Liquidity Policies with Opacity

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20 December 2023

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December 20, 2023

Abstract

We examine liquidity policies in an environment in which banks can cover liquidity needs by hoarding liquidity or selling legacy assets to expert investors. They can acquire costly information regarding asset quality and deprive banks with bad assets from accessing the asset market. To prevent expert scrutiny, banks must accept fire sale prices for their assets. These depressed prices induce banks to hoard inefficiently low (high) amounts of liquidity when the likelihood of a liquidity shock is relatively low (high). We show that policy interventions aimed at maintaining opacity in the asset market encourage (discourage) liquidity hoarding when there is underhoarding (overhoarding) of liquidity. This suggests that ex-post interventions can serve as substitutes for ex-ante liquidity regulations.

JEL Classification: D82, G01, G21.

Keywords: liquidity, information acquisition, financial crisis, liquidity regulation.

*I am grateful to seminar participants at Tohoku University. I gratefully acknowledge financial support from the Japan Society for the Promotion of Science through a Grant-in-Aid for Scientific Research (No.20K13448). All remaining errors are my own.

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1 Introduction

The 2007–2009 financial crisis revealed that illiquidity in markets was a central issue in the instability of the financial system and the downfall in overall economic activity. It was natural, therefore, that this period of turmoil turned academics' and policy makers' attention to liquidity management in financial institutions. An important concern about their liquidity management is the drastic changes in their liquidity hoarding in response to increased liquidity risk. Before the crisis, liquid assets held by financial institutions were not sufficient to weather a future liquidity shortfall. This idea calls for minimum liquidity requirements, such as the Liquidity Coverage Ratio (LCR) of the Basel III accord (e.g., Diamond and Kashyap, 2016, Allen and Gale, 2017). On the contrary, during the crisis, financial institutions exhibited strong liquidity-hoarding behavior, causing financial market malfunctions and economic downturns (e.g., Ashcraft et al., 2011, Acharya and Merrouche, 2013).

Why may financial institutions hoard too little liquidity in normal times and too much liquidity in times of stress? What policies can correct for inefficient liquidity hoarding? In this study, we answer these questions by developing a model in which banks can meet their liquidity needs by holding liquidity or selling legacy assets to expert investors who can screen out banks with bad assets at a cost. To maintain opacity and preserve access to the asset market, banks sell their assets at depressed prices, leading to inefficient liquidity hoarding. The banks hoard inefficiently low (high) amounts of liquidity when the likelihood of a liquidity shock is relatively low (high). We also show that interventions aimed at maintaining opacity in the asset market can improve welfare by encouraging (discouraging) liquidity hoarding by banks when there is underhoarding (overhoarding) of liquidity. This finding implies that the government resorts to ex-post interventions in financial markets when ex-ante liquidity regulations are difficult to impose.

In our model, bankers use the secondary market for their legacy assets to cover their future liquidity needs. These legacy assets are of a heterogenous quality and no one knows their true quality. However, investors can acquire information regarding the quality of legacy assets at a cost prior to buying them from bankers. Asset prices are determined through bargaining between bankers and investors. We interpret our model as representing an over-the-counter market in which opaque assets (e.g., asset-backed securities, real estate, and corporate bonds) are traded.

Our model is based on the idea that opacity in financial markets is socially desirable, as advocated by Gorton and Pennacchi (1990), Gorton and Ordoñez (2014), Farhi and Tirole (2015), and Dang et al. (2015). If investors identify bankers' assets as low-quality, the bankers are driven out of the asset market and into costly bankruptcy. The fear of bankruptcy compels bankers to accept lower prices for their assets, which in turn deters investors from acquiring information. Anticipating these lower asset prices, bankers hoard liquid assets as a precaution. However, because the private cost of maintaining opacity exceeds the social cost, equilibrium liquidity hoarding may be inefficient. When the likelihood of a liquidity shock is relatively low, bankers hold inefficiently low amounts of liquidity. In this case, once a liquidity shock materializes, information acquisition about the quality of assets leads to excessive costly bankruptcies. In contrast, when the likelihood of a liquidity shock is high, bankers hold inefficiently high amounts of liquidity. In this case, following a liquidity shock, a market freeze occurs.

We then derive policy implications. Our results suggest that the government eliminates inefficiencies by mandating minimum or maximum liquidity requirements for bankers, contingent on the likelihood of liquidity shocks. Instead, the government can resort to ex-post policy interventions in the markets. In particular, we focus on asset purchase programs, like the Public Private Investment Program, which was designed to support the functioning of markets for legacy assets in early 2009. Following Camargo et al. (2016), we formalize policy interventions as subsidies for investors who purchase low-quality assets at high prices. This policy discourages investors from acquiring information and increases asset prices, thereby reducing the cost for bankers to maintain opacity. If banks hold inefficiently low amounts of liquidity, the government encourages liquidity hoarding and reduces costly bankruptcy by committing to intervening in markets. If banks hold inefficiently high amounts of liquidity without intervention, the policy discourages liquidity hoarding and rejuvenates market liquidity.

Following the 2007–2009 financial crisis, ex-post policy interventions, such as bailouts, have been criticized because the expectations of these policies can induce banks to engage in excessive risk-taking, triggering booms and busts. This pushback has led policy makers to emphasize ex-ante regulations. However, our analysis shows that ex-post interventions aimed at maintaining opacity could encourage more conservative risk management by banks. This implies that ex-ante liquidity regulations and ex-post policy interventions can act as substitutes for each other.

Related Literature: This study is related to several strands of literature.

Our study is related to a large body of literature that investigates private liquidity holdings at banks (e.g., Bhattacharya and Gale, 1987, Acharya and Skeie, 2011, Acharya et al., 2011, Diamond and Rajan, 2011, Gale and Yorulmazer, 2013, and Kahn and Wagner, 2021). Similar to our model, Bolton et al. (2011), Malherbe (2014), and Heider et al. (2015) show that the anticipation of market illiquidity increases liquidity hoarding. However, while their work focuses on asymmetric information in financial markets, our study emphasizes the role of costly information acquisition in determining market liquidity.

Our paper also relates to the literature on information acquisition and liquidity. Our study shares the finding that no information acquisition enhances liquidity with Gorton and Pennacchi (1990), Gorton and Ordoñez (2014, 2020b), Farhi and Tirole (2015), Dang et al. (2015), and Asano (2024). In contrast to their work, our study focuses on the interplay between market liquidity and hoarding liquidity. The anticipation of low asset prices, driven by the fear of information acquisition, results in the hoarding of liquidity among banks.

Finally, our study contributes to the literature on optimal policies in markets with asymmetric information. Philippon and Skreta (2012), Tirole (2012), Camargo and Lester (2014), House and Masatlioglu (2015), and Chiu and Koeppl (2016) analyze an optimal form of government intervention in the asset market plagued by adverse selection. Camargo et al. (2016) and Gorton and Ordoñez (2020a) study optimal interventions by considering their effects on information production. In Camargo et al. (2016), excessive interventions decrease buyers' willingness to produce socially valuable information. In our model, interventions aimed at discouraging buyers from acquiring information reduce the incidence of costly bankruptcy, thereby improving welfare. In Gorton and Ordoñez (2020a), the central banker finds it optimal to engage in secret lending to bankers to prevent inefficient information acquisition about bankers' portfolios. In contrast, we focus on the effect of government policies not only on information acquisition but also on expertise acquisition.

Outline: The remainder of the paper is organized as follows. Section 2 describes the setting of the model. Section 3 analyzes the equilibrium. Section 4 examines efficiency and derives policy implications. Section 5 concludes.

2 Model

In this section, we describe the setup of the model.

There are three dates, $t = 0, 1, 2$, and a single perishable good. There is a continuum 1 of bankers and investors. Both agents have risk-neutral preferences without discounting: $c_0 + c_1 + c_2$, where c_t is their consumption at date t. At $t = 0$, each banker has a project that produces nonverifiable income R at $t = 2$. Bankers can start the project without cost at $t = 0$, but may face an aggregate liquidity shock at $t = 1$. With probability $\pi \in (0, 1]$, the liquidity shock hits and the projects require a liquidity injection I. If bankers do not reinvest I, they are forced into bankruptcy and their projects yield nothing. With probability $1 - \pi$, the liquidity shock does not hit and the projects do not require a liquidity injection. While an investor is endowed with a sufficient amount of goods at every date, a banker is endowed with a sufficient amount of goods only at $t = 0$. This implies that bankers need to arrange in advance how to cover their liquidity needs at $t = 1$.

Bankers can satisfy their liquidity needs with their holdings of liquid assets or through the sales of legacy assets. First, a banker has access to storage technology (liquid short-term assets) at $t = 0$. As in Tirole (2011) and Holmström and Tirole (2011, chapters 3 and 7), the banker must invest $g(x) = qx$ units of goods at $t = 0$, with $q > 1$, to receive x units of goods at $t = 1$. We can interpret the cost of hoarding liquidity ($q > 1$) as the opportunity cost of relinquishing investment in other profitable projects. An alternative interpretation is that the supply of liquid assets, such as government bonds, is scarce relative to the demand, and the scarcity of liquid assets yields a liquidity premium, $q - 1$ (see e.g., Krishnamurthy and Vissing-Jorgensen, 2012).

Second, a banker owns a legacy asset and sells it to an investor. The legacy asset has two types of quality: good and bad. At $t = 2$, the owner of the asset receives C units of goods if the asset is good, and nothing if it is bad. The asset is good with probability ϕ and bad with probability $1 - \phi$.

Once a liquidity shock materializes, the asset market is open. Trade occurs in the over-the-counter market in the sense that price setting involves bilateral bargaining.[1] Each banker is randomly matched with a single investor and makes a take-it-or-leave-it offer to sell the asset at price p. While no one knows the true quality of the legacy asset at $t = 0$, the investors can produce costly private information about the quality of the legacy asset before buying it from the banker. Specifically, after receiving the offer, each investor decides whether to know the true quality of the legacy asset perfectly by paying γ units of goods and whether to accept the offer. We assume that γ is publicly observable.

The timing of events is described in Figure 1. Our equilibrium concept is that of a perfect Bayesian equilibrium, which requires (i) that agents act optimally, where other

[1]See e.g., Duffie et al. (2005, 2007) for models of over-the-counter trading.

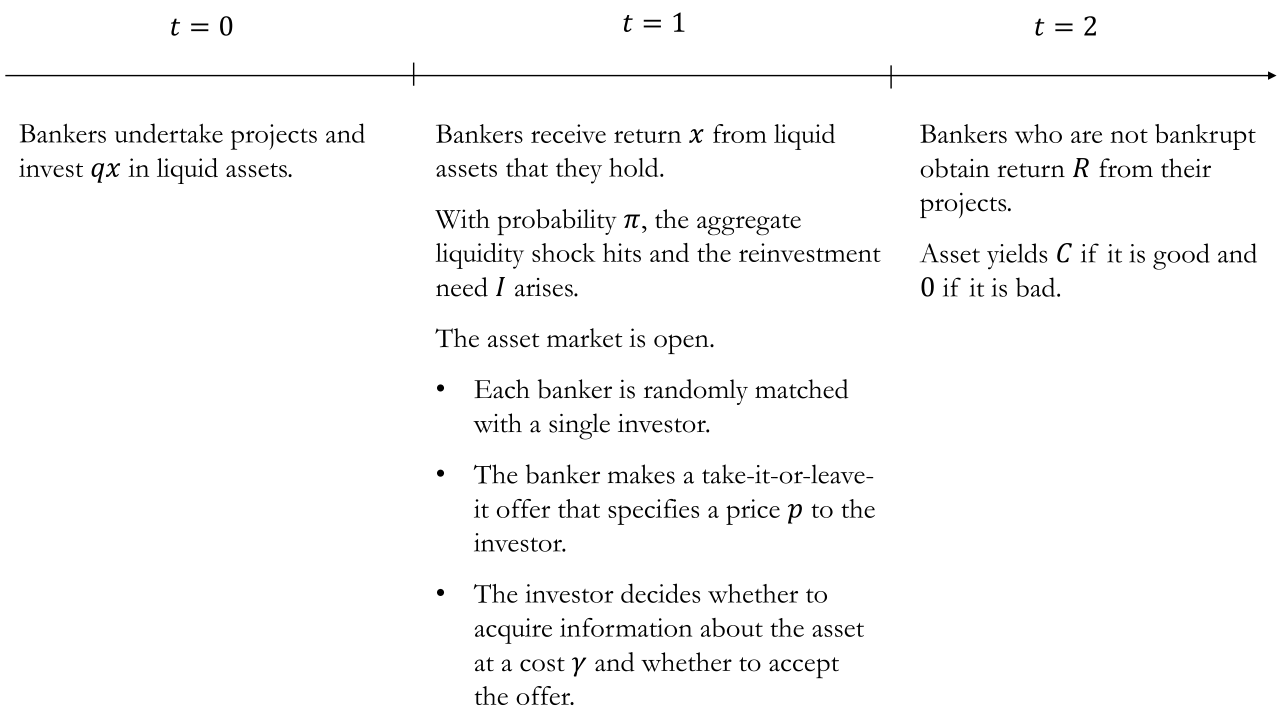


Figure 1: Timing

agents' strategies and beliefs are taken as given, and (ii) that beliefs are consistent with Bayes' rule, given the equilibrium strategies, whenever possible.

We make two parametric assumptions. First, the project has a positive net present value even if a liquidity shock hits:

Assumption 1 $R > I$.

Second, the expected value of the legacy asset is sufficiently high to cover the cost of reinvestment:

Assumption 2 $\phi C \geq I$.

This assumption ensures that if the asset price is equal to the expected value, trading is a more efficient source than holdings of liquidity.

2.1 Benchmark case

As a benchmark case, we consider that investors cannot acquire information about legacy assets. If bankers are hit by liquidity shock, they sell their assets at price $p = \phi C$ and cover their liquidity need I under Assumption 1 and Assumption 2. Since asset sales are a more efficient source than costly liquidity hoarding, the bankers have no incentive to hoard liquid assets; that is, $x = 0$. Thus, the total surplus is given by $R - \pi I$, which is equal to the first-best level.

3 Equilibrium Analysis

In this section, we analyze the equilibrium. Section 3.1 characterizes the equilibrium offer in the asset market at $t = 1$ and Section 3.2 analyzes the bankers' incentive to hoard liquid assets at $t = 0$. We show that bankers' holdings of liquidity depend on the probability of a liquidity shock. When the probability of a shock is high, the equilibrium liquidity holdings are sufficiently high that bankers do not rely on market liquidity. When the probability of a shock is moderate, bankers hold intermediate amounts of liquidity and use the asset market with opacity. When the probability of a shock is low, the equilibrium liquidity holdings are sufficiently low that the shock leads to costly bankruptcy.

3.1 The asset market

Using backward induction, we first focus on the asset market following a liquidity shock. At $t = 1$, a banker with liquid assets x is matched with an investor who can acquire information about these assets at a cost γ. If bankers have enough liquid assets to cover their liquidity needs (i.e., $x \geq I$), they do not need to sell their legacy assets. However, bankers with $x < I$ need to sell legacy assets to meet their liquidity needs. Such bankers optimally choose between an offer that does not trigger information acquisition (an information-insensitive offer) and an offer that triggers information acquisition (an information-sensitive offer).

3.1.1 Information-insensitive offer

We first consider an information-insensitive offer that specifies price, p_{II}. The bankers' optimization problem is as follows:

$$\max_{p_{II}} R - I + p_{II} - \phi C, \tag{1}$$

subject to

$$\phi C - p_{II} \geq 0, \tag{2}$$

$$R - I + p_{II} - \phi C \geq 0, \tag{3}$$

$$\phi C - p_{II} \geq \phi(C - p_{II}) - \gamma, \tag{4}$$

$$p_{II} \geq I - x. \tag{5}$$

(1) is the bankers' net payoff. (2) is the investors' individual rationality (IR) constraint, which requires that they earn the non-negative payoff by accepting the offer. (3) is the bankers' IR constraint, which requires that the bankers' net payoff is non-negative. (4) is the constraint that induces the investors not to acquire information about the asset. This constraint requires the payoff without information acquisition (left-hand side) to be larger than the payoff with information acquisition (right-hand side). In the case of information acquisition, the investor accepts an offer if the asset is good and refuses it if the asset is bad. (4) is rewritten as $\gamma \geq (1 - \phi)p_{II}$, meaning that the cost of information acquisition must be larger than its benefit arising from the bankers' ability to avoid purchasing bad assets with probability $(1 - \phi)$. (5) is the constraint that allows the bankers to meet the liquidity need.

We then solve the optimization problem (1)–(5). Given that a higher p_{II} relaxes (3) and

(5), bankers increase p_{II} until the asset price is determined when (2) or (4) bind:

$$p_{II} = \min \left\{ \phi C, \frac{\gamma}{1-\phi} \right\}. \tag{6}$$

Correspondingly, the bankers' net payoff (1) can be rewritten as

$$U_{II} = R - I - \max \left\{ \phi C - \frac{\gamma}{1-\phi}, 0 \right\}, \tag{7}$$

whereas investors obtain a net payoff of $\max\left\{\phi C - \frac{\gamma}{1-\phi}, 0\right\}$. If the remaining constraints, (3) and (5), are satisfied, bankers can make the information-insensitive offer given by (6) and obtain the date-1 net payoff given by (7).

If the cost of information acquisition γ is sufficiently large such that $\gamma \geq \phi(1-\phi)C$, (4) will not bind. The bankers set the price to make investors break even, that is, $p_{II} = \phi C$ from (2). In this case, the asset price is equal to the expected value, so that the bankers receive the entire social surplus, that is, $U_{II} = R - I$. This implies that (3) will not bind under Assumption 1. Since Assumption 2 holds, (5) is satisfied for any $x \geq 0$.

If γ is small such that $\gamma < \phi(1-\phi)C$, bankers must lower the price to stop investors from acquiring information. Thus, the asset price is below the expected value, and is given by $p_{II} = \frac{\gamma}{1-\phi}$ from (4). By creating fear of information acquisition, investors strengthen their bargaining positions with bankers and extract rents from them. As the cost of information acquisition γ decreases, the asset price p_{II} decreases, making the constraints (3) more restrictive. Thus, if γ is sufficiently high such that $\gamma \geq \underline{\gamma_1} \equiv (1-\phi)(I - R + \phi C)$, then (3) holds. Moreover, if bankers hold sufficient liquid assets to cover their liquidity needs, that is, $x \geq \max\left\{I - \frac{\gamma}{1-\phi}, 0\right\}$, then (5) holds.

Lemma 1 *Suppose that Assumptions 1–2 hold and $x < I$. If*

$$\gamma \geq \underline{\gamma_1} \quad \textit{and} \quad x \geq \max \left\{ I - \frac{\gamma}{1-\phi}, 0 \right\}, \tag{8}$$

then bankers can make the information-insensitive offer p_{II} given by (6) and cover their liquidity needs, regardless of the quality of legacy assets. The resulting bankers' net payoff at $t = 1$ is given by (7). If (8) does not hold, then bankers cannot make an information-insensitive offer.

Lemma 1 suggests that liquid assets x affect the condition in which the information-insensitive offer is feasible (8) but not the asset price p_{II} given by (6). The decrease in the cost of information acquisition γ strengthens investors' bargaining positions relative to the bankers and lowers the asset price p_{II}. This creates a gap between the liquidity need I and the asset price p_{II}. To make an information-insensitive offer, bankers must hoard liquid assets sufficiently to cover a shortfall.

3.1.2 Information-sensitive offer

Next, we consider an information-sensitive offer. Bankers set price p_{IS} by solving the following optimization problem:

$$\max_{p_{IS}} \phi(R - I + p_{IS} - C), \tag{9}$$

subject to

$$\phi(C - p_{IS}) - \gamma \geq 0, \tag{10}$$

$$\phi(R - I + p_{IS} - C) > 0, \tag{11}$$

$$(1 - \phi)p_{IS} > \gamma, \tag{12}$$

$$p_{IS} \geq I - x. \tag{13}$$

(10) is the investors' IR constraint, which requires that the investor has an incentive to accept the offer. (11) is the bankers' IR constraint, which requires that they have an incentive to sell the legacy asset. (12) is the information-acquisition constraint, where the left-hand side represents the benefit of rejecting the offer made by the bankers with bad

assets and the right-hand side represents the cost of information acquisition. (13) requires that the bankers can meet the liquidity need.

It is straightforward to characterize the solution to the problem (9)–(13). Since a higher p_{IS} raises the bankers' payoff (9), they increase p_{IS} until the investors break even; that is, (10) is binding. This implies that the price is determined by

$$p_{IS} = C - \frac{\gamma}{\phi}, \tag{14}$$

and correspondingly, bankers obtain the net payoff (9), which can be rewritten as

$$U_{IS} = \phi(R - I) - \gamma, \tag{15}$$

if the remaining constraints (11), (12), and (13) are satisfied. As long as (12), which is rewritten as $(1-\phi)C > \frac{\gamma}{\phi}$, holds, we have $p_{IS} - \phi C = (1-\phi)C - \frac{\gamma}{\phi} > 0$. Under Assumption 2, we have $p_{IS} > \phi C \geq I$, implying that (13) is satisfied for all $x \geq 0$. Thus, if γ is sufficiently low such that

$$\phi \min\{R - I, (1-\phi)C\} > \gamma, \tag{16}$$

then (11) and (12) hold; that is, the information-sensitive offer is feasible.

Lemma 2 *Suppose that Assumptions 1–2 hold and $x < I$. If (16) holds, then bankers can make the information-sensitive offer p_{IS} given by (14), and only bankers with good assets invest in projects. The resulting bankers' net payoff at $t = 1$ is given by (15). If (16) does not hold, bankers cannot make an information-sensitive offer.*

In contrast to the information-insensitive offer characterized by Lemma 1, Lemma 2 shows that an information-sensitive offer does not require liquid assets. The amount of liquid assets does not affect the condition that the information-sensitive offer is feasible, (16). The high asset price, p_{IS}, enables bankers with good assets to cover their liquidity

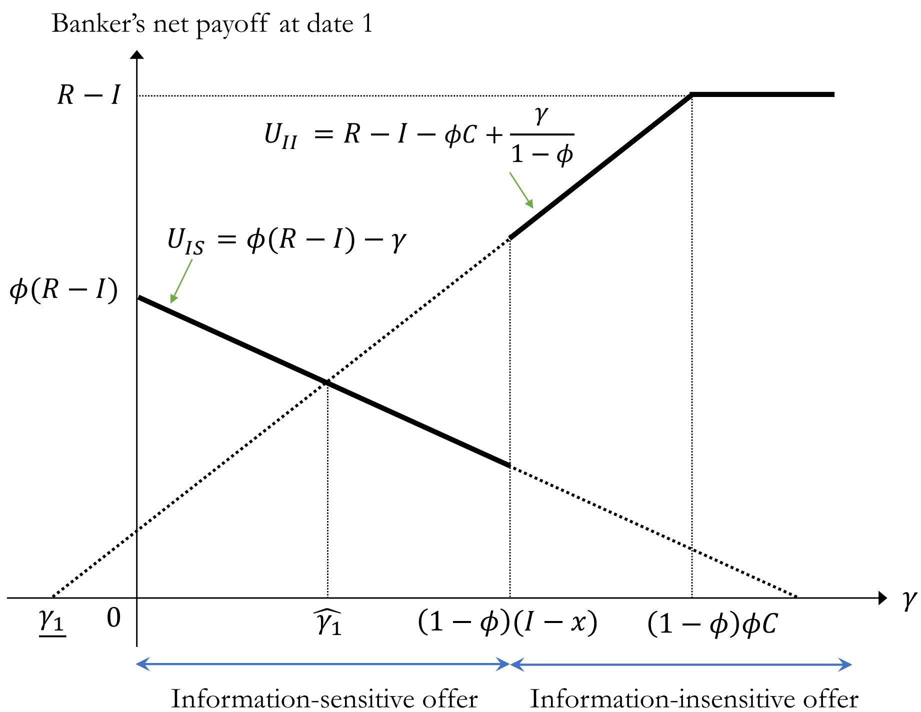


Figure 2: The bankers' net payoff depending on the cost of information acquisition γ

needs only through asset sales. Bankers making information-sensitive offers can save on the cost of hoarding liquidity, instead of bearing the risk of bankruptcy.

3.1.3 Equilibrium price

Based on Lemma 1 and Lemma 2, bankers choose between an offer that deters information acquisition and one that triggers information acquisition. Figure 2 illustrates bankers' net payoff for each offer, depending on the cost of information acquisition γ. In the case of the information-insensitive offer, (7) implies that the banker's payoff U_{II} is increasing in γ as long as $\gamma < (1-\phi)\phi C$. When $\gamma \geq (1-\phi)\phi C$, the payoff is equal to the entire social surplus $R - I$. On the contrary, in the case of the information-sensitive offer, the banker's payoff U_{IS} is decreasing in γ from (15). Thus, there exists a threshold level of γ at which $U_{II} = U_{IS}$, that is, $\widehat{\gamma}_1 \equiv \frac{1-\phi}{2-\phi}\{\phi C - (1-\phi)(R-I)\}$.

Bankers decide to choose an information-insensitive offer p_{II} if

$$\gamma \geq \max\left\{\underline{\gamma_1}, \widehat{\gamma}_1\right\} \quad \text{and} \quad x \geq \max\left\{I - \frac{\gamma}{1-\phi}, 0\right\}. \tag{17}$$

Under this condition, the information-insensitive offer is feasible because (8) holds, and it gives bankers a higher payoff than the information-sensitive offer because $\gamma \geq \widehat{\gamma}_1$. Thus, even though investors extract rents from the bankers, all of the bankers are able to cover their liquidity needs.

If (17) does not hold, bankers do not choose an information-insensitive offer. In this case, costly bankruptcy occurs. If (16) holds, bankers choose the information-sensitive offer and those with bad assets go bankrupt. If (16) does not hold, all of the bankers fail to sell their legacy assets and experience bankruptcy.

The following proposition summarizes this result.

Proposition 1 *Suppose that Assumptions 1–2 hold and $x < I$.*

(i) If (17) holds, bankers choose the information-insensitive offer p_{II} and there is no bankruptcy.

(ii) If (17) does not hold but (16) holds, bankers choose the information-sensitive offer p_{IS} and only bankers with bad assets become bankrupt.

(iii) If (17) and (16) do not hold, all bankers become bankrupt.

In the following analysis, to highlight the role of liquid assets in the asset market, we assume that bankers can choose the information-insensitive offer by using liquid assets:

Assumption 3

$$\max\left\{\underline{\gamma_1}, \widehat{\gamma}_1\right\} \leq \gamma < (1-\phi)I.$$

Under Assumption 3, liquid assets facilitate trade and reduce the incidents of costly bankruptcy. Bankers with liquid assets $x \geq I - \frac{\gamma}{1-\phi}$ make the information-insensitive offer and avoid bankruptcy. However, if bankers have liquid assets $x < I - \frac{\gamma}{1-\phi}$, then

(17) does not hold, and costly bankruptcy occurs. In this case, the bankers either make the information-sensitive offer or fail to sell their legacy assets.

Given that liquid assets do not affect the condition of the information-sensitive offer (16), if Assumption 3 does not hold, liquidity hoarding does not encourage trade. If γ is sufficiently high such that $\gamma \geq (1-\phi)I$, the second inequality of (17) meets for any $x \geq 0$, implying that bankers that make an information-insensitive offer do not need to hoard liquidity. If γ is sufficiently low such that $\gamma < \max\left\{\underline{\gamma_1}, \widehat{\gamma}_1\right\}$, then bankers cannot choose the information-insensitive offer.

3.2 Bankers' liquidity hoarding

We then analyze bankers' decisions to hoard liquid assets at $t = 0$. Since our model has a linear structure, there are three options with regard to liquidity choices: a low amount of liquidity ($x = 0$), an intermediate amount of liquidity ($x = I - \frac{\gamma}{1-\phi}$), and a high amount of liquidity ($x = I$). First, when bankers choose $x = 0$, (17) does not hold, meaning that with probability π, they make an information-sensitive offer or there is no trade. Given that $\gamma < (1-\phi)I < (1-\phi)\phi C$ from Assumption 2 and Assumption 3, if $U_{IS} = \phi(R-I) - \gamma > 0$, then (16) holds so that bankers make the information-sensitive offer. If $U_{IS} \leq 0$, then (16) does not hold so that bankers fail to sell their legacy assets. Thus, the bankers' net payoff in the case of the low holdings of liquidity ($x = 0$) is

$$U_L = (1-\pi)R + \pi \max\left\{U_{IS}, 0\right\}. \tag{18}$$

Second, when bankers choose $x = I - \frac{\gamma}{1-\phi}$, which is the minimum amount of liquidity required to meet condition (17), they make an information-insensitive offer at $t = 1$. The net payoff bankers obtain by holding an intermediate amount of liquidity ($x = I - \frac{\gamma}{1-\phi}$) is

$$U_M = (1-\pi)R + \pi U_{II} - (q-1)\left(I - \frac{\gamma}{1-\phi}\right). \tag{19}$$

Third, when bankers choose $x = I$, they rely only on liquidity hoarding to meet their liquidity needs. Once a liquidity shock materializes, a market freeze occurs because bankers continue to hold legacy assets. The net payoff of the bankers with a high amount of liquidity ($x = I$) is

$$U_H = (1 - \pi)R + \pi(R - I) - (q - 1)I. \tag{20}$$

We obtain the equilibrium liquidity hoarding (x^*) in the following proposition:

Proposition 2 *Suppose that Assumptions 1–3 hold.*

(i) If

$$\pi \leq \min\{\pi_{LM}, \pi_{LH}\} \tag{21}$$

where $\pi_{LM} \equiv \frac{(q-1)\{(1-\phi)I-\gamma\}}{(1-\phi)[R-I-\phi C-\max\{\phi(R-I)-\gamma,0\}]+\gamma}$ *and* $\pi_{LH} \equiv \frac{(q-1)I}{R-I-\max\{\phi(R-I)-\gamma,0\}}$, *then the equilibrium features the low liquidity holdings,* $x^* = 0$.

(ii) If

$$\pi_{LM} < \pi \leq \pi_{MH} \tag{22}$$

where $\pi_{MH} \equiv \frac{(q-1)\gamma}{\phi(1-\phi)C-\gamma}$, *then the equilibrium features the intermediate liquidity holdings,* $x^* = I - \frac{\gamma}{1-\phi}$.

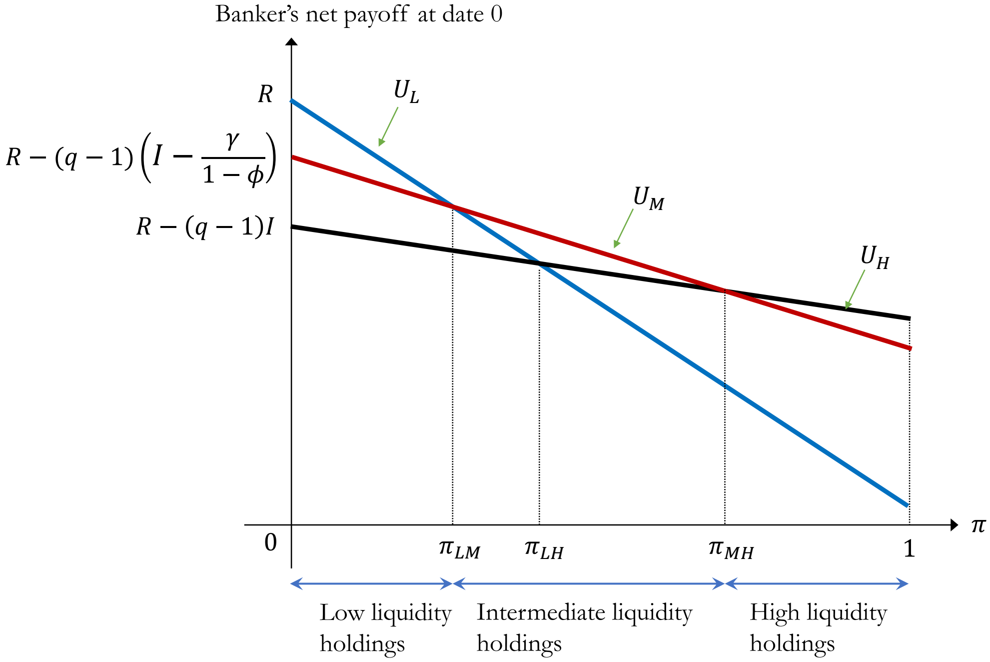
(iii) If

$$\max\{\pi_{LH}, \pi_{MH}\} < \pi \tag{23}$$

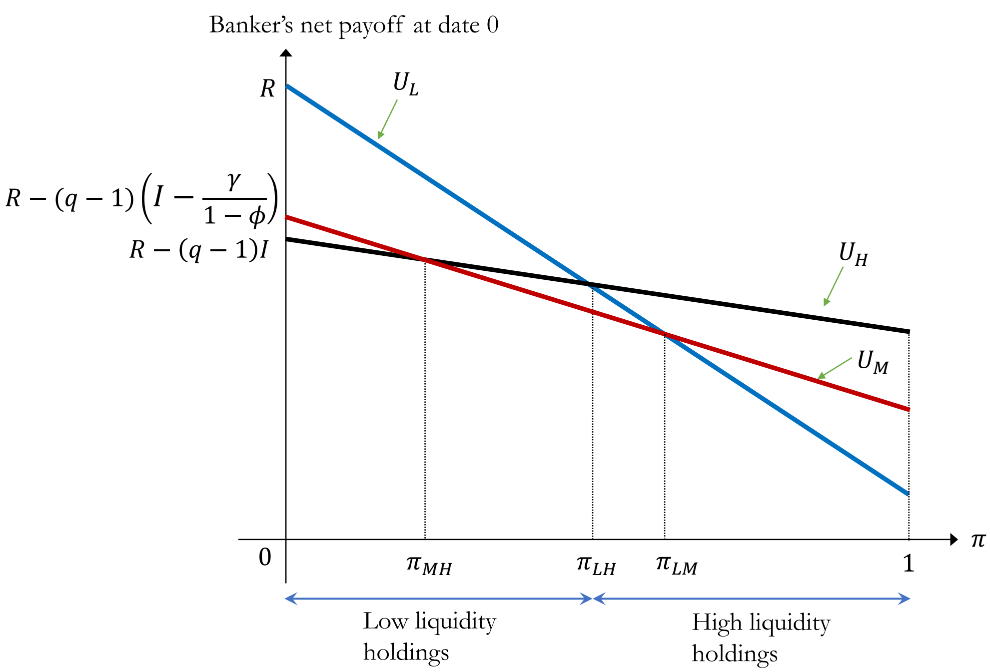
then the equilibrium features the high liquidity holdings, $x^* = I$.

Proof. See Appendix A. ■

Proposition 2 suggests that equilibrium liquidity hoarding depends on the probability of liquidity shock π. Figure 3 illustrates the bankers' date-0 payoff for each liquidity holding. Figure 3a depicts the case in which γ is high, which ensures that the payoff of



(a) U_M is so high that $\pi_{LM} < \pi_{LH} < \pi_{MH}$



(b) U_M is so low that $\pi_{MH} < \pi_{LH} < \pi_{LM}$

Figure 3: The bankers' date-0 payoff

bankers with intermediate liquidity holdings, U_M, is large. First, if $\pi \leq \pi_{LM}$, bankers prefer low liquidity holdings to intermediate and high liquidity holdings because the expected cost of bankruptcy is small relative to the cost of holding liquid assets. Second, if $\pi_{LM} < \pi \leq \pi_{MH}$, intermediate liquidity holdings are more beneficial for bankers than high liquidity holdings. If $\pi_{LM} < \pi$, the expected cost of bankruptcy is so large that bankers prefer intermediate liquidity holdings to low liquidity holdings. If $\pi \leq \pi_{MH}$, the cost of hoarding liquid assets outweighs the expected benefit of avoiding depressed prices. Finally, if $\pi > \pi_{MH}$, bankers choose high liquidity holdings to avoid selling legacy assets.

Figure 3b depicts the case in which γ is low and thus U_M is small. In this case, the equilibrium liquidity holdings change drastically, depending on π. If $\pi \leq \pi_{LH}$, bankers choose low liquidity holdings, leaving the economy susceptible to liquidity shocks. When a liquidity shock occurs, some or all bankers are forced to go bankrupt, and the output in the economy decreases significantly. If $\pi > \pi_{LH}$, then they choose high liquidity holdings. When a liquidity shock materializes, the market breaks down because bankers refuse to trade.

4 Policy Analysis

In this section, we turn to welfare analysis and derive policy implications. Section 4.1 identifies the source of inefficiency and discusses the role of liquidity requirements. Section 4.2 focuses on asset purchase programs implemented during the financial crisis. We demonstrate that the policy enables bankers to make information-insensitive offers and maintain opacity, thereby improving welfare.

4.1 The socially optimal amount of liquid assets

First, we analyze the effect of liquidity regulation on welfare. Consider a social planner who maximizes welfare W by choosing the bankers' holdings of liquidity x at $t = 0$, given an offer characterized by Proposition 1. Welfare is given by total surplus because the planner can use redistributive transfers between bankers and investors at $t = 0$. Thus, the banker's and planner's problems differ only in the objective function.

As in the equilibrium analysis, the planner chooses either low liquidity holdings ($x = 0$), intermediate liquidity holdings ($x = I - \frac{\gamma}{1-\phi}$), or high liquidity holdings ($x = I$). When $x = 0$, the total surplus equals to the bankers' net payoff, that is, $W = U_L$, because investors break even. When $x = I - \frac{\gamma}{1-\phi}$, the total surplus is given by

$$W = R - \pi I - (q-1)\left(I - \frac{\gamma}{1-\phi}\right), \tag{24}$$

which is larger than the bankers' net payoff U_M because the depressed price of legacy assets lowers the bankers' payoff but not the total surplus. When $x = I$, welfare is the same as the bankers' net payoff, namely, $W = U_H$.

Figure 4 illustrates the total surplus for each liquidity holding. The total surplus in the case of intermediate liquidity holdings given by (24) is always larger than that in the case of high liquidity holdings, U_H. This is because while costly bankruptcy does not occur in either case, higher holdings of liquidity reduce welfare. Thus, the planner chooses between $x = 0$ and $x = I - \frac{\gamma}{1-\phi}$. If $\pi \leq \pi^s \equiv \frac{(q-1)\{(1-\phi)I-\gamma\}}{(1-\phi)[R-I-\max\{\phi(R-I)-\gamma,0\}]}$, the planner chooses low liquidity holdings because the cost of hoarding liquid assets outweighs the expected cost of bankruptcy. However, if $\pi > \pi^s$, the expected cost of bankruptcy is large, thereby inducing the planner to choose intermediate liquidity holdings.

We then compare the equilibrium amount of liquidity (x^*) in Proposition 2 with the

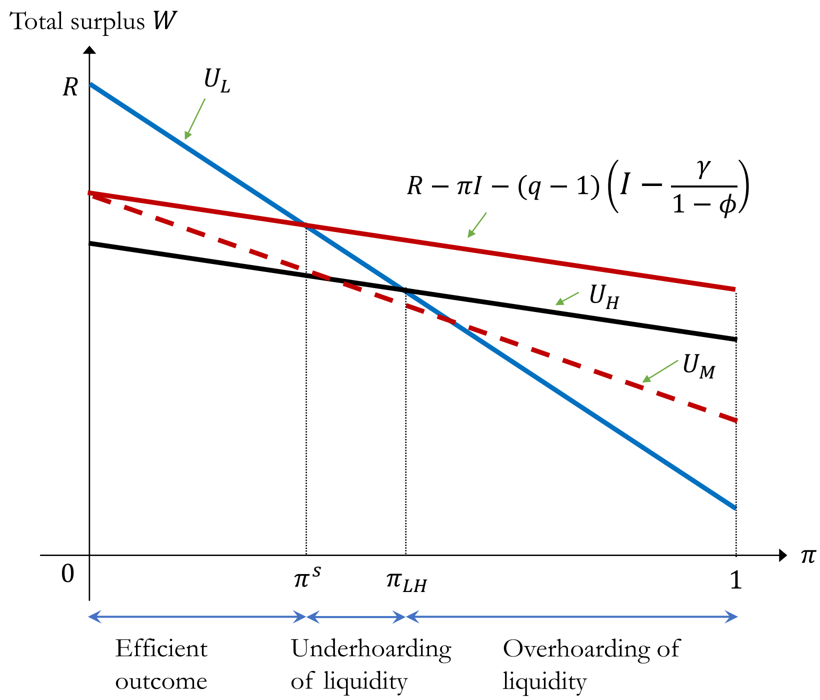


Figure 4: Efficiency of liquidity holdings when $\pi_{MH} < \pi_{LH} < \pi_{LM}$

socially optimal amount of liquidity (x^s). First, if

$$\pi^s < \pi \leq \min\{\pi_{LM}, \pi_{LH}\}, \tag{25}$$

the equilibrium liquidity holdings are less than the socially optimal one; that is, $x^* = 0 < x^s = I - \frac{\gamma}{1-\phi}$. This implies that private holdings of liquidity are too low, and the number of bankers who experience bankruptcy is too high at equilibrium. Second, if π is sufficiently high such that (23) holds, the equilibrium liquidity holdings are more than the socially optimal one; that is, $x^* = I > x^s = I - \frac{\gamma}{1-\phi}$. This implies that private liquidity holdings are too high. Finally, in the other cases, the equilibrium liquidity holdings coincide with the solution to the planner's problem, that is, $x^* = x^s$.

The following proposition summarizes the discussion above:

Proposition 3 *Suppose that Assumptions 1–3 hold.*

(i) If (25) holds, then the equilibrium liquidity holdings are inefficiently low ($x^* < x^s$).

(ii) *If* (23) *holds, then the equilibrium liquidity holdings are inefficiently high* ($x^* > x^s$)*.*

(iii) *Otherwise, the equilibrium liquidity holdings are the same as the socially optimal one* ($x^* = x^s$)*.*

Proof. See Appendix B. ∎

Proposition 3 suggests that ex-ante optimal regulation for bankers depends on the probability of liquidity shock. When the probability of a shock is relatively low such that (25) holds, a minimum liquidity requirement prevents bankers from going bankrupt, improving welfare. In contrast, when the probability of a shock is sufficiently high such that (23) holds, a cap on liquidity holdings induces bankers to use the secondary market to cover their liquidity needs, increasing welfare. However, in practice, it may be difficult to impose liquidity regulation that is sensitive to the likelihood of liquidity shocks. This motivates us to analyze whether ex-post government interventions improve welfare.

4.2 Asset purchase programs

We use our model to analyze the effects of asset purchase programs aimed at restoring liquidity in asset markets. Based on Camargo et al. (2016), we model this policy as the provision of insurance to investors acquiring bad assets. Formally, when an investor purchases an asset at price p at $t = 1$ and learns that it is of bad quality at $t = 2$, the investor receives a transfer τp, with $\tau \in (0, 1]$, from the government. This insurance policy seems consistent with the Public Private Investment Program introduced in 2009 for purchasing toxic assets. We assume that the government maximizes the total surplus by selecting policy τ before bankers choose their liquidity holdings. The government commits to implementing the policy when a liquidity shock hits. We assume that the cost of transfer for investors at $t = 2$ is $(1 + \lambda)\tau p$ with $1 + \lambda > q$.

The policy τ affects bankers' optimization problem regarding the information-insensitive offer through investors' IR constraint (2) and the non-information-acquisition constraint

(4). The two constraints are modified as follows:

$$\phi C - p_{II} + (1-\phi)\tau p_{II} \geq \max\left\{0, \phi(C - p_{II}) - \gamma\right\}. \tag{26}$$

The left-hand side of (26) represents the investors' payoff when accepting the offer. If investors realize that an asset they bought at price p_{II} is bad, they receive the transfer τp_{II} at $t = 2$. Thus, with the policy τ, bankers' optimization problem regarding the information-insensitive offer is given by the objective function (1) and constraints (3), (5), and (26). Since bankers increase p_{II} to maximize their payoff, p_{II} is determined when (26) is binding. Then, when the government intervenes, the price is determined by $p^g_{II}(\tau) = \min\left\{\frac{\phi C}{1-(1-\phi)\tau}, \frac{\gamma}{(1-\phi)(1-\tau)}\right\}$, which increases with τ because the policy increases the payoff of investors who do not acquire information about the quality of assets. Given that (3) is satisfied under Assumption 3, if $x \geq \max\left\{I - p^g_{II}(\tau), 0\right\}$ from (5), bankers can make the information-insensitive offer $p^g_{II}(\tau)$ and obtain their payoff $U^g_{II}(\tau) = R - I + p^g_{II}(\tau) - \phi C$. However, the policy τ does not affect the information-sensitive offer because investors do not have incentives to buy bad assets.

Anticipating these consequences, bankers choose liquidity holdings at $t = 0$. The bankers' payoffs in the cases of low and high liquidity holdings, U_L and U_H, respectively, do not change with the policy τ. However, it affects the amount of liquid assets required for bankers to make information-insensitive offers, that is, $x = \max\left\{I - p^g_{II}(\tau), 0\right\}$. As long as $I > p^g_{II}(\tau) = \frac{\gamma}{(1-\phi)(1-\tau)}$, bankers must hoard intermediate amounts of liquidity, $x = I - p^g_{II}(\tau)$, for an information-insensitive offer. The date-0 payoff for bankers making an information-insensitive offer becomes $U^g_M(\tau) = (1-\pi)R + \pi U^g_{II}(\tau) - (q - 1)\max\left\{I - p^g_{II}(\tau), 0\right\}$.

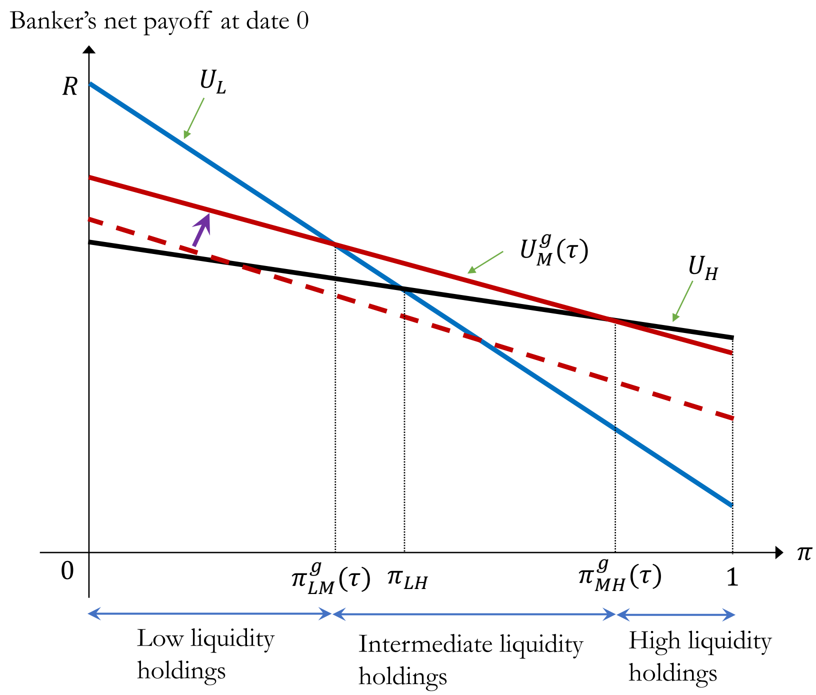


Figure 5: The effect of asset purchase programs

Define:

$$\pi_{LM}^g(\tau) \equiv \begin{cases} \frac{(q-1)\{(1-\phi)(1-\tau)I-\gamma\}}{(1-\phi)(1-\tau)[R-I-\phi C-\max\{\phi(R-I)-\gamma,0\}]+\gamma} & \text{if } \tau < 1-\frac{\gamma}{(1-\phi)I}, \\ 0 & \text{if } \tau \geq 1-\frac{\gamma}{(1-\phi)I}, \end{cases} \tag{27}$$

and

$$\pi_{MH}^g(\tau) \equiv \begin{cases} \frac{(q-1)\gamma}{\phi(1-\phi)(1-\tau)C-\gamma} & \text{if } \tau < 1-\frac{\gamma q}{\phi(1-\phi)C}, \\ 1 & \text{if } \tau \geq 1-\frac{\gamma q}{\phi(1-\phi)C}. \end{cases} \tag{28}$$

If $\pi \leq \min\left\{\pi_{LM}^g(\tau), \pi_{LH}\right\}$, we have $U_L \geq \max\left\{U_M^g(\tau), U_H\right\}$, implying that the equilibrium liquidity holdings is given by $x^g(\tau) = 0$. If $\pi_{LM}^g(\tau) < \pi \leq \pi_{MH}^g(\tau)$, bankers choose $x^g(\tau) = I - \frac{\gamma}{(1-\phi)(1-\tau)}$ at $t = 0$ and make an information-insensitive offer at $t = 1$. If $\max\left\{\pi_{LH}, \pi_{MH}^g(\tau)\right\} < \pi$, bankers hoard a high amount of liquidity, $x^g(\tau) = I$. Figure 5 shows that as τ increases, bankers find the information-insensitive offer more attractive, thereby decreasing $\pi_{LM}^g(\tau)$ if $\pi_{LM}^g(\tau) > 0$ and increasing $\pi_{MH}^g(\tau)$ if $\pi_{MH}^g(\tau) < 1$.

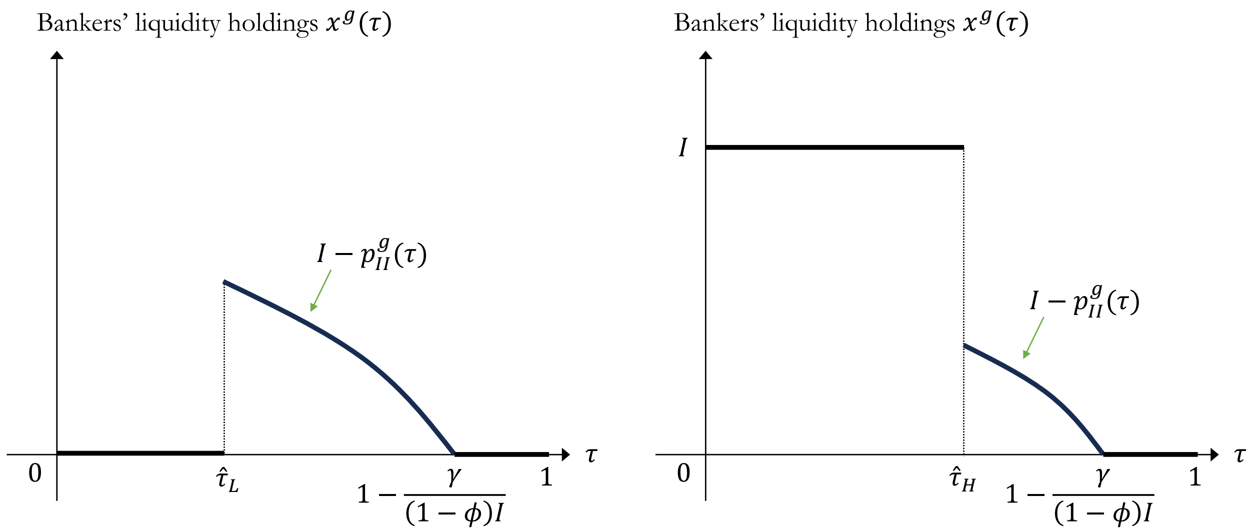
We then characterize the optimal government policy. The impact of the policy τ on bankers' liquidity hoarding and welfare depends on the probability of liquidity shock π. First, consider the case in which π is relatively low such that (25) holds and bankers hold inefficiently low amounts of liquidity, as shown in Proposition 3. Let $\hat{\tau}_L$ denote the minimum level of intervention such that $\pi^g_{LM}(\hat{\tau}_L) = \pi$. Then, the total surplus with policy τ is:

$$W^g(\tau) = \begin{cases} U_L, & \text{if } \tau < \hat{\tau}_L, \\ R - \pi I - (q-1)\max\left\{I - p^g_{II}(\tau), 0\right\} - \lambda\tau p^g_{II}(\tau), & \text{if } \tau \geq \hat{\tau}_L. \end{cases} \tag{29}$$

If $\tau < \hat{\tau}_L$, the bankers hold a low amount of liquidity and interventions do not occur in the equilibrium. In this case, the total surplus remains to be U_L. If $\tau \geq \hat{\tau}_L$, bankers choose $x^g(\tau) = \max\left\{I - p^g_{II}(\tau), 0\right\}$ at $t = 0$ and make an information-insensitive offer at $t = 1$. In this case, the total surplus is reduced by the cost of liquidity hoarding and the cost of transfers at $t = 2$.

Figure 6a illustrates the effect of τ on bankers' liquidity holdings, $x^g(\tau)$. When τ exceeds the minimum intervention level $\hat{\tau}_L$, an increase in τ increases the asset price $p^g_{II}(\tau)$ and reduces their liquidity holdings. Despite it, the total surplus decreases because the cost of transfer is high relative to the cost of hoarding liquidity. For $\tau \geq 1 - \frac{\gamma}{(1-\phi)I}$, bankers can cover their liquidity needs without relying on liquidity hoarding (i.e., $p^g_{II}(\tau) \geq I$) so that the increase in τ only raises the total costs of transfers. Thus, as long as the transfer cost λ is so low that $\lambda < \hat{\lambda}_L$ (where $\hat{\lambda}_L$ is defined in Appendix C), $W^g(\tau)$ given by (29) is maximized at $\tau = \hat{\tau}_L$, implying that the benefit of preventing costly bankruptcy outweighs the sum of the liquidity hoarding costs and transfer costs.

Next, consider the case in which π is sufficiently high such that (23) holds and bankers hold inefficiently high amounts of liquidity, as shown in Proposition 3. Let $\hat{\tau}_H$ denote the minimum level of intervention such that $\pi^g_{MH}(\hat{\tau}_H) = \pi$. The total surplus with policy τ



(a) When π satisfies (25) (b) When π satisfies (23)

Figure 6: Bankers' liquidity holdings with policy τ

is

$$W^g(\tau) = \begin{cases} U_H, & \text{if } \tau < \hat{\tau}_H, \\ R - \pi I - (q-1)\max\left\{I - p_{II}^g(\tau), 0\right\} - \lambda\tau p_{II}^g(\tau), & \text{if } \tau \geq \hat{\tau}_H. \end{cases} \tag{30}$$

The effect of policy τ on bankers' liquidity holdings is illustrated in Figure 6b. If $\tau < \hat{\tau}_H$, bankers hold high amounts of liquidity and no intervention occurs, yielding total surplus U_H. Once τ exceeds $\hat{\tau}_H$, bankers reduce their holdings of liquidity to $\max\left\{I - p_{II}^g(\tau), 0\right\}$ at $t = 0$ and make an information-insensitive offer at $t = 1$. Therefore, if the transfer cost λ is so low that $\lambda < \hat{\lambda}_H$ (where $\hat{\lambda}_H$ is provided in Appendix C), then the total surplus given by (30) is maximized at $\tau = \hat{\tau}_H$. As the benefit of reducing costly liquidity hoarding outweighs the costs of transfers, the policy $\tau = \hat{\tau}_H$ ends up increasing the total surplus.

Finally, if the equilibrium liquidity holdings without interventions are the same as the socially optimal ones, government interventions cannot improve welfare because the cost of interventions is high. The following proposition summarizes the result.

Proposition 4 *Suppose that Assumptions 1–3 hold.*

(i) If (25) holds and $\lambda \in \left(q-1, \hat{\lambda}_L\right)$, the optimal government policy features $\hat{\tau}_L$, encouraging bankers to hoard liquidity.

(ii) *If* (23) *holds and* $\lambda \in \left(q-1, \hat{\lambda}_H\right)$, *the optimal government policy features* $\hat{\tau}_H$, *discouraging bankers from hoarding liquidity.*

(iii) *Otherwise, the government policy cannot improve welfare.*

Proof. See Appendix C. ■

Proposition 4 shows that ex-post interventions can contribute to financial stability. When the likelihood of a liquidity shock is relatively low, bankers are more willing to hoard liquidity in anticipation of government interventions that impede information acquisition. Consequently, the commitment to implementing policy during a liquidity crisis leads to the reduction in costly bankruptcy. This is in contrast to the common view that the anticipation of ex-post policy interventions (e.g., bailouts) could encourage risk-taking by banks and increase the likelihood of booms and busts. When the likelihood of liquidity shock is high, the anticipation of interventions mitigates excessive liquidity hoarding by bankers and restores market liquidity. These results suggest that ex-post interventions can be a substitute for ex-ante liquidity regulation. Thus, governments can resort to ex-post interventions when ex-ante regulations are difficult to impose, and vice versa.

The welfare implications of interventions aimed at maintaining opacity in markets differ from those of Camargo et al. (2016), who argue that such interventions can reduce welfare by discouraging investors from acquiring information that is valuable to other market participants. However, in our model, investor information acquisition leads to inefficient bankruptcy. Thus, interventions that are designed to reduce investors' incentives to acquire information are welfare enhancing.

5 Conclusion

We develop a model in which banks can meet their liquidity needs not only by hoarding liquidity but also by selling legacy assets to expert investors. The sale of assets is a more efficient way to meet their liquidity needs. However, investors can acquire costly information regarding asset quality, preventing banks with bad assets from relying on market liquidity. Instead of maintaining opacity in the asset market, asset prices are depressed and banks need to hoard liquidity. When the probability of a liquidity shock is relatively low, banks have inefficiently low amounts of liquidity, resulting in excessively costly bankruptcy. When the probability of a liquidity shock is high, banks hold inefficiently high amounts of liquidity, causing a market freeze. These results suggest that ex-ante liquidity regulations are necessary to achieve financial stability and improve welfare. Ex-post government interventions aimed at maintaining opacity in the asset market encourage liquidity hoarding when there is underhoarding of liquidity, and discourage liquidity hoarding when there is overhoarding of liquidity.

Our results imply that optimal liquidity regulations are sensitive to the likelihood of a liquidity shock; therefore, implementing them may be challenging. In contrast, commitment to interventions in asset markets is effective in addressing both the under- and overhoarding of liquidity and can thus be desirable in terms of robustness to the likelihood of a liquidity shock. An important future analysis would be to design macroprudential policy that is not sensitive to changes in economic situations.

Appendix A Proof of Proposition 2

Proof. First, consider an equilibrium in which bankers do not hoard liquidity ($x^* = 0$). Because (17) does not hold, bankers obtain the net payoff U_L given by (18). At equilibrium, U_L must exceed bankers' payoff in the case of intermediate liquidity holdings U_M given by (19). When $\pi = 0$, we have $U_L = R > U_M = R - (q-1)\left(I - \frac{\gamma}{1-\phi}\right)$ by using $p_{II} = \frac{\gamma}{1-\phi}$ under Assumption 3. Moreover, we have $\frac{\partial U_L}{\partial \pi} = \max\{U_{IS}, 0\} - R < \frac{\partial U_M}{\partial \pi} = U_{II} - R < 0$ because $U_{II} > \max\{U_{IS}, 0\}$ under Assumption 3. Thus, there exist a unique threshold π_{LM} that satisfies $U_L = U_M$; that is, $\pi_{LM} = \frac{(q-1)(I-\gamma/(1-\phi))}{U_{II}-\max\{U_{IS},0\}} > 0$.

In the equilibrium, U_L must be larger than the payoff in the case of high liquidity holdings U_H given by (20). When $\pi = 0$, we have $U_L = R > U_H = R - (q-1)I$. Furthermore, we have $\frac{\partial U_L}{\partial \pi} = \max\{U_{IS}, 0\} - R < \frac{\partial U_H}{\partial \pi} = -I < 0$. Thus, there exists a unique threshold π_{LH} that satisfies $U_L = U_H$, i.e., $\pi_{LH} = \frac{(q-1)I}{R-I-\max\{U_{IS},0\}} > 0$. Therefore, the condition for an equilibrium with low liquidity holdings is $\pi \leq \min\{\pi_{LM}, \pi_{LH}\}$.

Second, consider an equilibrium in which bankers hoard an intermediate amount of liquidity ($x^* = I - \frac{\gamma}{1-\phi}$). Because (17) holds, bankers obtain the net payoff U_M. When $\pi = 0$, then $U_M = R - (q-1)\left(I - \frac{\gamma}{1-\phi}\right) > U_H = R - (q-1)I$. Additionally, $\frac{\partial U_M}{\partial \pi} = U_{II} - R < \frac{\partial U_H}{\partial \pi} = -I < 0$ because $R - I > U_{II}$ under Assumption 3. Thus, there is a unique threshold $\pi_{MH} > 0$ that satisfies $U_M = U_H$, namely, $\pi_{MH} = \frac{(q-1)\gamma/(1-\phi)}{R-I-U_{II}} > 0$. Consequently, the condition for $U_M \geq U_H$ is $\pi \leq \pi_{MH}$ and the condition for $U_M > U_L$ is $\pi > \pi_{LM}$.

Finally, consider an equilibrium in which bankers hoard a high amount of liquidity ($x^* = I$). The condition for this equilibrium is $U_H > \max\{U_L, U_M\}$, or equivalently, $\pi > \max\{\pi_{LH}, \pi_{MH}\}$. ■

Appendix B Proof of Proposition 3

Proof. We define the total surplus in the case of intermediate liquidity holdings as $W_M \equiv R - \pi I - (q-1)\left(I - \frac{\gamma}{1-\phi}\right)$. First, we compare W_M with the total surplus in the case of high liquidity holdings, U_H given by (20). It follows that $W_M - U_H = (q-1)\frac{\gamma}{1-\phi} > 0$.

Next, we compare W_M with the total surplus in the case of low liquidity holdings U_L given by (18). When $\pi = 0$, then $U_L = R > W_M = R - (q-1)\left(I - \frac{\gamma}{1-\phi}\right)$. Additionally, $\frac{\partial W_L}{\partial \pi} = \max\{U_{IS}, 0\} - R < \frac{\partial W_M}{\partial \pi} = -I < 0$. Thus, there is a unique threshold $\pi^s = \frac{(q-1)\{I-\gamma/(1-\phi)\}}{R-I-\max\{U_{IS},0\}} < \min\{\pi_{LM}, \pi_{LH}\}$. Consequently, if $\pi \leq \pi^s$, the socially optimal amount of liquidity is $x^s = 0$, and if $\pi > \pi^s$, it is $x^s = I - \frac{\gamma}{1-\phi}$.

We then compare the equilibrium amount of liquidity (x^*) and the socially optimal amount of liquidity (x^s). If $\pi^s < \pi \leq \min\{\pi_{LM}, \pi_{LH}\}$, then (21) holds, implying that $x^* = 0 < x^s = I - \frac{\gamma}{1-\phi}$. If (23) holds, then $x^* = I > x^s = I - \frac{\gamma}{1-\phi}$. In the other cases, we have $x^* = x^s$; that is, if $\pi \leq \pi^s$, $x^* = x^s = 0$, and if (22) holds, $x^* = x^s = I - \frac{\gamma}{1-\phi}$. ■

Appendix C Proof of Proposition 4

Proof. First, we characterize asset prices with policy τ. When the liquidity shock hits at $t = 1$, bankers choose between information-insensitive and information sensitive offers. When bankers design an information-insensitive offer, they choose p_{II} to maximize the objective function (1) subject to (3), (5), and (26). Since bankers increase p_{II} until (26) is binding, it follows that $p_{II}^g(\tau) = \min\left\{\frac{\phi C}{1-(1-\phi)\tau}, \frac{\gamma}{(1-\phi)(1-\tau)}\right\}$, which is increasing in τ. Under Assumption 3, (3) is satisfied. Thus, if $x \geq \max\left\{I - p_{II}^g(\tau), 0\right\}$ from (5), the information-insensitive offer is feasible; otherwise, bankers cannot make the information-insensitive offer. In contrast, policy τ does not affect bankers' optimization problem regarding the information-sensitive offer (10)–(13).

From Assumption 3, bankers making the information-insensitive offer receive a higher payoff $U_{II}^g(\tau) = R - I + p_{II}^g(\tau) - \phi C$ than the payoff in the case of the information-sensitive offer $U_{IS} = \phi(R - I) - \gamma$. This implies that if $x \geq \max\left\{I - p_{II}^g(\tau), 0\right\}$, bankers choose an information-insensitive offer; otherwise, costly bankruptcy occurs and bankers obtain the payoff, $\max\{U_{IS}, 0\}$.

Next, we analyze bankers' liquidity holdings x at $t = 0$. Bankers' net expected payoffs in the case of low liquidity holdings ($x = 0$), U_L, and the one in the case of high liquidity holdings ($x = I$), U_H, are given by (18) and (20), respectively. However, policy τ affects bankers' payoff in the case of intermediate liquidity holdings, $U_M^g(\tau) = (1-\pi)R + \pi U_{II}^g(\tau) - (q-1)\max\left\{I - p_{II}^g(\tau), 0\right\}$ because an increase in τ increases $p_{II}^g(\tau)$ and decreases liquidity holdings to cover their liquidity needs, $x = \max\left\{I - p_{II}^g(\tau), 0\right\}$. If $\pi \leq \min\left\{\pi_{LM}^g(\tau), \pi_{LH}\right\}$, where $\pi_{LM}^g(\tau)$ is non-increasing in τ, then $U_L \geq \max\left\{U_M^g(\tau), U_H\right\}$, implying that bankers choose low liquidity holdings. If $\max\left\{\pi_{LH}, \pi^g_{MH}(\tau)\right\} < \pi$, where $\pi^g_{MH}(\tau)$ is non-decreasing in τ, then $U_H > \max\left\{U_L, U^g_M(\tau)\right\}$, implying that bankers choose high liquidity holdings. If $\pi^g_{LM}(\tau) < \pi \leq \pi^g_{MH}(\tau)$, bankers choose intermediate liquidity holdings.

We then examine the effects of policy τ on the total surplus. First, consider the case in which (25) holds. The government chooses τ to maximize the total surplus given by (29). Because $\pi^g_{LM}(\hat{\tau}_L) = \pi$, $\pi^g_{LM}\left(1 - \frac{\gamma}{(1-\phi)I}\right) = 0$, and $\pi^g_{LM}(\tau)$ is decreasing in τ for $\tau < 1 - \frac{\gamma}{(1-\phi)I}$, we have $\hat{\tau}_L < 1 - \frac{\gamma}{(1-\phi)I}$. If $\tau < \hat{\tau}_L$, bankers choose $x^g(\tau) = 0$ and $W^g(\tau)$ is independent of τ. If $\tau \in [\hat{\tau}_L, 1 - \frac{\gamma}{(1-\phi)I})$, then $p^g_{II}(\tau) = \frac{\gamma}{(1-\phi)(1-\tau)} < I$ and bankers choose $x^g(\tau) = I - p^g_{II}(\tau)$. In this case, we have

$$\frac{\partial W}{\partial \tau} = \frac{\partial p^g_{II}(\tau)}{\partial \tau}(q - 1 - \lambda\tau) - \lambda p^g_{II}(\tau) = p^g_{II}(\tau)\frac{q-1-\lambda}{1-\tau} < 0, \tag{31}$$

where the last inequality holds because $1 + \lambda > q$. If $\tau \geq 1 - \frac{\gamma}{(1-\phi)I}$, then $p^g_{II}(\tau) \geq I$ and bankers choose $x^g(\tau) = 0$. In this case, $W^g(\tau)$ is decreasing in τ. The minimum level of intervention $\tau = \hat{\tau}_L$ yields a larger total surplus than that without interventions if $W^g(\hat{\tau}_L) > U_L$, or equivalently,

$$\pi\left(R - I - \max\left\{U_{IS}, 0\right\}\right) - (q-1)\left(I - \frac{\gamma}{1-\phi}\right) > \frac{\gamma\hat{\tau}_L(1+\lambda-q)}{(1-\phi)(1-\hat{\tau}_L)}. \tag{32}$$

The left-hand side of (32) is positive because $\pi > \pi^s$ from (25). The right-hand side of (32) is increasing in λ and is sufficiently close to 0 if λ is sufficiently close to $q - 1$. Thus, there exists a unique threshold $\hat{\lambda}_L \equiv q - 1 + \frac{(1-\phi)(1-\hat{\tau}_L)}{\gamma\hat{\tau}_L}\left[\pi\left(R - I - \max\left\{U_{IS}, 0\right\}\right) - (q-1)\left(I - \frac{\gamma}{1-\phi}\right)\right]$ such that if $\lambda < \hat{\lambda}_L$, the optimal policy is given by $\tau = \hat{\tau}_L$, and if $\lambda \geq \hat{\lambda}_L$, any $\tau \in [0, \hat{\tau}_L)$ is optimal. Consequently, if $\lambda < \hat{\lambda}_L$, the optimal policy $\tau = \hat{\tau}_L$ increases bankers' liquidity holdings from 0 to $I - p^g_{II}(\hat{\tau}_L)$.

Second, consider the case in which (23) holds. The government chooses τ to maximize the total surplus given by (30). If $\tau < \hat{\tau}_H$, bankers choose $x^g(\tau) = I$ and $W^g(\tau)$ is independent of τ. If $\tau \geq \hat{\tau}_H$, bankers choose $x^g(\tau) = \max\left\{I - p^g_{II}(\tau), 0\right\}$ and $W^g(\tau)$ is decreasing in τ from (31). The minimum level of intervention $\tau = \hat{\tau}_H$ yields a larger total surplus than no intervention if $W^g(\hat{\tau}_H) > U_H$, or equivalently, $\lambda < \hat{\lambda}_H \equiv \frac{q-1}{\hat{\tau}_H} \min\left\{1, \frac{(1-\phi)(1-\hat{\tau}_H)I}{\gamma}\right\}$. This implies that if $\lambda < \hat{\lambda}_H$, then the optimal policy is $\tau = \hat{\tau}_H$, and if $\lambda \geq \hat{\lambda}_H$, any $\tau \in [0, \hat{\tau}_H)$ is optimal. Furthermore, the optimal policy $\tau = \hat{\tau}_H$ necessarily reduces bankers' liquidity holdings.

Finally, consider the situation in which the equilibrium holdings of liquidity without interventions are the same as the socially optimal one. If $\pi \leq \pi^s$, no policy increases the total surplus given by (29) because the left-hand side of (32) is nonpositive. If (22) holds, the total surplus is given by $W^g(\tau) = R - \pi I - (q-1)\max\left\{I - p^g_{II}(\tau), 0\right\} - \lambda\tau p^g_{II}(\tau)$, which decreases with τ. ■

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