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Costly Liquidation, Interbank Trade, Bank Runs and Panics*

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Standard models of panics do not allow for trade between banks and assume that a run bank's liquidation costs are determined exogenously. We develop a model in which banks trade with each other and liquidation costs are determined endogenously in a strategic environment. The model reproduces a panic's characteristic fall in stock prices, rise in interest rates, and wave of bank runs. It also accounts for the seasonal timing of panics, the change in interest rates across panics, and international differences in panic frequency. The roles of withdrawal suspension, lender of last resort, and deposit insurance are also investigated. *Journal of Economic Literature* Classification Numbers: G21,N21,E42.

I. INTRODUCTION

A thorough investigation of financial intermediation and the operation of financial intermediaries will eventually include a discussion of banking and financial crises. This article focuses on the most severe form of crisis: the panic. A panic has two components: (a) widespread bank run activity,

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as evidenced by a significant decline in bank reserves and deposits, and (b) a sudden decline in the cash value of noncash assets, as evidenced by a decrease in stock prices and an increase in interest rates. Table I contains a summary of the relevant weekly data from America's most serious post-National Bank Act panics.

Several approaches have been taken in an attempt to uncover the causes of panics and to explain the type of statistical regularities documented in Table I. The initial investigations of authors such as Noyes (1909), Kemmerer (1910), Sprague (1910), and Myers (1931), for example, focus on various institutional features of the American banking sector, and on certain features of the macroeconomy in which the banks operated, as the key to understanding panics. Of particular concern in these works are the seasonal nature of the agricultural sector's demand for cash and the various bank regulations, which (i) placed restrictions on bank note issue and thus prevented rapid expansion of the currency supply to meet periods of increased currency demand, (ii) encouraged the small rural "country banks" to keep very low cash reserves compared to the large urban "reserve agents," and (iii) prevented risk diversification through branching. Panics in these early studies are thus frequently described as having foundations in (seasonally dependent) macroeconomic shocks which increased the demand for cash facing the country banks. Since the country banks had low reserves and could not diversify the shocks, and since the reserve agents could not increase the cash supply with speed sufficient to satisfy the suddenly increased demand, a "currency famine" and general panic would result.

During the 1980s, the trend in panics research shifted to focus less attention on the aforementioned regulatory and macro concerns and more attention on the microfoundations of deposit contracts and bank runs. Work by authors such as Bryant (1980), Diamond and Dybvig (1983), Waldo (1985), and Postlewaite and Vives (1987), for example, focuses on the first-come-first-serve sequential service feature of demand deposits and the fact that there are substantial (exogenously imposed) costs associated with premature liquidation of a bank's long-term investments, as reasons why "run the bank" exists as an equilibrium depositor strategy. Widespread panics occur in these models when each depositor believes that others will run an intermediary and force it into costly liquidation.

The work of authors such as Jacklin (1983), Smith (1984), Gorton (1987), Chari and Jagannathan (1988), Jacklin and Bhattacharya (1988), Williamson (1988), Calomiris and Schweikart (1991), and Mishkin (1991) continues in the microfoundations vein by focusing on various informational asymmetries between banks and depositors in a search for the trigger which sets in motion the initial wave of bank runs and the conduit which causes these runs to expand into a general panic. The primary focus of this research remains on explaining bank runs, however, as opposed to explaining the sudden alteration in the rate of exchange between cash and noncash assets that also occurs during panics. As a result, we now have a much clearer understanding of how bank runs can occur as equilibrium phenomena (through coordination failures, information, asymmetries, etc.) than of the equally important role played by the money and stock markets in the inception and propagation of panics.

In an attempt to better understand the importance of stock and money market transactions in panics and the roles of lender of last resort and deposit insurance, we focus in this paper on the way run banks acquire the cash their depositors demand during panics. In doing so, we note that the inability of standard models to investigate this issue is a function of the assumptions imposed by these models on the way panics are financed. In particular, it is usually assumed (i) that, when run, a single bank will *by itself* convert its investment assets back into the deposited commodity without having to engage in interim trades with other agents and (ii) that this conversion is accompanied by an *exogenously imposed* liquidation cost. Thus there is no role for borrowing and lending between banks and no place for the security markets in which run banks sell their noncash assets in an attempt to raise the funds demanded by depositors.

The preceding shortcoming of standard models is noted by Chari and Jagannathan (1988) who, in their comment on the current approach to bank panics, state that

> The most troublesome (to us) issue is the fact that liquidation costs are exogenously imposed rather than generated from deeper elements of technology and preferences. Obviously a richer model would have many intermediaries . . . and would generate liquidation costs [endogenously]. The obvious extension is to consider interbank trades in the interim stage. (pp. 756–757)

The purpose of this article is to develop a model in which there are many different financial intermediaries who raise the cash their depositors demand by selling assets to, or borrowing from, other intermediaries, and in which a run bank's liquidation costs are determined endogenously. Indeed, in our model it is the endogenous cost of liquidation, along with a random productivity shock, which determines the number of banks that are run and whether or not there is a general panic.

In keeping with historical divisions between the rural "country banks" and urban "reserve agents" mentioned above, the financial intermediaries in our model are separated into two classes: banks, which have low currency–deposit ratios, and reserve agents, which possess large cash reserves. A bank is "fundamentally insolvent," and therefore run, when it receives an adverse technology shock which reduces the profitability of its investments below the level required to pay depositors. The run bank obtains the funds its depositors demand by engaging in interim trades with the reserve agents who act strategically when deciding how much cash to offer the bank for its securities. In most cases, competition among reserve agents produces high security prices and low interest rates. In rare cases, however, some reserve agent may discover that economy-wide cash reserves are sufficiently small, and/or that the demand for cash is sufficiently large, that his reserves are essential to satisfy demand, and thus that he need not compete. Using the modeling framework of Dunn and Spatt (1984), we show that such an agent will act strategically to raise the price of his cash above the competitive price, with the result that security prices fall and interest rates rise. At the new higher-than-competitive rate of exchange between cash and securities, some fundamentally solvent banks may discover that the market value of their assets has fallen to the point where, if run, they would be "liquidation insolvent." These banks are therefore also run and a general panic ensues. The model thus reproduces Table I's increase in interest rates, decrease in stock prices, and wave of bank runs. For reasons detailed below, it also accounts for the seasonal timing of American panics, the movement in high panic interest rates over time, the increased spread between high and low interest rates during panics, and international differences in the frequency of panics.

While it differs in many ways from existing work, our model shares several features with more standard panic theories. The model is consistent, for example, with the liquidity-drain theories of Sprague (1910), Miron (1986), and others in that our panics are most likely to occur during (seasonal) periods when cash reserves are at their lowest level. It is also consistent with the fundamental insolvency stories of Jacklin and Bhattacharya (1988) and others in that our panics begin with a run on a fundamentally insolvent bank. This initial fundamental run then creates the increased demand for cash that causes the endogenously determined liquidation cost to rise and thus leads to a general panic. Since the fundamental insolvency of the initially run bank is the product of a random shock to a sequentially servicing intermediary, however, the model is also consistent with Diamond and Dybvig (1983) and others who model panics as randomly occurring Nash equilibria.

The current article is most closely related to the recent works of Bhattacharya and Gale (1987), Champ *et al.* (1991), and Smith (1991). Like the current article, these studies attempt to return attention to the concerns of the earliest panic researchers (e.g., Sprague (1910), Kemmerer (1910), and Myers (1931)) over the way in which the economy's inelastic supply of cash was managed during pre-Fed panics. Champ *et al.* (1991), for example, demonstrate that, by restricting the ability of banks to elasticize the currency by issuing additional bank notes in times of crisis, banks may be unable to accommodate the currency demand shocks of their depositors and that this lack of liquidity can lead to a general panic. Smith (1991) shows how a private reserve agent can respond to location-specific liquidity shocks by supplying emergency cash to location-specific banks. Large or multiple shocks still lead to contagious panics, however, due to the private reserve agent's inability to expand the total cash supply. In a similar context, Bhattacharya and Gale (1987) investigate the ability of a central planner/reserve agent (i.e., the Fed) to accommodate isolated location-specific liquidity shocks by shifting cash reserves around the economy through lending and borrowing via a discount window.

While the current study shares with papers in the preceding paragraph its discussion of liquidity and costly liquidation, it differs from previous work in two important ways. First, this article focuses on the determination of the equilibrium prices at which run banks sell their noncash assets to suppliers of liquidity during panics, while in previous papers this price is imposed exogenously. A second major difference concerns the way in which cash is supplied to troubled banks during panics. Bhattacharya and Gale (1987), for example, envisage liquidity provision by a benevolent social planner, while Smith (1991) assumes that the cash-supplying reserve agent acts in the interests of the cash-demanding country banks to which he provides liquidity. In contrast, we assume that liquidity is provided by a group of reserve agents who act strategically in an attempt to maximize their *own* profits when supplying funds to run banks in need of cash. As demonstrated below, this assumption of profit-maximizing behavior on the part of the reserve agents seems to capture some important features of American panics. In particular, a switch in our model from a regime in which private reserve agents supply cash strategically to a regime in which a central planner acts benevolently toward the banks seems to capture some important differences between the pre- and post-Fed panic experience.

The remainder of this paper proceeds as follows. Section II presents some evidence in support of the claim that cash suppliers may have acted strategically when providing liquidity to banks during pre-Fed panics. Section III presents a formal model of this process, which is based on the strategic analysis of price determination introduced by Dunn and Spatt (1984). Section IV documents our model's ability to reproduce the statistical patterns found in Table I, as well as other assorted empirical regularities, and investigates the roles of withdrawal suspension, deposit insurance, and the lender of last resort in preventing panics. Section V concludes.

II. INTEREST RATES AND THE CASH-SUPPLY PROCESS

For our purposes, the most important features of the pre-Fed economic environment are: (i) due to the structure of reserve requirements, most of the economy's mobilizable cash reserves were controlled by a very small number of commercial and investment bankers in New York City, sometimes referred to as "the reserve agents," while other intermediaries kept little vault cash;[1] and (ii) because of the gold standard and the inability of banks to print new notes backed by general assets, the money supply was not easily expanded on short notice. As noted above, these features combined to create a financial system that could not cope well with a sudden increase in the demand for liquidity, such as that which occurs when depositors run to their banks and demand cash during a bank panic.

During a pre-Fed panic, a typical bank, trust company, or other deposit-issuing institution responded to depositors' cash demands by first drawing on its own limited cash reserves and by calling in outstanding loans. Next, it would sell its marketable securities and/or try to obtain a loan from New York's cash-rich reserve agents. If the demand for cash from the initially run bank was small, and if there was plenty of liquidity in the market, then the effect that the run bank's increased demand for cash had on interest rates and security prices was usually minimal. Indeed, the pre-Fed reserve mechanism functioned remarkably well in the vast majority of situations. When cash was particularly scarce and/or a run bank's liquidity needs were particularly large, however, the dumping of securities by banks and investors in need of cash resulted in a substantial increase in interest rates and decrease in security prices. When evaluated at the new market prices, the assets of other previously solvent and unrun banks would then fall in value and, fearing insolvency at the new lower security prices, depositors would sometimes run their own intermediary and thus cause the run on the initial bank to become "contagious" and spread to other institutions. The result was a banking and financial panic.

A crucial aspect of pre-Fed panics was the manner in which the market's suddenly increased demand for cash was financed. Although the high interest rates characteristic of panics often attracted some inflow of specie from abroad, the primary suppliers of emergency liquidity to financial markets were the domestic reserve agents. That these agents possessed considerable market power in providing access to cash and credit during panics is not in dispute.[2] The important issue is whether or not the reserve agents used their power to increase interest rates above their

[1] The National Bank Act, in force from 1863 to 1913, imposed a 25% cash reserve requirement on the New York reserve banks, but only a 5% requirement on smaller banks and trust companies. As a result, between 1870 and 1910 the reserve banks, which comprised between 0.2% to 1.5% of all banks, held from 25% to 40% of all cash reserves. The fraction of rapidly mobilizable reserves controlled by these banks was even higher.

[2] Tallman and Moen (1990), for example, report that during the panic of 1907 ". . . nearly all the funds contributed to aid the panic were controlled by J. P. Morgan, [who headed a syndicate of the largest reserve agents and] who decided how much money to use and where" (p. 9).

competitive levels. On this question there is some conflict among traditional commentaries on pre-Fed panics. That many historians use phrases like "rescue operation" and "aid" to describe the process by which the reserve agents exchanged cash for run banks' noncash assets implies an almost altruistic behavior on the part of reserve agents. Other observers of the period, however, argue that, because of the shortage of cash during panics, some reserve agents were occasionally able to increase profits by acting as monopolists over the supply of liquidity.

Much of the available evidence concerning the reserve agents' behavior is suggestive but not decisive. One can find numerous anecdotal accounts of both heroics and profiteering by the reserve agents, but hard statistical facts are difficult to come by. Ideally, one would like to search for this evidence in the board-meeting minutes and books of the various institutions that supplied and demanded cash during panics. In most cases, however, the required information is unavailable. This leaves only aggregate data where the major problems are, as usual, availability and reliability. In this respect the weekly data on interest rates, deposits, cash reserves, and stock prices contained in Table I are of most use in determining whether suppliers of cash always charged competitive interest rates or whether they sometimes charged higher-than-competitive rates for the funds they provided to the market during panics.

The standard loanable funds theory of interest rates (e.g., Jaffee (1989)) states that the supply of funds, L^S, depends positively on the interest rate, r, and the excess reserves held by the reserve agents, C: $L^S = L^S(r, C)$; $L_1^S > 0$, $L_2^S > 0$. The demand for funds depends negatively on the interest rate r, the demand for deposits, D, and stock returns, S: $L^D = L^D(r, D, S)$; $L_1^D < 0$, $L_2^D < 0$, $L_3^D < 0$. Thus, in equilibrium, the interest rate should rise as bank reserves, deposits, and stock prices fall: $r = L(C, D, S)$; $L_1 < 0$, $L_2 < 0$, $L_3 < 0$. The question now is: How much should the interest rate rise during panics? One response is obtained by regressing various functions of the interest rate on various functions of C, D, and S, allowing for separate panic effects, and then testing for evidence of structural change. A finding that panic and nonpanic interest rates are determined by the same economic structure would support the hypothesis that reserve agents continued to price cash competitively during panics but that, due to the fall in reserves and increase in demand, the competitive price (i.e., the opportunity cost of funds) just rose. A finding of structural change between the panic and nonpanic periods, however, would suggest that the interest rate is determined by a different mechanism during panics than during nonpanic periods and thus that the reserve agents may indeed have used their market power to price cash at some higher-than-competitive level during panics.

Table II reports the results obtained from OLS regressions of the interest rate on a constant, C, D, and S, allowing each to have a separate effect

TABLE I

A SUMMARY OF THE WEEKLY DATA FROM SEVEN MAJOR PANICS

Year	1873	1884	1890	1893	1907	1914	1933
Begin and end weeks	38–47	20–21	46–50	26–31	43–52	31–49	9–13
(A) Evidence of Bank Runs							
Bank deposits (million dollars)							
1 week before the panic	207.30	329.80	392.20	398.00	1025.70	1478.00	6183.00
First week of the panic	198.00	317.20	386.50	397.90	1023.70	1454.00	5759.00
Extreme value attained	150.80	296.50	376.70	370.30	1023.70	1185.00	5564.00
Last week of the panic	168.20	296.50	376.70	372.90	1050.90	1187.00	5564.00
1 week after the panic	174.50	298.30	380.30	372.20	1048.40	1199.00	5654.00
13 weeks after the panic	239.80	304.40	410.70	447.40	1189.30	1402.00	6177.00
Cash reserves (million dollars)							
1 week before the panic	57.10	86.80	95.50	104.90	267.60	393.00	830.00
First week of the panic	53.10	82.40	95.70	100.70	254.70	374.00	775.00
Extreme value attained	19.60	67.50	91.80	76.50	215.80	208.00	665.00
Last week of the panic	48.40	67.50	94.70	76.50	242.50	216.00	789.00
1 week after the panic	55.60	70.10	99.50	89.20	250.60	214.00	780.00
13 weeks after the panic	86.80	107.60	112.40	163.80	337.10	256.00	827.00
(B) The changing rate of exchange between cash and noncash assets							
Stock price index							
1 week before the panic	61.61	66.34	67.00	57.00	92.00	94.00	27.00
First week of the panic	60.57	64.81	63.00	55.00	87.00	stock	24.00
Extreme value attained	54.77	63.41	60.00	44.00	82.00	market	24.00
Last week of the panic	56.14	63.42	60.00	49.00	88.00	closed	27.00
1 week after the panic	57.21	62.26	61.00	48.00	89.00	91.00	24.00
13 weeks after the panic	63.97	65.53	65.00	57.00	94.00	90.00	47.00
Interest rate (high/average/low, %)							
1 week before the panic	11/10/5	6/4/2	25/6/3	25/9/3	10/5/3	3.87	1.00
First week of the panic	548/162/5	127/49/2	186/8/3	74/15/4	125/40/5	7.00	2.06
Extreme value attained	548/162/7	188/66/2	186/8/3	74/15/4	125/50/6	7.00	4.31
Last week of the panic	23/17/6	188/66/1	186/6/2	51/9/2	25/20/6	4.25	3.60
1 week after the panic	11/9/6	8/4/1	6/4/2	6/5/2	9/6/2	3.50	1.91
13 weeks after the panic	5/4/3	3/2/1	4/3/2	2/2/1	2/2/1	2.00	1.00

Note (Data definitions and sources). Beginning and ending dates: *Financial Review* Retrospects of 1873, 1884, 1890, 1893, and 1907, and Friedman and Schwartz (1963). Cash reserves and deposits: the New York Clearinghouse Weekly Statement as reported in the *Financial Review* and *Banking and Monetary Statistics*. Stock price: the Dow railroad index as reported in "Dow Jones Indexes" 1885–1985 and reconstructed before 1885 by Donaldson (1990); the market closed in 1914 panic so the data are for most recently quoted price. Interest rate: the rate charged on a call loan at the New York Stock Exchange during the week in question as reported in the *Financial Review* and *Banking and Monetary Statistics*. The average is available only for 1914, 1933.

during panics. While we report the results from a linear specification, other functional forms, such as log-linear, and other configurations, such as using lagged values of the independent variables as instruments, were also attempted with similar results.[3] Estimates are reported for the entire sample as well as for the pre- and post-Fed splits. Note from part A (1867–1933) that the signs on the first four variables are consistent with the

[3] See Donaldson (1990) for a more complete analysis of this data, for a more careful discussion of the statistical differences between panic and nonpanic periods, and for an investigation of the data's ability to help predict panics out-of-sample on the basis of events in the money and stock markets.

TABLE II
DETERMINANTS OF THE INTEREST RATE

Constant	Cash reserves	Deposit changes	Stock changes	Panic constant	Panic cash reserves	Panic deposit changes	Panic stock changes	F test for structural change	R^2
				A. 1867–1933					
4.179	−0.012	−0.054	−0.004	1.164	−0.054	−1.899	−0.131	196.0	0.22
(53.99)	(−12.1)	(−1.64)	(−0.11)	(1.990)	(−8.82)	(−14.1)	(−0.85)	(43475)	
*	*				*	*		*	
				B. 1867–1913					
4.192	−0.013	−0.087	0.003	14.41	−0.011	−6.534	−0.202	252.5	0.42
(44.45)	(−12.4)	(−1.93)	(0.051)	(7.770)	(−1.46)	(−26.4)	(−0.93)	(42386)	
*	*			*		*		*	
				C. 1914–1933					
4.197	−0.001	−0.014	−0.002	−1.114	−0.021	−0.090	0.159	0.55	0.01
(59.21)	(−0.44)	(−0.58)	(−0.10)	(−0.87)	(−0.80)	(−0.80)	(1.171)	(41032)	
*									

Note. This table reports results from the OLS regression:

$$r_t = \beta_0 + \beta_1 C_t + \beta_2 D_t + \beta_3 S_t + \gamma_0 P_t + \gamma_1 P_t C_t + \gamma_2 P_t D_t + \gamma_3 P_t S_t + u_t,$$

where r is the average interest rate on a call loan at the NYSE, C is the percentage deviation from trend in the excess cash reserves of the New York reserve banks, D is the percentage rate of change in bank deposits, S is the percentage rate of change in stock prices, P is the dummy variable 1 = panic/0 = nonpanic, u is a random shock, and the βs and γs are parameters to be estimated. t statistic or degrees of freedom are in parentheses. An asterisk notes that the null hypothesis of a zero coefficient or of no structural change rejected at 95%. All data were measured at weekly intervals from 1867 to 1933. Data sources are given in the note to Table I (since the stock market was closed during the panic of 1914, stock prices for this period are the last quotation available).

loanable funds theory outlined above: interest rates rise as cash reserves, deposits, and stock prices fall.

The test for structural change in part B of Table II (1867–1913) reveals that cash was indeed priced differently during pre-Fed panics than it was during nonpanic periods. That the panic-specific constant is positive and the panic-specific coefficients on C, D, and S are negative further reveals that the interest rate not only rose during pre-Fed panics, but that it rose by even more than the nonpanic structure would have suggested. In other words, using the nonpanic relationship, the fitted value of the interest rate rises during panics but, in the case of pre-Fed panics, it is still below the actual panic interest rate. Assuming that the interest rate was being determined competitively during nonpanic periods, we can therefore conclude that the interest rate may have been set at some higher-than-competitive level during pre-Fed panics. Conversely, part C of Table II (1914–1933) reveals that there was no change between the way cash was priced during post-Fed panics; the post-Fed panic interest rate is adequately accounted for by the estimated post-Fed nonpanic relationship. That the Fed seems to have had an effect on the way cash is priced during panics is an important observation which is discussed in detail in Section IV below.

Before developing our formal model, we close this section with an example, based on the analysis of Dunn and Spatt (1984), in which security prices and interest rates are determined by two different structures—panic and nonpanic—and which approximates the flavor of Table II's results and the preceding discussion of historical events. Suppose that two identical reserve agents each possess half of the economy's \$100 total cash reserve and that a cash-poor nonreserve bank is known to have made "bad" investments and is therefore run. The run bank raises cash by selling its assets to the reserve agents. If the total demand for cash is \$40 then the two reserve agents will be forced to bid against each other when supplying cash since so single reserve agent's stock of reserves is essential in satisfying the market's liquidity needs. If either reserve agent was removed from the market, the remaining reserve agent's \$50 worth of vault cash could still satisfy the \$40 demand and thus standard Bertrand arguments reveal that neither agent can expect to receive more than the competitive rate of return on his cash holdings.

Now suppose that the bank requires more cash than either reserve agent alone can supply, as would be the case if the demand for cash rose above \$50, the total supply of cash fell below \$80, or some combination of the two occurred. Consider, for example, the effects of reducing each supplier's reserves from \$50 to \$25. Even if the bank obtains all \$25 of one reserve agent's cash, it must still rely on the other reserve agent to supply \$15 of the \$40 required. Thus, each reserve agent has a captive demand for \$15 of his \$25. Realizing that he faces no competition for this portion of his reserves, each reserve agent maximizes his profits by demanding a higher-than-competitive rate of return on the *first* \$15 he supplies. The bank will therefore obtain a total of \$10 from the reserve agents by paying the competitive rate of exchange between cash and noncash assets, but will be forced to pay an endogenously determined "liquidity premium" on \$30 (\$15 from each supplier) of the \$40 acquired. The result is the increase in interest rates and decrease in security prices characteristic of panics. This alteration in the rate of exchange between cash and noncash assets may also cause the run on the initially insolvent bank to become "contagious" and spread to other previously solvent banks if the resulting decline in security prices drives the market value of previously solvent banks' noncash assets below that of their deposit liabilities. A formal model of this process is presented below.

III. A MODEL OF INTERBANK TRADE, LIQUIDATION COSTS, AND PANICS

Most bank run models are concerned with the intertemporal process by which depositors elect to place funds in a bank at an initial point in time and then decide when and how much to withdraw at some later date.

Since the focus is on depositor behavior through time, multiperiod models in which depositor behavior is endogenous and liquidation costs and the nature of interbank trade are exogenous are traditionally employed. Conversely, as stated in the introduction, our focus is on the interbank trades which occur at the moment when depositors approach their bank to withdraw funds. Our problem is therefore essentially atemporal in that all the action occurs at the specific point in time when funds are withdrawn. We therefore develop an atemporal model in which depositors are constrained to reproduce historically observed behavior while liquidation costs and the nature of interbank trade are determined endogenously.

In our model economy, there are two tradeable goods: cash, denominated in units called "dollars," and securities, which represent claims to cash payments. Each security has a face value of \$1 and can be thought of as either a \$1 discount bond, or as a collection of stocks with final payoffs of \$1. Hence, a fall in the equilibrium price of securities represents both an increase in interest rates and a fall in stock prices. These goods are traded by four classes of agents (savers, foreigners, banks, and reserve agents) which, by virtue of their objectives and financial positions, are stylized representations of their historical counterparts.

Savers. Savers possess no liabilities and have demand deposits at sequentially servicing banks as assets. The savers run banks which, if run, would be unable to satisfy all withdrawal requests.[4]

Foreigners. Designed to represent both foreigners (e.g., the Bank of England and its gold reserves) and domestic hoarders of legal tender, our foreigners possess an unlimited supply of cash which they use to purchase all available securities as soon as the rate of return from doing so rises above R^f ($R^f > 1$).

Banks. There are $j = 1, \ldots, n$ banks which have demand deposits as liabilities and investment projects as assets. In an effort to account for the fact that the nonreserve banks and trust companies of the pre-Fed era kept relatively small cash reserves, our stylized banks possess no cash reserves. When faced with the withdrawal requests of depositors, the banks maximize their profits (i.e., minimize their liquidation costs) by selling securities, which represent ownership of their investment projects, to the highest bidder. The cash so acquired is then distributed to depositors on a first-come-first-serve sequential basis.

Let α_j be the number of \$1 deposits in bank j and R_j^* ($0 \leq R_j^* < \infty$) be the

[4] This assumption follows Diamond and Dybvig (1983) and many other bank run models. Participation in a run on such a bank is rational since, if the bank's other depositors run, then the sequentially servicing intermediary will exhaust its resources before all depositors can be serviced. Failure to participate in the run therefore results in the certain loss of funds. While explaining the timing of panics becomes more difficult under alternative assumptions concerning saver behavior, this paper's key results will not be altered by allowing for other possible saver behavior.

universally observed fundamental (or physical) rate of return, per dollar deposited, on bank j's projects.[5] The total number of \$1 securities bank j can issue is then given by S_j:

$$S_j = \alpha_j R_j^*. \tag{1}$$

Next, define R^{nk} to be the rate of return demanded by agents who supply cash at the competitive rate of exchange between cash and securities (i.e., the inverse of the competitive cash price of a security whose face value is \$1), R^k to be the higher-than-competitive rate of return demanded by agents who are able to hold captive a portion of the market (i.e., the inverse of the price that suppliers who hold the market captive are willing to pay for a \$1 security), and ϕ ($0 \leq \phi \leq 1$) to be the common fraction of total securities that each cash demander sells to cash suppliers at the lower-than-competitive captive price $1/R^k$. The average cash value of a security with a \$1 face value is then

$$\delta = \phi/R^k + [1 - \phi]/R^{nk} \tag{2}$$

and the total amount of cash bank j can raise by selling securities is given by

$$C_j^{\mathrm{D}} = \delta\alpha_j R_j^*. \tag{3}$$

Finally, let R^d be the rate of return on deposits that banks promise savers, so that bank j's total deposit liabilities are $\alpha_j R^d$.

DEFINITION 1. Bank j is *fundamentally solvent* if the fundamental rate of return on its investments is no less than that promised to depositors (i.e., the number of \$1 securities it can issue is at least as great as the number of dollars it owes), or $R_j^* \geq R^d$.

DEFINITION 2. Bank j is *liquidation insolvent* if the cash value of its liabilities, $\alpha_j R^d$, exceeds the cash liquidation value of its assets, $\delta\alpha_j R_j^*$. This condition, in per depositor terms, is given by

$$R^d > \delta R_j^*. \tag{4}$$

Reserve agents. There are $i = 1, \ldots, m$ reserve agents (or syndicates of reserve agents) who purchase the securities of banks who need cash. Let C_i^{A} be the quantity of cash (i.e., the number of dollars) possessed by

[5] Allowing for nonuniversal observation of R_j^* (i.e., asymmetric information) will not alter this paper's conclusions concerning liquidation costs and interbank trade. It will, however, complicate significantly savers' decisions concerning whether to run a bank or not. Since this information problem does not affect the paper's results of interest, the simplifying assumption of symmetric information is chosen.

reserve agent i. Although many reserve agents, such as New York's reserve banks, did issue demand deposits, their primary function during banking and financial panics was to supply the money and stock markets with liquidity. In order to capture this feature, our stylized reserve agents control the entire supply of cash other than that held by foreigners and possess no deposit liabilities.[6]

As was demonstrated in Section II's example, and as proven below, there are two possible environments in which a reserve agent can purchase securities from demanders of cash: one in which every reserve agent behaves like a perfect competitor and one in which some reserve agents find themselves in a position to hold the market captive for a portion of its liquidity needs. The market power enjoyed by a reserve agent who can hold the market captive for a portion of its liquidity needs is defined as follows:

DEFINITION 3. Reserve agent i's *captive power*, Q_i, is defined to be the greater of (i) the total quantity of cash demanded by security-selling banks, C^{D}, minus the sum of all other reserve agents' supplies of cash, and (ii) zero.

$$Q_i = \max[C^{\mathrm{D}} - \sum_{l \neq i}^{m} C_l^{\mathrm{A}}, 0]. \tag{5}$$

DEFINITION 4. Cash over which captive power can be exercised is defined as *captive cash*.

Each reserve agent knows the value of the following variables: C_i^{A}, the amount of cash he possesses; C^{A}, the total quantity of cash possessed by all reserve agents; C^{D}, the total quantity of cash demanded by run banks (the value of which will be derived below); R^f, the foreigners' reservation rate of return; and R^d, the rate banks promise their depositors. Given this information, each reserve agent maximizes profits by announcing a schedule of the rates of exchange between cash and securities that he will offer to cash demanders. Agent i's schedule, $R_i(C)$, takes the form: "for the first dollar I supply I require $R_i(1)$ securities, I will charge $R_i(2)$ securities for the second dollar I supply, $R_i(3)$ securities for the third, and so forth," Let $\overline{C}_i$ be the number of dollars that reserve agent i supplies to banks at the rates of exchange dictated by his chosen strategy, and normalize i's opportunity cost of one dollar at 1.[7] Reserve agent i's profits Π_i are then

[6] As argued below, allowing the reserve agents to issue deposits will not alter the paper's key results, but will make these results technically more difficult to obtain.

[7] Alternatively, we could allow the opportunity cost of cash to fluctuate, rising during panics as suggested by the β coefficients in Table II. This will not change this paper's results, however, since it will be demonstrated below that the panic value of cash rises above its opportunity cost, as suggested by the significant γ coefficients in Table II. Allowing for a fluctuating opportunity cost just makes the following algebra more complicated.

$$\Pi_i = \sum_{C=1}^{\bar{C}_i} [R_i(C) - 1]; \qquad \bar{C}_i \leq C_i^{\mathrm{A}}. \tag{6}$$

It is assumed that all reserve agents select and announce their pricing schedules simultaneously and that the reserve agents' chosen schedules (i.e., strategies) constitute a subgame perfect equilibrium of the schedule-selection game played among the reserve agents.

From the definition of captive power, we know that no matter what agent i charges he will face no competition from the other reserve agents over the *first* Q_i dollars he provides to the banks. If he charges more than R^f securities per dollar, however, the foreigners will enter the market, undercut his asking rate, and steal his customers. For the *first* Q_i dollars he supplies, agent i therefore maximizes profits by asking the highest possible rate that will not induce competition from the foreigners. Thus, $R_i(C) = R^f = R^k$ for $0 < C \leq Q_i$.[8] Since any dollars i tries to supply *in excess* of his Q_i captive units are—by the definition of captive power—nonessential in satisfaction of the banks' cash needs, however, agent i will face price-setting competition from the other reserve agents when supplying anything in excess of Q_i dollars. Standard Bertrand arguments reveal that agent i will therefore receive only the competitive (i.e., common opportunity cost) rate for any dollars he supplies in excess of the number of dollars over which he has captive power. Thus, $R_i(C) = 1 = R^{nk}$ for $Q_i < C \leq C_i^{\mathrm{A}}$. It can therefore be proven that the unique subgame perfect equilibrium pricing schedule for all reserve agents is[9]

[8] If reserve agent i had his own deposits, his captive asking price would also be bounded from above by R_i^* (the rate of return on his own investments) since, as demonstrated below, an equilibrium rate of return above R_i^* would result in agent i's bankruptcy. Allowing reserve agents to issue deposits would therefore result in the captive asking price R_i^k not being the same for all i (since rates of return are different for each agent). This would make our calculations more difficult without altering our key results.

[9] Note that what might normally be thought of as sensible potential deviations from (7) reduce profits. Suppose, for example, that i has positive captive power over Q_i dollars. One might think that he could increase profits by offering to sell $Q_i + 1$ dollars at the price $R^f - \varepsilon$, thereby undercutting the other agents. The definition of Q_i, however, reveals that the banks need not acquire the extra dollar from i and will therefore purchase only Q_i dollars from i and acquire the next unit from one of i's competitors who sells his noncaptive dollars for 1 security each. One might then suggest that i should offer the all-or-nothing proposition "purchase $Q_i + 1$ dollars from me at R^f or I will sell nothing." Since the banks require only Q_i dollars from i, however, this is the same as paying $(R^f(Q_i + 1) - 1)/Q_i > R^f$ for each captive dollar. Since this exceeds the foreigners' price, the banks will reject the all-or-nothing offer. The only all-or-nothing offer the banks accept is one which leaves unchanged the total number of securities relinquished, which will not increase the profits of agent i. Finally, since each reserve agent's captive power depends on demand and the other reserve agents' inventories, *but not on his own level of inventory*, it never pays an agent to withhold a portion of his own inventory from the market or to otherwise reduce his own capacity to supply cash. This separates our paper's equilibrium from Kreps and Scheinkman's (1983) problem of oligopoly pricing with capacity constraints.

$$R_i(C) = \begin{cases} R^f; & 0 \le C \le Q_i \\ 1; & Q_i < C \le C_i^{\mathrm{A}}. \end{cases} \tag{7}$$

Given (7), we can calculate the equilibrium quantity of cash obtained by security-selling banks. To do this, first arrange the $j = 1 \cdots n$ banks in ascending order according to rates of return on their investment projects (i.e., $R_{j+1}^* \ge R_j^*$) and let z denote the position of the run bank with the highest rate of return. Note that since run banks sell all of their securities, the total number of securities sold is $\sum_{j=1}^{z} \alpha_j R_j^*$. Second, since by Definition 3 each agent's captive cash is essential in satisfaction of the market's demand for liquidity, all captive cash is spent. Banks therefore acquire $\sum_{i=1}^{m} Q_i$ captive dollars by selling reserve agents $R^f \sum_{i=1}^{m} Q_i$ securities. The fraction of liquidated securities that are sold at the captive price (captive sales divided by total sales), ϕ, is therefore

$$\phi = \frac{R^f \sum_{i=1}^{m} Q_i}{\sum_{j=1}^{z} \alpha_j R_j^*}. \tag{8}$$

By using Eq. (7) and (8) to replace R^k, R^{nk}, and ϕ in Eq. (2) with R^f, 1, and the right-hand side of (8), respectively, the average cash value of a security, δ, can be rewritten as

$$\delta = 1 - (R^f - 1)\left[\frac{\sum_{i=1}^{m} Q_i}{\sum_{j=1}^{z} \alpha_j R_j^*}\right]. \tag{9}$$

As captive power $\sum_{i=1}^{m} Q_i$ increases, the average security price falls below the competitive value of 1, or the rate of exchange between securities and cash, $1/\delta$, rises above 1. Inserting (9) into (3), summing over all $j = 1, \ldots, z$ run banks, and rearranging the result yields

$$C^{\mathrm{D}} = \sum_{j=1}^{z} \alpha_j R_j^* - (R^f - 1) \sum_{i=1}^{m} Q_i, \tag{10}$$

which states that the total quantity of cash raised by cash demanders is equal to the total number of securities sold minus the difference between the captive and competitive rates of return multiplied by aggregate captive power.

To calculate aggregate captive power ($\sum_{i=1}^{m} Q_i$), arrange the $i = 1, \ldots, m$ reserve agents in descending order according to their individual cash holdings (i.e., $C_i^{\mathrm{A}} \ge C_{i+1}^{\mathrm{A}}$) and let w ($1 \le w \le m$) denote the position of the last (i.e., the poorest) agent with positive captive power. Then substitute (10) into (5), sum over all reserve agents, and rearrange the result to yield

$$\sum_{i=1}^{m} Q_i = \frac{\sum_{i=1}^{m} \max[(\sum_{j=1}^{z} \alpha_j R_j^* - \sum_{l \neq i}^{m} C_l^A), 0]}{w(R^f - 1) + 1}. \tag{11}$$

The total quantity of cash demanded by banks can then be calculated by substituting (11) into (10) to produce

$$C^D = \sum_{j=1}^{z} \alpha_j R_j^* - (R^f - 1)\left[\frac{\sum_{i=1}^{m} \max[(\sum_{j=1}^{z} \alpha_j R_j^* - \sum_{l \neq i}^{m} C_l^A), 0]}{w(R^f - 1) + 1}\right]. \tag{12}$$

Finally, recall that run banks sell a total of $S^D = \sum_{j=1}^{z} \alpha_j R_j^*$ securities and acquire $C^D \leq S^D$ dollars. Then, since one security fetches either one noncaptive dollar or $1/R^f < 1$ captive dollars, the average cash price of securities sold is

$$\delta = C^D/S^D = \left(\frac{1}{w} \sum_{i=1}^{w} \sum_{l \neq i}^{m} \frac{C_l^A}{\sum_{j=1}^{z} \alpha_j R_j^*} + \frac{1}{w(R^f - 1)}\right) \Big/ \left(1 + \frac{1}{w(R^f - 1)}\right). \tag{13}$$

Since reserve agents acquire S^D securities and relinquish only C^D dollars, total reserve agent profits are

$$\Pi = S^D - C^D = \frac{\sum_{j=1}^{z} \alpha_j R_j^* - (1/w) \sum_{i=1}^{w} \sum_{l \neq i}^{m} C_l^A}{1 + (1/w(R^f - 1))}. \tag{14}$$

We turn now to an investigation of the preceding model's ability to account for historically observed panic behavior and statistical data.

IV. ACCOUNTING FOR THE HISTORICAL EVIDENCE

Isolated runs on individual insolvent banks were a fairly common feature of the pre-Fed era and did not generally result in widespread panic or in a significant alteration in interest rates or security prices. Occasionally, however, economy-wide panics occurred during which these isolated runs became "contagious" and spread to previously solvent banks. For the preceding model to be valid, it must be able to account for both panic and nonpanic bank runs. It should also be consistent with various features of panics, such as the data patterns observed in Tables I and II and the fact that panics tended to occur in the fall when cash reserves were typically at their seasonal low.

Recall that a bank is run in our model when it receives a productivity shock R_j^* such that, if forced to liquidate by selling its assets at the current market price δ in Eq. (13), the proceeds from the asset sales would be insufficient to pay the promised amount R^d to each depositor. Begin by considering the case in which each bank's random draw of R_j^* and the distribution of cash among reserve agents are such that the cash demands of all banks for which $R_j^* < R^d$ (i.e., the fundamentally insolvent banks) are small enough, and the supply of cash is large enough and distributed among reserve agents evenly enough, so that when the fundamentally insolvent banks are run the resulting demand for cash is insufficient to produce positive captive power for any reserve agent (i.e., $Q_i = 0\ \forall i$). In this case, all securities trade at the competitive rate \$1/security. A bank whose fundamental rate of return on investment is R_j^* can therefore raise R_j^* dollars per depositor by selling all its assets. Thus, since savers only run banks whose asset liquidation value is less than that of its liabilities, only fundamentally insolvent banks (i.e., those for which $R_j^* < R^d$) are run. These "fundamental runs" do not produce an increase in the interest rate above the competitive rate and do not result in a general panic.

Now consider the opposing case in which the initial fundamental demand for cash is so large, and the supply of cash so small and highly concentrated in the vaults of but a few reserve agents, that some reserve agent possesses captive power (i.e., $Q_i > 0$ for some i). Each agent with captive power therefore demands a return of $R^f > 1$ on his captive cash and therefore pays only $1/R^f < 1$ dollars for each security purchased with cash over which captive power can be exercised. A run bank can therefore produce an asset liquidation rate of return per dollar deposited of only $\delta R_j^* < R_j^*$. Given our assumption that savers run any bank whose asset liquidation rate of return is less than that promised on deposits, banks that are fundamentally solvent ($R_j^* > R^d$) but liquidation insolvent ($\delta R_j^* < R^d$) are therefore run *in addition* to the fundamentally insolvent banks (i.e., banks for which $R_j^* < R^d$). Thus, a general panic occurs during which the initial fundamental runs become "contagious" and spread to previously solvent institutions.[10]

As for interest rates and stock prices, we see from Eq. (13) that, during the panic when some suppliers hold captive power, security prices (δ) fall and the average interest rate ($1/\delta$) rises. This result is in accord with the historical data from Table I. A spread between the high rate charged on captive cash and the low rate charged on competitively supplied cash is also observed during the panic. Thus, even though this paper's model ignores the issue of differential risk, we are able to mimic the increased spread between high and low interest rates observed during the panics summarized in Table I. We are further able to account for Table II's finding that interest rates during pre-Fed panics seem to have risen by more than can be accounted for by the nonpanic structure.

[10] Note that, depending on the values of δ and $R_j^* \forall j$, it is not necessary for 100% of the fundamentally solvent banks to be run. Consistent with economic history, some banks may avoid being run, although many of them will indeed be part of the panic.

Unlike standard models, ours can also account for Table I's observation that pre-Fed panic interest rates fell throughout the nineteenth century but rose again during the panic of 1907. The fall in panic interest rates between 1873 and 1893 can be explained by the fact that, due to a decline in shipping costs and the advent of the finance bill (an instrument used to transfer the ownership of gold from a British to American investor, and *vice versa*), the cost of acquiring gold from abroad declined during the second half of the nineteenth century. This cost reduction is akin to a decline in R^f over time and therefore to a decline in the high panic interest rate. That the high panic interest rate was higher during the panic of 1907 than it was during the panic of 1893 can be accounted for by the fact the Bank of England had just issued a new regulation which restricted the use of American finance bills to rapidly transfer gold claims between London and New York, thereby necessitating the time consuming and costly shipment of actual gold bullion across the Atlantic. This increased R^f_{1907} and thus 1907's high panic interest rate.

As for profits, we see from Eq. (14) that the profits of cash suppliers increase along with the interest rate. It is important to note, however, that our model is highly stylized and that this result should not necessarily be taken to imply that reserve agents actively attempted to create panics to increase profits from the supply of cash reserves, although some "populists" in the 19th and early 20th centuries did make this claim. In particular, we have assumed that the reserve agents have no deposits and can therefore not be run. If they did have deposits, our model's equilibrium would be altered so that the rate each reserve agent demands on captive cash is bounded from above by the agent's own rate of return on investments (see footnote 8). The subset of reserve agents with investment rates of return below R^f would then be run along with the banks. In general, however, some reserve agents would be left unrun to supply the rest of the market with cash. And this is precisely what we usually observe in the historical accounts.

Statistical evidence of reserve agent profits from supplying cash during panics is impossible to obtain for most panics since individual balance sheets are not generally available and the aggregate data usually lump cash suppliers and demanders together. The panic of 1907 is the exception to this rule in that this panic was almost completely confined to New York City's trust companies, cash was supplied almost exclusively by New York City's reserve banks, and we do have aggregate data for the broad categories of trusts and reserve banks. This data and events surrounding the 1907 panic are studied in detail in Donaldson (1992). In short, it appears that the cash suppliers profited handsomely from their activities. It also appears that, in the particular case of 1907, the reserve agents colluded to increase their captive power and thus their profits. Several technical subtleties associated with a formal analysis of collusion place a meaningful discussion of the numerous effects of syndicate formation beyond the scope of the general approach taken in this article. The issue of collusion among cash suppliers during a panic is addressed formally in Donaldson (1992), however, which focuses specifically on the panic of 1907 and the effects of collusion but does not deal with broader issues such as how bank runs can become "contagious," the seasonal timing of panics, deposit insurance, and other issues discussed in this article.

To study the seasonal timing of panics, recall from our discussion of the conditions that are necessary to produce panics, that, while individual banks can be run for reasons of fundamental insolvency at any time, in order to have an economy-wide panic, two criteria must be satisfied: (i) the demand for cash by fundamentally insolvent banks must be large and (ii) the stock of competitively supplied cash must be small. Thus, the first factor affecting the timing of a panic is the production shock $R_j^* \; \forall j$. Given a predetermined distribution of cash among the reserve agents (i.e., given $C_i^A \; \forall i$), panics in our model are most likely to coincide with bad production shocks. This also seems to be true in the historical data. Indeed, Gorton (1988), among others, documents the fact that almost all panics occurred at or just after the beginning of a recession.

For an isolated bank run to become contagious and expand into an economy-wide panic in our model, the distribution of cash among reserve agents must be such that some reserve agent possesses captive power. Given a specific realization of the investment outcome $R_j^* \; \forall j$, a panic in our model is therefore most likely to occur when the total supply of cash is small.[11] We would therefore expect panics to occur when the total cash supply was lowest and, indeed, this seems to have been the case. Kemmerer (1910), Myers (1931), Friedman and Schwartz (1963), Miron (1986), and others have documented the fact that, prior to creation of the Fed, the reserve agents' stock of vault cash followed a seasonal cycle with excess reserves typically at their lowest levels during the "autumn harvest" and "spring revival" when the economy's virtually inelastic supply of cash was required both to facilitate the movement of crops from interior farms to coastal ports *and* to provide emergency funds to the banking and financial sectors. These authors also blame this seasonal shortage of liquidity for the fact that almost all American panics occurred during either the spring or the fall. This paper's conclusion, that panics are caused by

[11] To see this formally, consider a shift in the distribution of reserve agent cash holdings such that the relationship between any two reserve agents' cash holdings remains constant but the total stock of vault cash (i.e., $\sum_{l=1}^{m} C_l^A$) rises or falls. Equation (13) states that the average cash value of a security falls along with the average one-reserve-agent-with-captive-power-excluded stock of vault cash (i.e., $(1/w) \sum_{i=1}^{w} \sum_{l \neq i}^{m} C_l^A$). Thus, as $C_l^A \; \forall l$ falls, δ falls and each bank has its liquidation value—from (4)—reduced. Hence, the smaller the total stock of vault cash and the greater the number of run banks, the smaller the rate of exchange between cash and securities.

shortages of competitively supplied cash *relative* to demand, is therefore consistent with the observation that most American panics occurred during the spring and fall when reserve banks' cash reserves were at their lowest level in the seasonal cycle and hence the probability that some reserve agent would possess captive power was at its seasonal peak.

Finally, we need to examine the ability of our model to account for the various ways in which a panic can be prevented or stopped. Recall that there are four exogenous variables in the model: R^d (the rate banks promise to depositors), C_i^A $\forall i$ (the cash positions of all reserve agents), R^f (the upper bound on liquidation costs; the rate above which foreigners enter the market), and R_j^* $\forall j$ (the rates of return on each banks' assets). Panics occur when banks promise depositors more than they can pay (i.e., when R^d is too high or R_j^* is too low) and when a shortage of cash increases liquidation costs (i.e., C^A is too low and R^f is too high). Policies aimed at preventing or stopping panics must therefore be aimed at affecting one or more of these variables.

One policy is suspension of withdrawal payment. In the context of the current model, this is akin to setting $R^d = 0$ so that the bank's need for cash is zero. This policy was traditionally employed not only to stop bank runs but also to retain the maximum amount of cash within the banking system during panics. Thus, while suspension decreased liquidity in some markets, such as deposits, it increased it in others, such as interbank loans. As Gorton (1987) and others have shown, such a suspension can increase social welfare under fairly general conditions. Furthermore, by suspending payments to depositors and issuing "clearinghouse certificates" to settle internal accounts, the reserve agents were able not only to protect themselves from a potential run but were also able to free up their sizable cash reserves and provide emergency loans to, and purchase the assets of, banks.[12]

A second policy of stopping panics removes the incentive for cash

[12] The fact that the reserve agents typically suspended payments to depositors during panics is not necessarily evidence against the idea that the reserve agents may have realized an increase in profits from the distribution of scarce cash reserves during panics. In particular, as noted above, suspension of withdrawal payment left the reserve agents with more funds to make high interest loans to those short of cash. Furthermore, suspension usually occurred only after the panic had been in effect for some time, during which the reserve agents purchased securities from and provided loans to those short of cash at favorable rates. Smith (1991) notes, for example, that, during the panic of 1893, banks in the south and west of the United States suffered major runs and many suspended operations before the reserve agents finally suspended payment. Sprague (1910), Myers (1931), and others have criticized the reserve banks—composed largely of members of the New York Clearinghouse Association—for waiting "too long" to suspend. In addition to the standard argument that the reserve agents wanted to be absolutely sure that suspension was necessary before taking such a drastic action, our analysis suggests that the delay may have allowed the reserve agents to earn some profit on their usually idle sizable cash reserve.

suppliers to exercise their captive power by tying their profits to those of the cash demanders. This is in effect the arrangement adopted by Canada's branch banking system, which suffered significantly fewer panics than the United States' unit banking system. In Canada, the central reserve banks (i.e., the large institutions in Toronto) owned most of the rural banks and therefore supplied emergency liquidity freely to their branch offices instead of sometimes demanding captive rates of return on cash borrowed during panics. Panics also may have been less frequent in Canada's branch banking system because of the greater diversification branching allows and thus the greater protection it provides against local shocks.

A third policy is to increase C^A so as to wipe out the reserve agents' captive power. This was basically the policy enacted by passage of the Aldrich–Vreeland Act (AVA) of 1908, which was put forth by the U.S. Congress in response to the severe problems created by the cash shortage that occurred during the panic of 1907. The AVA allowed banks to print additional dollars, backed by securities, during panics and thus elasticize the money supply; essentially increasing C^A. Indeed, the banking sector's ability to rapidly expand the money supply under the provisions of the AVA has been credited with greatly reducing the severity and duration of the crisis which began with closure of the New York Stock Exchange at the outbreak of World War One.

A fourth policy is the Federal Reserve policy, which creates a lender of last resort who is supposed to enter the market during times of crisis to discount the securities of cash-short banks. In the context of this model, the Fed's presence is in effect a policy to lower R^f, the interest rate needed to attract new funds into the economy, and thus is a policy to prevent panics by ensuring the liquidity of banks. The statistical results of Table II reveal that, unlike pre-Fed panics, after the Fed there was no shift to a different (i.e., captive) cash-pricing mechanism during panics. It is true that the interest rate rose during the bank runs of 1933, but from Table II it is also true that the increase is adequately accounted for by the estimated nonpanic relationship. This suggests that 1933 was not like previous panics and leaves us with the task of explaining the 1933 bank runs.

One explanation is that the 1933 runs were fundamental, and not liquidity runs, in that they were caused by the Great Depression's unusually bad realization of the production shock R^*. The obvious way to deal with this problem is to insure depositors against bad realizations of R^*. This is precisely the role of deposit insurance. Of course, if deposit insurance is to be incomplete (e.g., a \$100,000 limit per depositor), then the insurance policy must be offered in conjunction with a policy designed to prevent liquidity crises. This is because captive power can still potentially be exercised over the stock of cash demanded by intermediaries who are responsible for the uninsured portion of their withdrawn deposits. It may therefore be optimal to create both a Federal Reserve System *and* deposit insurance, the same combination of policies which has been in effect in the United States since 1934.

V. CONCLUSIONS

When studying panics in an attempt to better understand the history of banking crises and the effectiveness of various policies aimed at preventing panics, there are two key relationships which need to be investigated: the relationship between banks and their depositors and the relationship between banks and reserve agents. The standard approach is to focus on the first relationship in an effort to better understand the microfoundations of bank runs and the optimality of the sequentially serviced demand deposit contracts which make "run the bank" an equilibrium depositor strategy. Conversely, the purpose of this article has been to investigate the way in which reserve agents and banks interact to arrive at equilibrium liquidation costs. Results produced suggest that the determination of liquidation costs through interbank trade has important implications for the way in which isolated bank runs turn into "contagious" panics, as well as for the way in which interest rates and asset prices rise and fall between nonpanic and panic periods.

Using a variant of Dunn and Spatt's (1984) model of strategic bond pricing, we have demonstrated that even a small adverse production shock R^* can be magnified by a shortage of competitively priced cash to produce a big panic with the characteristic increase in interest rates, decrease in security prices, and wave of contagious runs. The attractiveness of our approach is enhanced by our model's consistency with such factors as the international differences in panic experiences, the historical progression of high panic interest rates across various episodes of crisis, and the seasonal timing of panics. We have also accounted for the historical data patterns and statistical results of Tables I and II.

Finally, our model has been useful in distinguishing between the separate roles of deposit insurance and a lender of last resort in preventing banking and financial crises; deposit insurance guarantees (at least to some limit) the fundamental solvency of banks while the lender of last resort assures banks that, should the need arise, they will be able to discount their securities at reasonable rates of interest. In other words, the Fed ensures that banks which are fundamentally solvent are also liquidation solvent. The results of this article clearly reveal that, even with deposit insurance, there is still a need for a Federal Reserve System that responds quickly to sudden increases in the demand for liquidity. The Fed's recognition of this fact is evidenced by their rapid responses to the surges in the demand for liquidity that occurred during the stock market crash of 1987 and the minicrash of 1989. The Fed's continued vigilance in this respect will be even more crucial to the financial sector's stability if, as is currently being proposed, the scope of deposit insurance is to be reduced.

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