributional consequences. Donaldson's work raises another question concerning bank panics and the efficiency of the private-sector arrangements designed to ameliorate their effects: why were the parties who earned the largest profits during panic periods (the large New York banks) the strongest advocates of a central banking institution that would ostensibly aim to prevent panics?

Our work points to the inability of the clearinghouse organizations to compel universal membership as a fatal flaw in the private system of regulation that existed in the National Bank period. While we believe that the clearinghouses did attempt to solve the problems of reserve provision in light of uncertain reserve demand and supply as Gorton, Mullineax, and Timberlake suggest, they were unable to prevent cheating on reserve requirements of nonmembers, nor were they able to prevent the establishment of the trusts, a particularly illiquid type of intermediary, that nonetheless offered payment services. Our results are consistent with Donaldson's, but are derived in a competitive framework.

We will address these issues in the following fashion. First, in Section II we present a stylized model of a banking industry that permits efficient interbank clearing and settlement. Second, in Section III we present a set of sufficient restrictions on banks' behavior to guarantee a rational expectations equilibrium implementation of the efficient allocation. Third, we show that, absent one of these restrictions, an inefficient outcome can be supported by another rational expectations equilibrium, the inefficient equilibrium being more sustainable in a well-defined sense than the efficient equilibrium. Finally, in Sections IV and V we relate these two equilibria to the historical phenomenon of bank panics and the efficiency of present-day bank regulation. Proofs are presented in the Appendix.

II. THE MODEL

Our analysis follows Bryant (1980) and Diamond and Dybvig (1983) in assuming away any inherent riskiness on the asset side of banks' balance sheets. This assumption places our model squarely within what Calomiris and Gorton (1991) characterize as the "random-withdrawal-risk" camp of models, wherein bank panics can occur solely as a result of a random shock to liquidity preferences. There is another group of "asymmetric-information" models, e.g., Calomiris and Kahn (1991). In these, banks make risky investments, and bank panics can occur when less-than-completely informed depositors observe noisy signals related to the quality of the banks' assets.

Gorton (1988) and Calomiris and Gorton (1991) present historical evidence on bank panics that is more consistent with the second set of models than the first. They point out that reserve stringencies often occurred during the period 1864–1913, without these stringencies resulting in a bank panic. Moreover, every major bank panic was clearly preceded by a negative signal concerning the asset quality of a bank or similar institution, usually near a business cycle peak and usually coinciding with a decline in stock prices. Given these findings, an appropriate question is whether a model that abstracts from asset quality can contribute to our understanding of bank panics.

We believe that our model makes a contribution for the following reasons. First, we do not perceive the two theoretical explanations of bank panics to be necessarily mutually exclusive. It is likely that shocks to perceived asset quality were often the incendiary element in bank panics; yet it seems unlikely that perceptions of asset quality can explain all aspects of the panics. Evidence for this view is provided, for example, in Cannon's (1910, pp. 80–81) account of the money market crisis following the election of Lincoln in November 1860. This crisis caused banks to call in their loans and contract credit, resulting in interest rates exceeding 24% for the most creditworthy commercial paper issuers. On November 23, 1860, the New York Clearing House Association made its first-ever issue of loan certificates (emergency reserve currency), resulting in an immediate drop of higher-grade commercial paper rates to the neighborhood of 7–8%. Similarly, Moen and Tallman (1993) offer econometric evidence of the importance of liquidity shocks during the periods surrounding the panics of 1893, 1896, and 1907. As in the case of the Cannon anecdote above, positive shocks to the domestic gold stock are associated with sharp negative movements in short-term rates, as well as increases in industrial production.

A second reason for studying a banking model without risky investment is the difficulty in constructing models that allow for uncertainty on both sides of the banks' balance sheets. In view of this difficulty, we believe that models that abstract from investment uncertainty provide a worthwhile step toward more complete models of bank panics.

Preferences, Endowments, and Technology

Our model closely follows that of Chari (1989). Our banking industry consists of a large number of identical banks, uniformly distributed on the unit interval. Each bank is identified by an index $i \in (0, 1)$, and we refer to the index i as a "location" for convenience. However, in the analysis below, the term "location" need not imply any sort of geographical separation of banks and/or their customers. What is important in our model, as in other Bryant/Diamond–Dybvig models, is that the banks' customers not have direct access to securities markets.

At each location i there are a large number, N, of consumers, each of whom are endowed with a one-unit claim on the funds of bank i.[1] All banks are ex ante identical. Consumers (also called depositors) will eventually write checks on their bank funds to buy consumption goods. For analytical convenience, we assume that consumers do not use cash.

There are three time periods: period 0, the planning period; period 1, the intermediate period; and period 2, the final period.[2] In period 0, consumers at each location i make the only choice initially available to them, which is to deposit their claim to bank funds with bank i. Bank i can do two things with its deposits: buy bank reserves in the "world market" at a price of \$1 per unit, or invest its deposits in a project that with certainty returns \$$R$ per unit in period 2, where $R > 1$. Banks make their portfolio decision in a way that will maximize the period 0 expected utility of their customers; there are no agency problems. By assumption, individuals may not participate in these investment projects.

At each location i there are two types of individuals: Type-1, impatient people; and type-2, patient individuals. Type-1 people derive utility only from consumption during period 1, denoted c_1, and Type-2 people derive utility only from consumption during period 2, denoted c_2. The proportion of Type-1 people is $\tau \in (0, 1)$, and τ is the same across all locations, is unknown in period 0, and is a random draw from a uniform distribution on the unit interval.

We introduce a transactions role for money with a device known as "the corn merchant," as in Selgin (1993). A corn merchant is a sort of vending automaton who is always willing to supply a bushel of corn for the fixed world price of \$1 per bushel. In our model, we assume that there is at least one corn merchant who has an account at bank i and no other bank, for all $i \in (0, 1)$. All corn merchants who are customers of bank i produce a variety of corn unique to i.

To introduce a role for interbank payments in the model, we postulate preferences as follows. In period 1, Type 1 people at location i feel the need to consume during period 1. However, not just any type of consumer good will do. A certain number (density) of location i people become

[1] The clearing demand generated by having the agents place their endowment in one bank is not significantly altered by having the agents diversify over a finite number of banks. Furthermore, according to Elliehausen and Wolken (1992), even modern-day consumers use 2.72 financial institutions on average, with 2.29 of these being local institutions. Having all agents use one local bank each seems a justifiable simplification.

[2] Our analysis follows Diamond and Dybvig (1983) in modeling bank panics as an outcome of a one-shot game. The Diamond and Dybvig setup can be embedded in an overlapping generations model (see, e.g., Bryant, 1980; Champ *et al.* 1991; Freeman, 1988; or Loewy, 1991) to yield a fully dynamic environment. However, the static mode of analysis seemed more appropriate for a first attempt at modeling the role of clearinghouses.

impatient and hungry for the variety of corn available at location j. Assuming for the moment that all Type-1 people everywhere each have a \$1 bank balance at the start of period 1, then each Type-1 writes a check for \$1 to their preferred corn merchant, resulting in a *payments density* or *payments surface* $p(i, j)$.

In period 1, all banks have a proportion τ of Type-1 depositors who wish to immediately consume. However, the only products demanded by Type-1 depositors will be the products of merchants associated with a subset m of the banks. The subset $\mathbb{M}$ is of random size $\mu \sim U(\mu_l, 1)$, where $\mu_l > 0$, and membership in $\mathbb{M}$ is determined by a random locational parameter m.[3] Thus, in contrast to Chari's model, Type-1 depositors are "mobile" in that they travel to different locations to purchase their preferred consumption goods. Their purchases will determine payments $p(i, j; \tau, m, \mu)$, given by

$$p(i, j, \cdot) = \begin{cases} \tau/\mu \text{ for all } i \text{ and for all } j \in \mathbb{M} \\ 0 \text{ for all } i \text{ and for all } j \notin \mathbb{M}. \end{cases}$$

We assume that the clearing and settlement of the checks written by the Type-1 depositors are on a multilateral net basis, as was the case with the 19th century clearinghouses.[4] If these checks are each for \$1, then the net debit position $\nu(i)$ (net credit counting as a negative debit) of bank i will be defined by

$$\nu(i) = \int_0^1 [p(i, j; \cdot) - p(j, i; \cdot)]\, dj.$$

Demand for reserves is created by a *net settlement constraint.* That is, if $\nu(i)$ is positive, then bank i must settle its net debit by payment of $\$\nu(i)$ in reserves to a central clearing account. Similarly, if $\nu(i)$ is negative, then bank i receives $|\$\nu(i)|$ from the central clearing account. Settlement must occur if the corn merchants are to accept the checks of the Type-1 depositors

[3] Suppose that all the banks are arranged in a circle so that $2\pi i$ represents bank i's angular location in radians. Let $\langle i, j\rangle$ denote the arc length, or minimum angle divided by 2π, between banks i and j. Now let $m \sim U(0, 1)$ independently of τ, and let $\mu \sim U(\mu_l, 1)$ independently of m and τ, where $\mu_l \in (0, 1)$. Then the set of merchants whose products will be in demand in period 1 will be $\mathbb{M}$, defined as $\mathbb{M} = \{i \text{ s.t. } i \in (0, 1) \text{ and } \langle i, \mathbb{M}\rangle \leq \mu/2\}$.

[4] This assumption, while not necessary for our results on the existence and characterization of the equilibria, rules out many undesirable and empirically irrelevant equilibria, for example, the autarky equilibrium in which everyone pays in cash the gross amount of their purchase. These equilibria are all Pareto-dominated by the Equilibrium 1 we characterize later. The institution of multilateral net settlement around which clearinghouses formed has been adopted for centuries in virtually all well-developed banking systems.

as valid payment. The settlement constraint is motivated in our model (as in the real world) by a need for a merchant at location i to check the validity of a customer j's claim to good funds at bank j. During settlement, bank j verifies this claim, if valid, by remitting a corresponding amount of reserve funds to bank i, on a multilateral net basis. We assume that the transfer of reserves is the only feasible way of verifying this claim.

In contrast to Type-1 depositors, Type-2 depositors are indifferent as to what variety of corn they consume. In fact, we assume that in period-2 all goods become fungible at a price of unity, so there are no liquidity constraints operating during the second period.

The Market for Reserves

At the end of period 1, consumption demands by the Type-1 depositors, plus the net settlement constraint, will result in demand for reserves by banks. If each Type-1 depositor writes a check for \$1, then the aggregate demand for reserves across all banks will be

$$F(\tau, \mu) = \int_0^1 \max\{\nu(i), 0\}\, di = \tau(1 - \mu).$$

Thus, if the measure μ of the set of net creditor banks cannot fall below the lower bound μ_l, then the aggregate demand for reserves cannot rise above the amount $F_M = (1 - \mu_l) < 1$. It is fairly straightforward to calculate the probability distribution of F over $(0, 1 - \mu_l]$ as

$$G(F) = (F/F_M)(1 - \log(F/F_M)),$$

with corresponding probability density

$$g(F) = -[\log(F/F_M)]/F_M.$$

The fact that the support of $F(\cdot)$ is bounded strictly less than unity has an important implication for banks' reserve demands. Suppose that the standard deposit contract offers Type-1 depositors a constant consumption level $c_1 < F_M^{-1}$. Then aggregate average reserve holdings of $F_M c_1 < 1$ will satisfy all reserve demands resulting from Type 1 consumption demands for almost all draws of the "liquidity shocks" τ, ν, m, and μ, provided that net creditor banks are willing to lend net debtor banks the reserves necessary to settle their accounts. The remaining portion of banks' deposits $1 - F_M c_1$ would then be available for investment. In the presence of a period-1 interbank market for reserves, then, banks should be able to promise a positive rate of return to at least some of their depositors, at least some of the time.

In our model, the period-1 market for reserves has the following rules. First, only banks may participate; the "world market" where the banks initially bought their reserve holdings in period 0 is closed in period 1. Second, the market is competitive, anonymous, and symmetric; individual banks must take the interbank rate of interest as given, and the participation of all net creditor (debtor) banks in the market must be the same as for all other net creditor (debtor) banks. We denote the gross rate of interest on interbank loans as R^*.

III. EQUILIBRIUM

As there is only one nontrivial market in this model, i.e., the period-1 interbank market for reserves, the definition of equilibrium in this model consists of the appropriate definition of equilibrium in the interbank market. In our initial consideration of equilibrium, we assume that there are no sunspot-generated bank runs.

DEFINITION OF EQUILIBRIUM. Let the random triple (τ, μ, m) be defined as above, with joint probability distribution function H. Then an *equilibrium* is a constant reserve requirement L and a set of ordered pairs of (τ, μ, m)-measurable functions $[c_{1i}(\cdot), c_{2i}(\cdot)]$ indexed by $i \in (0, 1)$ and a (τ, μ, m)-measurable function $R^*(\cdot)$ such that $c_{1i}(\cdot)$ and $c_{2i}(\cdot)$ maximize the expected utility of their depositors, i.e.,

$$\int \{\tau u[c_{1i}(\cdot)] + (1 - \tau)u[c_{2i}(\cdot)]\}\, dH(\tau, \mu, m),$$

where $u(\cdot)$ represents the consumers' standard von Neuman–Morgenstern utility function with a coefficient of relative risk aversion of at least 1, subject to the following conditions:

(1) The period-1 interbank market for reserves is anonymous. $R^*(\tau, \mu, m) = \underline{R}^*(\tau, \mu)$ for almost all $i \in (0, 1)$.

(2) Equilibrium deposit contracts promise period-2 payoffs symmetric across all net creditor or all net debtor banks. $c_{2i}(\tau, \mu, m) = c_{2i'}(\tau, \mu, m)$ for almost all $i, i' \in \mathbb{M}$, and almost all $i, i' \notin m$.

(3) This is a "sequential service constraint" in the sense that banks may not condition period-1 payoffs on random events. Also, we require that $\underline{c}_1 \geq 1$, meaning that banks may not even partially suspend payments in period 1.

(4) Depositors may not lose money; period-2 bankruptcy is not an option for banks. $c_{2i}(\tau, \mu, m) \geq 1$ for almost all i, (τ, μ, m).

(5) Deposit contracts must be incentive compatible in the sense that Type 2's should have no incentive to consume in period 1. $c_{2i}(\tau, \mu, m) \geq c_{1i}(\tau, \mu, m)$.

(6) Payments are settled on a multilateral net basis and there are sufficient reserves for net settlement in all situations, i.e., almost surely $L \geq (1 - \mu_1)c_1(\cdot)$.

(7) Reserves are not held outside the banking system.

The following budget/market-clearing constraints must be satisfied: Define aggregate interbank loan demand as $B(\tau, \mu, m) \equiv \max\{(1 - \mu)(\tau c_1 - L), 0\}$. Then if $B(\cdot) > 0$ and $i \notin \mathbb{M}$ (i is a net debtor and borrower of reserves).

(8) $\tau c_{1i} \leq B(\cdot)/(1 - \mu) + L$,

i.e., first-period settlement for net debtors must be financed out of reserves or borrowings; and

(9) $(1 - \tau)c_{2i}(\cdot) + R^*(\cdot)B(\cdot)/(1 - \mu) \leq R(1 - L)$,

i.e., a net debtor bank must pay off its patient depositors in amounts $(1 - \tau)c_2$, and repay its interbank loans in amount $R^*B/(1 - \mu)$. These liabilities should not exceed the bank's only asset, which is the return $R(1 - L)$ from its original investment. Recall that the bank's reserves were all used up in settlement of period-1 payments.

If $B(\cdot) > 0$ and $i \in \mathbb{M}$ (i is a net creditor and lender of reserves), then

(10) $(\tau/\mu)c_1(\cdot) + (1 - \tau)c_{2i}(\cdot) \leq (L - B)(\cdot)/\mu) + c_1\tau(\mu^{-1} - 1) + R(1 - L) + R^*(\cdot)B(\cdot)/\mu$, i.e., in period 2 a net creditor bank i must pay off the corn merchant who provided $(\tau/\mu)\underline{c}_1$ units of corn to period-1 consumers at location i, and the bank must also pay off patient depositors in amount $(1 - \tau)c_{2i}$. These liabilities should not exceed the bank's assets, which are of four types: reserves not loaned in period 1, $(L - B/\mu)$; reserve funds received in settlement at the end of period 1, $c_1\tau(\mu^{-1} - 1)$; returns on the bank's investments $R(1 - L)$; and repayments of interbank loans, R^*B/μ.

Finally, it must almost surely hold that

(11) $\tau\int_0^1 c_1(\cdot)\, di + (1 - \tau)\int_0^1 c_{2i}(\cdot)\, di \leq L + R(1 - L)$,

i.e., there is an aggregate resource constraint that consumption by both types cannot exceed the future (period-2) value of bank assets.

The equilibrium reserve requirement L will be called *self-enforcing* if L

is an optimal choice for a bank's constrained objective, given equilibrium c_1, c_2, R^*.

Existence of Equilibrium

The definition of equilibrium given above requires that equilibrium deposit contracts not involve suspension of payments or liquidation of banks, that contracts adhere to a sequential service constraint, and that net settlement of period-1 payments always occurs. Though it can be shown that many such equilibria exist, we have been unable to characterize all possible equilibria. Instead, we consider two benchmark equilibria.

We state the existence of the first benchmark equilibrium as the following proposition.

PROPOSITION 1. *There exists an equilibrium (call this the "constrained-efficient equilibrium") such that c_1, c_2, and R^* are constant across all random events and all banks. In this equilibrium, $c_1 = c_2 = \underline{c} = R/[1 + (R - 1)(1 - \mu_l)]$, $R^* = 1$, and $L = (1 - \mu_l)c_1$. (All proofs are in the Appendix.)*

Note that in the constrained-efficient equilibrium, depositors are promised a constant gross return $\underline{c}$, where $1 < \underline{c} < R$, irrespective of the time they choose to draw on their funds. The social cost of the net settlement constraint is held to a minimum by the fact that interbank loans carry no interest.

We now show the existence of a second benchmark equilibrium.

PROPOSITION 2. *There exists an equilibrium (call this the "crisis equilibrium") such that $c_1 = 1$; $L = (1 - \mu_l)$; $R^*(\tau) = 1 + (R - 1)\mu_l/[\tau - (1 - \mu_l)]$ if $\tau > (1 - \mu_l)$, $R^*(\tau) = 1$ if $\tau \leq (1 - \mu_l)$; and*

$$c_{2i}(\tau, \mu, m) = \begin{cases} [1 + (R - 1)(\mu_l/\mu) - \tau]/(1 - \tau) & \text{if } i \in \mathbb{M} \text{ and } \tau > (1 - \mu_l) \\ 1 & \text{if } i \notin \mathbb{M} \text{ and } \tau > (1 - \mu_l) \\ [1 + (R - 1)\mu_l - \tau]/(1 - \tau) & \text{for all } i \text{ if } \tau \leq (1 - \mu_l). \end{cases}$$

In the equilibrium of Proposition 2, when there is an active interbank loan market, i.e., when the demand for reserves by net debtor banks exceeds their reserve holdings so that $\tau > (1 - \mu_l)$, then interbank loan rates are so high as to require all of the net debtors' surplus from investment, i.e., $(1 - \mu)(R - 1)\mu_l$ in aggregate, in order to pay the cost of borrowing reserves.

COROLLARY 1. *The reserve requirement $L = (1 - \mu_l)$ in the crisis equilibrium is self-enforcing.*

COROLLARY 2. *The equilibrium in Proposition 2 remains an equilibrium if $R^*(\tau) = 1$ for all τ except over a positive interval containing $\tau = 1$.*

IV. IMPLICATIONS

Proposition 1 confirms Chari's (1989) result for an environment with interbank payments. That is, Proposition 1 shows how a decentralized mechanism (a banking industry with a clearinghouse) can attain the same welfare as could a fully informed central planner, as long as the planner was subject to the same resource and settlement constraints as the clearinghouse. The constrained-efficient equilibrium of our model shares another feature with the equilibrium of Chari's model, which is the requirement that in order to sustain this equilibrium the clearing organization must be able to observe individual banks' reserve holdings and must be able to enforce the equilibrium reserve requirement. In other words, the reserve quantity L in the constrained-efficient equilibrium is not self-enforcing. To see this, note that equilibrium consumption in Proposition 1 is given by

$$c_1 = c_2 = 1 + (R - 1)\{1 - [(1 - \mu_1)]\underline{c}\},$$

which means that the net return promised depositors by the banks is the gross return on investment R, adjusted for the opportunity cost of holding reserves, which is $(R - 1)L = (R - 1)(1 - \mu_1)c_1$. Given an interbank real rate of zero, however, banks would prefer to hold no reserves and promise a constant level of consumption equal to the return on investment, R.

Proposition 1 is weaker than Chari's result, however, in the sense that a "full-insurance" equilibrium is not guaranteed to hold, even if all banks have access to the clearinghouse and even if a reserve requirement can be enforced. Proposition 2 shows that a less-preferred equilibrium (given sufficient risk aversion on the part of depositors) can result even when these conditions are satisfied. To guarantee the occurrence of the full-insurance equilibrium, some mechanism is required whereby the equilibrium real return on interbank loans is pegged at zero.

A comparison of the equilibria of Propositions 1 and 2 also reveals a somewhat paradoxical result concerning the organization of clearinghouses. That is, a well-run clearinghouse, like the one in Proposition 1, creates larger incentives for "chiseling" on the clearinghouse agreement than does a clearinghouse that penalizes borrowing institutions in a suboptimal fashion, such as that in Proposition 2. In the constrained-efficient equilibrium, all consumers are fully insured, but at the cost of a reserve tax that is borne equally by all consumers. In the crisis equilibrium, consumers are no longer fully insured; yet their banks are willing to hold a fairly high level of reserves (though less than they must hold in the efficient equilibrium) as protection against spikes in the interbank lending rate.

Implications for Bank Panics

With modifications, the model presented above can account for many of the observed features of the bank panics observed in the United States during the National Banking period of 1864–1913. We would characterize bank panics during this period as an outcome resembling that of the crisis equilibrium described above, in which a fairly large (though not necessarily extraordinary) demand for reserves may exist even at high real interest rates. And we would characterize nonpanic periods as representing a situation more closely resembling the constrained-efficient equilibrium, in which interbank loans of reserves are extended freely at relatively low rates.

The model above incorporates a number of assumptions that are clearly at odds with banking practice during the National Banking period. Several of these can be weakened or eliminated via algebraic manipulations of the model. One such modification would allow the holding of cash by the public. Another would incorporate branching restrictions by allowing for banks outside the central clearinghouse ("country banks" or, later on, trusts) that could not *directly* clear and settle their interbank obligations on a multilateral net basis.

With these modifications, the suboptimal equilibrium described in Proposition 2 displays a number of features of bank panics. As in Donaldson's (1992a) model, the interest rates in the crisis equilibrium correspond to those that would be charged by a rent-seeking monopolist; when the interbank market is active in the crisis equilibrium, lenders of reserves are successful in extracting all possible rents from borrowers. In contrast to the Donaldson model, the crisis equilibrium does not result from deliberate price-setting behavior on the part of the lenders, but rather an inability of banks to precommit to an efficient price for reserves, and/or an inability to enforce the reserve requirement necessary to maintain the efficient reserve market. The model also suggests why even the ex post beneficiaries of a bank panic (i.e., the lenders of reserves in the crisis equilibrium) may have an ex ante preference for some regulatory mechanism intended to prevent panics.

As pointed out in Calomiris and Gorton (1991), however, a key aspect of any putative theory of bank panics is not an explanation of why bank panics occurred during the National Banking era, but rather why bank panics did not occur more frequently during this period, even when demands for reserves were fairly large. Further, any theory of bank panics should be able to explain the conditions under which and the manner in which a transition took place from a state of "business as usual" to a state of panic.

Let us first address the issue of why bank panics were infrequent. It is clear from much of what has been written about clearinghouses of this period that most of the time the day-to-day operations of the clearinghouses closely resembled the equilibrium described in Proposition 1 above. Reserve requirements for clearinghouse member banks were typically high, e.g., 25% for the New York Clearing House Association (NYCHA). Despite the high reserve requirements, the clearinghouses tried to minimize the cost of the reserve tax associated with large transaction volumes by means of a multilateral net settlement of daily clearings, and by taking steps to guarantee a ready market for reserves among their member banks. In the case of the NYCHA, for example, Cannon (1910, p. 221) documents that the average ratio of cash reserves exchanged in settlement to gross transactions volume ("clearings") averaged about 4.5% for the years 1854–1908. Similarly, the institution of various procedures designed to ensure the quality of the member banks' assets (reports of condition and independent examinations) contributed to the liquidity of the interbank markes. Clearinghouse loan certificates made an additional source of reserves available to member banks, even in the midst of a bank panic. Reserve loans arranged via loan certificates were made at prearranged, low rates of interest (see Cannon, 1910, Chapters 10 and 11).

There is also a body of evidence to suggest that the clearinghouse banks, and particularly the NYCHA, were to some degree the victims of their own success at liquidity provision. As in the constrained-efficient equilibrium above, the clearinghouses were able to keep the cost of liquidity low by holding large amounts of reserves, settling interbank payments on a multilateral net basis, and when necessary, operating a discount window for member banks by use of loan certificates during times when cash was in great demand. One effect of these measures was to drive a wedge between the real intertemporal cost of liquidity and the real return on productive assets.

Given the fragmented nature of contemporary U.S. bank regulation, there was no shortage of parties seeking to exploit the arbitrage opportunity presented by the clearinghouses. For example, Cannon (1910, pp. 58–74) describes in great detail, and with outrage, the ease with which country banks and their customers could exploit the opportunities for float creation inherent in the NYCHA's customary procedures for clearing and collecting checks on nonmember banks. NYCHA members felt obliged by "competitive pressures" to grant customers depositing checks on country banks immediate access to funds represented by these checks, even though the lag between deposit and collection of funds from the country bank could drag on for days, if not weeks. A more serious problem was that of NYCHA members clearing and settling for nonmember financial intermediaries; this problem became more acute with the advent of bank-like intermediaries known as trusts (see Cannon, 1910, pp. 167–189; and McCulley, 1992, pp.

145–149, 199–211). Unlike the NYCHA banks, the trusts in New York State were virtually exempt from cash (specie or the equivalent) reserve requirements until after the 1907 panic.

The possibility of a bank panic, with its accompanying high reserve demands and high real rates, may have served as the clearinghouse banks' most effective weapon against loss of market share to the trusts, country banks, and other potential competitors. There is some evidence to suggest that in the case of the 1907 panic, the panic served the banks well in this regard. During the panic of 1907, deposits at New York City trusts contacted by about 40% over 2 months, according to Moen and Tallman (1992, p. 617). Most of the deposits lost to the trusts subsequently turned up in the accounts of the national banks, which experienced no runs during the panic.

Thus, from the standpoint of our model, a key question is how to incorporate the tensions resulting from the liquidity-creating actions of the clearinghouse associations on the one hand, and the attempts of trusts and other intermediaries to exploit the arbitrage opportunities created by the clearinghouses, on the other. In the following section, we present a modification of the model that attempts to capture this tension.

V. MODELING INTERMEDIARIES OUTSIDE THE CLEARINGHOUSE

The model of Section II can be extended to allow for the presence of "trusts," i.e., financial intermediaries outside of clearinghouses, and therefore not subject to a clearinghouse-wide reserve requirement. Suppose that in period 0, all intermediaries have a choice of remaining "banks" and joining the clearinghouse, or becoming "trusts" and remaining outside the clearinghouse. For algebraic simplicity, we assume that corn merchants will keep accounts only at banks. Let γ represent the proportion of financial intermediaries that join the clearinghouse. Clearinghouse members will be subject to an enforceable reserve requirement of $(1 - \mu_1)c_1^B$ where c_1^B is the constant amount promised by banks to early consumers, implying that banks will hold $\gamma(1 - \mu_1)c_1^B$ reserves in aggregate.

Trusts are not constrained in their portfolio allocations. Trusts may invest any proportion of their portfolio in the investment, which returns R in period 2, and they may hold any proportion of their investment in reserves. Not having direct access to the clearinghouse, each trust must settle the period-1 demands by their depositors by a reserves payment equal to the gross amount of checks drawn on the trust. For each individual trust, this amount will be τc_1^T, where c_1^T is the amount promised by trusts to early consumers. The aggregate period-1 reserve demand of trusts will therefore be $(1 - \gamma)\tau c_1^T$.

Suppose that it is optimal in equilibrium for trusts to hold no reserves, and suppose further that both banks and trusts offer impatient consumers the amount $\underline{c}$ as defined in Proposition 1. Then the total reserve demand in period 1, due to both banks and trusts, will be

$$F(\tau, \mu, \gamma, \underline{c}) = [\tau(1 - \mu) + (1 - \gamma)\tau]\underline{c}.$$

In contrast to the analysis of Section II, it can now happen with positive probability that aggregate reserve demand $F(\cdot)$ will exceed aggregate reserve supply $\gamma(1 - \mu_1)\underline{c}$. In this case we assume that the members of the clearinghouse can cover the shortfall by settling the clearinghouse demands with clearinghouse loan certificates, which are available at a zero real rate, while lending out their available reserve to the trusts, at the "equilibrium" rate. However, the banks' reserves $\gamma(1 - \mu_1)\underline{c}$ will cover the trusts' demands $(1 - \gamma)\tau\underline{c}$ for all values of τ only if $\gamma \geq (2 - \mu_1)^{-1}$, which we will take as a lower bound on the size of the clearinghouse. We assume that legal restrictions prevent the clearinghouse from issuing loan certificates except in cases for which the period-1 demand for reserves exceeds the total amount of reserves available. This can only happen for $\tau > \underline{\tau} \equiv \gamma(1 - \mu_1)/(2 - \mu_1 - \gamma)$.

In order for an equilibrium such as the one described in Proposition 2 to hold in the economy with trusts, it must be the case that in a state of panic, the surplus of the trusts is exhausted. Continuing to assume that the trusts' contract offers period-1 consumers $\underline{c}$ and that trusts hold no reserves in equilibrium, then evaluating the budget constraint (9) at $c_1 = c_2 = \underline{c}$ and $L = 0$ implies that in a panic,

$$R^* = R_p^* \equiv 1 + \frac{R - c}{\tau\underline{c}}.$$

In the proposed equilibrium, both banks and trusts will always offer impatient consumers the amount $\underline{c}$. If there is no panic, then the real rate on reserve loans will be zero and patient (period-2) bank depositors will also receive an amount $\underline{c}$. If there is no panic, patient trust depositors will receive $\underline{c}$ plus a prorated amount of the trust's excess return over $\underline{c}$. If there is a panic, then the real return on reserve loans will be R_p^*. Patient trust depositors will receive only $\underline{c}$, while patient bank depositors will get $\underline{c}$ plus a prorated amount of the bank's proceeds from loan of reserves to the trusts.

A complication with the extended version of the model is that there is no natural definition of what constitutes a panic that derives from the notion of a "reserve stringency," as in Proposition 2. That is, if the net settlement constraint can be relaxed by issue of loan certificates in response to a reserve stringency, it is even less clear than above what the market price of reserves should be. The analytics can be simplified if we model a panic as a response to a sunspot, i.e., a Bernoulli random variable ε, independent of anything substantive in the model, which can take on two values, "panic" with probability σ and "no panic" with probability $(1 - \sigma)$. An equilibrium may then be defined as before, with the additional restrictions that all deposit contracts should be ε-measurable, and that the expected utility of depositing funds in a trust should equal the utility of depositing funds in a bank. We can now show the following proposition.

PROPOSITION 3. *Suppose that the size of the clearinghouse $\gamma \geq (2 - \mu_l)^{-1}$. Then there exists a sunspot probability of a panic σ, such that there exists an equilibrium (the "trust" equilibrium) in which the banks' and trusts' depositors have the same ex ante expected utility when the banks' and trusts' deposit contracts offer the following:*

$$c_1^B = c_1^T = \underline{c}, \text{ almost always;}$$

$$c_2^T = \begin{cases} \underline{c}, \text{ if there is a panic} \\ \underline{c} + (R - \underline{c})/(1 - \tau), \text{ if there is no panic} \end{cases}$$

$$c_2^B = \begin{cases} \underline{c} + \dfrac{(1-\gamma)}{\gamma}\left[1 + \dfrac{(R - c)}{\tau\underline{c}(1 - \underline{c})}\right], \text{ if there is a panic} \\ \underline{c}, \text{ if there is no panic} \end{cases}$$

and

$$R^* = \begin{cases} R_p^*, & \text{if there is a panic} \\ 1, & \text{if there is no panic.} \end{cases}$$

COROLLARY. *The expected utility of depositors in equilibrium 3 exceeds that of depositors in equilibrium 1, by first-order stochastic dominance.*

Implications of Proposition 3

Proposition 3 suggests why lower-cost, but relatively illiquid, competitors such as the trusts would not necessarily have been costly for the clearinghouses and the member banks. The occurrence of panic episodes in which the returns on liquid assets were abnormally high may have served to equilibrate the utility of holding claims on the relatively liquid portfolios of city banks to the utility of holding claims on the relatively illiquid portfolios of other intermediaries.

The corollary to Proposition 3 states that the average welfare of depositors in the trust equilibrium is higher than the case of the "no-panic" equilibrium of Proposition 1. However, this result does not imply that runs represent a globally optimal outcome. Proposition 3 merely suggests that the presence of panics was one way of reconciling the simultaneous existence of both liquid and illiquid financial intermediaries, given contemporary legal constraints. The welfare gain of the trust equilibrium over the constrained-efficient equilibrium results from a reduction in the average incidence of the reserve tax. Recall that in Proposition 1 the average incidence of the reserve tax is $(R - 1)(1 - \mu_l)\underline{c}$. In Proposition 3 the average (over banks and trusts) incidence of the reserve tax is only $\gamma(R - 1)(1 - \mu_l)\underline{c}$ since only banks hold reserves in equilibrium. If the lower reserve requirement of Proposition 3 could be uniformly applied to all financial intermediaries, then a more efficient arrangement could be constructed, akin to that of Proposition 1. It is important to note, however, that the legal environment of the National Banking period effectively precluded any such arrangement; until 1907, at least, the characteristic "pyramiding of reserves" and bank panics of the National Banking era apparently constituted a more politically acceptable means of lowering the incidence of the reserve tax.

The National Banking period ended with the establishment of the Federal Reserve System. In the context of the present model, the presence of the Fed as an official lender of last resort and the Fed's subsequent policies of holding short-term interest rates at typically low real levels could be viewed as an attempt to move from the trust equilibrium to a more efficient arrangement resembling the constrained-efficient equilibrium with a lower reserve tax. Once again, this is not a statement about the global efficiency of central banking or any other system of financial intermediation. Rather, the founding of the Fed may have represented a relatively efficient use of the lower average reserve holdings that were a *fait accompli* by the end of the National Banking period.

Finally, it should be noted that in Proposition 3, a state of high reserve demand (high value of τ, low value of μ) is a necessary, though not a sufficient condition for a panic to occur. This feature of the trust equilibrium accords with the results of some empirical studies, e.g., Calomiris and Gorton (1991), that find high liquidity demands did not always result in panics. Similarly, in Proposition 3, the injection of additional liquidity into the economy via the issue of loan certificates does not necessarily mean that there will be no state of panic, a feature which is again consistent with the empirical evidence. We would caution that these features follow directly from the sunspot-driven character of panics in our model.

Gorton (1988) examined panic episodes during the National Bank period and found that they were correlated with business cycle peaks and the widely publicized failure of one or more financial institutions. Gorton interprets the subsequent panics as being consistent with a change in perceived riskiness of banks' assets by depositors. Donaldson (1992b) examined panic episodes in the 1867–1933 period and found that they were associated with a lack of liquidity, and that they were "special events" in that panic and nonpanic data were "generated by different economic systems." Because our model is atemporal, it does not address the regime change from a normal state to a panic equilibrium. However, a possible explanation for the generation of panics, consistent with our model and the empirical evidence, is that at times of high demand for reserves (business cycle peaks), a negative random shock (the failure of a particular financial institution) is interpreted by all participants as a signal that demand for reserves is abnormally high, and their price is bid up to panic levels. A panic then ensues. While our sunspot can be consistent with Gorton's information story, the mechanism for the generation of panics is strikingly consistent with Donaldson's evidence.

VI. CONCLUSION

We have attempted to model banks as efficient aggregators of information. The notion is that banks, and particularly banks organized into clearinghouse organizations, can economize on the "good funds" needed to convey the veracity of people's claims to different types of goods (see Garber and Weisbrod, 1991, for a more detailed exposition of this idea). Our model suggests that in equilibrium banks may be able to perform this task efficiently (as in Proposition 1) but need not do so (as in Proposition 2). Moreover, attempts to ensure the efficient equilibrium, such as the creation of clearinghouses and the imposition of reserve requirements, can easily result in the creation of incentives that tend to undermine the original equilibrium (as in Proposition 3). However, during the National Banking period, attempts by trusts and other "fringe" intermediaries to circumvent the high incidence of the reserve tax may have led to efficiency gains, via a reduction in the burden of reserves, even if these same actions may have contributed to panics. All of the above discussions of efficiency assume that either the net transfer of reserves (Propositions 1 and 2) or, among clearinghouse members, the net transfer of loan certificates (Proposition 3) represents the only feasible way of verifying claims to different banks' assets and, ultimately, to consumption goods. If less costly means exist for verifying these claims, then clearly the transfer of reserves is inefficient. A deeper comparison of the efficiency of payment mechanisms would require a treatment of the informational asymmetries that characterize such intermediary arrangements. This is a topic for future research.

APPENDIX

Proof of Proposition 1. Following Chari (1989), we show that the equilibrium proposed above corresponds to the solution of the problem of fully insuring consumers against random shocks (τ, μ, m), subject to the aggregate resource constraint and the net settlement constraint. That is, a deposit contract can do no better than to fully insure the risk-averse depositors at all banks against all undiversifiable risks, to the maximum extent feasible. The insurance problem can be stated as:

$$\max_{c_1, c_2} \int \tau u[c_1(\cdot)] + (1 - \tau)c_2(\cdot)]\, dH(\tau, \mu, m),$$

subject to $\tau c_1(\cdot) + (1 - \tau)c_2(\cdot) \leq (1 - \mu_1)c_1^u + R[1 - (1 - \mu_1)c_1^u]$, for almost all (τ, μ, m), where c_1^u is the supremum of $c_1(\cdot)$.

First-order conditions for this problem imply that c_1 and c_2 are constant over (τ, μ, m) and equal to $\underline{c}$. To verify that the optimal insurance contract is an equilibrium, note that conditions (1)–(7) are trivially satisfied for the proposed equilibrium. It is straightforward but tedious to show that budget constraints (8)–(11) are also satisfied. Hence the constrained-efficient allocation is an equilibrium. ■

Proof of Proposition 2. The proof consists of showing that given the equilibrium interbank loan rate schedule $R^*(\tau)$, banks have no choice but to offer the equilibrium contract as described above. We begin by noting that under the no-suspension condition (3) and the no-liquidation condition (4), banks may not offer a contract that promises less than $c_1 = 1$ and/or $c_2 = 1$. Also, since the reserves market is anonymous and symmetric, a bank cannot improve on the equilibrium contract by offering a higher return to Type-2 depositors when the bank is a lender in the reserves market, since holding additional reserves does not guarantee that these reserves can be loaned. Individual banks have zero measure and cannot bid down the price of reserves. Therefore, to offer a contract that improves on the equilibrium contract, the bank must promise a higher return either to Type-1 depositors or to Type-2 depositors when the bank is a net borrower of reserves. If the bank holds $L = (1 - \mu_1)$ in reserves, then net returns higher than zero are impossible when the bank is a net borrower, since borrowing costs absorb all of the bank's surplus.

Suppose, then, that a bank tries to improve on the equilibrium contract by holding some amount of reserves $L < (1 - \mu_1)$. To satisfy its period-2 budget constraint as a net debtor, however, the bank cannot violate condition (9). In the proposed equilibrium, condition (9), holding $c_1 = 1$ momentarily, implies that

$$(1 - \tau) + R^*(\tau)(\tau - L) \leq R(1 - L),$$

which can be rearranged to yield

$$(1 - \tau) + R^*(\tau)\tau - R \leq [R^*(\tau) - R]L.$$

If $\tau = 1$, both sides of the above inequality reduce to zero, since $R^*(1) = R$. If $(1 - \mu_1) < \tau < 1$, then the above inequality is equivalent to, after some algebra,

$$(1 - \tau)(R - 1)(1 - \mu_1)/[\tau - (1 - \mu_1)] \leq L(1 - \tau)(R - 1)/[\tau - (1 - \mu_1)],$$

which implies

$$L \geq (1 - \mu_1),$$

which is a contradiction. In other words, because the cost of reserves $R^*(\tau) > R$ when there is an active reserve market (except when $\tau = 1$, which is a zero-probability event), there is no way that holding less reserves is optimal.

Likewise, a bank will not hold more reserves than $(1 - \mu_1)$. Holding more reserves cannot benefit Type-2 depositors, since they would prefer that these reserves be invested. By symmetry, additional reserves will not be lent in the reserves market. Thus the only possible benefit of holding more reserves would be to increase payments to Type-1 depositors to an amount c_1 greater than 1, say $c_1 = 1 + \delta$, where $\delta > 0$. The increase in first period consumption is to be financed by increased reserve holdings, say $L = 1 - \mu_1 + \varepsilon$, where $\varepsilon > 0$. In this case consider the bank's budget constraint (9) as a net debtor, which would be

$$(1 - \tau) + R^*(\tau)(\tau c_1 - L) \leq R(1 - L),$$

which is equivalent to

$$(1 - \tau) + R^*(\tau)[\tau(1 + \delta) - (1 - \mu_1 + \varepsilon)] \leq R[1 - (1 - \mu_1 + \varepsilon)].$$

Since $R^*(\tau) \geq R$, the above inequality implies that

$$(1 - \tau) + R[\tau(1 + \delta) - (1 - \mu_1 + \varepsilon)] \leq R[1 - (1 - \mu_1 + \varepsilon)],$$

which is equivalent to

$$\tau \leq \tau_\delta = [(R - 1)/(R - 1 + R\delta)] < 1.$$

Thus, constraint (9) cannot hold for $\tau_\delta < \tau \leq 1$, which occurs with positive probability. In other words, if a bank promises a larger $c_1 = 1 + \delta$ and tries to fund this amount through larger reserve holdings, then for values of τ "close to" unity, the bank will be unable to borrow reserves sufficient to clear and settle the checks written in the amount $\tau(1 + \delta)$ by Type-1 depositors.

Since the bank cannot offer any contract other than the equilibrium contract without suspending or liquidating, it must offer the equilibrium contract. ∎

Proof of Proposition 3. If $\tau < \underline{\tau}$, then the banking system cannot run out of reserves. We assume that this is publicly known and that panics will not occur for these values of τ. The period-0 expected utility of a bank depositor is, after simplification

$$U_B \equiv \int_0^1 \tau u(\underline{c})\, d\tau + \int_0^{\underline{\tau}} (1 - \tau)u(\underline{c})\, d\tau + \int_{\underline{\tau}}^1 (1 - \tau)u(\underline{c})(1 - \sigma)\, d\tau$$
$$+ \int_{\underline{\tau}}^1 (1 - \tau)u\left(\underline{c} + \left[\frac{1-\gamma}{\gamma}\right]\left[1 + \frac{R - \underline{c}}{\tau\underline{c}(1 - \underline{c})}\right]\right)\sigma\, d\tau,$$

whereas the period-0 expected utility of a trust depositor is

$$U_T \equiv \int_0^1 \tau u(\underline{c})\, d\tau + \int_0^{\underline{\tau}} (1 - \tau)u\left(\underline{c} + \frac{R - \underline{c}}{1 - \tau}\right) d\tau$$
$$+ \int_{\underline{\tau}}^1 (1 - \tau)u\left(\underline{c} + \frac{R - \underline{c}}{1 - \tau}\right)(1 - \sigma)\, d\tau + \int_{\underline{\tau}}^1 (1 - \tau)u(\underline{c})\sigma\, d\tau.$$

If $\sigma = 0$, then evidently $U_T > U_B$, and if $\sigma = 1$, $U_B > U_T$. Since U_T and U_B are linear in σ, there exists a $\sigma^* \in (0, 1)$ such that $U_T = U_B$.

To complete the proof we need to show that trusts will hold no reserves in equilibrium. Following the strategy of the proof of Proposition 2, suppose that a trust promises impatient depositors an amount $c_1^T = \underline{c} + \delta$, $\delta > 0$, to be partly financed through reserve holdings of $\varepsilon > 0$. In a panic, the trust's period-2 budget constraint will be

$$(1 - \tau)\underline{c} \leq R(1 - \varepsilon) - R_p^*[\tau(\underline{c} + \delta) - \varepsilon],$$

for τ sufficiently large. Since $(1 - \tau)\underline{c} = R - R_p^*\tau\underline{c}$ by construction, the above simplifies to

$$R^*\tau\delta \leq (R_p^* - R)\varepsilon.$$

The above inequality cannot hold for τ sufficiently close to one, however, since R_p^* goes to $(R/\underline{c}) < R$ as $\tau \rightarrow 1$. Hence the trust's budget constraint would be violated with positive probability, and trusts will hold no reserves in equilibrium. ■

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