CBDC-based New Banking System, Bank Runs, Efficient Allocation, and Monetary Policy Tradeoff between Price and Financial Stability

Sunjoo Hwang

Korea Development Institute

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Abstract

The current banking system cannot prevent bank runs completely. Nor can it achieve a socially efficient allocation, since bank competition can restrain banks' money creation. As an alternative, I consider a CBDC-based new banking system in which deposit-taking is centralized by a central bank through CBDC while lending is decentralized by commercial banks. I show theoretically that this new banking system prevents panic-based bank runs entirely. Commercial bank runs cannot occur as banks do not take customer deposits and central bank runs can be prevented due to some special powers only central banks can exercise. I also find that this new banking system induces a first-best allocation by solving a tradeoff between competition and money creation. Furthermore, this new system can mitigate a monetary policy tradeoff between price and financial stability, by neutralizing negative effects of monetary policy tightening on bank run risks.

Key words: Retail CBDC, Pass-through lending, Bank run, Allocative efficiency, Fountain pen money, Competition

JEL Code: E58, G21

1. Introduction

Is there a way to prevent bank runs completely while achieving a socially efficient resource allocation? Is there a way to enjoy the full benefits of bank competition while maintaining financial stability intact? Recent digital financial innovations characterized by fintech or big tech companies have the potential to improve the well-being of financial consumers through competition. However, on the other hand, as the recent Silicon Valley Bank run showed impressively, rumor or unreliable negative information can easily lead to bank runs with an unprecedented speed through digital communication media such as SNS. Then, how can we address a related tradeoff between competition and financial stability?

A potential solution is a CBDC-based new banking system in which deposit-taking is centralized by a central bank through retail CBDC while lending is decentralized by commercial banks in a competitive loan market (see Figure 1 and 2).[1] In this new system, the central bank offers CBDC-based current accounts to all economic agents including individuals, companies, and institutions. Commercial banks are not allowed to take deposits and hence economic agents deposit only with the central bank. Nevertheless, banks can still make loans since in this new system the central bank provides a pass-through lending. Not just traditional banks but also fintech or big tech companies can freely enter the loan market as lenders and get the central bank pass-through funding.

[1] At the first glance, the CBDC-based new banking system looks similar with a narrow banking system. This is true in a sense that loan-making banks are not allowed to take demand deposits from the general public. Relatedly, the Swiss Sovereign Money Initiative (or *Vollgeld*) was proposed but defeated in June 2018 in a vote. According to this initiative, only the Swiss central bank can take demand deposits from Swiss citizens. However, such a narrow banking system is fundamentally different from the CBDC-based new banking system in the sense that the central bank does not provide pass-through lending and, hence, financial intermediation between demand deposits and loans disappears (see Figure 1, 2, and 3).

Figure 1: Traditional banking system

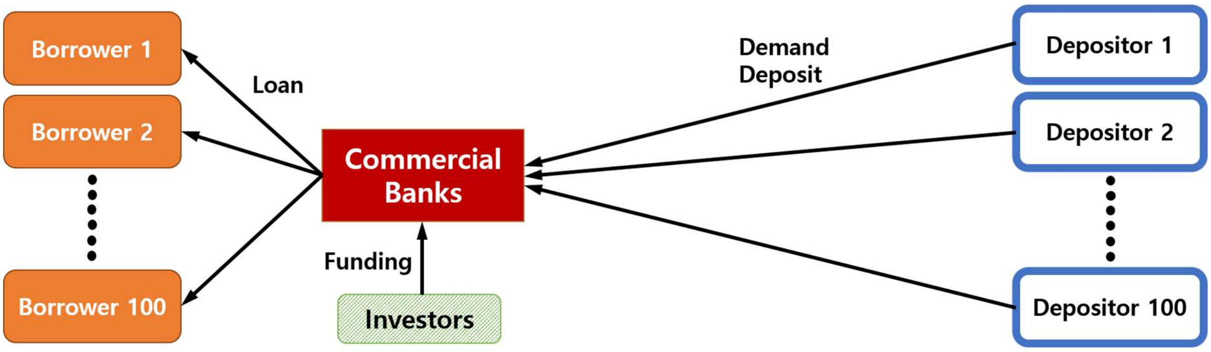


Figure 2: CBDC-based new banking system

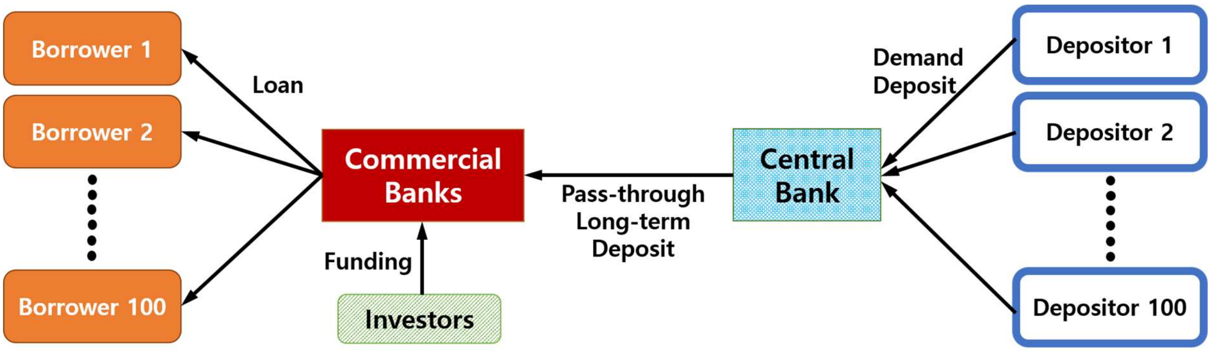
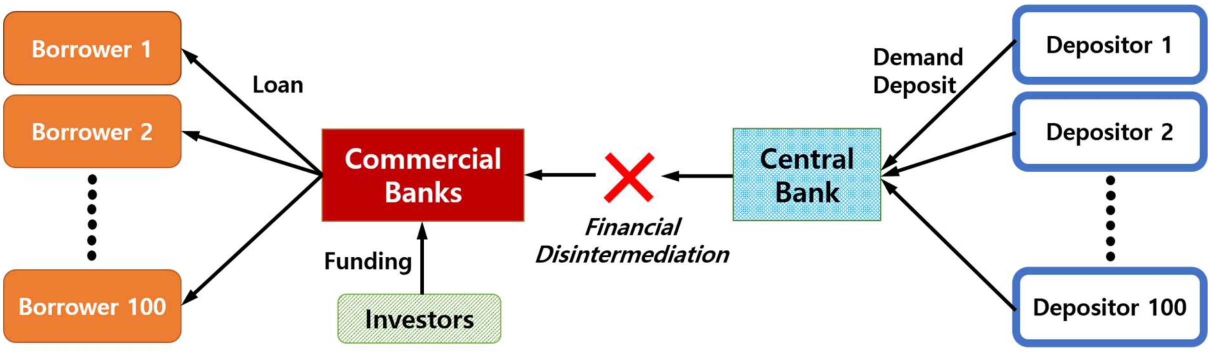


Figure 3: A narrow banking system or the Swiss sovereign money initiative



There are two closely related papers on these issues. As for bank runs, Bossone and Haines (2023) informally argue that runs never occur in this new system since money, which is mostly CBDC, is circulated unlimitedly within the boundary of the central bank and hence never leaves, though they obtain the result without analyzing a formal model. With regard to resource allocation, Fernandez-Villaverde et al. (2021) examine a Diamond-Dybvig type model and find that this new system does not outperform the traditional banking system, though their result is obtained under the implicit assumption that there are no frictions on money creation.

To analyze whether and how this CBDC-based new banking system prevents panic-based bank runs completely while achieving a superior allocation than in the traditional banking system, I develop a model of bank run and money creation by extending Diamond and Dybvig (1983)'s standard model of bank run and Parlour et al. (2022)'s model of fountain-pen-money creation. An important feature of my model is that banks create money by making loans. Unlike the conventional view of fractional reserve banking, real-life banks do not lend out of pre-existing deposits. Instead, they make loans out of nothing in the first place, though they must have enough cash or liquid assets to settle subsequent payment transactions. The mechanism is as follows. Whenever a bank makes a loan, it increases the balance of the borrower's deposit account as much as the loan amount with a stroke of a pen (or an electronic pen in this digitalized banking system). The borrower can use this created deposit as money. Tobin (1963) calls it the fountain pen money. This practice recently attracted much attention in the literature, as researchers in the Bank of England confirmed that it is a reality (see MeLeay et al. (2014)).[2] Unlike the extant literature on the CBDC-based new banking system, I explicitly consider this money creation power of banks and obtain a different result on resource allocation.

The first main result is that there is a tradeoff between competition and money creation under the traditional banking system. If there is a monopolistic bank, all deposits are held in the single bank. If a consumer buys goods or services from a merchant, the former may transfer her deposits to the latter's account to pay for the price. Notably, it is an "on-us" payment since the consumer and merchant have deposit accounts in the same bank and hence the money never

[2] See also Werner (2014, 2016) who confirms this practice by conducting a well-devised lending experiment with a German bank.

leaves the bank.[3] Thus, the bank needs not prepare liquid assets to settle the payment transaction. That's why this monopolist bank faces virtually no constraint on money creation. By contrast, an atomic bank in a perfectly competitive market faces a strong money creation constraint. Every deposit it creates by making loans will highly likely flow out to other banks, as borrowers and their counterparties most likely use different banks (i.e. "off-us" payment). Thus, each bank must prepare a lot of liquid assets to meet depositors' withdrawal requests. In general, the more competitive is the banking market, the more liquidity outflows each bank faces for a given amount of loans, which meaning that banks can make less loans. To the best of my knowledge, this tradeoff of competition and money creation is new to the literature.

The second main result of this paper is that the CBDC-based new banking system is superior to the traditional banking system in terms of resource allocation. Consider the traditional banking system. If the banking market is competitive, banks are unable to provide efficient amount of lending since the tradeoff between competition and money creation significantly restrains their lending capacity. By contrast, if the banking market is monopolistic, although the single bank is able to provide loans unlimitedly, it would nevertheless make socially insufficient loans in order to enjoy a monopoly rent. In general, I show that, for any degree of bank competition, the equilibrium amount of lending is smaller than the efficient level. However, the CBDC-based new banking system can solve this inefficiency problem. Under this new system, the central bank is a monopolist of deposit-taking and, hence, every deposit by any economic agent is circulated within the central bank. Also, the central bank does not maximize its profit but the social welfare. Therefore, this central bank is able to and willing to provide an efficient amount of loans through banks in the competitive loan market. This is in a stark contrast to Fernandez-Villaverde et al. (2021). They do not consider banks' ability of fountain pen money creation but rather assume that banks lend out of pre-existing deposits and, hence, the tradeoff between competition and money creation does not arise. Under the absence of this friction, they find that both the traditional banking system and a kind of the CBDC-based new banking system induce a first-best allocation.

[3] I consider a closed economy where local banks and economic agents do not trade with foreign entities.

The previous two results are obtained in cases where there is no panic across depositors on banks' ability to repay deposits. The third main result is that the CBDC-based new banking system can eliminate panic-based bank runs entirely unlike the traditional banking system. Under the traditional system, if panic spreads out, all depositors run on banks and hence bank runs cannot be prevented (see Diamond and Dybvig (1983)). In contrast, under the new system, commercial bank runs cannot take place because banks do not take deposits from the general public. Although the central bank becomes a sole depositor of commercial banks via pass-through lending, there is no maturity mismatch any more since the terms on bank loans and central bank pass-through loans are the same. Also, central bank runs can be prevented since the central bank is always able to satisfy its obligation to repay depositors without liquidating loans earlier than the maturities, by exercising some of the following special powers. Firstly, real-life central banks can repay depositors with newly printed public money. Although some depositors suffer from a subsequent inflation, the central bank can force them to accept this new money since the central bank money is the unit of account based on which deposit contracts are written. Secondly, central banks can have central governments impose taxes on economic agents and use the tax proceeds to fill the gap between the liquidity outflows and the available liquid assets. Third, central banks can get or borrow liquid assets from governments to repay depositors.

In several extensions of the baseline model, I also find the following additional results. First, the previous three main results hold regardless of whether the equilibrium is symmetric or asymmetric across banks.

Second, a new tradeoff between competition and bank run can arise under the traditional banking system if a third type of depositors is introduced to the Diamond-Dybvig world in which there are only two types, patient or impatient. Suppose there are three types of depositors, impatient, patient-and-sensitive, and patient-and-insensitive, where the patient-and-sensitive depositors strategically choose to run on banks or wait until the maturity while the patient-and-insensitive depositors always wait. In this setup, I show that panic-based bank runs occur more likely if the banking market is more competitive.[4] The CBDC-based new banking system

[4] In the baseline model with only patient and impatient types, panic-based bank runs always occur no matter how concentrated in the banking market if panic is spread out. That is, this tradeoff between competition and bank run

solves this tradeoff and therefore eliminates bank runs.

Third, there is a monetary policy tradeoff between price and financial stability under the traditional banking system. In particular, I show that monetary policy tightening increases the likelihood of panic-based bank runs under the assumption that patient depositors become more likely sensitive than insensitive as the monetary policy is tightened. The CBDC-based new banking system prevents bank runs completely and hence this monetary policy tradeoff is mitigated. This result implies that monetary policy authority can focus on its primary mandate of stabilizing inflation without worrying about negative side effects on liquidity risks in the banking sector.

Last but not least, I examine an important but informal argument by Bossone and Haines (2023). They argue that depositors would not suffer any loss under a CBDC-based new banking system even if banks are in default since no money lent to banks leave the boundary of the central bank. Contrary to this argument, I show theoretically that depositors or taxpayers bear some real losses since valuable resources are used for no good. This result has an important implication on the architecture of prudential regulation for the banking sector. In the traditional banking system, banks face both liquidity and solvency risks and therefore they are subject to liquidity and capital requirements. However, under the new banking system, the liquidity risk is eliminated, while the solvency risk still exists. Consequently, there is no ground for liquidity regulations, while capital adequacy requirements should still be in place.

Relation to the literature. There are four strands of related literature. First is the literature on the effects of competition on liquidity creation. There are two opposing perspectives. The first suggests negative effects of competition on liquidity creation. Jiang et al. (2019) argue that increased competition ends up squeezing bank profits and buffers against risk-taking and hence only banks with relatively high risk-absorbing capacity can provide lending. Peterson and Rajan (1995) formalize this argument in the context of relationship lending. In contrast, the second perspective stresses out positive effects. Boyd and De Nicolo (2005) show that more banks make more aggregate loans as much as more firms produce more aggregate quantity. The empirical literature finds mixed results. Jiang et al. (2019) find that interstate branching

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does not exist in the baseline model.

deregulation in the United States decreased liquidity creation. Horvath et al. (2016) and Ali et al. (2022) find similar results in the Czech Republic and the six Gulf Corporation Councils countries, respectively. By contrast, Beck et al. (2004) and Hainz et al. (2013) find that more bank competition results in increased financing obstacles. These findings imply that liquidity creation can shrink. My paper suggests a new mechanism through which competition affects liquidity creation. On the one hand, increased competition in the loan market pushes the banking sector to provide more aggregate lending simply because more firms typically produce more aggregate outputs. On the other hand, more competition ends up tightening a constraint on money creation and therefore banks are less able to extend loans. Due to these offsetting effects, there is an inverse U-shaped relationship between competition and liquidity creation. That is, increased competition pushes up liquidity creation if the degree of competition is low, while it pushes down liquidity creation otherwise. In this sense, my paper harmonizes the mixed findings in the empirical literature.

The second strand of related literature is on economies of scale in banking and payments. There is a large body of empirical literature that finds the existence of increasing returns to scale in banking. For instance, Wheelock and Wilson (2015) show that most US banks face increasing returns to scale in cost. Similarly, Becalli et al. (2015) find that economies of scale are widespread across European banks. Many existing studies find that economies of scale are pronounced particularly in payment services (see Beijnen and Bolt (2009), Gowrisankaran and Stavins (2004), Humphrey (2009)). However, these empirical studies do not find a detailed mechanism for why economies of scale occurs. Bossone (2020) provides an informal argument for why size or market share matters. If there is a monopoly bank, all payments and money transfers via deposit accounts are “on-us” transactions for the single bank and hence the bank needs not prepare liquid assets to settle the transactions. However, if there is a large number of atomistic banks, virtually all transactions are “off-us” and hence each bank must hold an asset portfolio with a very large share of liquid assets. My paper formalizes this argument by examining a theoretic model and therefore provides a ‘money-creation and payment’ mechanism through which economies of scale arises.

The third strand of literature is on the competition and stability tradeoff. In practice, many market participants and policy makers believe that competition is detrimental to financial stability. However, there are countervailing theoretic findings. One seminal paper of Keeley

(1990) shows that increased competition reduces the long-term bank values of continuation, i.e. the charter values, and, therefore, makes banks myopic and invest more on risky assets. Banking stability is then reduced. By contrast, another seminal paper of Boyd and De Nicolo (2005) show that bank competition in the loan market lowers loan interest rates and, therefore, borrowers are less likely in default. As a result, banking stability is improved. Other many theoretic and empirical studies find mixed results (see Freixas and Ma (2014)). Interestingly, the theoretic studies mostly focus on how the solvency risk is affected by competition, even though the liquidity risk is another important risk in banking. A few studies consider the liquidity risk. Freixas and Ma (2014) show that the liquidity risk increases, as more competition reduces bank cash flow and hence banks are less able to repay depositors. In contrast, Boyd et al. (2003) find that the liquidity risk can instead decrease, as increased competition reduces the opportunity loss from investment on short-term rather than long-term assets and, hence, banks invest more on short-term liquid assets. Notably, none of these papers consider the real-life practice of fountain pen money creation, even though this practice plays an important role in determining the liquidity risk. My paper is one of the first trials to examine how competition affects the liquidity risk through a channel of the fountain pen money creation and related payment process. I show that the likelihood of bank run increases due to increased competition, since then more payment transactions are off-us than on-un and, hence, liquidity outflows increase during the payment process.

The fourth strand of related literature studies retail CBDC and its effects on bank runs and resource allocation. Bossone and Haines (2023) discuss in detail but informally that the CBDC-based new banking system eliminates bank runs completely. Brunnermeier and Niepelt (2019) also argue that financial stability will be improved, as the central bank arises as a large and reliable depositor. My paper is in line with this literature since I formalize the argument of Bossone and Haines (2023) by analyzing a model of bank runs and money creation. Fernandez-Villaverde et al. (2021) also find a similar theoretic result. However, as for resource allocation, my paper and the literature find different results. A number of existing studies find an equivalence result that CBDC coupled with central bank pass-through lending does not change equilibrium outcomes (see Brunnermeier and Niepelt (2019), Niepelt (2020), Kim and Kwon (2022)). In particular, Fernandez-Villaverde et al. (2021) show that both the CBDC-based new banking system and the traditional banking system induce a first-best allocation under the absence of frictions on money creation. In contrast, I explicitly consider banks' ability of money creation via lending and find that this ability is limited by competition. Under this competition-induced friction on money creation, I show that the traditional banking system induces a socially suboptimal allocation, while the CBDC-based alternative leads to a first-best allocation by solving the friction. Besides, Schilling et al. (2022) show that CBDC can be utilized in eliminating central bank runs while achieving an efficient allocation but only by sacrificing price stability, though they consider a very different setting in which the central bank monopolizes not just deposit-taking but also lending. Furthermore, they do not consider bank's money creation through lending.

Structure of the paper. In section 2, I develop a theoretic model of bank runs and money creation. In section 3, I consider the planner's problem to find a benchmark. Section 4 examines symmetric equilibria and finds the main results. In section 5, I confirm that the main results still hold in asymmetric equilibria. In section 6, I extend the baseline model and find that the CBDC-based new banking system solves a tradeoff between competition and bank runs. Section 7 shows that the new banking system also solves a monetary policy tradeoff between price stability and bank runs. In section 8, I refute an important argument from the literature that depositors or the central bank lose nothing in the new system even if banks are in default. Section 9 draws concluding remarks.

2. The Model

I consider an economy with households, entrepreneurs, and banks. There are a continuum of households with unit mass, a representative entrepreneur, and $n \in [1, \infty)$ homogeneous banks. There is a single consumption good. The price of consumption is denominated by units of the consumption good. There are three dates 0, 1, and 2 (see Figure 1). At date 0, each household is endowed with E units of real cash such as gold. At this time, they are also endowed with an unlimited quantity of labor.

All households are identical at date 0. However, at date 1, the types of households are realized: a fraction λ of households become an impatient type and the remaining $(1 - \lambda)$ of households become a patient type. The impatient type households value consumption only at date 1, while the patient type value consumption only at date 2. Therefore, at date 1, the impatient households want to buy the consumption good from the patient households. Unlike the impatient ones, the patient households are endowed with an unlimited quantity of labor again at date 1 and they can produce one unit of the consumption good for every unit of labor provided. That is, they can access to a non-value-added one-to-one production technology.[5] Therefore, if the impatient households pay the price, the patient ones work and produce the consumption good and deliver the good to the impatient ones.

Each household obtains utility from consumption C_t, $t = 1,2$, and disutility from labor W_t, $t = 0,1$. The utility of one unit of consumption is equivalent in magnitude to the disutility of one unit of labor. The utility functions of the impatient and patient types are denoted by u^{IP} and u^P, respectively, and they are given by

(1) $u^{IP} = C_1 - W_0$ and $u^P = C_2 - W_0 - W_1$

Figure 4: Timeline under the Traditional Banking System
with the Optimistic Expectation

Date 0	**Date 1**	**Date 2**
1. Households deposit real cash E to banks. 2. Each bank lends l_i to the entrepreneur. 3. The entrepreneur transfers deposits $\sum_i l_i$ to households and have them provide labor $W_0 = \sum_i l_i$.	1. A fraction λ of impatient households transfer deposits to patient households. 2. Banks transfer cash to other banks to settle payments demanded by impatient households. 3. Patient households produce the consumption good for impatient households.	1. The entrepreneur produces output $Y(W_0)$ and repay loans. 2. Banks repay patient households.

[5] The main results do not change if one replaces the one-to-one production technology with an endowment of commodity, which cannot be deposited in banks but can be consumed as much as the consumption good.

At date 0, households can deposit the endowed cash with demand deposit accounts held in banks or store it by themselves. However, self-storage is costly and inconvenient and, hence, households deposit the cash in banks. The net interest rate on these demand deposit accounts is assumed to be zero, as households can withdraw cash at any time and the accounts provide valuable and convenient payment services. Each household uses only one bank. As there are n identical banks, each bank receives $\frac{E}{n}$ in total.

A representative entrepreneur owns an increasing and concave production technology $Y(W_0) = AW_0 - \frac{1}{2}W_0^2$ where $A > 1$ is a measure of productivity. To produce output, the entrepreneur needs to buy labor W_0 from households at date 0. The production technology needs a long time to yield fruits and hence generates output at date 2. The entrepreneur does not have net worth to pay for labor. That's why it has to borrow bank loans. At date 0, each bank $i = 1, 2, \ldots, n$ makes a long-term loan l_i to this representative entrepreneur. This loan is matured at date 2 and the gross loan interest rate is R_i .

To make a loan, a bank creates private money and then deposits it with the entrepreneur's demand deposit account held in the bank. For example, suppose that the entrepreneur has zero balance in its account in a bank i. If the bank i gives one unit of loan to the entrepreneur, it simply raises the entrepreneur's deposit balance from zero to one with a stroke of a (electronic) pen. Tobin (1963) calls this bank-created deposit money as the 'fountain pen money.' The entrepreneur can buy labor from households by paying the salary with this deposit money. There are two ways to conduct these payments. First, the entrepreneur withdraws deposits as cash and then hand it on to households. Second, she transfers her deposits into households' bank accounts. Between these two options, the entrepreneur will choose the latter to save a little cash handling cost ϵ. Since the unit is the same, the entrepreneur transfers l_i units of deposits in exchange for l_i units of labor.

This deposit money is accepted in transactions by all economic agents only if the deposit-issuing bank has enough cash to satisfy all withdrawal requests. Therefore, banks face a constraint that puts an endogenous limit on the amount of money creation. To be more specific, note that at the end of date 0, each household has $\left(\frac{E}{n} + l_i\right)$ in their deposit accounts held in a bank i since it initially deposited cash $\frac{E}{n}$ and gets transferred l_i from the entrepreneur as the salary. At date 1, the impatient households need money to buy the consumption good from the patient households. Although they can withdraw deposits as cash, they instead choose to transfer deposits into the patient households' bank accounts in order to save the little cash handing cost. The patient households can withdraw at date 1 or 2. Suppose for the moment that they withdraw at date 2. Then, the net liquidity outflow a bank i faces at date 1 is $\lambda\left(\frac{E}{n}+l_i\right)\left(1-\frac{1}{n}\right)$ for the following reason. The impatient households transfer $\lambda\left(\frac{E}{n}+l_i\right)$ in total to counterparty patient households. Since a fraction $\frac{1}{n}$ of the counterparties have deposit accounts in the same bank, $\lambda\left(\frac{E}{n}+l_i\right)\frac{1}{n}$ is transferred within the bank i and hence never leaves the bank (i.e. "on-us" payment). In contrast, the remaining fraction $\left(1-\frac{1}{n}\right)$ of the counterparties have deposit accounts in other banks and, thus, the bank i should send money to those other banks as much as $\lambda\left(\frac{E}{n}+l_i\right)\left(1-\frac{1}{n}\right)$. Note that this money to be sent must be cash but not bank-created deposits. Although nonbank economic agents can use both types of money to buy the consumption good and labor, only cash is accepted in the settlement of interbank payments with finality. Thus, the bank i must send $\lambda\left(\frac{E}{n}+l_i\right)\left(1-\frac{1}{n}\right)$ in cash to other banks.

The bank i has to have enough 'standing' cash to accommodate the net liquidity outflow since otherwise it goes bankrupt. The initial deposit $\frac{E}{n}$ comprises a part of this standing cash. In addition, the bank may get some other cash from other banks, as impatient households using those other banks also transfer their deposits at date 1. However, this inflow from other banks does not count towards the standing cash for the following reason. During the first period between the beginning and end of the date 1, i.e., $[1,2)$, impatient households transfer deposits from their own banks to other banks. Some banks may face these demands for money transfer at time points near to the beginning of date 1, while others may see it at time points near to the end of date 1. Since there are uncountably many time points in $[1,2)$, while there are only a finite number of banks, I assume that no two banks face the demands of money transfer at the same time during the first period. If the inflow from other banks is made after the bank i is demanded money transfer by its impatient customers, the inflow is useless to meet the demand.

If the inflow is instead made before the bank i is demanded money transfer, it can be used to meet the demand. However, the bank does not know when the inflow occurs, while it must satisfy the demand for money transfer immediately at any time. That is, the inflow from other banks is not always guaranteed (i.e. non-standing) but only occasionally occurs with an uncertainty on timing. Therefore, each bank i faces the following constraint on money creation.

(2) $$\lambda\left(\frac{E}{n}+l_i\right)\left(1-\frac{1}{n}\right)\leq\frac{E}{n}$$

This money creation constraint can be rearranged into the following inequality (see Figure 5).

(3) $$l_i\leq\frac{E}{n}\left(\frac{1-\lambda\left(1-\frac{1}{n}\right)}{\lambda\left(1-\frac{1}{n}\right)}\right)\equiv\bar{l}(n)$$

Here $\bar{l}(n)$ is the maximum amount of loan that a bank can make subject to the money creation constraint (2). This loanable amount is the product of an initial deposit $\frac{E}{n}$ and an augmentation factor $\left(\frac{1-\lambda\left(1-\frac{1}{n}\right)}{\lambda\left(1-\frac{1}{n}\right)}\right)$. If the banking market is perfectly competitive, i.e. $n\to\infty$, the loan augmentation factor converges down to a minimum level $\frac{1-\lambda}{\lambda}$. In this case, each bank's market share in the payment transactions is so little that any money transfer demanded by a household most likely results in an 'off-us' transaction and, hence, each bank must send cash to other banks. If the amount of loans made at date 0 is larger, each bank has to send more cash to other banks at date 1. Thus, the loanable amount is small due to the tight money creation constraint (2). In contrast, if the market is monopolistic, i.e. $n=1$, the augmentation factor tends to infinity. That is, a monopolist bank has an unlimited power to create money. This is simply because whenever impatient households demand a monopoly bank to transfer their deposits to patient households, the money moves from one account to another within the same bank. As the money does not leave the bank, the monopoly bank faces 'zero' net outflow of liquidity even if a large number of households demand money transfer at the same time. It implies that the constraint (2) is never binding for any amount of money creation and lending. In general, the more competitive (i.e. more n) is the banking market, the less is the loan augmentation factor. In other words, banks can make less loans out of the same amount of initial cash deposits if they face more competition.

For simplicity, I implicitly assume that banks cannot raise a wholesale funding. However, even if this assumption is relaxed and, hence, banks can borrow from other banks in the interbank market or from the central bank via the discount window, a similar money creation constraint like (2) arises unless the wholesale borrowings are frictionless. In contrast, if banks can immediately borrow whatever amount whenever they want at favorable terms, there will be no constraint on the amount of lending. Faure and Gersbach (2021) consider this ideal case in a model of fountain pen money creation and show that banks face no constraints that restrict the quantity of lending such as (3). However, I expect that the real-life wholesale borrowings are always involved with some frictions. In the real world, banks cannot borrow more than their holdings of qualified collateralizable assets like Treasury bonds. Also, banks cannot always borrow whenever they want without a delay. In March 2023, Silicon Valley Bank collapsed immediately after 85% of total deposits were withdrawn for just two days (see Federal Reserve (2023)). If it could borrow such a huge amount of money from other banks or the Federal Reserve within a second, it would not have failed.

Upon receiving bank loans, the entrepreneur buys labor. Since the unit of deposit money and labor is the same, the total amount of labor bought is $W_0 = \sum_{i=1}^{n} l_i$. Thus, the entrepreneur maximizes the following profit.

$$(4)\quad \max_{l_1,\ldots,l_n} \Pi = AW_0 - \frac{1}{2}W_0^2 - \sum_{i=1}^{n} R_i l_i \ \ \textit{subject to}\ \ W_0 = \sum_{i=1}^{n} l_i$$

The first order condition with respect to each l_i leads to the following inverse demand function for each bank.

(5) $R_i \ = A - \sum_{i=1}^{n} l_i$

Given this inverse demand function R_i, each bank faces the following profit function (6). To see this, note that each bank receives $\frac{E}{n}$ as deposits at date 0. At date 2, the entrepreneur repays $R_i l_i$. At date 1 and 2, each bank repays $\left(\frac{E}{n} + l_i\right)$ in total to impatient and patient households. Therefore, the profit function equals $R_i l_i - l_i$.

(6) $\pi_i(l_i, l_{-i}) = \frac{E}{n} + R_i l_i - \left(\frac{E}{n} + l_i\right) = R_i l_i - l_i = (A - \sum_{i=1}^{n} l_i - 1) l_i$

3. Planner's Problem

In the following section, I normalize the endowment E as 1 because the amount of E does not affect the main result. As a benchmark, I consider a central planner's problem. This benevolent planner chooses the amount of labor W_0 and W_1 to maximize the output $Y(W_0) = AW_0 - \frac{1}{2}W_0^2$ minus the social cost of input W_0 subject to the following participation constraints and resource constraints.

(7) $(C_1 - W_0) \geq 1$ and $(C_2 - W_0 - W_1) \geq 1$

(8) $\lambda C_1 \leq (1-\lambda) W_1$ and $(1-\lambda) C_2 \leq Y(W_0) + 1$

All households are endowed with one unit of the consumption good and hence 1 is their reservation payoff. The impatient households consume at date 1 and work at date 0. The patient households consume at date 2 and work at date 0 and 1. Therefore, the two constraints in (7) should be satisfied to ensure households' participation. In addition, the planner needs enough resources to allocate the consumption good to households. At date 1, the patient households should provide enough aggregate labor $(1-\lambda)W_1$ to accommodate the impatient households' aggregate consumption needs λC_1. At date 2, the long-term project should yield a sufficient amount of aggregate output $Y(W_0)$ to meet the patient households' aggregate consumption needs $(1-\lambda)C_2$ in conjunction with the endowments 1. Therefore, the planner solves the following problem. The subsequent proposition states a solution to this problem.

$$(9) \quad \max_{(W_0,W_1)\in[0,\infty)^2} [Y(W_0) - W_0] = \left[AW_0 - \tfrac{1}{2}W_0^2 - W_0\right] \text{ subject to (7) and (8)}$$

Proposition 1: (i) The unique first-best labor at date 0 and the corresponding output are $W_0^{fb} \equiv (A-1)$ and $Y^{fb} \equiv \frac{(A-1)^2}{2} + (A-1)$, respectively.

(ii) A first-best allocation of labor at date 1 and consumption at date 1 and 2 is $W_1^{fb} \equiv \frac{\lambda}{1-\lambda}A$, $C_1^{fb} \equiv A$, and $C_2^{fb} \equiv \frac{1}{1-\lambda}A$

Proof: (i) The first order condition shows that the objective function (9) is maximized at $W_0 = (A-1)$ and in this case $Y(W_0^{fb}) = \frac{(A-1)^2}{2} + (A-1)$. (ii) Choose $C_1^{fb} = A$, $C_2^{fb} = \frac{1}{1-\lambda}A$, and $W_1^{fb} = \frac{\lambda}{1-\lambda}A$. Then, the two constraints in (7) and the first constraint in (8) are satisfied as equality. Since $(1-\lambda)C_2^{fb} = A$, the second constraint in (8) is also satisfied. ■

4. Symmetric Equilibrium

As in the original bank run model proposed by Diamond and Dybvig (1983), equilibria typically depend on households' expectations on bank runs. Since there are n banks in this model, households can expect that bank runs take place in some banks but not in other banks. However, in this section, I focus on symmetric equilibria in which households expect that bank runs occur in either all banks or no banks. The next section considers an asymmetric equilibrium as an extension.

In the following, I shall show that there are both good equilibrium and bad equilibrium where in the former all patient households believe at date 1 that there are no bank runs (i.e. an optimistic expectation), while in the latter they believe there are bank runs (i.e. a pessimistic expectation). An important point to note is that each bank chooses an amount of loan at date 0, which is before patient households form an expectation. Therefore, the choice of loan amount at date 0 results in different consequences at later dates depending on which expectation is formed. That's why, in the following, I shall characterize equilibria by backward induction.

A. Bad equilibrium

I shall first consider a subgame in which the patient households form a pessimistic expectation. It is worth noting that the money creation constraint (2) is relevant only under the assumption that patient households withdraw deposits at date 2. In the following, I shall analyze what happens if they choose to withdraw at date 1 (i.e. bank runs).

Suppose that a patient household, say HH1, expects that all other patient households withdraw deposits at date 1. These other patient households run on all banks perhaps because they do not trust any bank. Therefore, it is reasonable to assume that they are reluctant to transfer deposits to other banks but want to withdraw deposits as cash. Given this assumption, each bank runs out of cash, as the liquidity outflow $\left(\frac{1}{n}+l_i\right)$ exceeds the cash holdings $\frac{1}{n}$. Then, each bank has to liquidate loans to get more cash. In real-life, early liquidation usually involves with some loss in value. Let δl_i be the liquidation value where $\delta \in [0,1)$ is a discount factor. Then, the total cash available for each bank is $\left(\frac{1}{n}+\delta l_i\right)$, which is smaller than the total liquidity outflow for any $l_i > 0$ and any $n \geq 1$. Therefore, the patient household HH1 will be repaid partially if it runs on bank at date 1. Instead, if it waits until date 2, HH1 will not be paid a penny, as its bank liquidated all loans and hence has no assets at all at date 2. Thus, HH1 will choose to run on bank and all others will do the same. That is, the pessimistic expectation of bank runs realizes as actual bank runs. The following proposition summarizes this result.

Proposition 2: (Bad equilibrium) Suppose that each patient household believes at date 1 that all other patient households will run on banks at date 1. Then, for any number of banks $n \in [1, \infty)$ and any amount of loan $l_i > 0$,

(i) All patient households actually run on banks and

(ii) The economy produces nothing.

Proof: (i) is straightforward from the discussion above. (ii) As all loans are liquidated early at date 1, the entrepreneur produces nothing at date 2. ■

B. Good equilibrium

Next, I consider another subgame in which the patient households form an optimistic expectation. That is, all patient households believe that no other patient households will run on banks. This optimistic expectation realizes as an actual outcome if (i) the money creation constraint (2) is satisfied and (ii) each bank earns a nonnegative profit. To see this, suppose that a patient household, say HH1, expects that all other patient households will stay until date 2. If HH1's bank satisfies the money creation constraint (2), it means that the bank has enough cash to accommodate all withdrawal requests made by impatient households and, hence, it does not have to liquidate any loan at date 1. As all loans are maintained until the maturity, the entrepreneur yields some output and hence repay the HH1's bank. If HH1's bank earns a nonnegative profit, it means that the bank receives large enough repayment from the entrepreneur to pay for all patient and impatient households. Thus, HH1 can be fully repaid if it waits until date 2. If these two conditions (i) and (ii) are both satisfied, and hence, HH1 does not run, every other patient household does the same, and hence, bank runs do not take place. I shall momentarily show that these two conditions are satisfied.

In the subgame with the optimistic expectation, bank profit is (6) and it depends on the amount of loan l_i. In contrast, in the pessimistic expectation subgame, bank profit is zero for any amount of loan, as banks spend all their assets to repay deposits at date 1 and get nothing at date 2. Therefore, when it comes to decide on how much loan to make at date 0, each bank targets only the optimistic expectation subgame and chooses a loan amount that maximizes the profit (6) subject to the money creation constraint (2). Recall that the constraints (2) and (3) are equivalent. For the moment, suppose that the constraint is nonbinding. Then, the optimal amount of loan is characterized by the following first order condition.

(10) $l_i = \frac{1}{2}\left(A - \sum_{j \neq i} l_j - 1\right)$

Since I focus on a symmetric equilibrium, all banks make the same amount of loan. Therefore, the unconstrained optimal loan l^{uc} is characterized as follows (see Figure 5).

(11) $l^{uc}(n) = \frac{A-1}{n+1}$

This l^{uc} is indeed optimal if it satisfies the money creation constraint (3). Let l^* denote the optimal loan. By (3) and (11), it is straightforward to see that

(12) $l^*(n) = \min\{l^{uc}(n), \bar{l}(n)\}$

In other words, the optimal loan l^* equals the unconstrained optimal loan l^{uc} if the money creation constraint is nonbinding but otherwise reduces to the loanable amount $\bar{l}$ (see Figure

5). When does the money creation constraint bind? The following lemma shows that it is binding if and only if n is sufficiently large. Before moving to this lemma, it is useful to define the aggregate amount of loan. Let $L \equiv nl$ be the aggregate loan. Similarly, the optimal aggregate loan L^*, the unconstrained optimal aggregate loan L^{uc}, and the aggregate loanable amount $\bar{L}$ are defined as $L^* \equiv nl^*$, $L^{uc} \equiv nl^{uc}$, and $\bar{L} \equiv n\bar{l}$. I shall consider the following reasonable assumption.

Assumption 1: $(A-1) > \left(\frac{1-\lambda}{\lambda}\right)$

The left-hand side term $(A-1)$ in the assumption 1 can be interpreted as the net return of the most profitable and innovative project of all in an economy. If we align all projects according to their net returns, the inverse demand function minus 1, i.e. $[R(L)-1] = (A-L-1)$, represents the net return of the L-th best project. Thus, $[R(0)-1] = (A-1)$ is the net return of the first-best project. The right-hand side term $\left(\frac{1-\lambda}{\lambda}\right)$ in the assumption 1 is the amount of funding the initial cash deposits can generate for each project when there are infinitely many banks. That is, it can be interpreted as the average available funding for each project when the restriction on money creation is the heaviest. Then, it would be reasonable to assume that the highest possible net return is greater than this average available funding for a project. I shall maintain this assumption 1 for the remainder of the paper.

Lemma 1: There exists a unique $n^* > 1$ such that

(i) $l^{uc}(n) < \bar{l}(n)$ and $L^{uc}(n) < \bar{L}(n)$ for any $n < n^*$.

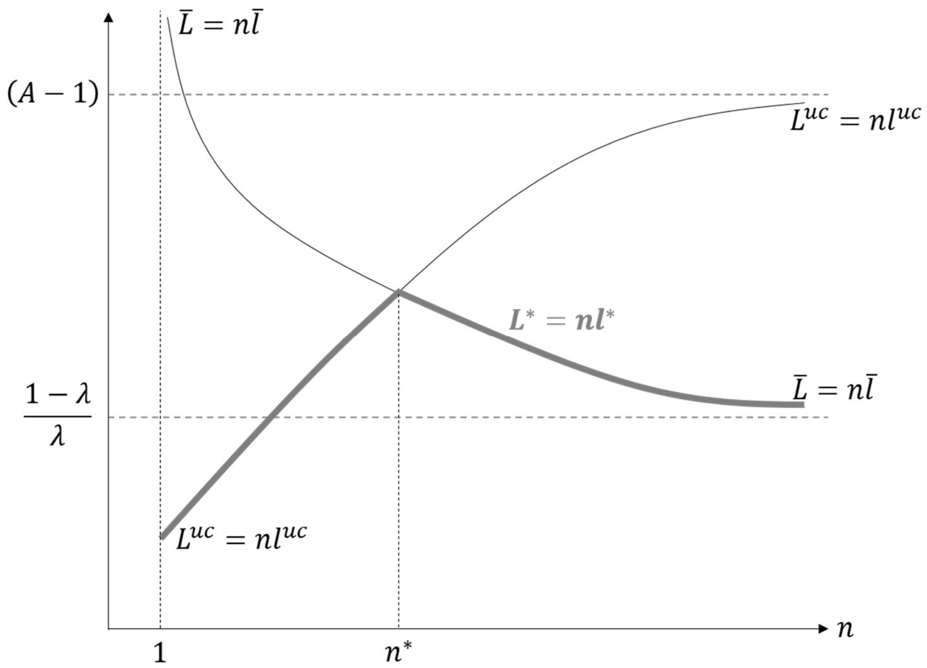
(ii) $l^{uc}(n) = \bar{l}(n)$ and $L^{uc}(n) = \bar{L}(n)$ for any $n = n^*$.

(iii) $l^{uc}(n) > \bar{l}(n)$ and $L^{uc}(n) > \bar{L}(n)$ for any $n > n^*$.

Proof: Since $n > 0$, $l^{uc}(n) < \bar{l}(n)$ if and only if $L^{uc}(n) < \bar{L}(n)$. Note that $L^{uc}(n) = \frac{n(A-1)}{n+1}$ is strictly increasing in n from $\lim_{n\to 1} L^{uc}(n) = \frac{(A-1)}{2}$ to $\lim_{n\to\infty} L^{uc}(n) = (A-1)$, whereas $\bar{L}(n)$ is strictly decreasing in n from $\lim_{n\to 1} \bar{L}(n) = \infty$ to $\lim_{n\to\infty} \bar{L}(n) = \left(\frac{1-\lambda}{\lambda}\right)$. Since $\lim_{n\to 1} L^{uc}(n) < \lim_{n\to 1} \bar{L}(n)$ and $\lim_{n\to\infty} L^{uc}(n) > \lim_{n\to\infty} \bar{L}(n)$ by the assumption 1, there exists a unique $n^* \in (1, \infty)$ at which $\bar{L}(n)$ crosses $L^{uc}(n)$ from above. ■

Lemma 1 implies that the money creation constraint (2) is binding if and only if the banking market is sufficiently competitive that $n > n^* \in (1, \infty)$. Therefore, by (12), a bank in a monopolistic market chooses the unconstrained optimal loan as the money creation constraint is nonbinding, while a bank in a perfectly competitive market chooses the loanable amount in (3) as the money creation constraint is binding. The analysis given above reaches to the following proposition.

Figure 5. Equilibrium Lending vs. Efficient Lending



Proposition 3: (Good equilibrium) Suppose that each patient household expects no other patient household will run on banks at date 1. Then,

(i) No patient households run on banks.

(ii) The equilibrium output $Y(L^*(n))$ is smaller than the efficient level Y^{fb} for any n.

(iii) The equilibrium output $Y(L^*(n))$ is increasing in n if $n \leq n^*$ but otherwise decreasing.

Proof: (i) Recall that there are no bank runs if the money creation constraint in (2) is satisfied and each bank gets a nonnegative profit. In equilibrium, each bank chooses the optimal loan $l^*(n) = \min\{l^{uc}(n), \bar{l}(n)\}$. Consider firstly the case where $n \leq n^*$. Then, the money creation constraint in (2) is satisfied with the optimal loan choice $l^*(n) = l^{uc}(n) = \frac{A-1}{n+1}$ by the lemma 1. Also, each bank gets a positive profit $\left(\frac{A-1}{n+1}\right)^2$ by (6). Consider secondly the case where $n > n^*$. The money creation constraint in (2) is still satisfied with the optimal loan $l^*(n) = \bar{l}(n) = \frac{1}{n}\left(\frac{1-\lambda\left(1-\frac{1}{n}\right)}{\lambda\left(1-\frac{1}{n}\right)}\right)$. Each bank then gets the profit of $\left[(A-1) - \left(\frac{1-\lambda\left(1-\frac{1}{n}\right)}{\lambda\left(1-\frac{1}{n}\right)}\right)\right]\frac{1}{n}\left(\frac{1-\lambda\left(1-\frac{1}{n}\right)}{\lambda(1-1/n)}\right)$ by (6). Recall that the money creation constraint (2) is binding and hence $l^{uc}(n) = \frac{A-1}{n+1} > \frac{1}{n}\left(\frac{1-\lambda(1-1/n)}{\lambda(1-1/n)}\right) = \bar{l}(n)$. Therefore, the terms in the bracket is positive and so is the profit.

(ii) and (iii) By the proposition 1, the efficient amount of output is achieved if and only if no loans are liquidated early and the equilibrium amount of aggregate loan L^* equals $(A-1)$. By (i) of the current proposition, there are no bank runs and, hence, no early liquidation. However, $L^*(n)$ is smaller than $(A-1)$ for any n. To see this, note that $L^{uc}(n)$ is strictly increasing in n while $\bar{L}(n)$ is strictly decreasing and they meet at only $n = n^* \in (1, \infty)$ by Lemma 1. Therefore, $L^*(n) = \min\{L^{uc}(n), \bar{L}(n)\}$ achieves its maximum at $n = n^*$, which meaning that $L^*(n) \leq L^*(n^*) = \frac{n^*(A-1)}{n^*+1} < (A-1)$ for all $n \geq 1$. As the output function equals $Y(L) = AL - \frac{1}{2}L^2$, the output is an increasing function of L whenever $L < A$. Since $L^*(n)$ is increasing in n if $n \leq n^*$ but otherwise decreasing in n, so is $Y(L^*(n))$. ■

Proposition 3 is one of the main results of this paper (see Figure 5). It implies that there is a tradeoff between money creation and competition. If the banking sector is monopolistic, the money creation constraint (2) is never binding and hence the single bank is able to make an unlimited amount of lending by creating private money. This is because the money circulates within the single bank and never flows out no matter how large is the money creation. Nevertheless, this monopolist bank provides an inefficiently small amount of lending in order to attain a monopoly rent. By contrast, if the banking sector is perfectly competitive, banks are willing to provide an efficient amount of lending but they are unable to do so since there are virtually no within-bank transfers and hence the money creation constraint is very tight.

Proposition 3(iii) implies that there is an inverse U-shaped relationship between bank lending and competition. If the degree of competition is small, the bank lending and total output increases due to more competition. However, if the degree of competition is higher than a certain threshold, the bank lending and total output decreases due to further increase in competition. This result implies that, in the banking market, an oligopoly is better than either monopoly or perfect competition. In real-life, the industrial organization of the banking sector in most countries are neither monopoly nor perfect competition. This paper provides an explanation for why oligopolies are prevalent in the real world. This is because an oligopoly structure in the banking sector is a best compromise between competition and money creation.

C. Separation of lending from funding using CBDC

The previous analysis shows that the traditional commercial banking system faces a fundamental dilemma between money creation and competition. As an alternative, I consider a new banking system discussed in detail by Bossone and Haines (2023) in which funding is centralized at the central bank with CBDC while lending is decentralized by commercial banks in a competitive banking market.

In this CBDC-based new banking system, banks are not allowed to take deposits. Instead, every economic agent deposits directly with the central bank.[6] To this end, central bank offers current accounts to all economic agents including individuals, companies, and institutions. This is a fundamental change from the traditional banking system where the central bank provides current accounts only to banks.[7]

Although banks cannot take deposits, they can still make loans since in this new system the central bank lends to them as much as what they need. That is, banks borrow from the central bank to lend. This is in a stark contrast to the traditional banking model in which banks borrow from depositors to lend. A detailed mechanism works as follows. If a bank wants to make a loan to an economic agent, it requests a central bank loan to finance the bank loan. The central bank then creates an electronic cash, which is CBDC, and deposits it with the bank's current account held in the central bank. The maturity of the central bank loan is matched with that of the bank loan and so there is no maturity mismatch. The difference between interests on the bank loan and central bank loan is the bank's net interest margin.

Furthermore, in this CBDC-based new banking system, the central bank or the relevant authority relaxes the entry regulation in the loan market substantially in order to facilitate perfect competition. See Bossone and Haines (2023) for more institutional details.

In the following, I shall analyze the equilibrium under this new system. The loan market is perfectly competitive and hence the number of banks is arbitrarily large. Each bank chooses a loan amount to maximize the profit (6). However, banks face no constraints on money creation since the central bank always finances the bank loans and banks are required to repay the central bank only after the bank loans are matured. Therefore, the equilibrium aggregate loan amount

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[6] The central bank does not have to conduct daily operations of deposit-taking. It can delegate these operations to commercial banks by paying them fair value of commissions. However, the central bank plays as a legal debtor of deposits and take them as its own liabilities. See Bossone and Haines (2023) for more details.

[7] Bossone and Haines (2023) discuss that the traditional banking system can be converted smoothly and quickly into the CBDC-based new banking system in the following way. The central bank makes special loans to banks by creating CBDC on the banks' reserve accounts in the central bank with the requirement that these special loans must be used to repay existing bank deposits in full. Banks then repay all their deposits with the CBDC. Consequently, banks have no customer deposits. The central bank becomes the sole depositor of each bank. Each non-bank economic agents will see that their bank deposits are converted into central bank CBDC.

equals $\lim_{n\to\infty} L^{uc}(n) = (A-1)$.

At first, consider the optimistic expectation case in which patient households expect that no other patient households will run on the central bank. In this case, the central bank faces the following money creation constraint.

(13) $\lambda(1+L)(1-1) \leq 1$

To explain the constraint (13), suppose that banks want to make loans L at date 0. The central bank then creates CBDC as much as L and deposits it with the banks' current accounts held in the central bank. The banks then transfer L to the representative entrepreneur's current account in the central bank. The entrepreneur then transfers the CBDC L to households' current accounts in the central bank to buy their labor. Therefore, at the end of date 0, the households have $(1+L)$ in total in their central bank accounts. At date 1, the impatient households need $\lambda(1+L)$ to purchase the consumption good from the patient households. Although the impatient households can withdraw the money as cash or CBDC, they withdraw it as CBDC to save the little cash handling cost. But that means the impatient households transfer CBDC to the patient households' current accounts, as CBDC is an electronic central bank claim. Notice that all current accounts are held in the central bank. Thus the money transferred by the impatient households does not leave but only circulates within the central bank. That is, the money creation constraint is nonbinding for any aggregate loan amount L even though the total cash deposited is just 1. Therefore, it is straightforward to conclude that the optimistic expectation realizes as an actual outcome.

Secondly, consider the pessimistic expectation case where each patient household believes that all other patient households will withdraw their deposits in the central bank. They believe such a central bank run perhaps because they lose confidence on the central bank. Therefore, it would be reasonable to assume that they want to withdraw deposits in the central bank as cash rather than as CBDC. Note that, in this model, cash is a real good and can be converted one-to-one into the consumption good. Therefore, one unit of cash has always the power of purchasing one unit of the consumption good. However, CBDC is not a real good but a claim issued by the central bank and, hence, it may not always have the same purchasing power as the real cash. One unit of CBDC is equally valuable as one unit of cash only if the central bank has enough cash to accommodate all cash withdrawal requests CBDC holders demand. This is impossible in this case, as CBDC holders demand $(1 + L)$ in cash, while the available cash is only 1.

If the central bank is a private monopoly bank, it cannot satisfy its liquidity constraint and, hence, goes bankrupt. However, the central bank is a government-related public entity that can exercise some of the following special powers to overcome this liquidity problem without liquidating loans prior to the maturity.

Firstly, the central bank can fulfill its obligation to repay households by using a public money creation power. I assume that the central bank can force households to accept CBDC instead of real cash. Recall that cash is real in this model and therefore has an intrinsic value. However, a bank claim has the same purchasing power as cash only if the claim-issuing bank has enough cash to meet liquidity outflows initiated by claim holders. If households demand cash, private banks must repay by cash. If they instead repay by issuing more bank claims, they are in default. By contrast, the central bank can fulfill its debt obligation by issuing more claims, that is, more CBDC. In the real world, a central bank claim is a legal tender and hence is the unit of account based on which deposit contracts are written. Therefore, real-life central banks can always repay its depositors by issuing more central bank claims. Even though the purchasing powers of these central bank claims may decrease accordingly, depositors must bear this cost of inflation. In this sense, the public money creation power of a central bank is different from the private money creation power of a commercial bank. A central bank can issue public money and force economic agents to accept it, whereas a commercial bank cannot force economic agents to accept privately-issued bank money.

Secondly, the central bank can impose taxes on households to reduce its obligation. The central bank may have the central government levy taxes on households and use the tax proceeds to fill the gap between total liquidity outflows and the available cash when the former exceeds the latter.

Third, the central bank may get some financial assistance from the government. It may borrow from the government to increase cash. Given the utmost importance of the central bank in an economy, the government is least likely let the central bank fail.

Due to these special powers, the central bank can meet all demands of cash withdrawal and, hence, needs not liquidate central bank loans given to commercial banks. Therefore, commercial bank loans are maintained until the maturity. The entrepreneur thus produces value-added output.

Suppose that there is a patient household (i.e. HH1) who is to choose whether run or wait. Given the aforementioned special powers of the central bank, HH1 knows that the central bank would not liquidate loans in any case and, hence it will be fully repaid if waits until date 2. Therefore, HH1 chooses to wait. All other patient households will do the same and, hence, the bad equilibrium with central bank runs does not exist. It is noteworthy that that the central bank does not exercise the special powers on the equilibrium path. The mere existence of these special powers prevents panic-based central bank runs from the first place. Note also that commercial bank runs cannot take place as no commercial banks take deposits from the general public. The following proposition summarizes these findings. The proof is omitted as it is fully explained in the text.

Proposition 4: Consider the CBDC-based new banking system described above. Whether the patient households expect central bank runs or not, the following results hold.

(i) There are no bank runs.

(ii) The economy produces the efficient amount of output Y^{fb}.

Proposition 4 implies that commercial or central bank runs never take place even if economic agents are panicked. It also implies that the money creation and competition tradeoff prevailing in the traditional banking system is resolved. As the banking system is immune to the money creation constraint and the loan market is perfectly competitive, banks provide a socially efficient amount of lending to the production sector.

Therefore, this CBDC-based new banking system can outperform the traditional banking system, which cannot prevent bank runs nor induce an efficient allocation. This superiority of the new banking system does not rely on the assumption that the net deposit interest rates are zero. In this model, I assume zero deposit rates in order to reflect the reality that demand deposit accounts usually pay almost no interests. Instead, suppose that the net deposit rates are positive. In this case, it would be reasonable to assume that bank competition for attracting depositors ends up increasing deposit rates. Then, the negative effect of competition on money creation under the traditional banking system would be magnified, as more competition results in increases in deposit interest payments to impatient households and, hence, banks need even more cash to settle the payment transactions (i.e. the money creation constraint (2) becomes more restrictive). Interestingly, this new assumption on deposit rates does not affect the equilibrium under the CBDC-based new banking system, simply because the central bank is a monopolist of the deposit market and, hence, its deposit rate is unaffected by bank competition. Consequently, the new system is even more attractive than the traditional banking system.

Proposition 4 has an important implication on liquidity risks and liquidity regulations. Traditional banks face liquidity risks and hence required to set aside enough liquid assets against expected net liquidity outflows. However, under the CBDC-based new banking system, commercial banks face no liquidity risks and therefore there is no ground for bank liquidity regulations.

This paper is closely related to Fernandez-Villaverde et al. (2021). They also study the effect of a CBDC-based new banking system on resource allocation and bank runs in the context of the Diamond-Dybvig model. However, Fernandez-Villaverde et al. (2021) find that the new banking system is not superior to the traditional banking system in terms of allocation. They find that a CBDC-based new banking system and the traditional *competitive* banking system result in the same amount of aggregate lending. This equivalence result arises because they do not consider banks' ability of fountain pen money creation by making loans and, hence, the money creation and competition tradeoff does not exist. If this ability is considered as in this paper, banks face stronger money creation constraints and thus reduce lending accordingly as the banking market is the more competitive. The CBDC-based new banking system resolves this money creation and competition tradeoff and therefore generates a superior allocation.

As for bank run risks, Fernandez-Villaverde et al. (2021) also find that a CBDC-based new banking system eliminates central bank run risks, though the underlying assumption is different. They assume that central banks cannot be bankrupt under bankruptcy laws since they are governmental bodies or public agencies. Therefore, even if households are panicked and run on a central bank at date 1, the central bank uses only the pre-existing deposits in repaying households but not liquidate any loan. All loans then are maintained until the maturity and, hence, at date 2, the central bank gets full repayment from entrepreneurs. Thus, patient households will be repaid in full if wait until date 2. That's why no patient households run at date 1 and thus central bank runs do not occur.

However, this assumption is not unquestionable. In the United States, local governments can file for bankruptcy and then restructure debt conditional on court's approval. More than 600 municipalities filed for bankruptcies until 2012 (see Amanda (2012)). Setting aside legal issues, it will be unrealistic to assume that central banks do not repay their depositors even if they can do so by liquidating loans. This is because maintaining credibility is a matter of the upmost importance for real-life central banks. Instead of the impossibility of central bank bankruptcy, my paper assumes that central banks can always fulfill its obligations by using some special powers such as money printing, taxing, or getting help from the central government and, hence, early liquidation is unnecessary and central bank runs will not occur.

5. Asymmetric Bank Runs

In the baseline model, I focus on symmetric equilibria where households expect bank runs take place in either all banks or no banks. Alternatively, suppose that each patient household believes at date 1 that all other patient households run on $m \in (1, n)$ specific banks. That is, they believe bank runs occur in some unlucky banks but not in other lucky banks. In this case, a bank j of the $(n-m)$ lucky ones faces the following new constraint on money creation.

(14) $\lambda\left(\frac{1}{n}+l_j\right)\left(1-\frac{1}{n-m}\right) \leq \frac{1}{n}+\left(\frac{1}{n}+l_i\right)\frac{m}{n-m}$ for $j \in \{1, \dots, (n-m)\}$ and $i \in \{1, \dots, m\}$

This new constraint can be understood in the following way. All households in the unlucky m banks withdraw money and transfer it to the lucky banks. That is, each of the lucky banks receives $\left(\frac{1}{n}+l_i\right)\frac{m}{n-m}$ in addition to the initial deposit $\frac{1}{n}$. The impatient households in each of the lucky banks then withdraw $\lambda\left(\frac{1}{n}+l_j\right)$ and transfer it into the $(n-m)$ lucky banks while a fraction $\frac{1}{n-m}$ of the money immediately returns to the original bank due to within-bank transfers. For simplicity, I assume that the discount factor δ of early liquidation is zero. Note that this new constraint on money creation is weaker than the original one in (2) since the lucky banks see smaller liquidity outflow due to more within-bank transfers and attract additional deposits from unlucky banks. This constraint can be rewritten as (15). Note that (15) is weaker than the original money creation constraint (3). In particular, if the number m of unlucky banks is sufficiently large, the terms in the bracket in (15) is negative and, hence, an unlimited amount of loan can be generated.

(15) $l\left[\lambda\left(1-\frac{1}{n-m}\right)-\frac{m}{n-m}\right]\leq\frac{1}{n}\left(1+\frac{m}{n-m}-\lambda\left(1-\frac{1}{n-m}\right)\right)$

What is an optimal loan amount in this case? Note that each bank chooses the amount of lending at date 0 before the patient households form an expectation on bank runs. Therefore, l is not expectation-contingent. Furthermore, l is the same for all banks since banks are identical at date 0. Banks cannot consider the expected profit as the objective function since there is no probability distribution over the expectations. In this model, I assume that the likelihood (not probability) of patient households expecting any bank run in any bank is almost zero since a bank run is a very unlikely event in real-life. Therefore, banks choose the amount of loan by targeting the optimistic expectation case where patient households expect no bank runs occur in any bank. Thus, the optimal loan amount is still $l^*(n)$ defined in (13). As the new constraint on money creation facing each lucky bank is weaker than the original constraint (2), $l^*(n)$ satisfies the new constraint (15) and hence feasible.

The expectation that every patient household will run on only m specific banks leads to a fulfilled expectation equilibrium. To see this, suppose that a patient household HH1 shares this expectation. If her bank is one of the m unlucky ones, she will definitely run on her bank. If she is using one of the $(n-m)$ lucky banks, her bank satisfies the money creation constraint (15) and hence unnecessary to liquidate loans at date 1. Since then this bank can get large enough revenue to repay all obligations at date 2, HH1 can receive a full payment if it waits until date 2. Therefore, HH1 will wait and all other patient households do the same. Consequently, the expectation of bank runs by m specific banks is realized as an equilibrium outcome.

As banks choose the same amount of loan l^* in the symmetric equilibrium and this asymmetric equilibrium, the final allocation also is the same. That is, the allocation is inefficiently small. Although all-bank runs do not take place, some banks and depositors still suffer from bank runs.

As an alternative, consider the CBDC-based new banking system. In this case, all households deposit only on the central bank and, hence, the only possible expectations that can be formed are whether patient households run on the central bank or not. Therefore, the proposition 4 still holds, meaning that the new banking system still results in a bank-run-proof and efficient outcome.

6. Tradeoff between Competition and Bank Run

In the baseline model with the traditional banking system, the expectation of bank runs always realizes as the actual outcome no matter how concentrated is the banking market. This is because there is only one type of households, i.e., the patient type, who forms an expectation on bank runs. Since they are identical to each other, they form the same expectation and chooses the same action. If they choose to run, it means that the entire households run on bank and, hence, bank runs cannot be prevented even if the banking market is monopolistic and hence restrictions on money creation is the least.

However, more realistic results can be obtained if another type of expectation-forming households is introduced. In this case, the likelihood of bank runs depends not just on the expectation but also on the degree of competition. To see this, suppose that there are three types of households. A $\lambda_1 = \lambda$ fraction of impatient households, a $\lambda_2 \in (0,1-\lambda)$ fraction of patient-and-sensitive households, and the remaining λ_3 fraction of patient-and-insensitive households. That is, households are basically patient or impatient while the patient one splits into sensitive or insensitive. The patient-and-sensitive type is equivalent with the patient type in the baseline model in that they form an expectation on bank runs at date 1 and choose strategically an optimal timing of withdrawal. However, the patient-and-insensitive type is newly introduced in this extended model. They are patient and hence consume at date 2, while they are insensitive and hence do not form an expectation at date 1 nor choose to withdraw early. For the following, I shall assume for simplicity that the discount factor δ of early liquidation is zero.

Consider a traditional banking system. I call it a 'good' expectation if every patient-and-sensitive household expects that every other patient-and-sensitive household will not run. Given the three types of households, the money creation constraint under this optimistic expectation is equivalent to (2). However, the money creation constraint under a 'bad' expectation such that every patient-and-sensitive household expects every other will run is instead as follows (see Figure 6.)

$$(16)\quad \lambda\left(\frac{1}{n}+l_i\right)\left(1-\frac{1}{n}\right)+\lambda_2\left(\frac{1}{n}+l_i\right)+\frac{\lambda_2}{\lambda_2+\lambda_3}\lambda\left(\frac{1}{n}+l_i\right)\frac{1}{n}\leq\frac{1}{n}$$

This new money creation constraint (16) can be interpreted in the following way. At date 1, the impatient households of a bank i transfer deposits to the patient households to purchase the consumption good, though $\frac{1}{n}$ fraction of the deposit money returns immediately to the same bank i due to within-bank transfers. At the same date, the patient-and-sensitive type in the bank i also withdraw deposits since they expect bank runs. Unlike the impatient households, they withdraw money as cash as they are afraid of bank runs on all banks. These patient-and-sensitive households withdraw not just what they initially deposited $\lambda_2\left(\frac{1}{n}+l_i\right)$ into the bank i but also what they receive from the impatient households $\frac{\lambda_2}{\lambda_2+\lambda_3}\lambda\left(\frac{1}{n}+l_i\right)\frac{1}{n}$ as the price for the consumption good since the impatient households paid $\lambda\left(\frac{1}{n}+l_i\right)\frac{1}{n}$ to all patient households in the bank i and a fraction $\frac{\lambda_2}{\lambda_2+\lambda_3}$ of this payment was given to the patient-and-sensitive households.

In the baseline model, under the pessimistic expectation, all of the patient type households are sensitive and hence run on banks, implying that banks never meet the liquidity outflow. In contrast, in this extended model, some patient type households are insensitive and therefore do not demand withdrawal. Thus, banks can meet the liquidity outflow if there are sufficiently many patient-and-insensitive households. Nevertheless, this new money creation constraint (16) under the pessimistic expectation is stronger than the money creation constraint (2) under the optimistic expectation, as even the patient-and-sensitive households wait until date 2 under this optimistic expectation. This new constraint (16) can be rewritten by the following (17). That is, the new constraint is satisfied as long as each bank makes no more loans than a certain threshold $\hat{l}(n)$. Notice that this $\hat{l}(n)$ is smaller than the loanable amount $\bar{l}(n)$ under the optimistic expectation for each n. In this way, one can reconfirm that the new constraint (16) is more restrictive than (2) (see Figure 6).

$$(17)\quad l_i \leq \frac{1}{n}\left(\frac{1-(\lambda+\lambda_2)+\frac{\lambda}{n}\left(1-\frac{\lambda_2}{1-\lambda}\right)}{(\lambda+\lambda_2)-\frac{\lambda}{n}\left(1-\frac{\lambda_2}{1-\lambda}\right)}\right) \equiv \hat{l}(n)$$

Note that the liquidity outflow under the pessimistic expectation is smaller if the banking market is more concentrated since then more deposit transfers are within-bank transfers. To make an interesting case, I assume that the money creation constraint (16) is not so restrictive that it is nonbinding if the market is maximally concentrated, i.e. monopoly. (If this assumption does not hold, this extended model results in the same equilibrium obtained under the baseline model.)

Assumption 2: $\frac{A-1}{2} < \left(\frac{1-\lambda_2-\frac{\lambda\lambda_2}{1-\lambda}}{\lambda_2+\frac{\lambda\lambda_2}{1-\lambda}}\right)$

Analogous to the lemma 1, it can be shown that there is a critical number of banks $n^{**}(\lambda_2) \in (1, n^*)$ such that the unconstrained optimal aggregate loan $L^{uc}(n)$ satisfies the money creation constraint (16) if and only if $n \leq n^{**}(\lambda_2)$ (see Figure 6). It is worth noting that $n^{**}(\lambda_2)$ is smaller than the analogous critical number n^* under the money creation constraint (2). This is because the liquidity outflow under the pessimistic expectation is larger than that under the optimistic expectation and, hence, the money creation constraint (16) is more likely binding than (2).

Lemma 2: There exists a unique $n^{**}(\lambda_2) \in (1, n^*)$ such that $l^{uc}(n)$ satisfies the money creation constraint (16) if and only if $n \leq n^{**}(\lambda_2)$.

Proof: Let $\hat{L}(n)$ denote $n\hat{l}(n)$, where $\hat{l}(n)$ is defined in (17). Since $n > 0$, $l^{uc}(n) < \hat{l}(n)$ if and only if $L^{uc}(n) < \hat{L}(n)$. Note that $L^{uc}(n) = \frac{n(A-1)}{n+1}$ is strictly increasing in n from $\lim_{n\to 1} L^{uc}(n) = \frac{(A-1)}{2}$ to $\lim_{n\to\infty} L^{uc}(n) = (A-1)$, whereas $\hat{L}(n)$ is strictly decreasing in n from $\lim_{n\to 1}\hat{L}(n) = \left(\frac{1-\lambda_2-\frac{\lambda\lambda_2}{1-\lambda}}{\lambda_2+\frac{\lambda\lambda_2}{1-\lambda}}\right)$ to $\lim_{n\to\infty}\hat{L}(n) = \left(\frac{1-\lambda_2-\lambda}{\lambda_2+\lambda}\right)$. Since $\lim_{n\to 1} L^{uc}(n) < \lim_{n\to 1}\hat{L}(n)$ and $\lim_{n\to\infty} L^{uc}(n) > \lim_{n\to\infty}\hat{L}(n)$ by the assumption 1 and 2, there exists a unique $n^{**}(\lambda_2) \in (1, \infty)$ at which $\hat{L}(n)$ crosses $L^{uc}(n)$ from above. To reach a contradiction, suppose that $n^{**} \geq n^*$. Then, there exists $n \in [n^*, n^{**}]$ such that $\bar{L}(n) \leq L^{uc}(n) \leq \hat{L}(n)$, which implies that $\bar{l}(n) \leq \hat{l}(n)$, which is a contradiction to (3) and (17). Thus, we have $n^{**}(\lambda_2) < n^*$. ■

The equilibrium under the pessimistic expectation can be characterized as follows. At date 0, each bank chooses a loan amount l_i and later at date 1 patient-and-sensitive households form an expectation. Thus, the bank profit from the choice of l_i depends on expectation. However, as there is no probability distribution over the set of expectations and since bank run is very unlikely, I assume that banks target only the optimistic expectation case and chooses l^* in (12).

At date 1, suppose that a patient-and-sensitive household (HH1) believes that all other patient -and-sensitive households will run on banks. Consider the first case where the market is sufficiently concentrated, i.e. $n \leq n^{**}(\lambda_2)$. If HH1 also runs at date 1, she will be fully repaid since the optimal loan l^* satisfies the money creation constraint (16). HH1 can also get a full repayment if she waits until date 2 since each bank gets a positive profit $\left(\frac{A-1}{n+1}\right)^2$ even after repaying all households. Therefore, HH1 chooses to wait until date 2. Since every other patient and sensitive household does the same, no bank run takes place despite all patient-and-sensitive households expect bank runs. This pessimistic expectation is not realized since the banking market is so concentrated that most deposit transfers occur within a bank (i.e. "on-us" payment) and hence banks are able to meet all demands for deposit withdrawals.

Consider the second case in which the market is not so concentrated that $n > n^{**}(\lambda_2)$. In this case, the money creation constraint (16) is violated. Thus, HH1 will be repaid partially if she runs on her bank at date 1 but gets nothing if waits until date 2 since all loans are liquidated early at date 1 and hence no assets remain at date 2. Thus, the pessimistic expectation leads to the bad outcome of bank runs.

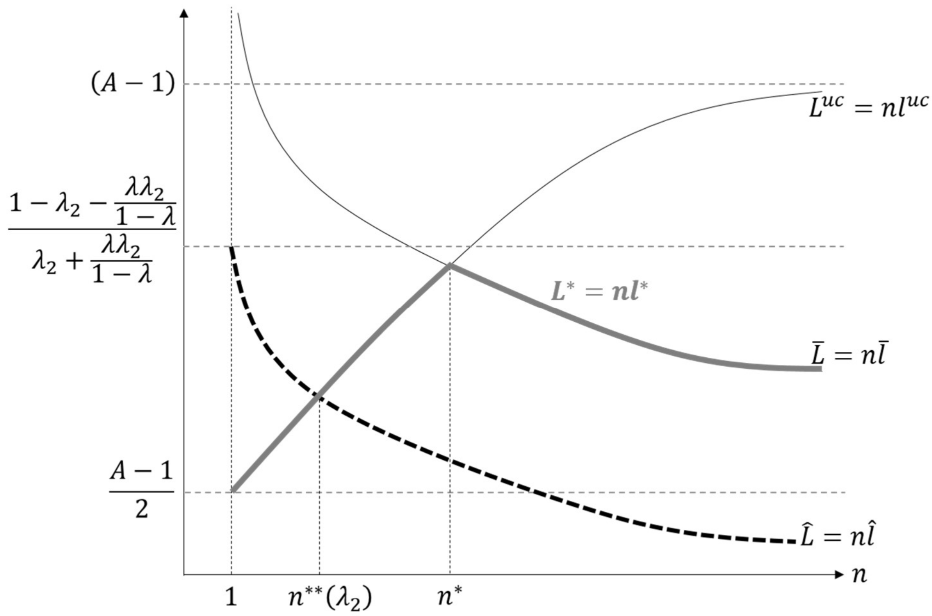
The first part of the following proposition is about the pessimistic expectation case and summarizes the analysis provided so far. The second part of the proposition is straightforward as nothing changes with respect to the optimistic expectation case.

Proposition 5: Consider a traditional banking system.

(i) (Pessimistic expectation case) Suppose that every patient-and-sensitive household believes that all other patient-and-sensitive households will run on banks. Then, bank runs do not take place if and only if $n \leq n^{**}(\lambda_2)$, where $n^{**}(\lambda_2) \in (1, n^*)$. In addition, the equilibrium output is $Y\left(L^*(n)\right)$ if bank runs do not take place but zero otherwise.

(ii) (Optimistic expectation case) Suppose that every patient-and-sensitive household believes that all other patient-and-sensitive household will not run on banks. Then, bank runs do not take place for any n, and the equilibrium output is $Y\left(L^*(n)\right)$.

Figure 6. Tradeoff between Bank Run and Competition



Proposition 5(i) is the main result in this extended model (see Figure 6). Recall that in the baseline model bank runs occur for any number of banks n if patient households believe bank runs. In contrast, in this extended model, bank runs do not take place if there are a sufficiently small number of banks even if the patient-and-sensitive households expect bank runs. This new result implies that there is a tradeoff between bank run and competition. The more competitive is the banking market, the more likely bank runs take place.

This tradeoff between bank run and competition exists only under this extended model but not the baseline model. In the baseline model, bank runs always take place no matter how concentrated is the banking market if the pessimistic expectation is prevalent. However, the aforementioned tradeoff between money creation and competition exists under both models. In both models, if the optimistic expectation prevails, the same equilibrium arises: banks in the perfectly competitive banking market are willing to but unable to provide the socially efficient amount of loans due to a tight constraint on money creation, while a monopoly bank is able to but not willing to provide the efficient lending.

The equilibrium under the CBDC-based new banking system does not change when the baseline model is replaced by this extended model. The impatient households withdraw deposits and transfer them to the central bank accounts of the patient households. The patient-and-sensitive households withdraw deposits as CBDC and redeposit them into their central bank accounts. Therefore, central bank runs never take place no matter the expectation is good or bad. Note that the equilibrium output is efficient since the perfectly competitive banks provide the efficient amount of loans. That is, the new banking system can be a solution to the tradeoff between bank run and competition.

This result is still true when the net deposit interest rates are positive and increasing in bank competition. Under this alternative assumption, increased competition causes bank runs even more likely as competition increases liquidity outflows, by not just making more transactions as off-us rather than on-us but also increasing deposit interest payments to impatient households. That is, the tradeoff between bank run and competition under the traditional banking system becomes even stronger. However, this new assumption on deposit rates does not affect the CBDC-based new banking system, since the central bank is a monopoly deposit-taker and, hence, bank competition does not affect the central bank's deposit rate. Consequently, the new banking system is even better alternative to the traditional banking system.

7. Monetary Policy Tradeoff between Price Stability and Bank Run

In the extended model with three types of households, monetary policy is not considered at all. Everything in the model is real and hence monetary policy does not play any role. However, in the following section, I shall draw an implication on monetary policy by linking it to the composition of patient households.

If the central bank implements a tight monetary policy, economic players will be more sensitive to liquidity-related issues as economic activity shrinks and liquid assets decrease. In particular, they will pay more attention to whether their banks are stable enough to repay deposits on demand and therefore eager to collect information on bank stability. In this sense, I assume that monetary policy tightening results in an increase in patient-and-sensitive households λ_2 and a decrease in patient-and-insensitive households λ_3, while the total measure of patient households $\lambda_2 + \lambda_3 = 1 - \lambda$ is unaffected.

Then, when the pessimistic expectation prevails, more patient households demand immediate withdrawals since more patient households are sensitive. Therefore, the liquidity outflow increases, and hence, the money creation constraint (16) becomes more restrictive. Note that the maximum loan satisfying the money creation constraint (16) is $\hat{l}(n; \lambda_2)$ in (17) and this maximum loan is decreasing in λ_2 for any given n. Therefore, more concentration in the banking market is necessary to meet the increased liquidity outflow. That is, it can be shown that the threshold bank number $n^{**}(\lambda_2)$ decreases and closes to 1. Recall from the proposition 5 that bank runs are prevented if and only if $n \le n^{**}$ when the patient-and-sensitive households expect bank runs. Therefore, $\frac{1}{n^{**}(\lambda_2)}$ can be interpreted as a measure of bank run risk. If λ_2 increases due to monetary policy tightening, $n^{**}(\lambda_2)$ decreases and, hence, this bank run risk increases. This analysis is summarized in the following proposition.

Proposition 6: Suppose that more patient households become sensitive if the monetary policy is tightened. That is, λ_2 increases but $(1 - \lambda)$ is unchanged. Then, the measure of bank run risk $\frac{1}{n^{**}(\lambda_2)}$ increases.

Proof: Let λ_2' and λ_2'' be two levels of λ_2 such that $\lambda_2' < \lambda_2''$. To reach a contradiction, suppose that $n^{**}(\lambda_2') \le n^{**}(\lambda_2'')$. Then, by the lemma 2 and (17), there exists $n \in [n^{**}(\lambda_2'), n^{**}(\lambda_2'')]$ such that $\hat{L}(n, \lambda_2') \le L^{uc}(n) \le \hat{L}(n, \lambda_2'')$, which implies that $\hat{l}(n, \lambda_2') \le \hat{l}(n, \lambda_2'')$, which is a contradiction to (17). Thus, we have $n^{**}(\lambda_2') > n^{**}(\lambda_2'')$. ■

This result implies that there is a monetary policy tradeoff between price stability and bank run risk. If the inflation rate is high and so a central bank tightens monetary policy, more patient households run on banks, and hence, bank runs are more likely. An interesting point with this tradeoff is that competition in the banking market can exacerbate the problem. The more competitive is the banking market, monetary policy tightening can damage the financial stability the more likely. This is consistent with the recent bank runs. As the Federal Reserve raised policy rates rapidly in 2022-23, many banks suffered from bank runs. Interestingly, most bank runs took place in small regional banks such as Silicon Valley Bank and First Republic who have little market powers if any.

The CBDC-based new banking system can also be a solution to this tradeoff. Note that the proposition 4 still holds since any deposit withdrawal ends up with transfer within the central bank. This fact does not depend on λ_2 at all. Therefore, if the new banking system prevails, the central bank can focus on stabilizing inflation without worrying about bank run risks.

8. Is the CBDC-based New Banking System Immune to Loan Losses?

Bossone and Haines (2023) claim that under the CBDC-based new banking system “no losses or defaults by individual banks or borrowers hurt depositors.” They also argue that “the central bank would suffer no real loss” from “any bank loan that a borrower failed to repay” since it simply stays on the books of the central bank. Banks or borrowers could be in default due to loan losses. However, borrowers would have used the loan proceeds to buy goods, services or production factors from some individuals or companies. These individuals and companies would also have used the money to trade with others. Since all of these economic agents use central bank accounts, the loan proceeds never disappear but circulate within the central banking system. That’s why the central bank loses nothing from loan losses or bank default and therefore depositors are safe.

In the following section, I shall examine whether this argument by Bossone and Haines (2023) is valid. To this end, I modify the baseline model in that the entrepreneur can fail with the probability p and therefore repays nothing at all to banks at date 2. To make the analysis simple and tractable, I assume that this default probability tends to zero and hence the default is a measure-zero event. Therefore, the equilibria obtained under the baseline model where the entrepreneur never defaults still hold even under this modified model. Suppose that the default event realizes. As the entrepreneur repays zero to banks, the banks cannot repay a penny to the central bank. The central bank then has only 1 as cash while it has to repay $(1 + L)$ to patient households. The central bank may exercise the special powers of money printing or taxing to clear its obligations, but anyway, the patient households get hurt. If the central bank instead gets or borrows cash from the central government, the patient households will not suffer losses but the general taxpayers get hurt as government budget is spent.

Why do households suffer real losses? This is simply because the entrepreneur produces nothing by using resources. At date 0, households provide labor, which is a valuable social resource. The entrepreneur puts the labor into the production function and yields nothing. As the real resource available to the economy is reduced for no good, somebody must get hurt. The entrepreneur and the impatient households do not suffer since they buy labor or the consumption good before the entrepreneur fails. Thus, the victims are the patient households since they provided labor at cost and received CBDC but this CBDC is not worthy enough compensating their labor service. If the central government compensates losses of the patient households, then these losses spill over to taxpayers.

This finding that bank defaults cause losses to the economy even under the CBDC-based new banking system draws an important implication on the architecture of prudential regulation. Traditional banks face both liquidity risks and solvency risks and hence subject to liquidity regulations and capital adequacy requirements. By contrast, banks under the new banking system face only solvency risks but not liquidity risks. Therefore, capital adequacy requirements are still needed while liquidity regulations are no more necessary.

9. Conclusion

Digital financial innovations highlighted by fintech or big tech companies have the potential to significantly increase the well-being of financial consumers through competition. However, as the recent Silicon Valley Bank run showed impressively, unreliable negative information can easily lead to bank runs with an unprecedented speed through digital communication media. Then, how can we prevent panic-based bank runs entirely while achieving a socially efficient allocation? A potential solution is a CBDC-based new banking system in which deposit-taking is monopolized by a central bank while lending is decentralized through competitive commercial banks. To analyze the validity of this new banking system, I develop a model of bank run and money creation.

The main results of this paper are summarized as follows. Firstly, there is a tradeoff between competition and money creation under the traditional banking system. Increased competition reduces the market share of each bank in the payment system and, hence, payments and money transfers using deposit accounts are more likely "off-us" transactions. Therefore, each bank faces more liquidity outflows and thereby a bank's lending capacity is more reduced.

Secondly, the CBDC-based banking system outperforms the traditional banking system in terms of resource allocation. Banks in the traditional system do not provide efficient amount of loans either because of the money creation and competition tradeoff or because banks want to enjoy oligopoly rents. However, the CBDC-based banking system solves this inefficiency problem, as the central bank neither faces a constraint on money creation nor want to enjoy a rent.

Third, the new banking system can eliminate panic-based bank runs completely unlike the traditional banking system. Since no depositors have demand deposit accounts on banks, but only the central bank deposits a long-term money on banks, commercial bank runs cannot take place. Since the central bank has some special powers including the power of providing legal tender based on which legal deposit contracts are written it can always fulfill its legal obligation against depositors without liquidating loans. But then depositors can be repaid in full if they wait until the maturity. Therefore, central bank runs can be prevented.

These main results are obtained under an implicit assumption that depositors rarely withdraw deposits as cash or foreign currencies. If this is not the case, money can flow out from the central bank and hence the central bank can face some constraints in money creation. However, even if this assumption does not hold, I expect that the main results do not change qualitatively, as the central bank is better than commercial banks in dealing with liquidity outflows and hence mitigating the money creation constraint.

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