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Safe Payments

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Abstract

We use a simple model to study whether private payment systems based on bank deposits can provide the optimal level of safety. In the model, bank deposits backed by projects are subject to default risk that can be mitigated by a depositor's ex ante and ex post monitoring. Safe payment instruments issued by a narrow bank can also be used as a back-up payment system when the risky bank fails. Private adoption of safe payment instruments is generally not socially optimal when buyers do not fully internalize the externalities of their adoption decision on sellers, or when the provision of deposit insurance distorts their adoption incentives. Using this framework, we discuss the optimal subsidy policy conditional on the level of deposit insurance.

Bank topics: Central bank research; Digital currencies and fintech; Financial institutions; Payment clearing and settlement systems
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1 Introduction

Transactions in payment systems are often facilitated by transferring safe and liquid assets as a means of payment.[1] For many years, cash and bank deposits have been serving this role in retail payment systems. In many developed economies, the share of cash transactions in retail payments has become less important relative to other private payment methods. Some observers worry that a payment system dominated by privately issued money might not be sufficiently safe.[2] The concern is that, as bank deposits are subject to higher credit risk than cash, a cashless payment system would be inherently less robust. The above argument, however, ignores that the level of safety of a private payment system is endogenously determined. If there is a demand for safe payment balances in a cashless society, the private sector might be induced to create very safe balances to replace cash. For example, narrow banks can be set up to invest funds in highly liquid and safe government assets and allow payments in their liabilities (Mancini-Griffoli et al. 2018). In addition, public safety nets such as deposit insurance can also make bank deposits safer balances. This paper develops a simple banking model to study whether private payment systems based on bank deposits can provide the socially optimal level of safety.

In our model, bank deposits serve as a means of payments facilitating depositors' transactions. At the same time, banks can channel deposits to finance a high return investment project. Bank deposits backed by projects, however, are subject to default risks. To mitigate the risk, depositors can (1) perform ex-ante monitoring to reduce the likelihood of a default (e.g., monitoring to make sure that the bank invests properly), and/or (2) perform ex-post monitoring to detect signs and perform early liquidation of the bank to reduce loss. These activities are costly: monitoring requires costly efforts, and early liquidation implies that depositors lose liquid balances as a means of payment.

Besides these two measures, depositors can also set up a safe bank to issue balances backed by risk-free government bonds. The balance in the safe account/bank is perfectly safe and liquid.[3] This safe bank can be used as a back-up payment system, allowing depositors

[1] We say an asset is safe if the nominal redemption value is certain and an asset is liquid if it is widely accepted for retail payments.

[2] See, for example, Dyson and Hodgson (2016) and Sveriges Riksbank (2017).

[3] These safe accounts would be similar to 100% reserve banks and treasury money market funds with zero or very low nominal returns and no default risks. An underlying assumption of our analysis is that the government is willing to supply enough government bonds to satisfy the demand so that the return rate stays constant. By doing this, we separate the issue of insufficient liquid, safe assets (money) from the issue of insufficient illiquid, safe assets (government securities).

to transfer their funds to a safe account when the risky bank fails. Using the safe account, however, is also costly, incurring a setup cost and the opportunity cost of forgoing higher-return investments.

We use this model to study whether the private payment system based on bank liabilities achieves the optimal level of safety, and whether public intervention is required. We find that the adoption of safe accounts is in general sub-optimal because private agents do not fully internalize the externalities of their adoption decision. Interestingly, depending on the monitoring technology available, private agents may under- or over-adopt safe accounts. In particular, in a world with only ex-post monitoring, investments in safe payments and in monitoring are complements, implying that private agents tend to under-adopt safe accounts. Intuitively, setting up a safe account enables agents to consume without using deposits and hence reduces the cost of ex-post monitoring (liquidation). In a world with only ex-ante monitoring, investments in safe payments and in monitoring are substitutes, and private agents sometimes over-adopt the safe payment technology. In addition, private incentives to adopt safe accounts are also distorted by the provision of public safety nets such as deposit insurance. Ex-ante public intervention such as corrective taxes or subsidies on safe payment adoption can restore the optimal adoption of safe accounts.

Our findings are related to Tobin's (1987, 16) argument that "monetary and financial institutions involve some externalities, public goods and bads, and their functioning in the public interest requires wide availability of accurate information. The payments system and the integrity of the medium of exchange are public goods. The sovereign monetary fiat, partially delegated to private agents, must be protected." Tobin (1987, 13) also suggested that the government "should make available to the public a medium with the convenience of deposits and the safety of currency, essentially currency on deposit, transferable in any amount by check or other order" and "to restructure the systems of depository institutions so as to reduce significantly the moral hazard of federal safety nets, particularly deposit insurance."[4] Our analysis is related to the existing literature on banking.[5] Our focus on bank failures is related to the seminal works by Diamond and Dybvig (1983) and Calomiris and Kahn (1991). The monetary component of model is related to monetary search models such as Lagos and Wright (2005).

[4]Ioannidou and Penas (2010) provide empirical evidence that deposit insurance induces bank risk-taking and reduces market discipline from large depositors.

[5]See Freixas and Rochet (2008) for a comprehensive review.

Our paper is also related to the fast-growing literature on central bank digital currency (CBDC). [6] Various arguments have been offered to support central banks issuing a CBDC. If the main motivation to issue a CBDC is to provide a safe payment system in the absence of cash, our findings imply that this objective can be fulfilled by setting up a safe bank (or narrow bank) together with appropriate taxes or subsidies to ensure efficient adoption of the safe means of payments.

The remainder of the paper is organized as follows. We present the basic model environment with ex-post monitoring in Section 2. We characterize the equilibrium in Section 3. We discuss the optimal adoption subsidy in Section 4. In Section 5, we consider an environment with ex-ante monitoring. In Section 6 we conclude.

2 Environment

The economy lasts for four periods ($t = 1, 2, 3, 4$). There is a government and two risk-neutral private agents: a buyer (depositor) and a seller. There are two goods: a consumption good c and a numeraire good x.

Buyer and Seller. The seller can produce the consumption good c_3 in period 3 subject to a linear cost, and consumes numeraire goods x_4 in period 4. The seller's preference is given by

$$-c_3 + x_4.$$

The buyer is endowed with $\omega \geq 1$ units of numeraire good in period 1. The endowment can be transformed to numeraire goods in period 4 by some storage technologies described below. The buyer values consumption goods c_3 in period 3 and numeraire goods x_4 in period 4. The buyer's preference is given by

$$-h_1 + \theta c_3 + x_4,$$

where $\theta > 1$ is the marginal utility in period 3. In addition, the buyer can exert labor effort h_1 to activities described below.

Trading. In period 3, the buyer and the seller meet and trade consumption goods c_3. The terms of trade are determined by bargaining where the buyer gets a fraction λ of the

[6] See Andolfatto (2020), Brunnermeier and Niepelt (2019), Barrdear and Kumhof (2016), CPMI (2018), Chiu et al. (2019), Davoodalhosseini (2018), Davoodalhosseini and Rivadeneyra (2020), Dong and Xiao (2019), Fernandez-Villaverde et al. (2020a,b), Fung and Halaburda (2016), Kahn et al. (2019), Keister and Monnet (2020), Keister and Sanches (2019), Mancini-Griffoli et al. (2018), Monnet et al. (2019), Niepelt (2020), Williamson (2020), and Zhu and Hendry (2019).

trade surplus. Due to the lack of commitment, a liquid means of payment is required to finance the transaction. We assume that this is a cashless economy in which the seller can only recognize and accept bank IOUs backed by assets. An IOU is a claim in period 4 to the underlying asset backing the bank account.

Assets (Storage technologies). There are two storage technologies or assets in this economy. First, agents can invest in government bonds. It is a linear technology that stores x units of numeraire goods in any period to yield x units in period 4 (the rate of return of bonds is normalized to one). Second, there is a production project that transforms x units of numeraire goods in period 1 to xR units of numeraire goods in period 4, with $R > 1$.

Banking. The two types of assets—government bonds and projects—are illiquid and cannot be used directly as a means of payment in period 3.[7] However, the buyer can establish a bank (or a bank account) in period 1 and use bank IOUs backed by bonds or projects to trade with the seller in period 3. Setting up a bank requires a utility cost C. One can interpret C as the costs of creating IOUs that are not subject to counterfeits and hence can be used as a means of payment in period 3.

A bank that invests in a project (irrespective of the scale) is subject to a credit risk (call it a "risky bank"): with probability π, a crisis is triggered and the bank and all of its assets will be wiped out in period 3.[8] The credit risk can be mitigated if the buyer monitors the bank. By monitoring, the buyer might be able to detect the crisis *early* in period 2 and hence can withdraw the funds from the risky bank early.[9] The withdrawing request will force the bank to liquidate/terminate its investment in projects, and each unit of terminated investment yields γR unit of numeraire goods. We assume that $\gamma < \pi$ so that investment in projects will not be liquidated unconditionally. Monitoring the bank requires labor efforts in period 1. Specifically, by exerting effort h per unit of investment in projects, the buyer can detect a crisis with probability $p(h)$, where $p(0) = 0$, $p'(h) > 0$, and $p''(h) < 0$.

The buyer can also establish in period 1 a "safe bank" that invests purely in government bonds. IOUs of the safe bank are free from credit risks. If the buyer establishes a safe bank in addition to a risky bank (by incurring $2C$), the funds withdrawn from the risky bank in period 2 can also be deposited to the safe bank to purchase government bonds, and IOUs

[7] For example, the seller may not be able to verify the authenticity of bonds or projects in transactions.

[8] One interpretation is that a project must be managed by a banker, who may abscond with the entire bank asset in period 3 with probability π.

[9] In the extension, we discuss an alternative specification where the depositor's monitoring efforts can reduce the probability of a crisis event.

backed by the newly purchased bonds can be used to conduct transactions in period 3. A safe account can potentially serve two functions. Holding bonds in the safe account in period 1 can provide a perfectly safe means of payment for transactions in period 3. Alternatively, the safe account can provide a back-up payment technology to be used only when the risky bank collapses.

Deposit insurance (DI). In period 3, IOUs of a risky bank (call them "risky IOUs") have zero transaction values in a crisis state. We assume that the government provides deposit insurance to risky bank accounts, which guarantees that up to I units of deposits are fully protected. Specifically, the government stands ready to redeem up to I units of IOUs in period 4. We assume that the insurance payouts are financed by a lump-sum tax in period 4. The deposit insurance implies that, even in a crisis state, the buyer can still spend up to I units of IOUs backed by deposit insurance to buy consumption goods in period 3. With deposit insurance, a buyer may not want to withdraw all deposits even if a crisis is detected in period 2.

3 Equilibrium Characterization

The sequence of actions by the buyer is described in the Table 1. We impose the following restrictions on parameter values:

$$\pi R - 1 > C. \tag{1}$$

We solve the model backward starting from period 4.

Table 1: **Actions of the buyer**

$t = 1$	Banking and monitoring choices
$t = 2$	Withdrawal choice conditional on monitoring outcome
$t = 3$	Trading with the seller using bank IOUs
$t = 4$	IOU redemption and DI claim

3.1 IOU Redemption (Period 4)

In period 4, the bearer of safe IOUs can redeem 1 unit of numeraire goods. The bearer of risky IOUs receives R units of numeraire goods from the bank account in a normal state. In a crisis state, the bearer of risky IOUs receives zero from the bank account and up to I units from deposit insurance.

3.2 Trading (Period 3)

The state of the world is realized in period 3, so the seller can evaluate the continuation value of an IOU in the trading stage. Consider a buyer holding an IOU with a continuation value of m. Let c be the quantity of goods traded. The surplus of the buyer and the seller are respectively $\theta c - m$ and $m - c$. The bargaining power of the buyer is λ. The bargaining solution implies

$$\frac{\theta c - m}{m - c} = \frac{\lambda}{1-\lambda},$$

which leads to

$$c = \frac{m}{1 + (1-\lambda)(\theta - 1)}.$$

The total surplus is

$$\begin{aligned} S &= (\theta - 1)c \\ &= \frac{\theta - 1}{1 + (1-\lambda)(\theta - 1)} m, \\ &= \Delta m \end{aligned}$$

where $\Delta \equiv (\theta - 1)/[1 + (1-\lambda)(\theta - 1)]$ captures the gains from trade. Note that the gains from trade are maximized ($\Delta = \theta - 1$) when $\lambda = 1$, and $d\Delta/d\lambda > 0$ as the trade size c increases with λ. The buyer's surplus is

$$\lambda S = \lambda \Delta m,$$

and the seller's surplus is

$$(1-\lambda)S = (1-\lambda)\Delta m.$$

Note that λ is a key parameter that captures the degree of externality involved in payment choices. The lower the value of λ, the lower the incentives of the buyer to conduct the transaction. Hence we have the following result.

Lemma 1 *In period 3, the buyer's valuation of an IOU that redeems m is $(1 + \lambda\Delta)m$.*

3.3 Withdrawal Choice (Period 2)

Conditional on the monitoring outcome, buyers will revise their belief about the state of the world, and decide whether and how much to withdraw from the risky bank.

If a crisis is not detected, then buyers will revise upward their initial belief about the probability of the normal state from π to $\hat{\pi} = \frac{\pi}{\pi+(1-\pi)(1-p(h))}$. In this case, the buyer will not withdraw from the risky bank. This is obviously true when the deposit is fully insured, i.e., when the principal plus interest, aR, does not exceed the insurance limit I. Even if some balances are not insured, the expected payoff of keeping a marginal unit in the risky account, $\hat{\pi}(1+\lambda\Delta)R$, exceeds the expected payoff of withdrawing, which is at most $\gamma(1+\lambda\Delta)R$.[10]

Now suppose that the crisis state is detected. If the deposit is fully insured ($aR \leq I$), then the buyer does not want to withdraw (withdrawals will show up as a voluntary reduction in account balance and withdrawn funds are not covered by DI). If some balances are not insured ($aR > I$), then the buyer should leave the insured amount in the risky account and withdraw only the uninsured amount $aR - I$. The expected payoff is

$$\gamma(aR - I)(1 + s\lambda\Delta) + I(1 + \lambda\Delta),$$

where $s = \{0, 1\}$ indicates whether the buyer has a safe account or not. If the buyer did not set up a safe account in period 1 ($s = 0$), then the buyer invests the withdrawn amount $\gamma(aR-I)$ in bonds but cannot use it to trade in period 3. If the buyer sets up a safe account ($s = 1$), then the buyer can re-invest the withdrawn amount into the safe account and spend it in period 3. We summarize the withdrawal choice in period 2 in Lemma 2.

Lemma 2 *In period 2, the buyer withdraws* $\max\{0, aR - I\}$ *if the crisis state is detected. Otherwise, the buyer does not withdraw early.*

3.4 Banking and Monitoring Choice (Period 1)

In period 1, the buyer decides (i) whether to set up a safe account $s \in \{0, 1\}$, (ii) whether to set up a risky account $r \in \{0, 1\}$, (iii) what the intensity of their monitoring effort will be h, and (iv) how much to invest in in risky accounts a. Formally, the buyer chooses (s, r, h, a) to maximize[11]

[10] The payoff from withdrawing each unit from the risky account is $\gamma(1+\lambda\Delta)R$ if the buyer has chosen to set up a safe account in addition to the risky account, and γR if the safe account has not been set up. Given that $\hat{\pi} > \pi$, and the assumption $\pi > \gamma$, the expected payoff from keeping money in the risky bank is larger than the payoff from withdrawing.

[11] We can also allow the manager to hold bonds in risky accounts. Since $R > 1$, it is not optimal to hold any as the manager can abscond any assets not stored in the segregated account.

$$V_b(r,s,h,a) = \max_{r,s,h,a} \underbrace{(\omega - a)(1+s\lambda\Delta) - sC}_{\text{safe account}} + \underbrace{r \begin{bmatrix} a\pi R(1+\lambda\Delta) \\ +(1-\pi)(1+\lambda\Delta)\min\{aR, I\} \\ +(1-\pi)p(h)\gamma\max\{aR-I,0\}(1+s\lambda\Delta) \\ -ah - C \end{bmatrix}}_{\text{risky account}}. \quad (2)$$

The first line captures the payoffs of having a safe account. If $s=0$, the buyer invests $\omega - a$ in bonds and consumes $\omega - a$ numeraire goods in period 4. If $s=1$, then the buyer can use the IOUs backed by bonds to trade in period 3 for consumption goods, which yields utility $(\omega - a)(1+\lambda\Delta)$. Note that the deposit insurance is financed by lump-sum taxes irrespective of the buyer's choices of (r,s,h,a), and the taxes do not affect the buyer's payment choice. While analyzing the buyer's choice, we omitted the lump-sum taxes.

The second line captures the payoffs of setting up a risky account. In a normal state, the buyer derives $aR(1+\lambda\Delta)$ in period 3. In a crisis state, regardless of whether it is detected or not, the buyer can still use the insured IOUs to spend $\min\{aR, I\}$ on consumption goods in period 3. If the crisis state is detected, then the buyer can withdraw $\gamma\max\{aR-I,0\}$ from the bank. If there is a safe account, then the withdrawn funds can be converted to safe IOUs that can be used to buy consumption goods in period 3. Otherwise, the withdrawn amount can be invested in bonds and yield consumption in period 4.

To solve for the optimal banking and monitoring choices, we first consider the portfolio and monitoring choice conditional on the choice of bank accounts. We will then analyze the optimal account choice, choosing from four potential account choices: (1) risky account only, (2) both safe and risky accounts, (3) safe account only, and (4) no accounts.

3.4.1 Monitoring and Investment Conditional on Account Choices

We will examine the four potential account choices.

Case 1: Risky account only $(r=1, s=0)$. In this case, first suppose $aR \le I$, then

$$V_b(1,0,h,a) = \max_{h,a} \omega - a + aR(1+\lambda\Delta) - ah - C. \quad (3)$$

The marginal return of h is $-a \le 0$, so it is optimal to set $h=0$. The marginal return of

a is $-1 + R(1 + \lambda\Delta) > 0$. Hence it is optimal to set $a = I/R$. In words, if the investment in projects (principal plus interest) is less than the deposit insurance limit, then the buyer will always get the full face value of deposits irrespective of the state of the world and there is no need to monitor. In addition, insurance removes the credit risk of the risky account and ensures a high return of R, and the insured balance can be used to buy consumption in period 3, so it is optimal to increase investment in the risky account to $\max\{\omega, R/I\}$.

Next, suppose $aR > I$. Then

$$V_b(1, 0, h, a) = \max_{h,a} (\omega - a) + \left[\begin{array}{l} a\pi R(1 + \lambda\Delta) \\ +(1 - \pi)(1 + \lambda\Delta)I \\ +(1 - \pi)p(h)\gamma(aR - I) \\ -ah - C \end{array} \right]. \tag{4}$$

The first-order condition with respect to h is

$$(1 - \pi)p'(h)\gamma\,(aR - I) = a.$$

The left-hand side is the benefit of monitoring. Monitoring is useful in a crisis state by increasing the probability of detection. Once a crisis state is detected, the depositor can take the uninsured amount $(aR - I)$ to invest in bonds instead of losing it completely. Normalizing the cost and benefit by the size of investment in the risky account a, we can rewrite the equation as

$$(1 - \pi)p'(h)\gamma\,(R - I/a) = 1.$$

The derivative with respect to a is

$$\begin{array}{rl} & -1 + \pi R(1 + \lambda\Delta) + (1 - \pi)p(h)\gamma R - h \\ = & -1 + \pi R(1 + \lambda\Delta) + h\left[(1 - \pi)\dfrac{p(h)}{h}\gamma R - 1\right] \\ > & -1 + \pi R(1 + \lambda\Delta) + h[(1 - \pi)p'(h)\gamma R - 1] \\ = & -1 + \pi R(1 + \lambda\Delta) + h(1 - \pi)\gamma p'(h)\dfrac{I}{a} > 0. \end{array}$$

The cost of of investing one unit of fund in the risky account is the opportunity cost of investing it in bonds, which gives the return of 1. The expected return from the risky account consists of three components. With probability π, the state is normal and the return is R and the balance can be used for transactions in period 3. With probability $1 - \pi$, the economy hits a crisis state. With probability $p(h)$, the crisis state is detected and the

the depositor can retrieve a rate of return γR by investing in bonds (and note that bonds cannot be used directly for transactions in period 3). The third term captures the cost of monitoring per unit of investment in the risky account. It turns out to be optimal to invest all endowment in the risky account, i.e., $a = \omega$. The inequality from the derivation is implied by the properties of $p(h)$, and the last equality is implied by assumption 1. We summarize the optimal monitoring and investment decisions in the following lemma.

Lemma 3 *When the buyer sets up only a risky account, the optimal choices are $a_0 = \omega$ and h_0 that satisfies*

$$(1-\pi)\gamma p'(h_0)\left(R - \frac{I}{\omega}\right) = 1. \tag{5}$$

The buyer's expected payoff is

$$V_b^r = \pi\omega R(1+\lambda\Delta) + (1-\pi)(1+\lambda\Delta)I + (1-\pi)p(h_0)\gamma(\omega R - I) - \omega h_0 - C. \tag{6}$$

Case 2: $r = s = 1.$ In this case, suppose first $aR < I$, then

$$V_b(1,1,h,a) = \max_{h,a}(\omega - a + aR)(1+\lambda\Delta) - 2C - ah.$$

Similar to case 1, when $aR < I$, the marginal return of h is $-a < 0$, implying that it is optimal to set $h = 0$. The marginal return of a is $(1+\lambda\Delta)(R-1) > 1$, implying it is optimal to set $a = \max\{\omega, R/I\}$.

Now, suppose $aR > I$, then

$$V_b(1,1,h,a) = \max_{h,a}(1+\lambda\Delta)\begin{bmatrix} (\omega - a) \\ +\pi a R \\ +(1-\pi)I \\ +(1-\pi)p(h)\gamma(aR - I) \end{bmatrix} - ah - 2C.$$

The first-order condition with respect to h is

$$(1-\pi)p'(h)\gamma\left(R - \frac{I}{a}\right)(1+\lambda\Delta) = 1.$$

The derivative with respect to a is

$$\begin{aligned}
& (1+\lambda\Delta)[-1+\pi R+(1-\pi)p(h)\gamma R]-h \\
= \;& (1+\lambda\Delta)[-1+\pi R]+h\left[(1+\lambda\Delta)(1-\pi)\frac{p(h)}{h}\gamma R-1\right] \\
> \;& (1+\lambda\Delta)[-1+\pi R]+h\left[(1+\lambda\Delta)(1-\pi)p'(h)\gamma R-1\right] \\
= \;& (1+\lambda\Delta)[-1+\pi R+h(1-\pi)p'(h)\gamma I/a] \\
> \;& -(1+\lambda\Delta)(\pi R-1)>0.
\end{aligned}$$

The first inequality follows the properties of $p(h)$, and the last inequality is implied by assumption 1. Hence it is optimal to set $a=\omega$. We thus have the following lemma.

Lemma 4 *When the buyer sets up both risky and safe accounts, the optimal choices are* $a_1=\omega$ *and* h_1 *that satisfies*

$$(1-\pi)p'(h_1)\gamma(R-\frac{I}{\omega})(1+\lambda\Delta)=1. \tag{7}$$

The buyer's expected payoff is

$$V_b^{sr}=\pi\omega R(1+\lambda\Delta)+(1-\pi)(1+\lambda\Delta)I+(1-\pi)p(h_1)\gamma(\omega R-I)(1+\lambda\Delta)-\omega h_1-2C. \tag{8}$$

Case 3: $r=0$, $s=1$. When there is only a safe account, it is optimal to set $a=\omega$ and the payoff is simply $V_b^s=\omega(1+\lambda\Delta)-C$.

Case 4: $r=s=0$. When no accounts are set up, it is optimal to set $a=\omega$ and the payoff is simply $V_b^0=\omega$.

3.4.2 Account Choices

We now compare the four cases to derive the optimal banking (and monitoring) choice. Investing in a safe account yields a low but risk-free return. Investing in a risky account yields a higher return but involves a credit risk that can be mitigated by exerting costly monitoring effort. Setting up both risky and safe accounts involves a higher set up cost, but it allows the buyer to take advantage of the higher expected return from investing on projects, and the buyer can still trade after detecting a crisis state by re-investing the withdrawn fund into the safe account.

First, it is easy to check that assumption 1 implies that "safe account only" (case 3) and autarky (case 4) are dominated by "risky account only" (case 1). Therefore, a risky account is always set up. The only remaining question is to set up a safe account in addition. Using equations (6) and (8), we find that the buyer adopts the safe account if and only if

$$V_b^{sr} > V_b^r, \tag{9}$$

or when the cost of setting up a bank account is lower than the threshold value C_b defined as:

$$\begin{aligned} C_b \equiv \; & \underbrace{(1-\pi)p(h_1)\gamma(\omega R - I)\lambda\Delta}_{\text{liquidity value of uninsured balances}} \\ & + \underbrace{(1-\pi)[p(h_1) - p(h_0)]\gamma(\omega R - I) - \omega(h_1 - h_0)}_{\text{net benefit from increased monitoring}}. \end{aligned}$$

The first term of C_b captures the liquidity value of having the safe account in the crisis state. The second term is the (net) benefit of increased monitoring efforts and crisis detection rates induced by the safe account.

3.5 Equilibrium

First, note that for buyers with $\omega R \leq I$, the optimal choice is to set up only the risky account, deposit all endowment to it, and exert no monitoring effort. The payoff is $(1 + \lambda\Delta)\,\omega R$. We therefore focus on the choices and actions of buyers with $\omega R > I$ and summarize it in the following proposition.

Proposition 1 (Equilibrium) *If $C \leq C_b$, then the equilibrium actions of the buyer are:*

- $t = 1$: *sets up both risky and safe accounts, deposits ω in the risky account, and exerts monitoring effort h_1, which solves (7);*
- $t = 2$: *withdraws $\omega R - I$ if detecting the crisis state early, and reinvests in the safe account;*
- $t = 3$: *consumes*

$$c_3 = \begin{cases} \frac{\omega R}{1+(1-\lambda)(\theta-1)} & \textit{in normal state,} \\ \frac{I+\gamma(\omega R - I)}{1+(1-\lambda)(\theta-1)} & \textit{in crisis state detected early, and} \\ \frac{I}{1+(1-\lambda)(\theta-1)} & \textit{in crisis state not detected early;} \end{cases}$$

- $t = 4$: *consumes no numeraire goods.*

When $C > C_b$, the equilibrium actions of the buyer are:

- $t = 1$: *sets up only a risky account, deposits ω in it, and exerts monitoring effort h_0, which solves (5);*
- $t = 2$: *withdraws $\omega R - I$ if detecting the crisis state early, and reinvests in illiquid government bonds;*
- $t = 3$: *consumes*

$$c_3 = \begin{cases} \frac{\omega R}{1+(1-\lambda)(\theta-1)} & \textit{in normal state, and} \\ \frac{I}{1+(1-\lambda)(\theta-1)} & \textit{in crisis state;} \end{cases}$$

- $t = 4$: *consumes $x_4 = \gamma(\omega R - I)$ numeraire goods if the crisis state is detected in period 2, and 0 if the crisis state is not detected in period 2.*

One observation is that the adoption of a safe account induces more monitoring as formalized in Proposition 2. The benefit of monitoring is that depositors can detect the crisis state with a higher probability and salvage their risky account balances. A safe account increases the value of the salvaged assets because they can be invested in the safe account to support trading in period 3 ($h_1 > h_0$).

Proposition 2 (Monitoring effort and safe account) *The adoption of a safe account induces more monitoring: $h_1 > h_0$.*

The following two propositions describe how the model parameters affect the buyer's monitoring and banking choices.

Proposition 3 (Comparative statics for the monitoring effort) *Monitoring effort h_0, h_1 increase with R, γ, ω and decrease with π and I. As the buyer's market power λ increases, h_1 rises.*

The propositions follow directly from equations (5) and (7), so we will omit the proofs. Monitoring allows the buyer to detect the crisis state early and salvage the bank's asset in time. The return from monitoring is higher if the salvage value is higher (h increases with R, γ, ω). In addition, a higher chance of the crisis state means that monitoring is useful with a higher probability (h decreases with π). A more generous deposit insurance program reduces the incentive to monitor (h decreases with I).

Proposition 4 (Comparative statics for safe account choice) *A safe account is adopted in equilibrium when C, π, I are low, and when γ, λ, R, ω are high.*

The proof is in Appendix A. Intuitively, a safe account involves a fixed setup cost in period 1. The buyer tends to adopt the safe account if the adoption cost (C) is low, or if the benefit is high. The benefit of the safe account is that it allows the buyer to use the salvaged value of the uninsured deposits to transact with the seller in period 3. The benefit of the safe account is therefore higher when the depositor has higher endowment (ω) and higher bargaining power (λ), if the probability of crisis is higher (or when π is lower), if the deposit insurance (I) is less generous, or if the salvaged value of the risky account (γR) is higher.

4 Optimal Payment Choice

In this section, we consider the socially optimal payment choice subject to decentralized choices of monitoring efforts, investment, liquidation and consumption and fixing the deposit insurance limit I. The social welfare sums up the expected private payoffs for both buyers and sellers ($V_b^r + V_s^r$) and considers the tax burden $\tau = (1-\pi)I$ imposed by deposit insurance (while analyzing the buyer's problem we abstracted from the lump-sum tax to finance DI because it does not affect the buyer's choices).

It is straightforward to write down the payoffs to the seller and the social welfare under the four different bank account arrangements. When only the risky account is used ($r = 1, s = 0$), the seller's expected payoff is $V_s^r = \pi(1-\lambda)\Delta\omega R + (1-\pi)(1-\lambda)\Delta I$ and the social welfare is[12]

$$\begin{aligned} V^r &= V_b^r + V_s^r - \tau \\ &= \pi\omega R(1+\Delta) + (1-\pi)\Delta I + (1-\pi)p(h_0)\gamma(\omega R - I) - \omega h_0 - C. \end{aligned}$$

When both risky and safe payments are used ($r = s = 1$), the seller's expected payoff is $V_s^{sr} = \pi\omega R(1-\lambda)\Delta + (1-\pi)(1-\lambda)\Delta I + (1-\pi)p(h_1)\gamma(\omega R - I)(1-\lambda)\Delta$ and the social welfare is

$$V^{sr} = \pi\omega R(1+\Delta) + (1-\pi)\Delta I + (1-\pi)p(h_1)\gamma(\omega R - I)(1+\Delta) - \omega h_1 - 2C.$$

[12] We are using the result that (similar to the buyer's investment choice) it is optimal to invest all endowment in the risky account when the risky account is established.

If only safe payment is adopted ($r = 0, s = 1$), the seller's expected payoff is $V_s^s = (1 - \lambda)\Delta$ and the social welfare is

$$V_b^s = \omega(1 + \Delta) - C.$$

In autarky ($r = s = 0$), the seller's expected payoff is $V_s^0 = 0$ and the social welfare is $V^0 = \omega$.

The optimal adoption choice that maximizes the welfare is the solution to $\max_{k \in \{r,sr,s,0\}} V^k$. Similar to the buyer's account choice problem, it can be shown that it is socially optimal to have the risky account, and the choice is to whether to adopt the safe payment technology in addition. It is socially optimal to adopt the safe payment iff $V^{sr} > V^r$ or $C \leq C_p$, where

$$\begin{aligned} C_p \equiv \; & \underbrace{(1 - \pi)p(h_1)\gamma(\omega R - I)\Delta}_{\text{liquidity value of uninsured balances}} \\ & + \underbrace{(1 - \pi)[p(h_1) - p(h_0)]\gamma(\omega R - I) - \omega(h_1 - h_0)}_{\text{net benefit of increased monitoring}}. \end{aligned}$$

Similar to the terms in C_b, the first term in C_p captures the liquidity value of having the safe account in the crisis state. The second term is the (net) benefit from higher monitoring efforts induced by the safe account.

Comparing C_b and C_p, we note that the only difference between the two is the liquidity value of the uninsured amount. While the social planner takes into consideration the total surplus, captured by the term Δ, the buyer only considers the buyer's own trading surplus, captured by the term $\lambda\Delta$. This implies that the buyer under-adopts the safe account as a result of externality whenever $C \in (C_b, C_p)$. There is optimal adoption for $C < C_b$ and optimal non-adoption for $C > C_p$. To correct for under-adoption, the planner can offer a subsidy in the amount of the difference between C_b and C_p. These results are summarized in the following proposition and corollary.

Proposition 5 *The buyer under-adopts safe payments whenever $\gamma > 0$, $\omega R > I$ and $\lambda < 1$.*

Corollary 1 *The socially optimal adoption choice can be supported by paying a corrective subsidy*

$$T_s = C_p - C_b = (1 - \pi)p(h_1)\gamma(\omega R - I)(1 - \lambda)\Delta \tag{10}$$

to safe payment adoption.

5 Extension: Ex-ante Monitoring

In the setup described above, we assume that depositors can exert efforts to detect the crisis state early to salvage the assets associated with their risky accounts. Another channel through which depositors may reduce the credit risk is to reduce the probability of the crisis state.[13] To capture this alternative channel, we modify the setup developed above by modelling the probability of the normal state as a function of the monitoring effort in period 1, i.e., $\pi = \pi(h)$. We assume that $\pi(0) = \underline{\pi}, \pi'(h) > 0$, and $\pi''(h) < 0$. We label this technology as ex-ante monitoring and the previous one as ex-post monitoring. For simplicity, in this section, we assume that the buyer can always detect the crisis state ex post. As before, we impose a modified version of Assumption A1:

$$\underline{\pi} R(1 + \lambda\Delta) > 1. \tag{11}$$

As before, we first characterize the equilibrium banking and monitoring choices, and then the socially optimal payment account choice taking as given the decentralized monitoring and consumption choice.

5.1 Equlibrium

The decision in period 2, 3 and 4 are basically the same as in the case with ex-post monitoring. In period 2, the buyer withdraws $\max\{0, aR - I\}$ in a crisis state. Otherwise, the buyer does not withdraw early. In period 3, the buyer's valuation of an IOU that redeems m is $(1+\lambda\Delta)m$. In period 1, the banking and monitoring choices can be described as

$$\begin{aligned} V_b(r, s, h, a) \quad = \quad & \max_{r,s,h,a} \underbrace{(\omega - a)(1 + s\lambda\Delta) - sC}_{\text{safe account or no accounts}} \\ & \underbrace{+r \begin{bmatrix} a\pi(h)R(1 + \lambda\Delta) \\ +(1 - \pi(h))(1 + \lambda\Delta) \min\{aR, I\} \\ +(1 - \pi(h))\gamma \max\{aR - I, 0\}(1 + s\lambda\Delta) \\ -ah - C \end{bmatrix}}_{\text{risky account}}, \end{aligned} \tag{12}$$

which is similar to the case with ex-post monitoring, except that the probability of the crisis state depends on the monitoring effort and the crisis state is always detected ex post. The

[13]Following the interpretation in footnote 7, depositors may reduce the probability of a bad manager by screening the managers more carefully.

result that it is always optimal to set up the risky account and deposit $\max\{\omega, I/R\}$ to take advantage of DI remains the same as before, and the account choice lies in whether to set up the safe account in addition to the risky account.

If only the risky account is set up ($r = 1, s = 0$), then[14]

$$V_b(1, 0, h, a) = \max_{h,a}(\omega - a) + \begin{bmatrix} \pi(h)aR(1 + \lambda\Delta) \\ +(1 - \pi(h))(1 + \lambda\Delta)I \\ +(1 - \pi(h)\gamma(aR - I) \\ -ah - C \end{bmatrix}.$$

The first-order condition for h is given by

$$\pi'(h_0)(a - I/R)R(1 + \lambda\Delta - \gamma) = a.$$

The LHS captures the benefit of monitoring. As in the case with ex-post monitoring, only the uninsured balance $(a - I/R)$ benefits from monitoring. Monitoring increases the probability of a normal state (or reduces the probability of a crisis state). One unit of investment in the risky account gives a return of R in a normal state and the account balance can be used in transactions in period 3. In a crisis state, the return is lower at γR; in addition, the depositor must withdraw from the account to invest in illiquid bonds. The wedge in the marginal value of investment in the risky account between the normal state and the crisis state is therefore $R(1 + \lambda\Delta - \gamma)$. We can rewrite the first-order condition for h (normalizing the benefit and cost by the size of the investment in the risky account) as

$$\pi'(h_0)(R - I/a)(1 + \lambda\Delta - \gamma) = 1. \tag{13}$$

The derivative with respect to a is given by

$$\begin{aligned} & -1 + \pi(h_0)R(1 + \lambda\Delta) + (1 - \pi(h_0))\gamma R - h_0 \\ > \quad & -1 + \underline{\pi}R(1 + \lambda\Delta) > 0 \end{aligned}$$

by assumption (11). Similar to the setup with ex-post monitoring, it is optimal to set $a = \omega$, or allocate all endowment to the risky account. The results are summarized in the following lemma.

[14] Again we will focus on the problems of the buyers with endowment $\omega > I/R$. For the ones with lower endowment, it is optimal to set up only the risky account, invest all endowment in it and exert no monitoring.

Lemma 5 *With ex-ante monitoring, when the buyer sets up only a risky account, the optimal choices are $a_0 = \omega$, and h_0 that satisfies (13). The buyer's expected payoff is*

$$V_b^r = \pi(h_0)\omega R(1+\lambda\Delta) + (1-\pi(h_0))I(1+\lambda\Delta) + (1-\pi(h_0))\gamma(\omega R - I) - \omega h_0 - C. \quad (14)$$

Now, we consider the case where <u>both the safe and risky accounts are set up</u> ($s = 1$, $r = 1$). The problem is given by

$$V_b(1,1,h,a) = \max_{h,a}(1+\lambda\Delta)\begin{bmatrix} (\omega - a) \\ +\pi(h)aR \\ +(1-\pi(h))I \\ +(1-\pi(h))\gamma(aR - I) \end{bmatrix} - ah - 2C.$$

The first-order condition with respect to h is

$$\pi'(h)aR(1+\lambda\Delta) - \pi'(h)(1+\lambda\Delta)I - \pi'(h)\gamma(aR-I)(1+\lambda\Delta) = a,$$

or

$$\pi'(h_1)(R - I/a)(1+\lambda\Delta)(1-\gamma) = 1. \quad (15)$$

The derivative with respect to a is

$$\begin{aligned} & -(1+\lambda\Delta) + \pi(h_1)R(1+\lambda\Delta) + (1-\pi(h))\gamma R(1+\lambda\Delta) - h_1 \\ > \; & (\underline{\pi}R - 1)(1+\lambda\Delta) > 0. \end{aligned}$$

Hence it is optimal to set $a = \omega$. We thus have the following lemma.

Lemma 6 *When the buyer sets up both the risky and safe accounts, the optimal choices are $a_1 = \omega$, and h_1 that satisfies (15). The buyer's expected payoff is*

$$V_b^{sr} = (1+\lambda\Delta)[\pi(h_1)\omega R + (1-\pi(h_1))I + (1-\pi(h_1))\gamma(\omega R - I)] - \omega h_1 - 2C. \quad (16)$$

Comparing equations (15) and (13) suggests that with ex-ante monitoring, setting up the safe account reduces the incentive to monitor (this result is formalized in Proposition 6). In the case of ex-ante monitoring, the benefit of monitoring comes from the reduction in the probability of the crisis state. If a safe account was set up, then in the crisis state (which is always detected), the buyer can transfer the withdrawn fund from the risky account to the safe account and use it to transact in period 3. The existence of a safe account therefore alleviates the pain in a crisis state, or reduces the relative advantage of being in a normal state. As a result, the incentive to monitor to reduce the probability of the crisis state is weaker. In that sense, ex-ante monitoring and the safe account are substitutes.

Note that the effect of the safe account on monitoring efforts is reversed in the case with ex-post monitoring. The benefit of ex-post monitoring is that it increases the probability that the crisis state is detected, and early detection allows buyers to withdraw from the bank to salvage their risky accounts in time. Having a safe account increases the liquidity value of the salvaged assets and therefore the incentive to monitor. In that sense, ex-post monitoring and the safe account are complements.

Proposition 6 (Safe account and monitoring efforts) *With ex-ante monitoring, setting up the safe account reduces the incentive to monitor, i.e., $h_1 < h_0$.*

Proposition 7 (Comparative statics for monitoring efforts) *Monitoring effort, h_0 and h_1, increase with R, ω, λ and decrease with γ and I.*

We omit the proofs as the proposition follow directly from equations (13) and (15). Monitoring allows the buyer to lower the probability of the crisis state. The return from monitoring is higher if the difference between the payoffs in the normal and crisis states is larger. As a result, h increases with R, ω, λ and decreases with γ. A more generous deposit insurance program reduces the incentive to monitor (h decreases with I).

Now we characterize the choice to set up the safe account. To facilitate the analysis, we rewrite V_b^r and V_b^{sr} respectively as

$$\begin{aligned} V_b^r &= (1+\lambda\Delta)I \\ &\quad +\gamma(\omega R - I) + \pi(h_0)(1+\lambda\Delta-\gamma)(\omega R - I) \\ &\quad -\omega h_0 - C, \end{aligned}$$

and

$$\begin{aligned} V_b^{sr} &= (1+\lambda\Delta)I \\ &\quad +\gamma(\omega R - I) + \pi(h_1)(1+\lambda\Delta-\gamma)(\omega R - I) + (1-\pi(h_1))\lambda\Delta\gamma(\omega R - I) \\ &\quad -\omega h_1 - 2C. \end{aligned}$$

The intuition of the expression V_b^r is as follows. The buyer is guaranteed the insured amount and can always use it to transact, represented by the term $(1 + \lambda\Delta)I$. For the uninsured amount $(\omega R - I)$, the buyer gets at least $\gamma(\omega R - I)$, which is the value in a crisis state by withdrawing the fund and investing in illiquid bonds. In a normal state, which occurs with probability π, the buyer gets more from the balance in the risky account, both in terms of the face value and liquidity, captured by the term $(1 + \lambda\Delta - \gamma)$. The last two terms in the expression of V_b^r are the monitoring cost and the cost of setting up the risky account. The terms in V_b^{sr} can be interpreted in a similar way. Compared with V_b^r, the expression for V_b^{sr} has an additional term: the last term in the second line represents the liquidity value of the withdrawn fund in a crisis. The buyer adopts the safe account if and only if $V_b^{sr} \geq V_b^r$, or if the account fee is lower than the threshold defined as below:

$$C \leq C_b \equiv \begin{bmatrix} \underbrace{(1-\pi(h_1))\lambda\Delta(\omega R - I)\gamma}_{\text{liquidity value of salvaged amount in crisis}} \\ + \quad \underbrace{\omega(h_0 - h_1)}_{\text{save on monitoring}} \\ \underbrace{-(\pi(h_0) - \pi(h_1))(1+\lambda\Delta-\gamma)(\omega R - I)}_{\text{increased prob of crisis}} \end{bmatrix}. \tag{17}$$

The terms in C_b capture the benefit of setting up the safe account. First, note that only uninsured amounts appear in the expression. The first term is positive and represents the liquidity value of the salvaged amount in case of a crisis. As shown in Proposition 6, setting up the safe account reduces the pain in crisis, and therefore the incentive to monitor. The effect associated with the changing effort is captured by the last two terms. The second term is positive and captures the saving on the monitoring effort. The third term is negative and captures the consequence of an increased probability of crisis. The term $(1+\lambda\Delta-\gamma)$ captures the relative advantage of being in a normal state relative to the crisis state.

The following proposition summarizes the comparative statics for the choice of setting up the safe account.

Proposition 8 (Comparative statics for safe account choice) *A safe account is adopted in equilibrium when C and I are low and when γ, λ, R, ω are high.*

The proof is in Appendix 11. Intuitively, a safe account involves a fixed setup cost in period 1. The buyer tends to adopt the safe account if the adoption cost (C) is low or if the benefit is high. The benefit of the safe account is that it allows the buyer to use the salvaged value of the uninsured deposits to transact with the seller in period 3. The benefit of the safe account is therefore higher when the depositor has higher endowment (ω) and higher bargaining power (λ), if the deposit insurance (I) is less generous, and if the salvaged value of the risky account (γR) is higher. Note that the qualitative comparative statics for the safe account choice are basically the same for ex-ante and ex-post monitoring because the benefit of safe account follows the same channel.

5.2 Optimal Safe Payment Adoption

In this subsection we consider the optimal payment account choice that maxmizes the social welfare subject to decentralized choices of investment, monitoring efforts, liquidation and consumption (and fixing the deposit insurance scheme). Similar to the analysis with ex-post monitoring, it is socially optimal to set up the risky account, and the choice lies in whether to set up the safe account in addition.

When only risky payment is used, the seller's expected payoff is $V_s^r = \pi(h_0)\omega R(1-\lambda)\Delta + (1-\pi(h_0))(1-\lambda)\Delta I$, and the social welfare is

$$V^r = V_b^r + V_s^r - \tau = \pi(h_0)\omega R(1+\Delta) + (1-\pi(h_0))\Delta I + (1-\pi(h_0))\gamma(\omega R - I) - \omega h_0 - C.$$

When both risky and safe payments are used, the seller' expected payoff is $V_s^{sr} = \pi(h_1)\omega R(1-\lambda)\Delta + (1-\pi(h_1))(1-\lambda)\Delta I + (1-\pi(h_1))\gamma(\omega R - I)(1-\lambda)\Delta$, and the social welfare is

$$V^{sr} = \pi(h_1)\omega R(1+\Delta) + (1-\pi(h_1))\Delta I + (1-\pi(h_1))\gamma(\omega R - I)(1+\Delta) - \omega h_1 - 2C.$$

To characterize optimal adoption of the safe payment account, we rearrange V^r and V^{sr} as follows,

$$\begin{aligned} V^r \; = \; & (1+\Delta)I \\ & +\gamma(\omega R - I) + \pi(h_0)(\omega R - I)(1+\Delta-\gamma) \\ & -(1-\pi(h_0))I \\ & -\omega h_0 - C \end{aligned}$$

and

$$\begin{aligned} V^{sr} &= (1+\Delta)I \\ &+\gamma(R\omega - I) + \pi(h_1)(\omega R - I)(1+\Delta-\gamma) + (1-\pi(h_1))\Delta(\omega R - I)\gamma \\ &-(1-\pi(h_1))I \\ &-\omega h_1 - 2C. \end{aligned}$$

It is welfare maximizing to adopt the safe payment technology iff $V^{sr} \geq V^{r}$ or $C \leq C_p$, where

$$C_p \equiv \left[\begin{array}{l} \underbrace{(1-\pi(h_1))\Delta\gamma(\omega R - I)}_{\text{liquidity value of salvaged amount in crisis}} \\ + \underbrace{\omega(h_0 - h_1)}_{\text{save on monitoring}} \\ \underbrace{-(\pi(h_0)-\pi(h_1))[(1+\Delta-\gamma)(\omega R - I) + I]}_{\text{increased prob. of crisis}} \end{array} \right].$$

The discrepancy between the private and public adoption thresholds is

$$\begin{aligned} & C_p - C_b \\ = \; & (1-\pi(h_1))(1-\lambda)\Delta\gamma(\omega R - I) \\ & -(\pi(h_0)-\pi(h_1))(1-\lambda)\Delta(\omega R - I) \\ & -(\pi(h_0)-\pi(h_1))I. \end{aligned} \tag{18}$$

While adopting the safe account and reducing the monitoring effort accordingly, the buyer generates both positive and negative trading externalities to the seller. On one hand (as captured by the first term), the seller benefits from being able to trade in the crisis state. On the other hand (as captured by the second term), the seller suffers from the lower likelihood of trading in a normal state because of the buyer's diminishing monitoring. In addition (as captured by the third term), since the government needs to finance deposit insurance claims in a crisis state, the increased probability of a crisis imposes a social cost that is ignored by the buyer. Depending on the relative magnitude of the overlooked benefits to the costs, either under- or over-adoption may occur (see Proposition 9). Finally, note that because ex-post monitoring affects only the probability of detecting a crisis state early, but does not affect the probability of a crisis state, the two terms involving the change in π do not appear in the expression for $C_p - C_b$. As a result, buyers tend to under-adopt the safe account if their monitoring efforts affect only the timely detection of the crisis state, while they may under- or over-adopt when their monitoring efforts affect the probability of a crisis event occurring.

Proposition 9 *If $C_b < C_p$, then the private sector under-adopts safe payments for $C \in (C_b, C_p)$; in this case, a corrective subsidy $T_s = C_p - C_b$ can support optimal adoption. If $C_b > C_p$, then the private sector over-adopts safe payments for $C \in (C_p, C_b)$; in this case, a corrective tax $T = C_b - C_p$ can support optimal adoption.*

6 Conclusion

This paper studies whether a private payment system based on bank deposits can provide an optimal degree of safety for retail payments. The private sector has the option to use a safe payment instrument to replace risky bank deposits in normal times or as a back-up payment system in crisis times when the risky bank fails. However, private provision of safe payments may not be socially optimal as a result of externalities and the existence of public safety nets. This suggests that there might be a role for public intervention. The welfare-improving role of intervention comes from two special features of the government. First, its objective internalizes external effects of safe payments. Second, it has taxation power to enforce transfers to solve private agents' commitment problems. In our model, sellers would like to make transfers to buyers/depositors to correct the under/over-adoption problems, but they cannot commit to do so. There are multiple ways to conduct an intervention to correct the problems. Subsidizing narrow banks or segregated payment accounts is one option. Public provision of safe payments might also solve the problem but the government needs to be at least as efficient as private providers (i.e., same or lower C). For example, if private banks are more efficient in offering payment services to end-users relative to the public sector, or there are economies of scope in offering risky and safe payments, then perhaps correcting their incentives by offering taxes or subsidies might be more desirable.

Our model is stylized and hence does not explicitly capture a few relevant considerations. First, we consider an environment with only one bank. It is possible to extend the analysis to allow depositors to set up multiple banks especially when the risks faced by different banks can be diversified. Given this, the bank failure in our current model should be interpreted as an aggregate risk and a collapse of the whole banking system. Second, we have assumed that banks look after the end-users' interest. The results might change when there are incentive problems. Third, we have assumed that there is an abundant supply of safe illiquid assets (e.g., reserve balances, government securities, etc.) because we want to separate the issue of the shortage of liquid safe assets from the shortage of illiquid safe assets. The latter issue is less related to the supply of payment balances for retail transactions as that can be solved by providing more government securities and central bank reserves.

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A Proofs

Proof of Proposition 4. All results can be obtained by differentiating condition (9) with respect to the parameters and applying the envelop theorem. For example, the effects of ω are given by the derivative

$$\begin{aligned}&\frac{d}{d\omega}[V_b^{sr} - V_b^r] \\ = \ & (1-\pi)p(h_1)\gamma R\lambda\Delta + (1-\pi)[p(h_1) - p(h_0)]\gamma R - (h_1 - h_0).\end{aligned}$$

To see that it is positive, note that

$$\begin{aligned} V_b^{sr} + C &= \pi\omega R(1+\lambda\Delta) + (1-\pi)(1+\lambda\Delta)I + (1-\pi)p(h_1)\gamma(\omega R - I)(1+\lambda\Delta) - \omega h_1 - C \\ &\geq \pi\omega R(1+\lambda\Delta) + (1-\pi)(1+\lambda\Delta)I + (1-\pi)p(h_0)\gamma(\omega R - I)(1+\lambda\Delta) - \omega h_0 - C \\ &> \pi\omega R(1+\lambda\Delta) + (1-\pi)(1+\lambda\Delta)I + (1-\pi)p(h_0)\gamma(\omega R - I) - \omega h_0 - C \\ &= V_b^r, \end{aligned}$$

where the first inequality is due to the optimality of h_1. Hence, the difference between the first and the third lines gives us

$$(1-\pi)p(h_1)\gamma(\omega R - I)\lambda\Delta + (1-\pi)[p(h_1) - p(h_0)]\gamma(\omega R - I) - \omega(h_1 - h_0) > 0$$

implying

$$\begin{aligned}&\omega[(1-\pi)p(h_1)\gamma R\lambda\Delta + (1-\pi)[p(h_1) - p(h_0)]\gamma R - (h_1 - h_0)] \\ > \ & (1-\pi)p(h_1)\gamma I\lambda\Delta + (1-\pi)[p(h_1) - p(h_0)]\gamma I > 0.\end{aligned}$$

■

Proof of Proposition 6. All results can be obtained by differentiating condition (17) with respect to the parameters and applying the envelop theorem. For example, the effects of ω are given by the derivative

$$\begin{aligned}&\frac{d}{d\omega}[V_b^{sr} - V_b^r] \\ = \ & (\pi(h_1) - \pi(h_0))(1+\lambda\Delta - \gamma)R + (1-\pi(h_1))\lambda\Delta R\gamma - (h_1 - h_0).\end{aligned}$$

To see that it is positive, note that

$$\begin{aligned}
V_b^{sr} + C &= \pi(h_1)(1+\lambda\Delta)\omega R + (1-\pi(h_1))(1+\lambda\Delta)I + (1-\pi(h_1))(1+\lambda\Delta)(\omega R - I)\gamma - \omega h_1 - C \\
&\geq \pi(h_0)(1+\lambda\Delta)\omega R + (1-\pi(h_0))(1+\lambda\Delta)I + (1-\pi(h_0))(1+\lambda\Delta)(\omega R - I)\gamma - \omega h_0 - C \\
&> \pi(h_0)(1+\lambda\Delta)\omega R + (1-\pi(h_0))(1+\lambda\Delta)I + (1-\pi(h_0))(\omega R - I)\gamma - \omega h_0 - C \\
&= V_b^r,
\end{aligned}$$

where the first inequality is due to the optimality of h_1. Hence, taking the difference between the first and the third lines gives us

$$\begin{aligned}
&\omega\{[\pi(h_1) - \pi(h_0)](1+\lambda\Delta-\gamma)R + (1-\pi(h_1))\lambda\Delta R\gamma - (h_1 - h_0)\} \\
> \; &[\pi(h_1) - \pi(h_0)]I(1-\gamma) + [\pi(h_1) - \pi(h_0)]\lambda\Delta I(1-\gamma) + \lambda\Delta I\gamma(1-\pi(h_0)) > 0.
\end{aligned}$$

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