RECONCILING BAGEHOT WITH THE FED'S RESPONSE TO SEPTEMBER 11

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Abstract

Bagehot (1873) states that in order to prevent bank panics a central bank should provide liquidity to the market at a "very high rate of interest." This seems to be in sharp contrast with the policy adopted by the Federal Reserve after September 11 when, for a few days, the federal funds rate was very close to zero. This paper shows that Bagehot's recommendation can be reconciled with the Fed's policy if one recognizes that Bagehot has in mind a commodity money regime so that the amount of reserves available is limited. A high price for this liquidity allows banks that need it most to self-select. In contrast, the Fed has a virtually unlimited ability to temporarily expand the money supply.

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1 Introduction

This paper shows, in the context of a model economy, that two apparently incompatible policies–Bagehot's recommended policy of lending at a high interest rate and the Fed's policy of lending at a very low interest rate–can both be justified.

Bagehot (1873) claims that a central bank (CB) can prevent panics by providing liquidity to the market. Specifically, "there are two rules. First. That these loans should only be made at a very high rate of interest... Second. That at this rate these advances should be made on all good banking securities and as largely as the public ask for them."[1] It is widely believed that by applying this policy the Bank of England avoided panics in 1866, 1878, and 1890 (see, for example, De Kock (1974), Redish (2001)). This, in turn, explains why Bagehot's views are still influential today. As pointed out by Peter Bernstein in his foreword to a 1999 reissue of *Lombard Street*, "After nearly 150 years, [Bagehot's] wise words are still the prescription of choice for containing financial crises, as well as a handbook for avoiding them... ."

In the aftermath of the September 11 terrorist attacks in 2001, the Federal Reserve followed the second rule prescribed by Bagehot, but not the first. It lent freely and vigorously, but at very *low* interest rates. For a few day, from September 13 to 19, the federal funds rate approached zero on several occasions (see Markets Group of the Federal Reserve Bank of New York (2002)). The Fed's response to September 11 is generally considered to have been very successful, so one might wonder why there is such a stark difference between Bagehot's proposed policy and the Fed's action.

There is some theoretical support for the Fed's policy. Allen and Gale (1998), Antinolfi, Huybens, and Keister (2001), Freeman (1996), Green (1997),

[1] Page 199.

Rochet and Vives (2002) all show that a central bank should lend at an interest rate of zero in order to prevent liquidity crises.[2] So was Bagehot wrong?

This paper reconciles Bagehot's recommendation with the Fed's policy. I consider a simple model of banks of the type introduced by Diamond and Dybvig (1983) and study liquidity provision policies under a fiat money and a commodity money regime. Because the amount of reserves is limited in a commodity money regime, the central bank must lend funds at a high interest rate to prevent panics. By doing so it allows banks to self-select so that only the ones that need it most obtain liquidity.

The results of this paper rely on four key assumptions. Two assumptions concern the marginal cost of increasing the supply of money. This cost is zero for fiat money and large for commodity money. The other two assumptions concern the nature of liquidity crises. They occur because of a liquidity shortage and are contagious in the sense that a crisis affecting a given bank can trigger further crises on other banks.

In case of panic, the CB can help by providing liquidity. If the marginal cost of increasing the money supply is zero, all panics can be eliminated and the CB should lend at a zero interest rate. If the marginal cost of increasing the money supply is sufficiently large, the CB will want to economize on its scarce reserves. If panics are contagious, the CB's objective is to prevent the "primary" failures, so that no "derivative" failure will occur. I show that an incentive compatible way to operate this selection it to charge a sufficiently high interest rate on CB reserves.

Contagion is essential for Bagehot's policy to be effective. Suppose instead that there is no contagion. If there is enough liquidity for all banks that need it, a liquidity crisis will be avoided. Otherwise, some banks will

[2] Throughout this paper I think of bank difficulties as arising because of a liquidity shortage and use the terms "panics" and "crises" interchangeably.

experience a panic, but in either case charging a high interest rate cannot help prevent panics. It does, however, reduce the utility of depositors in banks that obtain liquidity. Thus a CB that tries to maximize depositors' welfare would charge no interest.

I also show that, in a commodity money regime, if the CB chooses the amount of its reserves optimally, those reserves will be scarce in equilibrium in the sense that panics will occur with a positive probability. This is because with commodity money, increasing CB reserves must reduce consumption.

There is a growing literature on liquidity provision policies. See for example Cooper and Corbae (2002), Repullo (2000), Rochet and Vives (2002), Sleet and Smith (2000), Williamson (1998). These authors' work, however, does not consider the difference between commodity and fiat money regimes.

The rest of the paper is organized as follows. The next section provides some historical background. Section 3 presents the model. Section 4 considers liquidity provision in a fiat money regime, and section 5 does so for a commodity money regime. Section 6 shows that if the CB's objective is to maximize households' utility, it will choose reserves so that the probability of a panic is strictly positive. Section 7 concludes.

2 Some historical background

2.1 Bagehot's recommended policy

Although many of the ideas in *Lombard Street* had been expressed before, notably by Thornton (1802), Bagehot is often credited for exposing them in a more systematic way.[3] Bagehot's proposed policy contains two main

[3]Laidler (2002) studies the differences and the similarities between the views of Bagehot and Thornton.

elements. In times of crisis:

1) A CB should lend freely and vigorously.

2) Loans should be made at a very high interest rate.

Bagehot credits the Bank of England for having prevented a panic in 1866 by following this policy. Subsequently, in 1878 when the City Bank of Glasgow failed, and in 1890 when Baring Bank failed, the same policy is credited for preventing widespread crisis. This is in contrast to the crises of 1847 and 1857, when the Bank of England initially refused to lend, leading to bank panics.

My paper focuses on the second element of Bagehot's proposed policy: the interest rate at which loans should be made. There are, in the literature, two main arguments to justify Bagehot's claim that the CB should lend at a high interest rate. First, under the gold standard, a high rate of interest prevents a drain of gold. Second, a high rate of interest helps prevent moral hazard.

The first argument can be found in Humphrey (1975) and Humphrey and Keleher (1984). They note that following Thornton (1802), Bagehot distinguishes between two types of shocks: internal (or domestic) and external (or foreign) cash drains. The former shock occurs when pessimistic depositors withdraw their deposits to hold cash and can, according to Bagehot, be countered if the CB lends vigorously. The latter shock occurs when gold flows out of England to be deposited in a foreign country. To counter such a shock the CB should raise its lending rate, so as to attract foreign gold and retain domestic gold. When the two shocks arise simultaneously, the CB should lend vigorously and at a high rate of interest.

The argument about moral hazard can be found in Sheng (1991) and Summers (1991), among others. The basic idea is that banks may take excessive risk if they know that they can borrow at a low rate during difficult times. Proponents of this view usually argue that the high interest rate Bagehot mentions is a penalty rate.

To justify his policy, Bagehot argues that "[a very high interest rate] will operate as a heavy fine on unreasonable timidity, and will prevent the greatest number of applications by persons who don't require it. The rate should be raised early in the panic, so that the fine may be paid early; that no one may borrow out of idle precaution without paying well for it; that the banking reserve may be protected as far as possible."[4]

No reference is made in this passage to an external cash drain or to moral hazard. Indeed, there are very few references to moral hazard in *Lombard Street*, and Bagehot has been criticized by Hirsch (1977) for not realizing that his proposed policy could create such a problem.[5] Instead, the quote points to the need to allocate the CB liquidity in an appropriate way. Thus, this paper argues that lending at a high rate of interest allows banks to self-select.[6] Fisher (1999) seems to share this view as he notes that the high interest rate "limits the demand for credit by institutions that are not in trouble." This interpretation is also consistent with an interpretation of Goodhart (1999) that Bagehot does not propose a penalty rate.

The approach adopted by this paper is interesting for two reasons. First, from the perspective of history of thought, one wants to consider the internal

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[4]Page 199.

[5]The model in this paper does not consider moral hazard problems. Martin (2001) shows that a well-designed liquidity provision policy similar to the one considered here can prevent bank panics without moral hazard.

[6]It is interesting to note that Thornton, who writes at a time during which England is off the gold standard, does not mention the need to lend at a high interest rate. This is consistent with the argument in this paper and is further support for the view that Bagehot's main concern is self-selection and not external cash drains. I am indebted to Tom Humphrey for pointing this out to me.

consistency of Bagehot's argument. Hence, the case for a high interest rate should be made based on the type of economic mechanisms that Bagehot emphasizes, rather than some other mechanism. Second, this paper provides a formal analysis of the self-selection story which has not been studied yet.

2.2 The Fed's policy after 9-11-2001

The events of September 11 caused a breakdown in the usual means of communication between banks, and resulted in the temporary shutdown of the interbank market. Some banks found themselves with high liquidity needs, while others had large excesses of liquidity. Because the interbank market was not functioning, the latter banks were not able to lend to the former. To alleviate the effects of the liquidity shortage and prevent a more generalized panic, the Federal Reserve provided unusually large amounts of reserves.

The Fed typically provides liquidity to markets through the discount window (DW) and through open market operations (OMOs).[7] In an OMO the Fed provides funds to primary security dealers through a repurchase agreement (RP). The dealers lend these funds to banks on the interbank market. Ordinarily, the Fed auctions off a fixed amount of reserves and does not engage in transactions at prices that would imply a lending rate lower than its target.

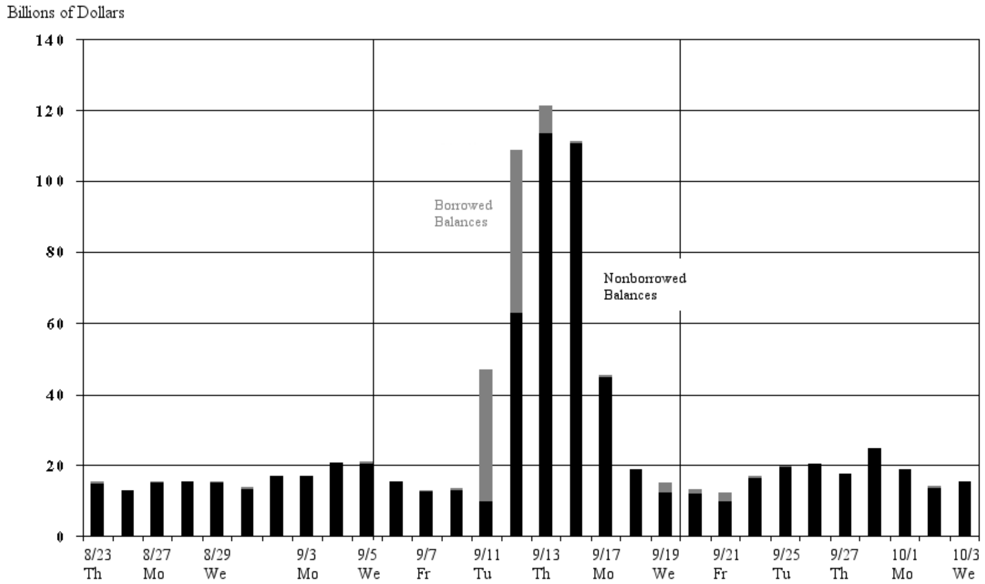
The DW allows banks to obtain funds directly from the Fed. At the time, the interest rate at the DW was 50 basis point lower than the federal funds market target rate.[8] Banks are not allowed to lend these funds on the interbank market. Because the Fed typically prefers that banks obtain liquidity

[7] A third source of liquidity is float.

[8] It was 3 percent until 9/14, 2.5 percent between 9/17 and 10/1, and 2 percent after that.

on the interbank market, borrowing at the DW is usually discouraged.

Chart 1
Total Fed Balances Around September 11, 2001

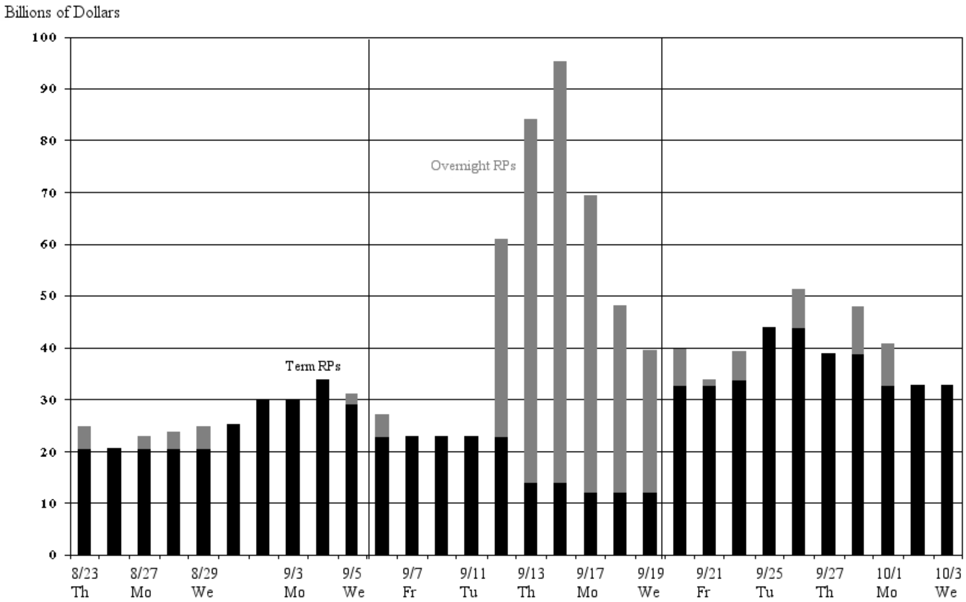


The following discussion details some of the actions of the Fed in the days following September 11. A good description of the Federal Reserve's policy after September 11 is provided by the Markets Group of the Federal Reserve Bank of New York (2000). Chart 1 shows borrowed balances (funds obtained through the DW) and nonborrowed balances (funds obtained through OMOs).[9] On September 11 and 12, large amounts of liquidity were provided through the DW because the interbank market was not functioning properly. On subsequent days, as interbank communications improved, OMOs provided much more liquidity than the DW. While the interest rate on DW loans did not change–until September 17, when the federal funds rate target

[9]Charts 1, 2, and 3 come from Markets Group of the Federal Reserve Bank of New York (2000).

was decreased by 50 basis points–banks were encouraged to borrow which made the effective cost of borrowing lower than usual.

Chart 2
Outstanding Term and Overnight RPs Around September 11, 2001

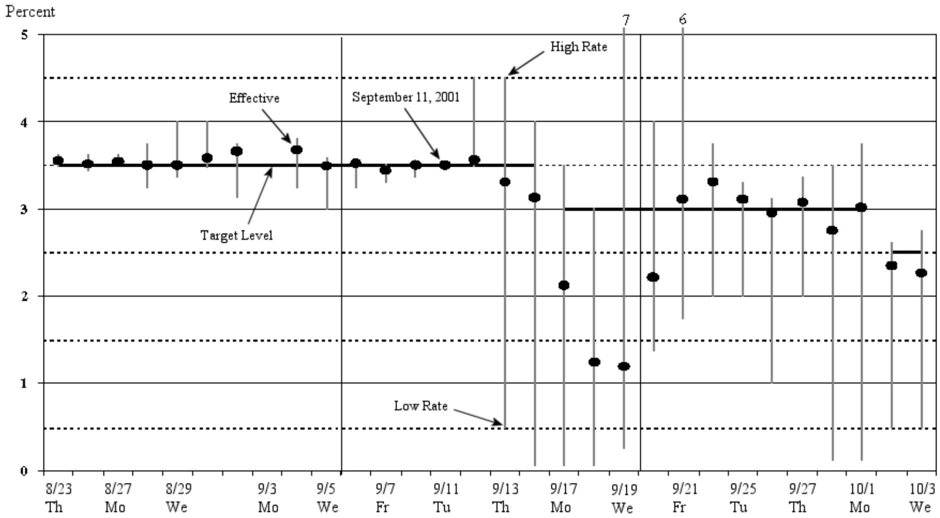


As far as OMOs are concerned, the Fed accepted virtually all dealers' bids for RPs, some at rates well below the federal funds rate target. The Fed's vigorous provision of liquidity would have satisfied Bagehot: "From Wednesday [9-12] through the following Monday [9-17], the size of open market operations were aimed at satisfying all the financing that dealers wished to arrange with the Desk, in order to mitigate to the extent possible the disruptions to normal trading and settlement arrangements."[10] Chart 2 shows overnight RPs and term RPs. Overnight RPs over this period can be associated with emergency lending. The size of these RPs between September 12 and 19 testify to the large amount of liquidity the Fed provided to the interbank market.

[10]Markets Group of the Federal Reserve Bank of New York (2000), page 22.

Contrary to what Bagehot would have advised, however, the Fed did not provide liquidity at a high rate: "[The Desk] had to accept the vast majority of propositions–even those offered at rates well below the new 3 percent target level–in order to arrange RPs of sufficient size."[11] The consequences of providing such large amounts of liquidity can be seen in Chart 3. The federal funds rate reached lows of zero on September 14, 17, and 18. The effective rate (a volume-weighted average of rates on trades arranged through the major brokers) was well below the target rate from September 17 to September 20.

Chart 3
Federal Funds Rates Around September 11, 2001: High, Low, and Effective Rates



It is interesting at this point to take a closer look at the key assumptions behind the results of my paper. First, concerning the marginal cost of increasing the money supply, this paper follows a large literature in setting that cost to zero for fiat money. For commodity money, it might seem that this cost must approach infinity in the short run as some time is required for

[11] Markets Group of the Federal Reserve Bank of New York (2000), page 24.

the CB to increase its reserves of gold. However, the Bank of England had the ability to expend its issue of notes and suspend their convertibility. The analysis remains valid if the cost of suspension of convertibility (real or perceived) is high enough. There is some evidence that this cost was indeed high; for example the panics of 1847 and 1857 subsided only after the Chancellor of the Exchequer announced it would cover the cost of the Bank of England if its Issue Department expanded its note issue without gold backing and was sued.

Another assumption is that bank panics arise from a liquidity shortage. The observation that panics in XIX century England and the problems faced by banks in the days following September 11 both originate in a lack of liquidity greatly facilitates the analysis in this paper. Indeed, a single model that emphasizes this liquidity problem can be used to study both types of events. In the case of XIX century English banks, the liquidity shortage arises because of unusually large withdrawals from pessimistic depositors. Bagehot notes, "... in a panic there is no new money to be had; everybody who has it clings to it, and will not part with it."[12] After September 11, the breakdown of the interbank market is responsible for the liquidity shortage experienced by certain banks (see McAndrews and Potter 2002).

Liquidity shortages in this paper are modeled as in Diamond and Dybvig (1983). This approach has been widely used to study bank panics of the type Bagehot talks about. It has also been applied to modern interbank markets (see Rochet and Vives 2002) and thus seems particularly appropriate to the comparison between Bagehot's recommended policy and the Fed's response to the events of September 11, 2001.

The last key assumption mentioned in the introduction is that bank panics

[12]Page 191.

are contagious. This has long been believed to be true, and Bagehot clearly shares that view as he writes, “In wild periods of alarm, one failure makes many, and the best way to prevent the derivative failure is to arrest the primary failure which caused them.”[13] Contagion seems to have been a concern following the events of September 11 as well. Given the heightened amount of uncertainty it is not hard to imagine that the problems of a few banks could have propagated to other banks. In any case, the analysis in this paper only requires that panics in a commodity money regime be contagious.

3 The environment

There are three dates, 0, 1, and 2, and a continuum of households and banks, each of mass 1. Each household is endowed with an amount ω of the economy's single consumption good. There are two investment technologies: The *short-term* (storage) technology yields one unit of the consumption good at date t for each unit invested at date $t-1$, $t = 1, 2$. The *long-term* technology yields $R > 1$ units of the consumption good at date 2 for each unit invested at date 0.

Liquidating the long-term technology at date 1 carries a cost in terms of the consumption good. If a proportion l of the unit invested is liquidated at date 1, then the technology has return rl at date 1 and $(1 - l)R$ at date 2, where $r < 1$.

As is usual in this kind of model, households can be of two types: impatient or patient. The impatient type only derives utility from consumption at date 1 and the patient type derives utility only from consumption at date 2. Types are learned at the beginning of date 1 and are private information.

[13]Page 53.

Each household has a probability $\theta > 0$ of being impatient and it is assumed that a law of large numbers holds so that the proportion of impatient households in the population is θ. Let c_t denote the amount of goods consumed at date t. A household's expected utility is

$$U(c_1, c_2; \theta) = \theta u(c_1) + (1 - \theta) u(c_2).$$

Impatient households only want to consume goods at date $t = 1$ while patient households only want to consume goods at date $t = 2$.[14] Patient households can store the goods they buy at date 1 with the short-term technology. Alternatively, it could be assumed that they derive utility from the sum of their date 1 and date 2 consumption. The function u exhibits CRRA: $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$, with $\sigma > 1$.[15]

3.1 The planner's problem

To establish a benchmark allocation, consider the problem faced by a planner. The planner is assumed to know the type of each household so that "panics" is not an issue. The planner's objective is to maximize households' expected utility subject to feasibility constraints. Formally, the problem is

$$\max \theta u(c_1) + (1 - \theta) u(c_2),$$

subject to

$$i_1 + i_2 \leq \omega, \tag{1}$$

$$\theta c_1 \leq i_1, \tag{2}$$

$$(1 - \theta) c_2 \leq R i_2. \tag{3}$$

[14] The analysis can be extended to more general preferences as shown by Jacklin (1987) or Jacklin and Bhattacharya (1988).

[15] The restriction on σ is imposed to give banks a role in providing liquidity to households. If $r < 1$, this restriction can be relaxed to include some $\sigma < 1$.

Let $(c_1^*, c_2^*, i_1^*, i_2^*)$ denote the solution to this problem. I refer to it as either the planner's allocation or the efficient allocation. It is characterized by equations (2), (3), as well as

$$u'(c_1) = Ru'(c_2), \tag{4}$$
$$\theta c_1 + \frac{1-\theta}{R} c_2 = \omega. \tag{5}$$

It can be shown that $c_1^* > \omega$. Hence, the planner provides insurance against the risk of being impatient.

3.2 A deposit contract

It is possible to decentralize the planner's allocation with a *standard deposit contract*. Following Allen and Gale (1998), I assume such a contract is nominal and "noncontingent." The fact that the contract is nominal is important if a liquidity provision policy is to be effective as will be seen in the next section. The contract in noncontingent in the following sense: All depositors who withdraw at date 1 receive the same nominal amount unless the bank runs out of resources. If the bank runs out of resources, all depositors get an equal share of the available resources.[16] Depositors who withdraw at date 2 share the resources remaining in the bank.

Let p denote the price of goods in terms of money. A deposit contract is a pair (D_1, D_2), where D_i denotes the nominal payment promised to depositors at date i, $i = 1, 2$. If $pc_i^* = D_i$, $i = 1, 2$ the contract can implement the planner's allocation.[17]

[16] Note that, as in Allen and Gale (1998) and Cooper and Ross (1998 and 2002), there is no sequential-service constraint. Imposing a sequential-service constraint complicates the exposition without affecting the results of the paper.

[17] As pointed out by Jacklin (1987), it is important that households cannot resell their claims on the banks on a secondary market.

There is, however, another allocation which can be implemented by the above deposit contract. Indeed, if everyone believes that patient households withdraw at date 1, then it is individually rational for such households to do so. This equilibrium is associated with a bank panic.

Note that if the probability of a crisis is perceived to be strictly positive, a bank does not offer the deposit contract which can implement the planner's allocation. Instead, it will take into account the fact that a liquidity crisis might occur and adjust its investment in the long-term and the short-term technology accordingly.

Since there in no aggregate uncertainty in the model, it is possible to eliminate the panic equilibrium with a policy of suspension of convertibility. To simplify the exposition I rule out this kind of policy. In this I follow Allen and Gale (1998), Chang and Velasco (2000 and 2001), and Copper and Ross (1998 and 2002).

Several arguments can be offered in defense of this assumption. Chang and Velasco (2001) suggest that it might be undesirable to allow suspension of convertibility because of informational frictions. Indeed, a moral hazard problem could occur where a bank has an incentive to claim a bank run is taking place in order to default on its obligations. Diamond and Rajan (2001) study a model of banking in which the threat of runs disciplines bankers. In the context of that model, policies such as suspension of convertibility undermine the ability of banks to provide liquidity. As will be noted below, the type of liquidity provision policy that I consider, however, do not. Also, historically the ability for banks in the US to suspend convertibility was limited. Diamond and Rajan (2001) note that "banks were allowed to suspend convertibility only when they agreed to do so as a collective..."

An alternative assumption would have been to study a model in which the number of impatient depositors in random. In such models, suspension of convertibility is typically not a desirable policy. However, these models are considerably more complicated to handle and it does not appear that they provide additional insights on the issues my paper is concerned with.

3.3 Sunspot

One way to assign a probability to the occurrence of a crisis is to assume that it is triggered by a sunspot. This approach to dealing with multiple equilibria is common in the literature; see Allen and Gale (1998), Cooper and Ross (1998 and 2002), Peck and Shell (2003), among others. As in these papers the sunspot is assumed to be nonverifiable and hence deposit contracts cannot be made contingent on it.

With some positive probability depositors in a bank observe a sunspot. When this is the case, depositors in this bank believe all other depositors of the bank will withdraw at date 1. When no sunspot is observed, depositors believe all patient depositors of the bank will withdraw at date 2.

3.4 The banks' problem

Banks are assumed to maximize profits. Because of perfect competition, banks will offer, in equilibrium, a deposit contract that maximizes the utility of the representative depositor.[18] Depositors' beliefs are coordinated by a sunspot as described above and depositors choose when to withdraw so as to maximize their utility. Hence, impatient depositors always withdraw at date 1, since they get no utility from consuming later. Patient depositors

[18] Allen and Gale (1998), Cooper and Ross (1998), Schreft and Smith (1998), among others, adopt this approach.

withdraw at date 1 if they believe other patient depositors in their bank also withdraw at date 1 and withdraw at date 2 otherwise. Since there is no sequential-service constraint. All depositors receive the same nominal amount and share available resources whenever a crisis occurs. Let c_c denote the consumption enjoyed by depositors in this case.

Assume, for now, that if a sunspot occurs all banks in the economy are affected. Hence, I can consider a representative bank. Let μ denote the probability that a sunspot occurs. The bank solves

$$\max(1-\mu)[\theta u(c_1)+(1-\theta)u(c_2)]+\mu u(c_c)$$

subject to equations (1), (2), (3), and

$$c_c \leq i_1 + r i_2. \tag{6}$$

The solution to the bank's problem is denoted by $(\hat{c}_1, \hat{c}_2, \hat{c}_c, \hat{\imath}_1, \hat{\imath}_2)$. The bank offers a contract (D_1, D_2) such that

$$p\hat{c}_1 = D_1, \tag{7}$$

$$p\hat{c}_2 = D_2. \tag{8}$$

The first order conditions imply

$$(1-r)\mu u'(c_c)+(1-\mu)u'(c_1)=(1-\mu)Ru'(c_2).^{19} \tag{9}$$

The following two lemmas can be proved.

Lemma 1 *A unique solution exists to the bank's problem.*

Proof. It is enough to show that there exists a unique value of i_1 such that equation (9) is satisfied. Note that if $i_1 \to \omega$, then $c_2 \to 0$ and the RHS

[19]In equilibrium, equations (1), (2), and (3) hold with equality.

of (9) will tend to infinity while the LHS is finite. If $i_1 \to 0$, then $c_1 \to 0$ and the LHS of (9) will tend to infinity while the RHS is finite. The proof is complete since u' is a strictly decreasing function. ■

Lemma 2 $\hat{\imath}_1 > i_1^*$.

Proof. Equation 9 can be rewritten as $(1+r)\mu u'(c_c) = (1-\mu)[Ru'(c_2) - u'(c_1)]$. Since the LHS of this expression is strictly positive, it must be the case that $Ru'(c_2) > u'(c_1)$. The proof follows from the fact that i_1^* implies $Ru'(c_2) = u'(c_1)$. ■

Intuitively, when there is a strictly positive probability of a panic, banks prefer to invest a little more in the short-term technology because this increases the resources available in case such an event occurs.

Bank panics create two different distortions. On the one hand, the long-term technology is liquidated in the banks affected by the sunspot. On the other hand, the investment of all banks is distorted, compared to the planner's allocation.

Instead of offering the contract described above, banks could offer a contract such that crises never occur. In order to do that, they need to reduce the amount promised to impatient depositors enough so that even if all depositors pretend to be impatient there will be some resources leftover. Cooper and Ross (1998) study such contracts. In the present environment, as in their paper, if μ is sufficiently small banks will prefer the contract described above to the crisis-preventing contract. For the remainder of the paper it will be assumed μ is small.

3.5 Contagion

Crises are often believed to be contagious. The idea is that panic in one bank may trigger a panic in other banks. Contagion will be shown to play an important role in understanding Bagehot's recommendation. To introduce contagion in a tractable way I assume that the pessimistic expectation that generate a panic are influenced by two types of events. Depositors in a bank believe all other depositors in that bank will withdraw at date 1 if either they observe a sunspot or some other banks is affected by a crisis.

At date 0, nature chooses $n \in [0, 1]$ according to a probability distribution function f. At date 1, depositors in a fraction n of banks observe the sunspot. These banks are called "crisis-prone" and will be affected by a crisis unless, as will be seen below, they can borrow funds from the CB. Depositors in the remaining banks (a fraction $1 - n$) do not observe the sunspot. These banks are called "noncrisis-prone."

If depositors in a noncrisis-prone bank observe another bank being affected by a panic they learn that a sunspot has occurred. This leads them to believe that all other depositors in their bank will withdraw at date 1. In this way, a panic can spread from a crisis-prone bank to noncrisis-prone banks.[20] In the next section, I show that if a crisis-prone banks is able to obtain liquidity from the CB, it will not be affected by the panic. Hence, if the CB can provide liquidity to all crisis-prone bank, then depositors in noncrisis-prone banks never learn that a sunspot has occured. Whether a bank is crisis-prone or not is private information to the bank and its depositors. The distribution f could have a mass point at zero, so that with positive probability, no banks are affected by the sunspot and no liquidity crisis occurs.

[20] Contagion could be modeled more rigorously, but at the cost of tractability, along the lines of Chen (1999)

In the next section, I describe a liquidity provision policy that allows a CB to prevent crises if it has access to enough liquidity. Absent such policy, all banks in the economy are affected by a crisis as long as some bank is crisis-prone; i.e., depositors in some bank observe the sunspot. Indeed, in that case nothing can protect the crisis-prone bank and, because of contagion, all other banks suffer from the crisis.

4 Liquidity provision in a fiat money regime

The key element that makes crises in the model resemble the problems faced by banks after September 11 is that they arise from a liquidity shortage. Banks with high liquidity needs after September 11 can be associated with crisis-prone banks. A CB can help these banks by providing them with liquidity.

The liquidity provision policy I consider is very similar to the one presented in Allen and Gale (1998). Assume there is a CB with the ability to print non-falsifiable pieces of papers at no cost. These pieces of papers provide no utility and are called money. The CB can exchange money for assets held by the banks at date 1. The assets supplied by banks in this transaction are the rights to goods invested in the long-term technology. At date 2, the reverse operation takes place and banks exchange the money they hold for the assets now in the possession of the CB. This operation looks like a repurchase agreement or a discount window loan.[21] The interest rate on the repurchase agreement is zero if the CB buys and sells the banks' assets at the same price. Money is valued as long as depositors believe the CB will

[21]This environment is not rich enough to distinguish a repurchase agreement from a discount window loan. See Freeman (1999) for an environment in which these two policies have different effects.

exchange it for goods at date 2.

The fact that deposit contracts are nominal plays an important role. Banks can use the extra cash they obtain to pay households what to withdraw at date 1 without having to liquidate the long-term technology. Indeed, the CB become the owner of the assets and decides whether they should be liquidated. This provides a guarantee that there will be enough goods left for patient households at date 2. At the beginning of date 2 a bank must buy its assets back from the CB, before it can pays its depositors. In the process the CB retires the money it has injected.[22]

To prove that the liquidity provision policy prevents crises, I must show that banks are able to offer a nominal amount D_1 to all depositors who withdraw at date 1 and that patient depositors are willing to withdraw at date 2 even if they believe all other depositors withdraw at date 1. Consider what happens if the CB lends some money to a bank and all the bank's depositors withdraw at date 1. The bank gives each of its depositors a combination of money, M, and goods, $\bar{c}$, up to the nominal amount D_1 specified in the deposit contract.[23] Thus one can write

$$D_1 = p\bar{c} + M. \qquad (10)$$

Since the bank does not liquidate the long-term technology, $\bar{c} = i_1 = \theta c_1$, where c_1 denotes the amount of consumption enjoyed by impatient depositors if there is no crisis.

Patient depositors are willing to sell the goods they have in exchange for money if they believe they can obtain goods at date 2 with that money.

[22] I assume the CB retires all the money injected at date 1.

[23] Here it is assumed the CB takes the price p as given and chooses the amount of money M to provide to banks for that price. It would be equivalent to assume that the CB chooses and announces M first and that the price level adjusts.

Impatient depositors have no use for money but want to consume more goods. Market clearing implies

$$\theta M = (1 - \theta)p\bar{c}. \tag{11}$$

Combining equations (10) and (11) yields

$$\frac{D_1}{p} = \frac{\bar{c}}{\theta} = c_1. \tag{12}$$

Hence, if a crisis occurs and the CB provides liquidity, the bank is able to provide D_1 to all withdrawing agents and impatient depositors are able to consume the same amount as if no crisis had occurred. Patient depositors are able to exchange the money they hold for consumption goods and, since the long-term technology has not been liquidated, also consume the same amount as if no crisis had occurred. The fact that the long-term technology has not been liquidated also means that patient depositors are willing to wait and withdraw at date 2.

With such a scheme, patient depositors are indifferent between withdrawing at date 1 or 2.[24] However, if the CB charges the bank an arbitrarily small fee $\varepsilon > 0$ for the liquidity, patient depositors will strictly prefer to withdraw at date 2. Hence the liquidity provision policy prevents crises.[25]

This argument can be summarized in the following proposition.

[24]In particular, note that in an environment of the type studied by Diamond and Rajan (2001) this kind of liquidity provision policy does not remove the commitment value of deposits in the way deposit insurance or suspension of convertibility does. Indeed, if the banker tries to renegotiate, then all depositors withdraw early. Any liquidity that the banker is able to secure from the CB is distributed to depositors at date 1. At date 2, patient depositors can redeem this money with their banker or directly at the CB. The banker is thus unable to extract any resources from an attempt to renegotiate.

[25]It is assumed the CB can observe how much banks invest in the short-term and in the long-term technology and can thus limit access to liquidity for banks that invest too little in the short-term technology. Without this restriction, banks have an incentive to invest all their deposits in the long-term technology and borrow cash from the CB to give to their impatient depositors. This attempt to free ride on the short-term investment of

Proposition 1 *The liquidity provision policy prevents panics.*

It is easy to see that the equilibrium allocation under the liquidity provision policy is efficient. Banks invest optimally because the probability of a panic is zero. The CB maximizes the expected utility of depositors if it lends at a zero interest rate. Charging a positive rate lowers expected utility because depositors in crisis-prone banks consume less than those in noncrisis-prone banks. This uncertainty is disliked by risk-averse households.

This policy is similar to the policy adopted by the Federal Reserve in the days following September 11, 2001. It is consistent with the second part of Bagehot's recommendation that loans be made "as largely as the public asks for them," but it is not consistent with the first part that funds be lent at a "very high interest rate." The Fed did not restrict access to liquidity or try to ration the amount of liquidity it lent through high prices.[26]

5 Liquidity provision in a commodity money regime

This section shows that in a commodity money regime lending at a zero interest rate cannot prevent liquidity crises. However, if the CB charges an

other banks would distort the equilibrium allocation. Allen and Gale (1998) get around this issue by assuming there is only one bank in their economy. I am indebted to Nobu Kiyotaki for pointing this out to me.

[26]While the optimal policy calls for a rate of interest of zero, the effective federal funds rate only declined to near 1 percent. This is partly due to the fact that the Fed did not announce it would accept bids at any rate of interest. Maintaining such "constructive ambiguity," as well as the ability to reject some bids, might be a way for the Fed to reduce the risk of moral hazard. Also, observed interbank rates might include credit risk from which the model abstracts.

interest rate that is high enough, only crisis-prone banks borrow from the CB and some panics are prevented. This corresponds to the policy advocated by Bagehot.

In a commodity money regime the CB cannot issue pieces of papers called money. Instead, it holds units of gold as reserves.[27] Gold cannot be invested in the long-term technology but can be lent to banks as in the previous section. The price of goods in terms of gold is assumed to be fixed and normalized to 1. Given this normalization, it is equivalent to assume gold and goods are prefect substitute in consumption or to assume that consumption of gold yields no utility but that there exists a market on which gold can be exchanged for goods at price 1.

The CB holds a fixed amount of gold and the marginal cost of increasing the supply of gold is taken to be infinity.[28] Assume the CB's reserves are not large enough to prevent panics for all values of n. This assumption will be relaxed in the next section.

The CB sets the prices at which it buys and sells the assets implicitly determining an interest rate which will be denoted by i^{CB}. The repurchase policy is the same as in the fiat money case, except that the CB has to be concerned with the possibility that it might run out of reserves. Consider a bank that obtains funds from the CB. If all depositors withdraw at date 1 the bank gives each of them a combination of gold, G, and goods, $\bar{c}$, up to the nominal amount D_1 specified in the deposit contract. Thus, I can write

$$D_1 = \bar{c} + G, \tag{13}$$

where $\bar{c} = i_1 = \theta c_1$, and c_1 denotes the consumption enjoyed by impatient

[27]There are similarities between the CB in this section and the "asset trader" in Allen and Gale (1998). However, since these authors do not consider contagious panics, there is no scope for self-selection of banks in their model.

[28]The analysis remains valid if the cost is finite but sufficiently high.

agents when no crisis occurs.[29] To prevent a panic a bank needs to be able to borrow at least $G = (1-\theta)c_1$ from the CB.[30]

If the bank is able to obtain $G = (1-\theta)c_1$ from the CB and $i^{CB} = 0$, then patient depositors consume c_2 as was the case in the previous section. If $i^{CB} > 0$, however, patient depositors consume strictly less than c_2 because a transfer of resources occurs from banks to the CB.[31] Patient depositors do not have an incentive to withdraw early provided i^{CB} is not so great that their consumption is smaller than c_1.

To summarize, the CB can prevent panics but only *if it has enough reserves.* If a mass λ of banks need to borrow but the central bank has total reserves less than λG, then the CB cannot prevent panics at all banks. Given the pattern of beliefs I have assumed, such an event triggers a contagious panic.

Because panics are contagious, the CB would like to be able to target the banks to which it provides liquidity. Indeed, providing liquidity to noncrisis-prone banks increases the risk that there will not be enough liquidity for some crisis-prone bank. This, in turn, increases the probability of a contagious crisis. The difficulty lies in the fact that whether a bank is crisis-prone or not is private information. Thus, the CB need to find a way for banks to voluntarily reveal their type.

[29]Since the price of goods in terms of money has been normalized to 1, expressions in real and nominal terms are identical.

[30]I assume that if a bank cannot provide its depositors with D_1, it must default. In case of default, depositors are better off if their bank does not borrow reserves from the CB but instead liquidates the long-term technology and shares the assets. This is because when $i^{CB} > 0$ there is a transfer of resources from the bank to the CB. Alternatively, I could have assumed that the bank only needs to guarantee consumption of at least c_c to depositors who withdraw at date 1. In either case, there is a strictly positive amount of gold that the CB must be able to provide to banks in order to prevent a panic.

[31]It can be assumed that profits from the CB are redistributed to depositors.

I can now show that the liquidity provision policy which implemented the efficient allocation in a fiat money regime is completely ineffective in a commodity money regime. An important assumption here is that if the number of bank asking for liquidity exceeds the available reserves, each bank has an equal probability of obtaining liquidity.

Proposition 2 *If $i^{CB} = 0$, then each sunspot leads to bank panics.*

Proof. The proof has two parts. First I show that all banks have an incentive to borrow funds from the CB. Next, I show that if all banks ask for reserve, then some crisis-prone bank will be unable to acquire the liquidity it needs. This will trigger a contagious panic on all noncrisis-prone banks that are unable to obtain liquidity.

Recall that, because of perfect competition, banks maximize the expected utility of their depositors. Let u_{CP} denote the expected utility of depositors in a crisis-prone bank which does not borrow from the CB. Such banks experience a crisis with probability 1 so $u_{CP} = u(c_c)$. Let u_{NCP} denote the expected utility of depositors in a noncrisis-prone bank that does not borrow from the CB, *provided only crisis-prone banks borrow.* Let η denote the probability that n is so large that the CB cannot provide liquidity to all crisis-prone banks. By assumption, $\eta \in (0, 1)$. Hence, $u_{NCP} = (1 - \eta)[\theta u(c_1) + (1 - \theta)u(c_2)] + \eta u(c_c) > u_{CP}$. Let u_B denote the utility of the depositors in a bank that is able to borrow from the CB. It does not matter whether this bank is crisis-prone or not since all banks that are able to borrow from the CB are unaffected by panics. If $i^{CB} = 0$, then $u_B = [\theta u(c_1) + (1 - \theta)u(c_2)]$. This implies $u_B > u_{NCP} > u_{CP}$ so all banks have an incentive to borrow.

It remains to be shown that if all banks want to borrow, some crisis-prone bank will be unable to obtain liquidity. By assumption all banks have the same probability of getting funds from the CB. Since there are a continuum of banks, if a positive mass of banks are unable to acquire liquidity, then it must also be the case for a positive mass of crisis-prone banks. This is true for all $n > 0$. Since by assumption the CB does have enough reserves to provide all banks with liquidity there must be a contagious crisis. ■

This proposition shows that a liquidity crisis will occur even if the CB would have had enough reserves to prevent a panic had only crisis-prone banks tried to obtain liquidity. Because a bank's type is private information, the CB cannot choose to give the reserves only to crisis-prone banks.

If n were observable then it would be optimal for the CB to set $i^{CB} = 0$. If the fraction of crisis-prone banks were sufficiently small, noncrisis-prone banks would know they need not borrow, since the CB has enough reserves for all crisis-prone banks. If, on the other hand, the fraction of crisis-prone bank is too high, then a contagious panic cannot be avoided and it does not matter whether crisis-prone or noncrisis-prone banks get liquidity. In either case, setting $i^{CB} = 0$ maximizes the utility of depositors. Since n is unobservable, the CB needs an incentive-compatible way of finding out which banks are crisis-prone and which ones are not. The next proposition shows that bank will self-select if the CB sets the interest rate at which it lends high enough.

It is assumed that the mere possibility of borrowing from the CB is not enough to prevent panics. A bank must actually have the reserves on its books to convinces depositors not to withdraw early.[32]

Proposition 3 *There exists i^{CB} high enough such that it is a Nash equilibrium for crisis-prone banks to borrow and for noncrisis-prone banks not to*

[32]In a more complicated model, one could assume obtaining liquidity from the CB takes some time. Then a bank could prevent a panic if it borrowed early enough (when the sunspot occurs) but not if it waited until depositors showed up.

borrow from the CB.

Proof. u_{CP} and u_{NCP} are as defined in the proof of the previous proposition. Let $u_B(i^{CB})$ denote the utility of the depositors in a bank that is able to borrow from the CB at rate i^{CB}. $u_B(i^{CB}) = [\theta u(c_1) + (1-\theta)u(c_2(i^{CB}))]$, where $c_2(i^{CB}) < c_2$ if $i^{CB} > 0$ since in that case there is a transfer of resources from the borrowing bank to the CB. As i^{CB} increases, c_2 must decrease until it reaches c_1. If i^{CB} were to increase any more, patient depositors would prefer to withdraw early rather than wait. Hence, as i^{CB} increases $u_B(i^{CB})$ decreases until it reaches $u(c_1)$. Taking other banks' behavior as given, the level of the interest rate does not affect the utility of depositors in banks that do not borrow. Hence, u_{NCP} and u_{CP} are not affected by i^{CB}. If η is sufficiently close to 1, $u_{NCP} > u(c_1)$ and there exists $\hat{\imath}^{CB}$ such that $u_{NCP} \geq u_B(\hat{\imath}^{CB})$. Also, since $c_1 > c_c$, $u_B(\hat{\imath}^{CB}) > u_{CP}$. At this interest rate it is a Nash equilibrium for noncrisis-prone banks not to borrow if only crisis-prone banks borrow.[33] ■

Note that the interest rate i^{CB} is not a market clearing price. Goodhart (1999) argues that some authors have claimed, mistakenly, that the high interest rate of Bagehot's policy is a penalty rate. Proposition 3 supports Goodhart's point. The high interest rate is not a penalty but a self-selection device. Indeed, the CB chooses the *lowest* rate consistent with self-selection.

Bagehot's policy does not implement the efficient allocation for at least two reasons. First, it does not prevent all panics. Second, when it does prevent panics, the positive interest rate penalizes depositors at crisis-prone banks. However, it is the best policy in the class considered.

[33]Because I assume depositors who withdraw early receive c_1 regardless of i^{CB}, I have to impose the condition that η is sufficiently close to 1. However, if both c_1 and c_2 are allowed to depend on i^{CB}, then $u_B(i^{CB})$ decreases to $u(c_c)$ as i^{CB} increases. In that case, the proof holds for any $\eta \in (0, 1)$.

This exercise does not allow the determination of the best possible policy in a commodity money regime. What it shows is that the Fed's policy after September 11 is better than Bagehot's in a fiat money regime (indeed no other policy can do better), while Bagehot's policy is better than the Fed's in a commodity money regime.

5.1 The importance of contagion

Contagion is crucial in order to rationalize Bagehot's recommended policy. To see this, I show that when panics are not contagious it is optimal for the CB to set $i^{CB} = 0$. To eliminate contagion, assume noncrisis-prone banks are never affected by a panic.

Proposition 4 *If crises are not contagious, the CB maximizes depositors welfare if it sets* $i^{CB} = 0$*.*

Proof. If noncrisis-prone banks are never affected by a panic, they have no incentive to borrow from the CB. Since only crisis-prone banks borrow, the number of banks asking for liquidity will be independent of i^{CB} (provided i^{CB} is not so high that no bank asks for liquidity). Since the CB cannot affect the number of banks that borrow, it maximizes the utility of depositors in banks that borrow by setting $i^{CB} = 0$. ■

This point is more general than might appear at first. It applies to any environment in which liquidity shortages can lead to a panic and panics spread through contagion. In such environments, the optimal strategy for the CB depends on the marginal cost of liquidity. If this cost is sufficiently low, it is best to prevent all panics and set a low price for this liquidity. The equilibrium allocation converges to the efficient allocation as the marginal cost of additional liquidity goes to zero. In contrast, if the marginal cost of liquidity is sufficiently high, it is preferable to induce economic agents to self-select. One way of doing this is by setting a high price for liquidity.

Chang and Velasco (2002) consider the optimal lender-of-last-resort policy under different exchange rate regimes. Under a fixed exchange rate or a currency board, if the cost of abandoning the peg or the currency board is perceived to be high, their CB is in a situation very similar to that of a CB in a commodity money regime. Hence, had Chang and Velasco considered contagious panics, their optimal policy would look very different under these exchange rate regimes. Specifically, it would call for the CB to charge a high interest rate on the reserves it lends.

Lambertini (2001) studies liquidity-provision policies in a model of international debt default and shows that an international lender of last resort can prevent default with a liquidity-provision policy. For the same reasons as above, if the lender of last resort has limited resources, and if debt defaults are contagious, the optimal policy will look very different from the policy described by this author.

Thus, my paper emphasizes the importance of taking into account contagion when trying to think of lender-of-last-resort policies, if it is costly to increase the stock of liquidity.

6 The optimal quantity of central bank reserves

In the previous section it was assumed the CB had a fixed amount of reserves which was not big enough to prevent all crises. In this section, I allow the CB to choose its level of reserves and show that it will not hold enough reserve to prevent all crises if the probability of extremely severe panics is small.

In order to accumulate reserves, the CB must obtain goods from households. I assume the CB can raise lump-sum taxes before households deposit their endowment in a bank. If T denotes the taxes, equation (1) now becomes $i_1 + i_2 \leq \omega - T$. This makes apparent the fact that in a commodity money regime, in contrast to a fiat money regime, the amount of reserves the CB holds directly affects the households' consumption. In order to increase its reserves, the CB must increase taxes which means fewer goods will be invested by banks. Indeed, even if CB reserves and profits are redistributed to households through some scheme, increasing reserves reduces households' consumption because gold cannot be invested in the long-term technology.

The next proposition shows that if the probability of the most severe panics tends to zero, then the CB chooses reserves so that the probability of a panic is strictly positive.

Proposition 5 *Assume $f(n) \to 0$ as $n \to 1$. If the CB chooses its reserves optimally, panics will occur with strictly positive probability.*

Proof. The idea of the proof is that the gain of eliminating panics completely cannot compensate for the cost of reducing the amount of consumption of the households. Thus, there is always a positive probability of a panic.

Since $f(n) \to 0$ as $n \to 1$, the marginal expected utility gain to depositors of an increase in CB reserves tends to zero. This is because the reduction in the probability of a panic brought about by each additional unit of reserves tends to zero. On the other hand, increasing reserves reduces consumption. The marginal expected utility cost to the households of an increase in reserves is strictly positive and increasing, since marginal utility increases as consumption decreases. Thus, it cannot be optimal for the CB to have enough reserves to be able to prevent panics for any value of n. ■

Although the CB could eliminate all panics, it chooses not to do so if extremely severe panics are very rare because it is too expensive in terms of resources.

7 Conclusion

This paper reconciles Bagehot's recommended policy of lending reserves at a high interest rate with the practice of the Federal Reserve after September 11, 2001, of lending funds at interest rates close to zero.[34] The key is to recognize that Bagehot had in mind a commodity money world, while the Fed operates in a fiat money world. The paper shows that in a fiat money regime, no policy can do better than lending funds at a zero interest rate. In particular, Bagehot's policy is strictly worse. On the other hand, in a commodity money regime, lending funds at a zero interest rate cannot prevent bank panics, while Bagehot's policy can. The reason for this result is that when reserves are scarce and panics are contagious, the CB should allocate the reserves to crisis-prone banks rather than noncrisis-prone banks. Charging a high interest rate on reserves allows banks to self-select or, in other words, to credibly reveal their type.

The paper shows an optimal lender-of-last-resort policy will be very different depending on whether crises are contagious or not. If crises are not contagious, liquidity should be provided at zero interest rate so as not to penalize institutions in trouble. If crises are contagious and liquidity is scarce,

[34]The model implies that the Fed could have done even better if it had lowered the interest rate on discount window loans. In 2002 the Fed modified the way in which the discount window operates. The interest rate is now set to be 100 basis points above the federal funds rate target. However, it is specified that the interest rare can be lowered in special circumstances.

however, this policy is ineffective and a high rate of interest is necessary to screen banks. This result is likely to apply in other situations where a lender of last resort plays an important role; for example when thinking about currency crises, or sovereign debt default. Hence taking into account the contagious nature of panics can be very important in designing an effective lender-of-last-resort policy.

Finally, it is shown that if extremely severe panics are vanishingly rare, a CB that tries to maximize the household's expected utility will choose a level of reserves such that panics happen with strictly positive probability. Increasing reserves has the benefit of reducing the probability of a panic, but in a commodity money world it also reduces the amount of goods available for consumption. If extreme panics are sufficiently rare, the cost of eliminating liquidity crises completely is too high compared with the lost consumption.

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