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Bank Recovery and Resolution Planning, Liquidity Management and Fragility*

Luca G. Deidda[†] Ettore Panetti[‡]

Abstract

We study how regulation shapes the interaction between financial fragility and bank liquidity management, and propose a rationale for the complementarity between bank recovery and resolution planning. To this end, we analyze an economy in which a resolution authority arranges a bank resolution plan to suspend deposit withdrawals and create a "good bank" at a cost in the event of a depositors' run. In such a framework, banks find it optimal to establish recovery plans in advance, specifying how how to manage liquidity during runs. However, such plans are time inconsistent, and resolution authorities need powers to force their implementation at times of financial fragility.

Keywords: banks, liquidity, financial fragility, financial regulation, resolution.
JEL codes: G01, G21, G28

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1 Introduction

Several countries in the recent past, including the U.S. during the Global Financial Crisis and in 2023, have experienced banking crises with disruptive consequences for the financial system and the real economy (Laeven and Valencia, 2020). The economic literature has identified depositors' self-fulfilling expectations as a key driver of these episodes of financial fragility. This is because the liquidity and maturity transformation at the core of banks' business model, leads to a mismatch in their balance sheets that might induce depositors to lose confidence in the banks' ability to repay, thereby triggering a bank run (Diamond and Dybvig, 1983).

In principle, resolution plans – and in particular, a commitment to a timely suspension of deposit withdrawals – should be sufficient to calm depositors' expectations and avoid bank runs. Yet, in practice resolution plans are often ineffective and implemented with delays because of regulatory costs, political pressure, or imperfect coordination between regulatory layers.[1] This is the main reason why in the last decade the Financial Stability Board (FSB) has been coordinating international efforts to define more effective resolution regimes. This activity has led to the introduction of bank recovery and resolution planning, also known as "living wills".

Recovery planning should define strategies for banks to manage future severe financial shocks and liquidity shortfalls, and avoid resolution. Resolution planning instead should set a rulebook for the orderly resolution of troubled banks while ensuring their operational continuity. The FSB recommends that the responsibility for developing and maintaining recovery plans should lie with the banks' management. Regulators instead should be responsible for the definition and administration of resolution plans, including the establishment of bridge institutions to take over banks' operations. Regulators are also deemed responsible for the review of banks' recovery plans and the assessment of their credibility, and "should have the requisite powers to require the implementation of recovery measures" (Financial Stability Board, 2024).

This narrative highlights the role that recovery and resolution planning and bank liquidity management play as preemptive safeguards against banking crises and as means of coping with them.[2] Accordingly, the aim of this paper is to study how financial regulation shapes the interaction between financial fragility and bank liquidity management, and to provide a rationale for the complementarity of bank recovery and resolution planning. Our main result shows that, in the presence of costly resolution plans, expected welfare is maximized when banks establish recovery plans in advance, predetermining how to manage liquidity during depositors' runs. However, such plans turn out to be time inconsistent, as banks have incentives to renege on them to lower depositors' incentives

[1] Examples of papers studying delays of public intervention on distressed banks include Ennis and Keister (2009), Repullo (2018), Calzolari et al. (2019), Colliard (2020) and Carletti et al. (2021).

[2] For an early analysis of the role of recovery and resolution planning, see Avgouleas et al. (2013).

to run and leave more resources available to public authorities, should resolution be implemented. This argument rationalizes the powers of resolution authorities to force the implementation of recovery planning whenever necessary, as the FSB explicitly solicited.

More in detail, we propose a theory of banking that reflects some of the aforementioned elements of banking and financial regulation in the real world. The economy features two types of uncertainty, namely aggregate productivity shocks that hit banks' investments and idiosyncratic shocks that force depositors to withdraw funds on an interim date, i.e., before the maturity of the investment. In such an environment, there are multiple equilibria with the possibility of self-fulfilling runs by depositors on the interim date. We resolve the multiplicity of equilibria by following the "global game" approach of Carlsson and van Damme (1993) and Morris and Shin (1998). We assume that the depositors observe a noisy signal about the realization of the aggregate state, based on which they create beliefs about the behavior of all the other depositors and decide whether to withdraw funds on the interim date ("run on their banks") or not.

We extend this framework with a novel analysis of banks' liquidity management and with the introduction of a resolution authority (hereafter, RA). We assume that banks choose the initial liquidity of their asset portfolios and the asset pecking order to meet depositors' withdrawals in the case of a run on the interim date. As far as pecking orders are concerned, banks can either first deploy liquidity and then liquidate productive assets, or first liquidate productive assets and then deploy liquidity. Both pecking orders entail costs. Deploying liquidity might induce banks to hold excess liquidity in their initial asset portfolios as a precaution against future possible runs, thereby curtailing potentially productive investments. In contrast, liquidating productive assets is costly in terms of resources lost at liquidation, and forgone future investment returns. We compare two alternative settings regarding the timing of the asset pecking order decision. First, we analyze an economy without recovery planning, in which banks choose the asset pecking order on the interim date, at the same time as depositors' withdrawal decisions. Second, we study the case of recovery planning, in which banks choose the asset pecking order on the initial date, together with their own initial asset portfolios and before depositors' withdrawal decisions.

As far as the introduction of the RA is concerned, we instead assume that in the initial period the RA commits to a resolution plan that maximizes depositors' expected welfare. According to the plan, the RA suspends deposit withdrawals from banks when the fraction of depositors who withdraw on the interim date is above a certain threshold.[3] When this

[3]This assumption is consistent with common resolution practices around the world. For example, the European Systemic Risk Board states that "resolution occurs at the point where the authorities determine that a bank is failing or likely to fail, that there is no other supervisory or private sector intervention that can restore the institution to viability (for example by applying measures set out in a so-called recovery plan, which all banks are required to draft) within a short time frame and that normal insolvency proceedings would cause financial instability while having an impact on the public interest" (source: https://srb.europa.eu/en/content/what-bank-resolution).

occurs, the RA pays a verification cost to establish which depositors need liquidity on the interim date among those who are not served by banks, and reallocates the available resources between them and the remaining depositors. In particular, depositors with early liquidity needs still receive what banks have promised according to the deposit contract. Accordingly, such a resolution procedure resembles the creation of a "good bank" that shields insured deposits.[4] The verification cost serves as a proxy for mechanisms that might hinder bank resolution. This is crucial because, as we already mentioned, a credible commitment to a costless suspension of deposit withdrawals rules out depositors' runs altogether (Diamond and Dybvig, 1983). Moreover, in traditional bank-run models the asset pecking order would not matter, because once a run occurs, all assets are liquidated. What makes our framework novel is instead the fact that the RA always intervenes and banks are never liquidated. Therefore, banks' asset pecking orders determine the value of the residual assets available at resolution.

We start our analysis with the characterization of the equilibrium without recovery planning. In this case, banks always prefer the asset pecking order by which they first deploy liquidity and then liquidate productive assets. The reason for this is twofold. First, under this pecking order depositors' incentives to run are lower than under the alternative option of first liquidating productive assets and then deploying liquidity. Second, the amount of resources available to the good bank at resolution is higher. Anticipating this, on the initial date banks hold excess liquidity, i.e., in excess of the amount needed to cover depositors' idiosyncratic needs if no run occurs.

In the equilibrium with recovery planning instead, our results show that there exists a plausible parameter space under which banks find it optimal to first liquidate productive assets and then deploy liquidity if facing a depositors' run. This occurs despite the fact that this pecking order brings about a higher likelihood of a run and lower resources available at resolution. In fact, banks recognize that their choice of asset pecking order affects also their own asset portfolios and RA's resolution plan. In particular, under the chosen pecking order, holding more liquidity would increase depositors' incentives to run. Therefore, banks choose to hold no excess liquidity on the initial date. This in turn counterbalances the costs of a higher likelihood of a run (in terms of expected welfare) with higher long-term returns from productive assets if a run does not occur.

Comparing the two equilibria with and without recovery planning, it comes out that the expected welfare is higher with recovery planning, i.e., when banks choose the pecking order on the initial date rather than in the interim date. Yet, this choice turns out to be time inconsistent. In fact, although it is optimal for banks from an ex-ante perspective to predetermine the pecking order and commit to first liquidate assets and then deploy liquidity, once their own asset portfolios and the RA's resolution plan are fixed, it is

[4]This is coherent with the recommendations by the Basel Committee on Banking Supervision (2010) and is a crucial part of several resolution plans around the world.

optimal for them to switch to the alternative option of deploying liquidity first and then liquidating assets. In the interim date, this other strategy is still the one that minimizes depositors' incentives to run and maximizes resources at resolution.

The normative conclusion of this argument is that, in the presence of a regulatory commitment to resolution planning, the time inconsistency rationalizes the powers of resolution authorities to force the implementation of recovery planning and oblige banks to adhere to predetermined courses of actions at times of financial fragility. The combination of recovery and resolution planning has the potential to significantly alter banks' liquidity management in anticipation of self-fulfilling uncertainty and its eventual realization, thereby guaranteeing a more valuable allocation of resources and higher welfare.

Our paper contributes to several strands of the literature. To the best of our knowledge, we are the first to study banks' asset pecking orders in the literature on financial fragility. For example, in Goldstein and Pauzner (2005) banks hold no liquidity because it is dominated by the investment in productive assets, which have zero liquidation costs. In Rochet and Vives (2004) and Vives (2014), banks do hold liquidity, but the asset pecking order during runs is exogenous. Kashyap et al. (2023) develop a model of both sides of banks' balance sheets. However, differently from our study, banks do not hold excess liquidity against self-fulfilling uncertainty and do not choose asset pecking orders. Ahnert and Elamin (2020) also study banks' portfolio choices but assume that banks can liquidate the productive asset at zero cost on the interim date and do not have any liquidity available on the initial date. Moreover, banks have access to liquidity only after depositors' decisions to withdraw funds and eventually run, and after they receive a perfectly informative signal about the aggregate state.

More generally, we contribute to the literature on the liquidity management of financial institutions prone to self-fulfilling uncertainty.[5] Chen et al. (2010) develop a theory of investors' strategic complementarities for the connection between mutual funds' liquidity and performance. Zeng (2017) studies the optimal rebuilding of cash buffers by open-end mutual funds in a dynamic framework. Liu and Mello (2011) analyze the liquidity management of hedge funds facing coordination risk. Distinctly, our focus is on maturity transformation and the resulting fragility of banks. Moreover, we characterize the optimal asset pecking order, which the cited studies instead all leave to be exogenous. The empirical evidence on asset pecking orders is inconclusive. On the one hand, Chernenko and Sunderam (2016) find that mutual funds engage in liquidity "cushioning", i.e., a partial use of cash holdings to manage unexpected outflows. On the other hand, Morris et al. (2017) find evidence of liquidity "hoarding", i.e., mutual funds managing unexpected outflows by selling the underlying assets in their portfolios while retaining liquidity. Our characterization of the endogenous pecking order speaks to such contrasting evidence.

Finally, our paper contributes to the literature on the economics of bank resolution

[5]A classic example of this line of research is the seminal paper by Cooper and Ross (1998).

regimes. Keister and Mitkov (2021) show how the RA's lack of commitment in resolving banks leads to banks' delay in bail-ins. Colliard and Gromb (2018) explore the effect of the government's involvement in the private restructuring of distressed banks. Schilling (2023) studies the optimal delay of bank resolution and its effects on financial fragility. These studies do not analyze the consequences of recovery and resolution planning for banks' choices of asset pecking orders and liquidity management as we do.

The rest of the paper is organized as follows. Section 2 states the basic features of the environment. Section 3 studies the economy without recovery planning. Section 4 describes the equilibrium with recovery planning and analyzes its time inconsistency. Finally, Section 5 concludes the paper. All proofs are in Appendix A.

2 Environment

The economy lasts for three dates, labeled $t = 0, 1, 2$, and is populated by a unitary continuum of ex-ante identical depositors, a large number of banks, and a resolution authority (RA). Each depositor is endowed with 1 unit of a consumption good on date 0, and 0 afterwards. On date 1, all depositors are hit by a privately observed idiosyncratic shock θ, of value 0 with probability λ and value 1 with probability $1-\lambda$. The law of large numbers holds. Hence, the probability distribution of the shocks is equivalent to the cross-sectional distribution of their realization: on date 1, there is a fraction λ of depositors in the whole economy who experience the realized shock $\theta = 0$, and a fraction $1 - \lambda$ of depositors who experience the realized shock $\theta = 1$. Depositors are risk-neutral, and their utility function is $U(c_1, c_2, \theta) = (1 - \theta)c_1 + \theta c_2$. Accordingly, the idiosyncratic shock θ affects the point in time when depositors want to consume. Depositors experiencing the shock $\theta = 0$ are only willing to consume on date 1, and those experiencing the shock $\theta = 1$ are only willing to consume on date 2. In line with the literature, we refer to these two categories as early and late consumers, respectively.

There are two technologies available in the economy. The first is a storage technology, which we call "liquidity". It yields 1 unit of consumption on date $t + 1$ for each unit invested on date t. The second is a productive asset that yields a stochastic return Z on date 2 and can be liquidated on date 1 with a recovery rate $r < 1$. The stochastic return takes values $R > 1$ with probability p, and 0 with probability $1-p$, and its realization is publicly revealed at the beginning of date 2. The probability of success p represents the aggregate state of the economy and is uniformly distributed over the interval $\left[\frac{r}{R}, 1\right]$, with $\mathbb{E}[p]R > 1$.[6]

Banks operate in a competitive market with free entry. They offer a standard deposit contract that allows depositors to retrieve their deposits on date 1 upon demand.[7] On

[6] This assumption allows us to rule out efficient depositors' runs. These occur when p is below the threshold $\hat{\sigma} = \frac{r}{R}$, i.e., when the recovery rate is higher than the expected return on the productive asset.

[7] As common in the banking literature and as in recent contributions by Schilling (2023) and Carletti

date 0, the banks collect the deposits – the only liability on their balance sheets – and invest them in a portfolio of L units of liquidity and $1 - L$ units of the productive asset. Then, the banks on date 1 pay early consumption to all the depositors who demand funds, until the banks' resources are depleted. If resources are not exhausted on date 2, the depositors who have not withdrawn on date 1 are residual claimants on equal shares of the remaining resources on date 2, so the amount of late consumption $c_2(Z)$ is the one that clears banks' budget.

We assume that the depositors cannot observe the true value of p. However, each of them receives a signal $\sigma = p + e$ about it on date 1. The term e is an idiosyncratic noise, uniformly distributed over the interval $[-\epsilon, +\epsilon]$, where ϵ is positive but arbitrarily close to zero. Given the received signal, late consumers decide whether to wait and withdraw funds from the bank on date 2 or "run on the bank" and redeem their deposits on date 1. In particular, we assume that late consumers follow a threshold strategy:[8] they run if the received signal is lower than a threshold σ^*. This strategy is based on the expected advantage of waiting over running, which explicitly depends on depositors' beliefs and the bank's asset portfolio.

To rebate deposits on date 1, banks choose an asset pecking order. Under the pecking order {Liquidation, Liquidity}, banks first liquidate the productive asset in portfolio and then deploy the available liquidity. Under the pecking order {Liquidity, Liquidation}, they instead first deploy liquidity and then liquidate the productive asset. In what follows, we denote the pecking orders {Liquidation, Liquidity} and {Liquidity, Liquidation} by subscripts (1) and (2), respectively. Regarding the timing of such a decision, we consider two alternative settings: one with recovery planning in which banks choose the pecking order on date 0, and one without recovery planning in which they choose the pecking order on date 1, at the same time when depositors choose whether to withdraw.

Finally, the RA maximizes depositors' expected welfare by choosing a resolution plan on date 0. A resolution plan is an intervention scheme in case a run occurs on date 1, characterized by two elements. First, the RA chooses a suspension point, i.e., the maximum fraction ϕ of depositors that can redeem deposits from their banks on date 1. Second, when suspension takes place the RA creates a "good bank". The good bank observes the types of depositors (early or late) who are not served by banks after paying a verification cost $\psi(\phi)$, which is decreasing in ϕ. Then, it rebates deposits to early unserved depositors, and on date 2 equally shares the resources left among the remaining

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et al. (2023), we abstract from any consideration about the optimality of demandable deposit contracts. This arises endogenously, for example, in the presence of agency problems between banks and depositors (Calomiris and Kahn, 1991). Furthermore, the assumption that deposits can be redeemed at par on date 1 (i.e., the deposit rate on date 1 is equal to 1) comes without loss of generality. All our results would qualitatively hold for positive deposit rates, too.

[8]This comes at no loss of generality, as in this game every equilibrium strategy is a threshold strategy (Goldstein and Pauzner, 2005)

late consumers who have not withdrawn early.[9]

In a benchmark economy with perfect information, the representative bank can observe and verify the realizations of the idiosyncratic shocks hitting the depositors but not the realization of the aggregate state. In Appendix B, we show that in the equilibrium of this economy, there is no liquidation of the productive asset and no excess liquidity, i.e., $D = 0$ and $L = \lambda$. This is because liquidating productive assets to create liquidity on date 1 is too costly as the recovery rate r is smaller than 1. Consequently, with perfect information, the bank only uses liquidity to rebate deposits on date 1. Moreover, the advantage of holding excess liquidity, in terms of consumption in the bad state of the world when the productive asset yields zero, is dominated by its cost in terms of forgone return in the good state of the world. Hence, the bank in equilibrium holds just enough liquidity to cover the total early consumption λ.

3 The economy without recovery planning

We begin by analyzing the setting in which banks choose the asset pecking order on date 1, at the same time as when depositors make their withdrawal decisions. The timing of the actions is as follows.

- On date 0, banks choose asset portfolios $\{L, 1 - L\}$, and the RA chooses the resolution plan;
- On date 1, all depositors observe their private types (early or late) and signals, and decide whether to withdraw their deposits. Banks choose the asset pecking order to meet depositors' withdrawals. The RA applies the suspension point ϕ associated with the resolution plan chosen on date 0. If suspension occurs, it pays the verification cost and creates a good bank.
- On date 2, those late consumers who have not withdrawn on date 1 withdraw equal shares of the available resources left.

Banks, depositors and the RA play a game characterized by two stages, which take place on dates 0 and 1. On each date, agents' actions are simultaneous. On date 0, information is incomplete since none of the players knows the true realization of p but only its probability distribution. In other words, when the bank and the RA decide the asset portfolio and resolution plan respectively, they have the same information set. As depositors receive their private signals on date 1, they update their beliefs about p, while

[9]In other words, the RA does not have access to a contractual technology different from the one of banks, and must comply with the deposit contract. Appendix D shows the equivalence of this resolution regime to one with partial deposit insurance. Assuming that the good bank does not make any payout until date 2 would not alter our results, provided that it still pays a resolution management cost increasing in the number of depositors to serve. The formal analysis of this last point is available upon request.

all the other players receive no further information.[10]

We solve the model by backward induction and characterize a pure-strategy symmetric subgame perfect Bayesian equilibrium. Accordingly, we first study the subgame that takes place on date 1 between depositors who decide whether to withdraw and banks that decide the pecking order, for given banks' asset portfolio and RA's resolution plan. Then, we study the simultaneous game between banks and the RA on date 0, where banks choose their asset portfolios and the RA chooses the resolution plan. In doing so, we focus our attention on the behavior of a representative bank, hereafter referred to as "the bank".

The definition of equilibrium is as follows:

Definition 1. *Given the distributions of idiosyncratic shocks, the aggregate productivity shock and the individual signals, an equilibrium comprises an asset portfolio* $\{L, 1-L\}$ *and a pecking order chosen by the bank, a set of depositors' withdrawal decisions and a resolution plan decided by the RA that are best responses in every subgame, and such that players' beliefs are updated in a bayesian fashion.*

3.1 Depositors' withdrawal strategies

The presence of noisy signals allows us to apply global-game techniques. Late consumers act based on their private signals σ on date 1, and take as given the RA's resolution plan and bank asset portfolio fixed on date 0. Based on this information, they create posterior beliefs about the probability of the realization of the aggregate productivity shock and about the number n of depositors withdrawing funds on date 1, and decide their withdrawal strategies as best responses to the contemporaneous pecking order decision by the bank.

We assume the existence of two extreme regions such that, for signal realizations within them, the withdrawal decisions of late depositors are independent of such depositors' posterior beliefs. Following Goldstein and Pauzner (2005), we assume an "upper dominance region" above a threshold $\overline{\sigma}$ where the productive asset is safe, i.e., $p = 1$, and yields the same return R on dates 1 and 2. In this way, late consumers who wait are sure to receive $(R(1-L) + RL - n)/(1-n) > 1$ on date 2. Hence, they will never run for any fraction n of depositors withdrawing early. In the "lower dominance region" instead, the signal is so low that late consumers always withdraw on date 1 irrespective of the behavior of the other depositors. This occurs below the threshold signal $\underline{\sigma}$ that makes late depositors indifferent between withdrawing or not:

$$1 = \underline{\sigma}\frac{R(1-L) + L - \lambda}{1-\lambda} + (1-\underline{\sigma})\frac{L-\lambda}{1-\lambda}. \tag{1}$$

[10] Put differently, no agent has an informational advantage with respect to the RA when it takes its decision. This assumption is also in line with common practice in the literature on government intervention against bank runs (Allen et al., 2018; Schilling, 2023).

Table 1: Depositors' payoffs.

(a) Pecking order {Liquidation, Liquidity}

Date	$n \in (\lambda, \phi)$	$n \in [\phi, 1]$
$t=1$	$(1,1)$	$(1,0)$
$t=2$	$\max\left\{0, \frac{Z\left(1-L-\frac{n-\lambda}{r}\right)+L-\lambda}{1-n}\right\}$	$\max\left\{0, \frac{Z\left(1-L-\frac{\phi-\lambda}{r}\right)+L-\lambda-(1-\phi)\lambda}{(1-\lambda)(1-\phi)}\right\}$ $\forall Z \in \{0, R\}$

(b) Pecking order {Liquidity, Liquidation}

Date	$n \in (\lambda, n_2^*)$	$n \in [n_2^*, \phi)$	$n \in [\phi, 1]$
$t=1$	$(1,1)$	$(1,1)$	$(1,0)$
$t=2$	$\frac{Z(1-L)+L-n}{1-n}$	$\max\left\{0, \frac{Z\left(1-L-\frac{n-L}{r}\right)}{1-n}\right\}$	$\max\left\{0, \frac{Z\left(1-L-\frac{\phi-L}{r}-\frac{(1-\phi)\lambda}{r}\right)}{(1-\lambda)(1-\phi)}\right\}$ $\forall Z \in \{0, R\}$

Hence:

$$\underline{\sigma}(L) = \frac{1-L}{R(1-L)} = \frac{1}{R}. \tag{2}$$

The existence of the lower and upper dominance regions ensures the existence of an equilibrium in the intermediate region $[\underline{\sigma}, \overline{\sigma}]$, where late consumers decide whether to run or not based on their beliefs about the true realization of the aggregate state and other depositors' actions.

To characterize depositors' withdrawal strategies in the intermediate region, we first study the utility advantage of waiting over running under both pecking orders for any fraction n of depositors who withdraw funds on date 1, and for given bank's asset portfolio and RA's suspension point ϕ. Table 1 reports payoffs under both pecking orders. In each subtable, the lines referring to $t = 1$ report in parentheses the payoffs of early and late consumers if served on date 1. The lines referring to $t = 2$ instead report the payoff of late consumers only, because they are the only ones served on date 2.

In Table 1a (pecking order {Liquidation, Liquidity}) if the fraction of depositors who withdraw funds on date 1 is in the interval (λ, ϕ), suspension does not take place and the bank fulfills its contractual obligation on date 1 by liquidating productive assets first. It needs to fully rebate deposits to $n - \lambda$ depositors using resources rD from liquidation. Hence, the amount of productive assets to liquidate is $D = (n-\lambda)/r$. Then, if n depositors withdraw funds on date 1, consumption of a late consumer who waits until date 2 is

$$c_L(Z, n) = \max\left\{0, \frac{Z\left(1-L-\frac{n-\lambda}{r}\right)+L-\lambda}{1-n}\right\}, \tag{3}$$

depending on the realization of the aggregate productivity shock $Z \in \{0, R\}$, as the remaining liquidity $L - \lambda$ is rolled over from date 1 to date 2.

If the fraction of depositors who withdraw funds on date 1 is in the interval $[\phi, 1]$ instead, suspension takes place, and the good bank created by the RA holds an amount $1 - L - (\phi - \lambda)/r$ of productive assets yielding a return $Z \in \{0, R\}$ and excess liquidity $L - \lambda$. The good bank uses excess liquidity to serve the $(1 - \phi)\lambda$ early consumers who are not served by the bank (late consumers instead get zero on date 1). Notice that the good bank would never liquidate productive assets at this stage because, after paying the verification cost, is fully informed about depositors' types. Hence, it follows the same strategy as in perfect information. The good bank then uses the remaining liquidity and the proceeds from the productive assets to serve the remaining $(1 - \lambda)(1 - \phi)$ late consumers on date 2.

In Table 1b (pecking order {Liquidity, Liquidation}) instead, $n_2^* = L$ is the maximum fraction of depositors that a bank can serve on date 1 using the available liquidity fixed on date 0. If the fraction of depositors who withdraw funds on date 1 is in the interval (λ, n_2^*), suspension does not take place, and the bank fulfills its contractual obligation by using liquidity while retaining the productive asset. Hence, the consumption of a late consumer who waits until date 2 is $c_L(R, n) = (Z(1-L)+L-n)/(1-n)$ depending on the realization of the aggregate productivity shock $Z \in \{0, R\}$. If the fraction of depositors who withdraw funds on date 1 is instead in the interval $[n_2^*, \phi)$, the bank is forced to fulfill its contractual obligation by also liquidating productive assets. Hence, the total resources available on date 1 to rebate deposits are $L+rD$, and the amount that the bank liquidates is equal to $D = \frac{n-L}{r}$. Moreover, as the liquidity is exhausted, the consumption of a late consumer who waits until date 2 is

$$c_L^D(Z, n) = \max\left\{0, \frac{Z\left(1 - L - \frac{n-L}{r}\right)}{1-n}\right\}, \tag{4}$$

for any $Z \in \{0, R\}$. Finally, if the fraction of depositors who withdraw funds on date 1 is in the interval $[\phi, 1]$, suspension takes place: the good bank holds an amount $1-L-(\phi-L)/r$ of productive assets, and further liquidates an amount $(1-\phi)\lambda/r$ to serve early consumers (again, late consumers get zero on date 1). The remaining resources are equally split among the remaining $(1 - \lambda)(1 - \phi)$ late consumers on date 2.

In what follows, we restrict our analysis to the case of positive payoffs for late consumption, and therefore we get rid of the max operator for simplicity of notation.[11] Given the described payoff structure, under the pecking order {Liquidation, Liquidity} the utility advantage of waiting over running when suspension does not take place, i.e., when

[11]This is without loss of generality because such payoffs are always positive in equilibrium.

$n \in (\lambda, \phi)$, reads

$$v_1(\sigma, n) = \sigma \frac{R\left(1 - L - \frac{n-\lambda}{r}\right) + L - \lambda}{1-n} + (1-\sigma)\frac{L-\lambda}{1-n} - 1. \quad (5)$$

Under the pecking order {Liquidity, Liquidation} instead, the advantage of waiting over running is

$$v_2(\sigma, n) = \begin{cases} \sigma \frac{R(1-L)+L-n}{1-n} + (1-\sigma)\frac{L-n}{1-n} - 1 & \text{if } \lambda < n < n_2^*, \\ \sigma \frac{R(1-L-D)}{1-n} - 1 = \sigma \frac{R\left(1-L-\frac{n-L}{r}\right)}{1-n} - 1 & \text{if } n_2^* \leq n < \phi. \end{cases} \quad (6)$$

Figure 1 plots the two functions and highlights the role of suspension in this framework. We guess that the verification costs are so high that both $v_1(\sigma, \phi)$ and $v_2(\sigma, \phi)$ are negative, meaning that the announcement of a resolution plan on date 0 does not prevent a run. In fact, if $v_1(\sigma, \phi)$ and $v_2(\sigma, \phi)$ were positive, the value of waiting would exceed the value of running for any $n < \phi$. Thus, no late consumer would run. At the same time, we guess that the verification costs are sufficiently low such that under the pecking order {Liquidation, Liquidity}, when suspension occurs the bank has not liquidated all productive assets, i.e., $\phi \leq L + r(1-L)$.[12]

The strategic complementarities affecting a late consumer's decision to run depend on how the advantage of waiting over running varies with the fraction of depositors n withdrawing funds on date 1.

Lemma 1. *The function $v_1(\sigma, n)$ is decreasing in $n \in (\lambda, \phi)$. The function $v_2(\sigma, n)$ is increasing in $n \in (\lambda, n_2^*)$ and decreasing in $[n_2^*, \phi)$.*

Figure 1 shows that under the pecking order {Liquidation, Liquidity} the economy exhibits strategic complementarities, i.e., the advantage of waiting over running is decreasing in the fraction of depositors running.

In contrast, under the pecking order {Liquidity, Liquidation} the advantage of waiting over running is increasing in the fraction of depositors running as long as the bank holds sufficient liquidity to serve them, i.e., in the interval (λ, n_2^*). This occurs because the positive effect on the incentives to wait given by the lower number of depositors who wait dominates the negative effect given by the lower amount of liquidity rolled over from date 1. Yet, strategic complementarities emerge for n in the interval $[n_2^*, \phi)$. This is because as n increases the bank is forced to liquidate an increasing amount of productive assets, therefore lowering the date-2 payoff and increasing late consumers' incentives to run.

[12] Section 4.1 provides a numerical characterization of the equilibrium that verifies these guesses in a reasonable parameter space. As a further check on the plausibility of the guesses, we also numerically characterize a different equilibrium, in which we guess that under the pecking order {Liquidation, Liquidity} the suspension arrives after the bank has liquidated all productive assets. In such a framework, we are able to show that in the same parameter space as before the guess is not verified.

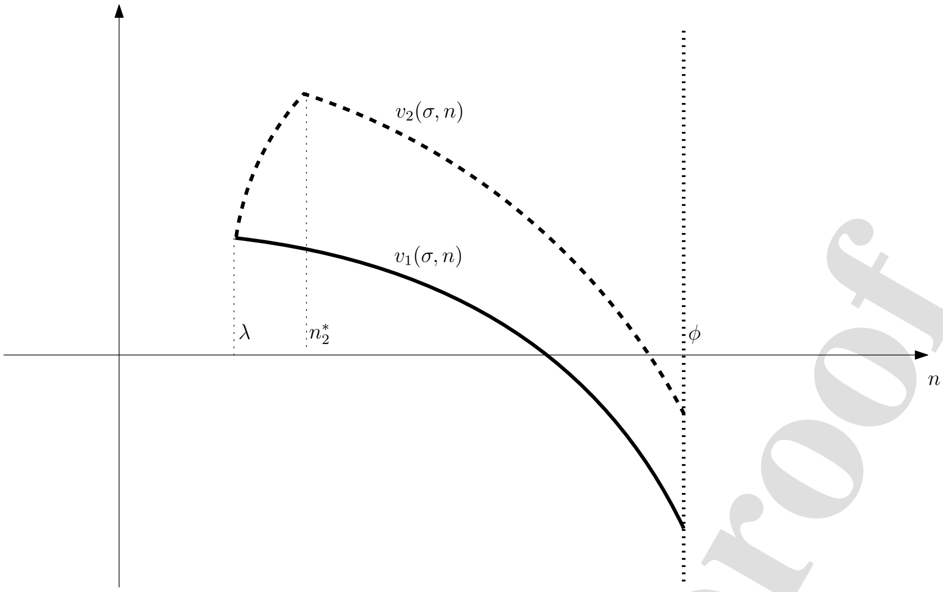

Figure 1: The advantage of waiting over running, as a function of the fraction of depositors running n, under the pecking orders {Liquidation, Liquidity} (solid line) and {Liquidity, Liquidation} (dashed line). The dotted line indicates the suspension point ϕ.

In any case, both functions $v_1(\sigma, n)$ and $v_2(\sigma, n)$ cross zero only once, and are increasing in σ. Altogether, these properties guarantee the existence and uniqueness of an equilibrium in which late consumers follow the strategy "withdraw if $\sigma \leq \sigma_j^*$" as best response to the bank's pecking order strategy under pecking order $j \in \{1, 2\}$ (Goldstein and Pauzner, 2005). The threshold σ_j^* is the value of σ that makes depositors indifferent in expectations between waiting and running, i.e., the one that solves $\mathbb{E}[v_j(\sigma, n)|\sigma_j^*] = 0$. We formalize the depositors' withdrawal strategies in the following proposition.

Proposition 1. *The late consumers' best-response withdrawal strategy is "withdraw if $\sigma \leq \sigma_j^*$ under pecking order $j \in \{1, 2\}$", where:*

$$\sigma_1^*(L, \phi) = \frac{\phi - \lambda - \displaystyle\int_\lambda^\phi \frac{L-\lambda}{1-n} dn}{\displaystyle\int_\lambda^\phi \frac{R\left(1-L-\frac{n-\lambda}{r}\right)}{1-n} dn}. \tag{7}$$

$$\sigma_2^*(L, \phi) = \frac{\phi - \lambda - \displaystyle\int_\lambda^{n_2^*} \frac{L-n}{1-n} dn}{\displaystyle\int_\lambda^\phi \frac{R(1-L)}{1-n} dn - \int_{n_2^*}^\phi \frac{R}{r} \frac{n-L}{1-n} dn}, \tag{8}$$

for given L and ϕ.

The two run thresholds are proxies for financial fragility, as the probability of a run under pecking order $j \in \{1, 2\}$ is prob$\{\sigma \leq \sigma_j^*\} = \frac{\sigma_j^* - r/R}{1-r/R}$ by the uniform distribution of the signals.[13] A comparative statics exercise clarifies the different channels through which bank liquidity L and the suspension point ϕ affect these thresholds.

Lemma 2. *Under {Liquidation, Liquidity}, the probability of a run is increasing in the suspension point ϕ_1 and in liquidity L_1.*

Intuitively, the higher the suspension point is, the smaller the resources available for late consumption if suspension takes place, and therefore the higher the depositors' incentives to run. The intuition is similar as far as liquidity is concerned: the higher liquidity is, the smaller the investment in productive assets, and therefore the higher the depositors' incentives to run.

Under the pecking order {Liquidity Liquidation} instead, we have:

$$\frac{\partial \sigma_2^*}{\partial L} = \frac{1}{DEN_{\sigma_2^*}}\left[-\int_{\lambda}^{n_2^*}\frac{1}{1-n}dn - \sigma_2^* R\left(-\int_{\lambda}^{\phi}\frac{1}{1-n}dn + \frac{1}{r}\int_{n_2^*}^{\phi}\frac{1}{1-n}dn\right)\right], \tag{9}$$

$$\frac{\partial \sigma_2^*}{\partial \phi} = \frac{1}{DEN_{\sigma_2^*}}\left[1 - \sigma_2^*\frac{R\left(1-L-\frac{\phi-L}{r}\right)}{1-\phi}\right], \tag{10}$$

where $DEN_{\sigma_2^*}$ is the denominator of σ_2^*. As far as the effect of liquidity is concerned, two forces are at play. On the one hand, higher liquidity implies higher excess liquidity (the first term of (9)) and reduces the need to liquidate productive assets (the third term of (9)), and these increase depositors' incentives to wait. On the other hand, higher liquidity reduces the investment in the productive asset (the second term of (9)), and therefore the depositors' incentives to wait. Therefore, the total effect is ambiguous.

As far as the suspension point is concerned, observe that the higher it is, the fewer resources are available for late consumption, and therefore the lower the depositors' incentives to wait. This implies that the RA wants to suspend withdrawals as soon as possible: in principle, it could announce a suspension before the advantage of waiting over running $v_2(\sigma, n)$ becomes negative, and rule out runs altogether. However, by suspending withdrawals the RA incurs the verification costs to create a good bank, and this might postpone the intervention. Again, the total effect is ambiguous.

3.2 Asset pecking order

We now study the bank's decision of the pecking order as best response to the depositors' withdrawal strategies characterized above, i.e., for any n. There are three cases to consider. The first is the one in which no depositor runs, i.e., $n = \lambda$. In this case, the bank never liquidates the productive asset, equivalently to what happens under perfect information as shown in Appendix B. Clearly, under this outcome, the choice of the pecking order turns out to be irrelevant.

[13]Notice that $\sigma = p + e$ with $p \sim U[r/R, 1]$ and $e \sim U[-\epsilon, +\epsilon]$ with $\epsilon \approx 0^+$ implies that $\sigma \sim U[r/R, 1]$.

The second outcome is when a run occurs, and the RA intervenes, so that ϕ depositors are served by the bank and $1-\phi$ by the good bank. In this case, the pecking order chosen by the bank is not irrelevant as it affects the type and amount of the residual resources available to the good bank at resolution. Finally, the pecking order influences the depositors' withdrawal strategies off-equilibrium (i.e., for any $n \in (\lambda, \phi)$). These affect the on-equilibrium withdrawal strategies through the characterization of the run thresholds of Proposition 1.

The following proposition characterizes the best response pecking order without recovery planning.

Proposition 2. *If $n \in (\lambda, \phi)$, the pecking order {Liquidity, Liquidation} is preferred to {Liquidation, Liquidity}. In the economy without recovery planning, the bank's best response asset pecking order is {Liquidity, Liquidation}.*

The intuition for these results is as follows. The bank acknowledges that its choice of the pecking order affects (i) depositors' incentives to run and (ii) the amount of resources available to the good bank at resolution.

As far as the first channel is concerned, there are two ways in which the bank can pay one unit of early consumption on date 1: deploy one unit of liquidity, or liquidate $1/r$ units of the productive asset. The second option entails a loss of expected return on date 2 and a loss from costly liquidation, hence it is more expensive than the first option. For any $n \in (\lambda, \phi)$, under {Liquidity, Liquidation} the bank has to liquidate a lower amount of productive assets to serve early withdrawers than under {Liquidation, Liquidity}. Therefore, late consumers' payoffs are higher under {Liquidity, Liquidation} than under {Liquidation, Liquidity}.

As far as the second channel is concerned, a pecking order is preferred to the other if it leaves more resources to the good bank, for it to give them to those late depositors who did not run. This happens since the good bank must serve early depositors at par irrespective of the pecking order, and is not subject to runs anymore. Under {Liquidity, Liquidation} the good bank holds extra productive assets compared to {Liquidation, Liquidity}. In contrast, under {Liquidation, Liquidity} the good bank holds extra liquidity compared to {Liquidity, Liquidation}. Since the expected return from the productive asset $\frac{pR}{r}$ is larger than 1 (i.e., the return from liquidity) the extra productive assets are more valuable than the extra liquidity, so the pecking order {Liquidity, Liquidation} is preferred to {Liquidation, Liquidity}.

3.3 Equilibrium without recovery planning

With the results of Propositions 1 and 2 in hand, we can characterize the equilibrium of the date-1 subgame between the bank and the depositors. Specifically, Proposition 2 states that the pecking order {Liquidity, Liquidation} is the bank's dominant strategy for any possible depositors' withdrawal strategy. This means that in equilibrium {Liquidity, Liquidation} is the chosen pecking order, and the depositors' equilibrium withdrawal strategy is characterized by the threshold $\sigma_2^*(L,\phi)$ as given by (8).

By backward induction, we now solve the date-0 subgame between the bank choosing the asset portfolio and the RA choosing the resolution plan. Both the bank and the RA maximize depositors' expected welfare:

$$W_2(L,\phi) = \int_{r/R}^{\sigma_2^*(L,\phi)} \left[\phi + (1-\phi)\left[\lambda + (1-\lambda)p\frac{R\left(1-L-\frac{\phi-L}{r}-\frac{(1-\phi)\lambda}{r}\right)}{(1-\lambda)(1-\phi)}\right] - \psi(\phi)\right] dp + \\ + \int_{\sigma_2^*(L,\phi)}^{1} \left[\lambda + (1-\lambda)\left[p\frac{R(1-L)+L-\lambda}{1-\lambda} + (1-p)\frac{L-\lambda}{1-\lambda}\right]\right] dp \tag{11}$$

subject to $\lambda \leq L \leq 1$. If $p \in \left[\frac{r}{R}, \sigma_2^*\right]$, a run occurs and suspension takes place:[14] ϕ depositors retrieve their deposits from the bank; among the $(1-\phi)$ depositors served by the good bank, λ are early consumers and also fully retrieve their deposits, while the remaining $1-\lambda$ are late consumers and receive an equal share of the available resources on date 2. If instead the signal is above the threshold $\sigma_2^*(L,\phi)$, a run does not occur. The fraction λ of depositors who are early consumers retrieves deposits on date 1, while the fraction $1-\lambda$ of depositors are late consumers who consume either $(R(1-L)+L-\lambda)/(1-\lambda)$ or $(L-\lambda)/(1-\lambda)$, depending on whether the productive asset yields a positive or a zero return, respectively.

To characterize liquidity and the suspension point, define the difference between the utility in the no-run case and the utility in the case of a run as

$$\Delta U_2 = L + \sigma_2^* R(1-L) - \phi - (1-\phi)\lambda - \sigma_2^* R\left(1 - L - \frac{\phi-L}{r} - \frac{(1-\phi)\lambda}{r}\right) + \psi(\phi). \tag{12}$$

Then, the first-order condition of the above optimization problem with respect to ϕ yields

$$-\left[\sigma_2^*(L,\phi) - \frac{r}{R}\right]\psi'(\phi) = (1-\lambda)\left[\frac{\sigma_2^{*2}(L,\phi) - \left(\frac{r}{R}\right)^2}{2}\frac{R}{r} - \sigma_2^*(L,\phi) + \frac{r}{R}\right] + \frac{\partial \sigma_2^*}{\partial \phi}\Delta U_2. \tag{13}$$

This expression states that the RA chooses the equilibrium suspension point ϕ so as to equalize its expected marginal costs, in terms of the verification costs that it needs to pay to set up a good bank (the left-hand side of (13)), and its expected marginal benefits, in terms of the lower amount of productive assets to liquidate and the effect on the probability of a run.

[14] This holds since we focus on the case of vanishing signal noises.

The first-order condition with respect to L yields

$$\frac{\sigma_2^{*2}(L,\phi)-\left(\frac{r}{R}\right)^2}{2}R\left(\frac{1}{r}-1\right)+\int_{\sigma_2^*}^{1}\left[-pR+1\right]dp-\frac{\partial\sigma_2^*}{\partial L}\Delta U_2+\xi-\chi=0, \tag{14}$$

where ξ and χ are the respective Lagrange multipliers on the constraints $\lambda \leq L \leq 1$. Compared to the equilibrium with perfect information, in this case, the bank takes into account two more effects of holding liquidity. First, higher liquidity allows the bank to postpone asset liquidation, thus leaving more resources to the good bank in case of resolution (the first term of (14)). Second, higher liquidity affects depositors' incentives to run, as represented by the marginal effect of L on $\sigma_2^*(L,\phi)$ (the third term of (14)). While the former effect is unquestionably positive, the latter has an ambiguous sign, as shown in (9). In other words, it is not clear whether the bank always holds excess liquidity in equilibrium. The following proposition provides a sufficient condition for this to happen.

Proposition 3. *In the equilibrium without recovery planning, the bank holds excess liquidity, i.e., $L > \lambda$, if the following sufficient condition is satisfied:*

$$1-(1-r)r^2-rR^2>0. \tag{15}$$

The intuition for this result is straightforward. If $L=\lambda$, under the pecking order {Liquidity, Liquidation} financial fragility is decreasing in liquidity as the first channel analyzed in (9) dominates the second. Then, for given recovery rate, if the return on the productive asset is sufficiently small, the marginal benefit of holding liquidity, in terms of postponing asset liquidation if resolution takes place, is larger than its marginal costs, in terms of lower investment in the productive asset. These unexploited marginal benefits imply that in equilibrium it must be the case that the bank does hold excess liquidity.

4 The economy with recovery planning

In this section, we proceed to the analysis of the setting in which the bank chooses a recovery plan. We model the recovery plan as a setting in which, differently from the previous section, the bank chooses the pecking order on date 0, at the same time as its own asset portfolio and RA's resolution plan. The timing of actions is otherwise the same as that of the economy without recovery plan.

As before, we solve the model by backward induction. Hence, we start from the characterization of depositors' withdrawal strategies σ_j^* for each pecking order $j \in \{1,2\}$ separately, given the bank's asset portfolio and pecking order, and RA's suspension point. To this end, we label suspension point and liquidity with a subscript that keeps track of the pecking order under which they are chosen. Except for this, the analysis yields the same results as in Proposition 1, and (7) and (8) are the run thresholds under the two pecking orders.

By backward induction, we now study the equilibrium bank's asset portfolio and RA's resolution plan. The analysis under the pecking order {Liquidity, Liquidation} is the same as in the previous section. Under {Liquidation, Liquidity} instead, the bank and the RA maximize depositors' expected welfare:

$$W_1(L_1,\phi_1) = \int_{r/R}^{\sigma_1^*(L_1,\phi_1)} \Bigg[\phi_1 + (1-\phi_1)\Bigg[\lambda + (1-\lambda)\Bigg[p\frac{R\left(1-L_1-\frac{\phi_1-\lambda}{r}\right)}{(1-\phi_1)(1-\lambda)} + \\ + \frac{L_1-\lambda-(1-\phi_1)\lambda}{(1-\phi_1)(1-\lambda)}\Bigg]\Bigg] - \psi(\phi_1)\Bigg]\,dp + \\ + \int_{\sigma_1^*(L_1,\phi_1)}^{1} \Bigg[\lambda + (1-\lambda)\Bigg[p\frac{R(1-L_1)+L_1-\lambda}{1-\lambda} + (1-p)\frac{L_1-\lambda}{1-\lambda}\Bigg]\Bigg]\,dp, \quad (16)$$

subject to $\lambda \leq L_1 \leq 1$. If $p \in \left[\frac{r}{R}, \sigma_1^*\right]$, a run occurs and suspension takes place: ϕ_1 depositors retrieve their deposits from the bank; among the $(1-\phi_1)$ depositors served by the good bank, λ are early consumers and also retrieve their deposits, while the remaining $1-\lambda$ are late consumers and receive an equal share of the remaining resources. Notice that, as explained above, the good bank at suspension does not liquidate assets to pay early consumers, as it is fully informed about depositors' types. Therefore, late consumers share the proceeds from the unliquidated productive assets $1-L_1-(\phi_1-\lambda)/r$ plus whatever excess liquidity is left after serving early consumers, i.e., $L_1-\lambda-(1-\phi_1)\lambda$.

To characterize liquidity and suspension point under {Liquidation, Liquidity}, we first define the difference between the utility in the case of no-run and the utility in the case of run as:

$$\Delta U_1 = \sigma_1^* R(1-L_1) - \phi_1 - \sigma_1^* R\left(1-L_1-\frac{\phi_1-\lambda}{r}\right) + \lambda + \psi(\phi_1). \quad (17)$$

Then, the first-order conditions with respect to ϕ_1 and L_1 yield the equilibrium conditions for the optimal suspension point and bank's liquidity as:

$$-\left[\sigma_1^*(L_1,\phi_1) - \frac{r}{R}\right]\psi'(\phi_1) = \left[\frac{\sigma_1^{*2}(L_1,\phi_1) - \left(\frac{r}{R}\right)^2}{2}\frac{R}{r} - \sigma_1^*(L_1,\phi_1) + \frac{r}{R}\right] + \frac{\partial\sigma_1^*}{\partial\phi_1}\Delta U_1, \quad (18)$$

$$\int_{\frac{r}{R}}^{\sigma_1^*}\big[-pR+1\big]dp + \int_{\sigma_1^*}^{1}\big[-pR+1\big]dp - \frac{\partial\sigma_1^*}{\partial L_1}\Delta U_1 + \xi - \chi = 0, \quad (19)$$

where ξ and χ are the Lagrange multipliers on the constraints $\lambda \leq L_1 \leq 1$. Under {Liquidation, Liquidity}, the RA chooses the suspension point so as to equalize its expected marginal costs and marginal benefits. The bank chooses liquidity taking into account that it would like to hold no excess liquidity if no run occurs. Moreover, higher liquidity increases depositors' incentives to run (the third term of (19) is positive as proved in Lemma 2) and the resources available to the good bank if suspension takes place. Notice that the good bank has no incentives to hold liquidity and lower the holding of productive assets until maturity, i.e., the third term of (19) is negative. Hence, the following holds:

Proposition 4. *Under {Liquidation, Liquidity}, the bank holds no excess liquidity, i.e.* $L_1 = \lambda$.

Put differently, the bank might want to tilt its liquidity holding away from the minimum amount that it would need to serve early consumers, in order to try to affect the run probability. However, under {Liquidation, Liquidity} the run probability is increasing in liquidity. Hence, the bank finds it optimal to hold no excess liquidity.

This result, together with the equilibrium condition for the optimal suspension point in (18), allows us to further derive a comparative statics result:

Corollary 1. *Under {Liquidation, Liquidity}, the equilibrium suspension point* ϕ_1 *is independent of the return on the productive asset* R.

The intuition for this result is the following. As the bank does not hold excess liquidity, the only way in which the return on the productive asset can affect the equilibrium suspension point is by directly influencing RA's incentives. This happens in two ways. On the one hand, R affects the expected marginal cost of suspension (the left-hand side of (18)) through its effect on the probability of a run. On the other hand, R also affects the marginal benefit of suspension (the right-hand side of (18)) through the marginal effect of suspension on the run probability, and the amount of productive assets that need to be liquidated by the good bank in case of a run. The corollary shows that these two channels perfectly offset each other.

4.1 Optimal pecking order with recovery planning

Having characterized depositors' withdrawal strategies, RA's choice of suspension point, and the bank's asset portfolio under the two pecking orders separately, we are left with the choice of the optimal pecking order with recovery planning. On date 0, the bank chooses the pecking order that maximizes depositors' expected welfare. As a consequence, the equilibrium welfare with recovery planning reads:

$$W = \max \{W_1(L_1, \phi_1), W_2(L_2, \phi_2)\}, \tag{20}$$

where $W_2(L_2, \phi_2)$ is the expected welfare under pecking order {Liquidity, Liquidation} that comes from the solution of the problem in Section 3 and includes verification costs.

As a closed-form solution to this maximization problem is not available, we propose a numerical solution. Assume quadratic verification costs of the form $\psi(\phi_j) = (1 - \phi_j)^2/2$ for both pecking orders $j \in \{1, 2\}$. We fix the probability of being an early consumer λ to 0.02, as in Mattana and Panetti (2021). We solve the model for a return on the productive

Table 2: Equilibrium with recovery planning.

Pecking order	pr(run)	ϕ	L	W_s	W_ℓ	W_a	W
{Liquidation, Liquidity}	0.2351	0.4670	0.0200	-0.0184	0.0093	0.7135	0.7043
{Liquidity, Liquidation}	0.1831	0.7413	0.5518	0.0704	0.2740	0.3413	0.6857

asset $R = 2.04$ and a recovery rate $r = 0.80$, as found by Acharya et al. (2007). Table 2 reports the probability of a run, suspension point, and liquidity under the two pecking orders. Moreover, the table shows depositors' expected welfare W under the two pecking orders, and its decomposition in three parts: the expected welfare W_s if a run occurs and suspension takes place; the expected welfare W_ℓ from liquidity when a run does not occur; the expected welfare W_a from the productive assets when a run does not occur.

The numerical results confirm Proposition 4: under {Liquidation, Liquidity} the bank holds no excess liquidity, i.e., $L_1 = \lambda = 0.02$. They also show that under {Liquidity, Liquidation} the bank does hold excess liquidity.[15] This occurs because the negative effect of higher liquidity on the likelihood of a run (the first and third terms of (9)) dominates the positive effect (the second term of (9)). Equilibrium excess liquidity in turn keeps fragility in check, and allows the RA to choose a higher suspension point under {Liquidity, Liquidation} than under {Liquidation, Liquidity}.

Despite the economy under {Liquidation, Liquidity} being more fragile, the last column of Table 2 shows that the expected welfare is higher than under {Liquidity, Liquidation}. In other words, the optimal pecking order under recovery planning is {Liquidation, Liquidity}. To understand why this happens, we analyze the welfare decomposition in columns 4-6. First, under the pecking order {Liquidation, Liquidity}, the suspension point is so low that verification costs are high, and this yields negative expected welfare if a run occurs and suspension takes place (column 4). Second, if a run does not occur, under {Liquidity, Liquidation} the bank brings about higher expected welfare from liquidity holdings than under {Liquidation, Liquidity}, because in this latter case, it holds zero excess liquidity (column 5). Third, the bank under {Liquidation, Liquidity} holds a substantially higher amount of productive assets than under {Liquidity, Liquidation}. Therefore, the expected welfare that the bank brings about from them is higher in the former case than in the latter (column 6).

To sum up, when choosing the asset pecking order in the initial period via recovery planning, the bank takes into account how this decision might affect (i) the expected returns from productive investments when a run does not occur, and (ii) the RA's resolution plan. Choosing the pecking order {Liquidation, Liquidity} in the initial date allows the bank to have the same asset portfolio as under perfect information, thereby

[15] Notice that this result holds despite the fact that (15) is not satisfied. This reflects the fact that the condition for excess liquidity in Proposition 3 is sufficient but not necessary.

obtaining a more effective liquidity management if a run does not occur. This motivation is sufficiently strong for the bank to prefer {Liquidation, Liquidity} over {Liquidity, Liquidation} despite the higher probability of a run.

4.2 Comparative statics

In order to assess the generality of the previous results, we study their robustness to alternative parameter configurations in a comparative statics exercise. In particular, we let the return on the productive assets R vary in the interval $[2.02, 2.06]$ and the recovery rate r in the interval $[0.78, 0.82]$, to stay within the range of reasonable values.[16]

The first row of Figure 2 shows that the probability of a run is decreasing in r and R under both pecking orders, because they increase the value of productive investment and therefore depositors' incentives to wait. The suspension point ϕ_1 is independent of the return on the productive asset R for given r, as proved in Corollary 1. Moreover, ϕ_1 is increasing in the recovery rate r for given R, because a higher r induces a lower probability of a run, that in turn decreases the RA's incentives to intervene. In contrast, the suspension point ϕ_2 is decreasing in R for given r. This is not due to a direct effect of R on the suspension point ϕ_2, as a result similar to Corollary 1 holds under {Liquidity, Liquidation} too (see equation (13)). However, a higher return on the productive asset has the effect of lowering the bank's liquidity holdings, and this in turn increases the RA's incentives to intervene, which is reflected in a lower suspension point. In a similar way, ϕ_2 is decreasing in the recovery rate r for given R, because a higher r lowers bank liquidity under {Liquidity, Liquidation} (see the third row of Figure 2) thereby increasing the RA's incentives to intervene. This effect is missing under {Liquidation, Liquidity} because by Proposition 4 the bank never holds excess liquidity when it chooses that pecking order.

The last row of Figure 2 shows that depositors' expected welfare under {Liquidation, Liquidity} is increasing in the return on the productive asset and recovery rate, as higher values represent more productive investment technologies. Under {Liquidity, Liquidation}, for given r a higher return on the productive asset R also increases depositors' expected welfare. The effect of recovery rate r is instead non-monotonic. On the one hand, increasing r lowers the probability of a run and bank liquidity, thereby lowering also expected welfare at resolution and from liquidity when a run does not occur. On the other hand, a higher r increases expected welfare from productive assets if a run does not occur. For low values of r the first two effects dominate, while for high values of r the last effect dominates instead. Moreover, the result of the main numerical analysis is confirmed: The pecking order {Liquidation, Liquidity} is always preferred to {Liquidity, Liquidation} for any combination of return on the productive asset and recovery rate.

[16] We also run comparative statics exercises on r and R separately, while keeping the ratio r/R constant. The results are qualitatively unaffected and are available upon request.

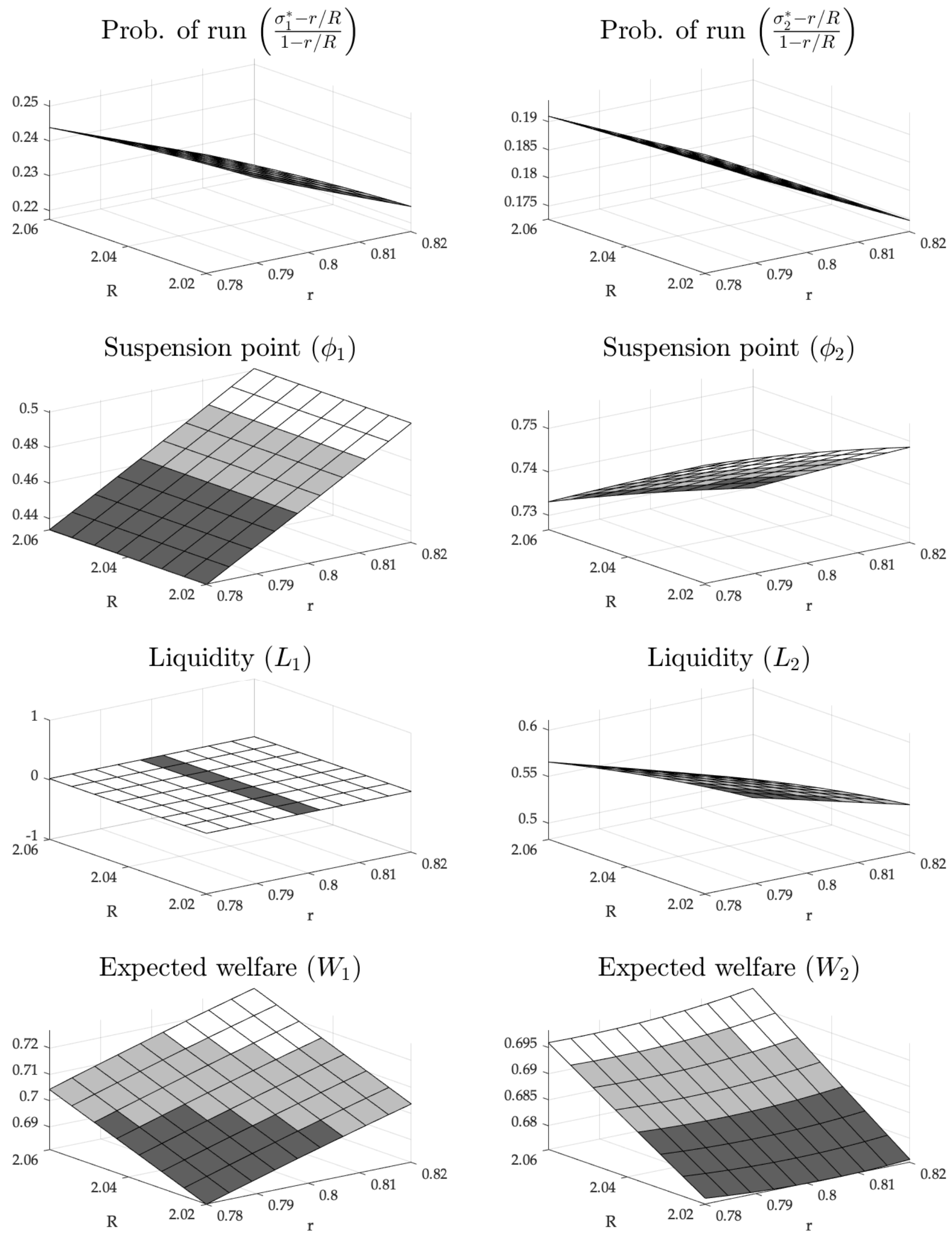

Figure 2: Comparative statics of the banking equilibrium with recovery planning. The left column reports results under {Liquidation, Liquidity}. The right column reports results under {Liquidity, Liquidation}.

Table 3: Equilibrium without resolution plan. The left column reports results under {Liquidation, Liquidity}. The right column reports results under {Liquidity, Liquidation}.

(a) Prob. of run $\left(\frac{\sigma_1^*-r/R}{1-r/R}\right)$

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.7425	0.6869	0.6304
$R=2.04$	0.7307	0.6759	0.6201
$R=2.06$	0.7193	0.6651	0.6101

(b) Prob. of run $\left(\frac{\sigma_2^*-r/R}{1-r/R}\right)$

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.5255	0.5204	0.5140
$R=2.04$	0.5238	0.5185	0.5120
$R=2.06$	0.5221	0.5167	0.5100

(c) Liquidity (L_1)

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.0200	0.0200	0.0200
$R=2.04$	0.0200	0.0200	0.0200
$R=2.06$	0.0200	0.0200	0.0200

(d) Liquidity (L_2)

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.3277	0.2683	0.2033
$R=2.04$	0.3149	0.2558	0.1911
$R=2.06$	0.3025	0.2437	0.1793

(e) Expected welfare (W_1)

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.6489	0.6763	0.6997
$R=2.04$	0.6622	0.6893	0.7126
$R=2.06$	0.6755	0.7023	0.7254

(f) Expected welfare (W_2)

	$r=0.78$	$r=0.80$	$r=0.82$
$R=2.02$	0.7083	0.7121	0.7178
$R=2.04$	0.7180	0.7224	0.7287
$R=2.06$	0.7278	0.7328	0.7396

4.3 Time inconsistency

The comparison between the previous two sections highlights a series of results. When the bank chooses the pecking order without recovery planning, it finds it optimal to first deploy liquidity and then liquidate productive assets. When instead the bank chooses a recovery plan on date 0, it recognizes that this decision impacts not only depositors' incentives to run and resources available at resolution, but also its own asset portfolio and RA's resolution plan.

Notice that the equilibrium without recovery planning is equivalent to the one under the pecking order {Liquidity, Liquidation} that we numerically evaluate in Section 4.1. Then, our analysis shows the existence of a plausible parameter space in which the expected welfare is higher when the bank chooses a recovery plan rather than not.

Accordingly, we would expect the bank to choose the asset pecking order on date 0, and stick to this plan on date 1. However, this is not what happens: the bank commitment to recovery planning is time inconsistent. To see that, start from a situation in which the bank commits to the pecking order {Liquidation, Liquidity} on date 0. On date 1, the bank could confirm its commitment, or in principle renege on it and choose {Liquidity, Liquidation} instead. This decision takes into account several considerations. First of all, depositors' welfare if a run does not occur only depends on the date-0 asset portfolio, so changing the pecking order on date 1 would have no effect on it. In a similar way, if a run occurs, ϕ depositors are served by the bank and $1 - \phi$ by the good bank, irrespective of the pecking order. Therefore, changing the pecking order would be inconsequential in that respect, too. As Proposition 2 shows, for given initial liquidity and resolution plan, choosing the pecking order on date 1 only affects depositors' run threshold and expected welfare at resolution, and {Liquidity, Liquidation} is preferred to {Liquidation, Liquidity} for any possible value of L and ϕ. In other words, once the bank has fixed a low initial investment in liquidity and induced the RA to commit to a tough intervention, it is optimal for the bank to renege on its commitment to a recovery plan and choose the one that minimizes depositors' incentives to run and maximizes welfare at resolution.

To get a better understanding of which of the two channels (lower run threshold or higher welfare at resolution) is at the root of the time inconsistency, in Appendix C we solve the model without resolution plan. In this case, if a run occurs the bank becomes insolvent, and must liquidate all assets and equally share the proceeds among all depositors, irrespective of the chosen pecking order. This means that the only channel through which the pecking order affects the equilibrium is by influencing depositors' off-equilibrium actions, which in turn influence the run threshold.

In such a framework, {Liquidity, Liquidation} is still the pecking order of choice when the decision is taken on date 1 without recovery planning, as a similar result to Proposition 2 holds. Table 3 reports instead the numerical characterization of the equilibrium when the bank chooses the pecking order on date 0. A comparison of the welfare measures in Tables 3e and 3f shows that no time inconsistency arises, i.e., {Liquidity, Liquidation} is preferred to {Liquidation, Liquidity} on date 0 as well as on date 1. The main reason for this is that the former pecking order is associated with lower financial fragility (see Tables 3a and 3b). This also implies that the bank keeps holding excess liquidity in equilibrium, as the comparison between Tables 3c and 3d makes clear. To sum up, the analysis conveys the message that what drives the time inconsistency of recovery planning is the bank's willingness to take into account the type and amount of resources available to the good bank if resolution occurs.

5 Concluding remarks

We have studied how regulation shapes the interaction between financial fragility and bank liquidity management and proposed a rationale for the complementarity between bank recovery and resolution planning. The novelty of our contribution lies in the analysis of the asset pecking order that banks follow to meet depositors' withdrawals when runs occur, and its interaction with resolution planning. Our results show that costly resolution planning makes it necessary to also impose the implementation of a commitment on banks' recovery planning against financial fragility. All in all, a credible recovery and resolution planning has the potential to lead to a more valuable allocation of financial resources, by allowing a more effective liquidity management by banks.[17]

Notice that in our framework, there is no deposit insurance. This can be justified by the increasing role of uninsured deposits on banks' balance sheets.[18] Moreover, Allen et al. (2018) show that deposit insurance functioning as in the real world (i.e., as a guarantee of a fixed repayment in any possible state of the economy) would not completely rule out self-fulfilling runs. A similar argument holds regarding liquidity requirements. Only forcing banks to be "narrow" would make them immune from financial fragility. However, that would come at the cost of losing maturity transformation and possibly making banks redundant (Wallace, 1996). This is the reason why in the real world, liquidity requirements do not force banks to be narrow and potentially leave some financial fragility unresolved. This means that the introduction of plausible deposit insurance schemes and liquidity requirements would alter neither the mechanism nor the conclusions of our argument.

Finally, it would be incorrect to draw further normative implications on the efficiency of recovery and resolution planning, by comparing our results to an economy without such policy interventions. In fact, that would imply a comparison of the equilibrium outcomes of two models with different environments. Nevertheless, a still noteworthy policy implication can be drawn. Changing the architecture of recovery and resolution planning by giving all decision-making powers to either RAs or banks, may not undermine the effectiveness of the intervention as long as banks are competitive and share with RAs the objective of maximizing depositors' welfare. The introduction of market power might change this argument, while possibly leaving qualitatively unaltered the mechanism behind depositors' incentives to run.[19] We leave the formal analysis of these issues to future research.

[17]In the real world banks, even if subject to recovery and resolution planning, hold significant amounts of liquidity. This is apparently at odds with the outcome of the model that, with recovery planning, banks hold no excess liquidity. Yet, in the real world banks are also subject to tight liquidity requirements, from which we abstract for simplicity.

[18]The total amount of uninsured checkable, time, and savings deposits held by U.S. chartered commercial banks in 2020 represented almost 40 percent of total U.S. bank liabilities (source: Financial Accounts of the United States). Furthermore, uninsured deposits represent about half of the total deposits in the largest commercial banks both in the U.S. (Egan et al., 2017) and in the Euro Area (source: ECB Bank Balance Sheet Items and European Banking Authority data).

[19]Carletti et al. (2023) develop a banking model with runs as global games, in which banks exert market power and offer a fixed repayment to late depositors. In such a framework, they show that strategic complementarities are still present, thereby leading to possible runs.

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Appendices

A Proofs

Proof of Lemma 1. In the interval (λ, ϕ),

$$\frac{\partial v_1(\sigma, n)}{\partial n} = \sigma \frac{-\frac{R}{r}(1-n) + R\left(1 - L - \frac{n-\lambda}{r}\right)}{(1-n)^2} + \frac{L-\lambda}{(1-n)^2}. \tag{21}$$

This is negative if

$$(L-\lambda)(1-\sigma R) < \sigma R\left(\frac{\lambda r + (1-\lambda)}{r} - 1\right). \tag{22}$$

As $\sigma > \underline{\sigma} = 1/R$, then $\sigma R > 1$. Hence, the left-hand side is negative, and the right-hand side is positive. In the interval (λ, n_2^*),

$$\frac{\partial v_2(\sigma, n)}{\partial n} = \sigma R \frac{1-L}{(1-n)^2} + \frac{L-1}{(1-n)^2}. \tag{23}$$

This is negative if $\sigma R < 1$ which is impossible because $\sigma > \underline{\sigma}$, where $\underline{\sigma} < 1$. In the interval $[n_2^*, \phi)$ instead,

$$\frac{\partial v_2(\sigma, n)}{\partial n} = \sigma \frac{-\frac{R}{r}(1-n) + R\left(1 - L - \frac{n-}{r}\right)}{(1-n)^2} = \sigma R \frac{1-L}{(1-n)^2}\left(1 - \frac{1}{r}\right) < 0. \tag{24}$$

■

Proof of Lemma 2. Taking the derivative of (7) with respect to ϕ_1 and L_1 yields:

$$\frac{\partial \sigma_1^*}{\partial \phi_1} = \frac{1}{DEN_{\sigma_1^*}}\left[1 - \frac{L_1 - \lambda}{1 - \phi_1} - \sigma_1^* R \frac{1 - L_1 - \frac{\phi_1 - \lambda}{r}}{1 - \phi_1}\right], \tag{25}$$

$$\frac{\partial \sigma_1^*}{\partial L_1} = \frac{1}{DEN_{\sigma_1^*}}(\sigma_1^* R - 1)\int_\lambda^{\phi_1} \frac{1}{1-n} dn. \tag{26}$$

The first expression is positive as $v_1(\sigma_1^*, \phi_1) < 0$. The second expression is also positive as by construction $\sigma_1^* > \underline{\sigma} = 1/R$. ■

Proof of Proposition 2. We know that for $n = \lambda$, $v_1(\sigma, \lambda) = v_2(\sigma, \lambda)$. Moreover, recall that by Lemma 1, $v_1(\sigma, n)$ is decreasing everywhere in $n \in (\lambda, \phi)$, and $v_2(\sigma, n)$ is first increasing in $n \in (\lambda, n_2^*)$ and then decreasing in $n \in (n_2^*, \phi)$. As a consequence, in the interval (λ, n_2^*), $v_2(\sigma, n) > v_1(\sigma, n)$.

In order to prove the lemma, we just need to show that the second arm of $v_2(\sigma, n)$ is higher than $v_1(\sigma, n)$ between n_2^* and ϕ, for given L. In fact:

$$\sigma \frac{R\left(1 - L - \frac{n-L}{r}\right)}{1-n} > \sigma \frac{R\left(1 - L - \frac{n-\lambda}{r}\right) + L - \lambda}{1-n} + (1-\sigma)\frac{L-\lambda}{1-n}. \tag{27}$$

Simplifying, we obtain $L \geq \lambda$ which is always true.

This result implies that $\sigma_2^*(L, \phi) < \sigma_1^*(L, \phi)$ for given L and ϕ. The rest of the proof requires showing that expected welfare under the pecking order {Liquidity, Liquidation} is higher than under {Liquidation, Liquidity}, i.e., $W_2(L, \phi) - W_1(L, \phi)$ is positive, for given L and ϕ. More formally:

$$W_2(L, \phi) - W_1(L, \phi) = \int_{r/R}^{\sigma_2^*(L,\phi)} W_{2,s}(L, \phi) dp + \int_{\sigma_2^*(L,\phi)}^{1} \left[W_\ell(L) + W_a(L)\right] dp +$$

$$- \int_{r/R}^{\sigma_1^*(L,\phi)} W_{1,s}(L,\phi)dp - \int_{\sigma_1^*(L,\phi)}^{1} \left[W_\ell(L) + W_a(L)\right] dp, \quad (28)$$

where $W_{j,S}(L,\phi)$ indicates depositors' expected welfare at suspension when a run occurs under pecking order j, and $W_\ell(L)$ and $W_a(L)$ indicates expected welfare from liquidity and from productive assets when a run does not occur, respectively. In formulae:

$$\begin{aligned} W_{2,s}(L,\phi) &= \phi + (1-\phi)\left[\lambda + (1-\lambda)p\frac{R\left(1 - L - \frac{\phi - L}{r} - \frac{(1-\phi)\lambda}{r}\right)}{(1-\phi)(1-\lambda)}\right] - \psi(\phi) = \\ &= \phi + (1-\phi)\left[\lambda + (1-\lambda)p\frac{R\left(1 - L - \frac{\phi-\lambda}{r} + \frac{L-\lambda-(1-\phi)\lambda}{r}\right)}{(1-\phi)(1-\lambda)}\right] - \psi(\phi) \quad (29) \end{aligned}$$

$$W_{1,s}(L,\phi) = \phi + (1-\phi)\left[\lambda + (1-\lambda)\left[p\frac{R\left(1 - L - \frac{\phi-\lambda}{r}\right)}{(1-\phi)(1-\lambda)} + \frac{L - \lambda - (1-\phi)\lambda}{(1-\phi)(1-\lambda)}\right]\right] - \psi(\phi), \quad (30)$$

$$W_\ell(L) = L, \quad (31)$$

$$W_a(L) = pR(1-L). \quad (32)$$

Notice that the last two expressions are independent of the pecking order because L is predetermined on date 0 and ϕ does not play any role for the depositors' expected welfare if a run does not occur.

Since $\sigma_2^*(L,\phi) < \sigma_1^*(L,\phi)$ for given L and ϕ, we can rewrite (28) as:

$$\begin{aligned} W_2(L,\phi) - W_1(L,\phi) = \int_{r/R}^{\sigma_2^*(L,\phi)} \left[W_{2,s}(L,\phi) - W_{1,s}(L,\phi)\right] dp - \int_{\sigma_2^*(L,\phi)}^{\sigma_1^*(L,\phi)} W_{1,s}(L,\phi)dp + \\ + \int_{\sigma_2^*(L,\phi)}^{\sigma_1^*(L,\phi)} \left[W_\ell(L) + W_a(L)\right] dp. \quad (33) \end{aligned}$$

The sum of the second and third element is positive, otherwise running would be optimal. As far as the first term is concerned, simple algebra allows us to rewrite:

$$\int_{r/R}^{\sigma_2^*(L,\phi)} \left[W_{2,s}(L,\phi) - W_{1,s}(L,\phi)\right] dp = \left[L - \lambda - (1-\phi)\lambda\right] \int_{r/R}^{\sigma_2^*(L,\phi)} \left[\frac{pR}{r} - 1\right] dp. \quad (34)$$

This last expression is larger than or equal to zero, because the integrand is increasing in p and at the lower extreme of integration it takes value 0. This ends the proof. ■

Proof of Proposition 3. We prove the proposition by contradiction. Assume that $L_2 = \lambda$, so that $n_2^* = L_2 = \lambda$. Then:

$$\sigma_2^*(\lambda, \phi) = \frac{\phi - \lambda}{\displaystyle\int_\lambda^\phi \frac{R}{1-n}\left[1 - \lambda - \frac{1}{r}(n - \lambda)\right] dn} > \frac{\phi - \lambda}{\displaystyle\int_\lambda^\phi \frac{R}{1-n}\left[1 - \lambda - (n - \lambda)\right] dn} = \frac{1}{R}. \quad (35)$$

Moreover:

$$\left.\frac{\partial \sigma_2^*}{\partial L}\right|_{L=\lambda} = -\frac{\sigma_2^* R}{DEN_{\sigma_2^*}}\left(\frac{1}{r} - 1\right)\int_\lambda^\phi \frac{1}{1-n} dn < 0. \quad (36)$$

So the third term of (14) is positive. The sum of the first two terms is equal to:

$$\frac{\sigma_2^{*2}}{2} R\left(\frac{1}{r} - 1\right) + 1 - \sigma_2^* - R\frac{1 - \sigma_2^{*2}}{2} = \frac{R}{2}\left[\frac{\sigma_2^{*2}}{r} - 1\right] + 1 - \sigma_2^* \quad (37)$$

Under $r < 1/R^2$ this expression is positive. Hence $L_2 = 1 > \lambda$, which is a contradiction.

■

Proof of Corollary 1. Using (7), (17) and (25) into (18), we obtain:

$$-\frac{R\sigma_1^* - r}{R}\psi'(\phi_1) = \frac{(R\sigma_1^*)^2 - r^2 - 2rR\sigma_1^* + 2r^2}{2rR} + \frac{1}{\displaystyle\int_\lambda^{\phi_1} R\frac{1 - L_1 - \frac{n-\lambda}{r}}{1-n} dn} \times$$
$$\times \left[1 - \frac{L_1 - \lambda}{1 - \phi_1} - R\sigma_1^* \frac{1 - L_1 - \frac{\phi_1 - \lambda}{r}}{1 - \phi_1}\right]\left[R\sigma_1^*(1 - L_1) - \phi_1 - R\sigma_1^*\left(1 - L_1 - \frac{\phi_1 - \lambda}{r}\right) + \right.$$
$$\left. + \lambda + \psi(\phi_1)\right]. \quad (38)$$

This expression implicitly characterizes the equilibrium suspension point ϕ_1 as a function of L_1. As the latter is equal to λ in equilibrium, and from (7) it is easy to notice that $R\sigma_1^*$ is independent of R, then it must be the case that ϕ_1 is independent of R, too. This ends the proof. ■

B Equilibrium with perfect information

In this appendix, we characterize a banking equilibrium in which depositors do not receive any signal about the aggregate state, and the bank is perfectly informed about their types, i.e., it can observe and verify the realizations of the idiosyncratic shocks hitting the depositors (but not the realization of the aggregate state) and maximizes their expected welfare subject to budget constraints. This is a reasonable benchmark to the main analysis, as its equilibrium outcome is equivalent to that of an economy with imperfect information in which banks cannot observe depositors' types and must induce truth-telling, but depositors do not observe signals about the aggregate state. Formally, the bank solves the following:

$$\max_{c_2(Z),L,D} \lambda + (1-\lambda)\mathbb{E}[c_2(Z)], \tag{39}$$

subject to

$$L + rD \geq \lambda, \tag{40}$$

$$0 \leq D \leq 1 - L, \tag{41}$$

$$L \geq 0, \tag{42}$$

$$(1-\lambda)c_2(Z) = Z(1-L-D) + L + rD - \lambda, \tag{43}$$

where the last constraint has to hold for any $Z \in \{0, R\}$. On date 0, the bank collects all endowments and invests them in an amount L of liquidity and $1 - L$ of productive assets. On date 1, the liquidity constraint (40) states that the amount of liquid assets, given by the sum of liquidity and the resources generated by liquidating an amount D of productive assets, must be sufficient to rebate deposits to λ early consumers. Any resource $L + rD - \lambda$ left constitutes excess liquidity and is rolled over to date 2. The excess liquidity, together with the return from the remaining productive assets, pays for late consumption according to (43) for any realization of the aggregate productivity shock $Z \in \{0, R\}$. The bank cannot liquidate a negative amount of assets and cannot liquidate more assets than are available on its balance sheet.

Substituting the budget constraints into the objective function yields the following banking problem:

$$\max_{L,D} \; \lambda + (1-\lambda)\int_0^1 \left[p\frac{R(1-L-D)+L+rD-\lambda}{1-\lambda} + (1-p)\frac{L+rD-\lambda}{1-\lambda}\right] dp, \quad (44)$$

subject to $L + rD \geq \lambda$, $L \geq 0$ and $0 \leq D \leq 1 - L$. The following result holds:

Lemma 3. *In the banking equilibrium with perfect information, there is no liquidation of the productive asset and no excess liquidity, i.e.,* $D = 0$ *and* $L = \lambda$.

Proof. Simplify the objective function as follows:

$$\max_{L,D} \; L + rD + \int_0^1 pR(1-L-D), \quad (45)$$

subject to $L + rD \geq \lambda$, $L \geq 0$, $D \leq 1 - L$ and $D \geq 0$. Assign Lagrange multipliers ξ, μ, η and ζ, respectively. The first-order conditions are

$$L: \qquad 1 - \mathbb{E}[p]R + \xi + \mu - \eta = 0, \quad (46)$$

$$D: \qquad r - \mathbb{E}[p]R + r\xi - \eta + \zeta = 0. \quad (47)$$

Substituting the first into the second, we obtain

$$-\mathbb{E}[p](1-r)R - r\mu - (1-r)\eta + \zeta = 0. \quad (48)$$

Hence, it must be that $\zeta > 0$ and $D = 0$ by complementary slackness. According to the liquidity constraint (40), this means that $L \geq \lambda > 0$. Thus, $\mu = 0$. Then, from (46) it follows that

$$\xi = \mathbb{E}[p]R - 1 + \eta, \quad (49)$$

which is strictly positive, as $\mathbb{E}[p]R > 1$. Therefore, $L = \lambda < 1$ and $\eta = 0$. ■

The above lemma states that liquidating productive assets to rebate deposits on date

1 is never part of an equilibrium with perfect information, because the recovery rate $r < 1$ implies that liquidation is too costly. Consequently, banks only use liquidity to serve early consumers. Moreover, the advantage of holding excess liquidity, in terms of consumption in the bad state of the world when the productive asset yields zero, is dominated by its cost in terms of forgone return in the good state of the world. Hence, the bank in equilibrium holds just enough liquidity to cover the total early consumption λ.

C Equilibrium without resolution plan

The aim of this appendix is to characterize the equilibrium of an economy in which the bank still chooses the pecking order with which to employ assets during runs (either on date 0 or on date 1) but without the intervention of a resolution authority. In this case, if a run occurs the bank becomes insolvent and must liquidate all assets and equally share the proceeds among all depositors, irrespective of the pecking order. Mimicking the structure of the main text, we solve for the two equilibria without and with recovery plan.

C.1 Equilibrium without recovery planning

We solve the model by backward induction. First, for a given asset pecking order and bank liquidity, we study the depositors' withdrawal decisions. Then, we characterize the equilibrium asset pecking order, and finally, the choice of the bank asset portfolio.

All the considerations of the main text regarding the upper and lower dominance region still hold. To characterize depositors' withdrawal behavior, we first study the utility advantage of waiting over running under both pecking orders, for a given fraction n of depositors who withdraw funds on date 1. Table 4 reports payoffs under the two pecking orders. Under the pecking order {Liquidation, Liquidity}, $n_1^* = \lambda + r(1 - L)$ and $n^{**} = L + r(1 - L)$ are the maximum fractions of depositors that a bank can serve on date 1, and either liquidating the whole amount of productive assets in the portfolio (up to n_1^*) or also using liquidity (up to n^{**}). If the fraction of depositors who withdraw funds on date 1 is in the interval $[n^{**}, 1]$, the bank becomes insolvent, as it does not hold sufficient resources to rebate all deposits on date 1. In this case, the bank is forced to liquidate all productive assets and close down. Therefore, a late consumer who waits

Table 4: Depositors' payoffs in the economy without resolution.

(a) Pecking order {Liquidation, Liquidity}

Date	$n \in [\lambda, n_1^*)$	$n \in [n_1^*, n^{**})$	$n \in [n^{**}, 1]$
$t = 1$	1	1	$\frac{r(1-L)+L}{n}$
$t = 2$	$\frac{Z\left(1-L-\frac{n-\lambda}{r}\right)+L-\lambda}{1-n} \quad \forall Z \in \{0, R\}$	$\frac{r(1-L)+L-n}{1-n}$	0

(b) Pecking order {Liquidity, Liquidation}

Date	$n \in [\lambda, n_2^*)$	$n \in [n_2^*, n^{**})$	$n \in [n^{**}, 1]$
$t = 1$	1	1	$\frac{r(1-L)+L}{n}$
$t = 2$	$\frac{Z(1-L)+L-n}{1-n} \quad \forall Z \in \{0, R\}$	$\frac{Z\left(1-L-\frac{n-L}{r}\right)}{1-n} \quad \forall Z \in \{0, R\}$	0

until date 2 receives zero. The total liquidation value of the bank's assets (equal to $L + r(1 - L)$) is split pro-rata among the n depositors withdrawing funds on date 1. Accordingly, consumption at insolvency is $c^B(n) = (L + r(1 - L))/n$. Under the pecking order {Liquidity, Liquidation} instead, $n_2^* = L_2$ and $n^{**} = L + r(1 - L)$ are the maximum fractions of depositors that a bank can serve on date 1 by deploying liquidity (up to n_2^*), and by also liquidating the whole amount of productive assets in its portfolio (up to n^{**}).

Given the described payoff structure, under the pecking order {Liquidation, Liquidity} the utility advantage of waiting over running is

$$v_1(\sigma, n) = \begin{cases} \sigma \frac{R\left(1-L-\frac{n-\lambda}{r}\right)+L-\lambda}{1-n} + (1-\sigma)\frac{L-\lambda}{1-n} - 1 & \text{if } \lambda \leq n < n_1^*, \\ \sigma \frac{r(1-L)+L-n}{1-n} + (1-\sigma)\frac{r(1-L)+L-n}{1-n} - 1 & \text{if } n_1^* \leq n < n^{**}, \\ -\frac{r(1-L)+L}{n} & \text{if } n^{**} \leq n \leq 1, \end{cases} \tag{50}$$

while under the pecking order {Liquidity, Liquidation} it is

$$v_2(\sigma, n) = \begin{cases} \sigma\frac{R(1-L)+L-n}{1-n} + (1-\sigma)\frac{L-n}{1-n} - 1 & \text{if } \lambda \leq n < n_2^*, \\ \sigma\frac{R(1-L-D)}{1-n} - 1 = \sigma\frac{R\left(1-L-\frac{n-L}{r}\right)}{1-n} - 1 & \text{if } n_2^* \leq n < n^{**}, \\ -\frac{r(1-L)+L}{n} & \text{if } n^{**} \leq n \leq 1. \end{cases} \tag{51}$$

The strategic complementarities affecting a late consumer's decision to run depend on how the advantage of waiting over running varies with the fraction of depositors n withdrawing funds on date 1. Under both pecking orders, in the interval $[n^{**}, 1]$ the advantage of waiting over running is increasing in n, as after insolvency, equal service prescribes the total resources to be shared pro-rata with all depositors. The following lemma characterizes the strategic complementarities in the other intervals under the two pecking orders.

Lemma 4. *The function $v_1(\sigma, n)$ is decreasing in $n \in (\lambda, n^{**})$. The function $v_2(\sigma, n)$ is increasing in $n \in (\lambda, n_2^*)$ and decreasing in $[n_2^*, n^{**})$.*

Proof. In the interval (λ, n_1^*),

$$\frac{\partial v_1(\sigma, n)}{\partial n} = \sigma\frac{-\frac{R}{r}(1-n) + R\left(1-L-\frac{n-\lambda}{r}\right) + R(L-\lambda) - R(L-\lambda)}{(1-n)^2} + \frac{L-\lambda}{(1-n)^2}. \tag{52}$$

This is negative if

$$(L-\lambda)(1-\sigma R) < \sigma R\left(\frac{\lambda r + (1-\lambda)}{r} - 1\right). \tag{53}$$

As $\sigma > \underline{\sigma} = 1/R$, then $\sigma R > 1$. Hence, the left-hand side is negative, and the right-hand side is positive. In the interval $[n_1^*, n^{**})$, $v_1(\sigma, n)$ is decreasing, as $1 > L + r(1-L)$. In the interval (λ, n_2^*),

$$\frac{\partial v_2(\sigma, n)}{\partial n} = \sigma R\frac{1-L}{(1-n)^2} + \frac{L-1}{(1-n)^2}. \tag{54}$$

This is negative if

$$1 - L > \sigma R(1-L), \tag{55}$$

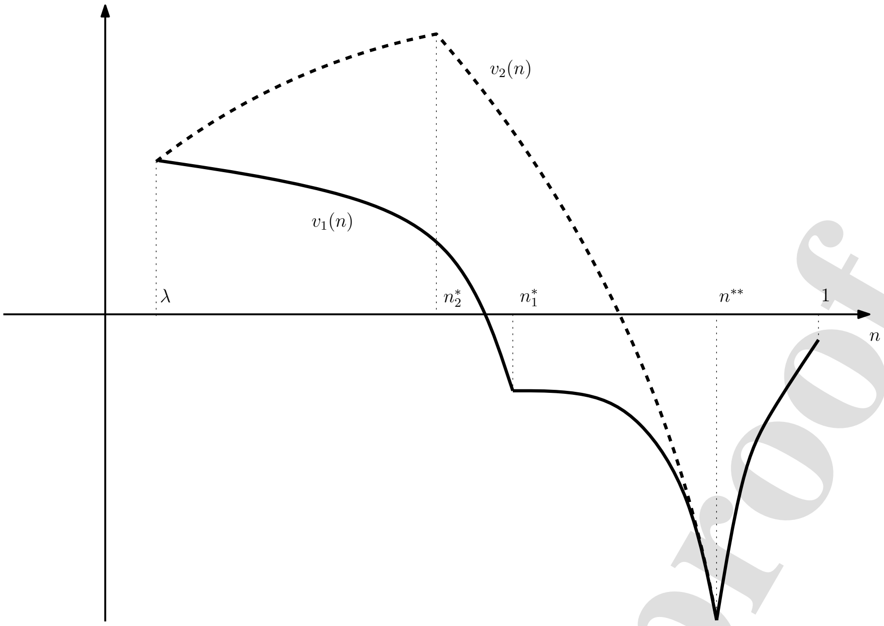

Figure 3: The advantage of waiting over running, as a function of the fraction of depositors running, under the pecking orders {Liquidation, Liquidity} (solid line) and {Liquidity, Liquidation} (dashed line).

which is impossible because $\sigma > \underline{\sigma}$. In the interval $[n_2^*, n^{**})$ instead,

$$\frac{\partial v_2(\sigma, n)}{\partial n} = \sigma \frac{-\frac{R}{r}(1-n) + R\left(1 - L - \frac{n-L}{r}\right)}{(1-n)^2} = \sigma R \frac{1-L}{(1-n)^2}\left(1 - \frac{1}{r}\right) < 0. \tag{56}$$

■

Figure 3 shows that under both pecking orders the advantage of waiting over running crosses zero only once, thereby guaranteeing the existence and uniqueness of the equilibrium (Goldstein and Pauzner, 2005). Since the the resolution procedure in case of a run is the same irrespective of the pecking order, the amount of resources at resolution is also the same. Therefore, for a result similar to Proposition 2 to hold, it is just necessary to prove the following lemma.

Lemma 5. *If $n \in (\lambda, n^{**})$, the pecking order {Liquidity, Liquidation} is always preferred to {Liquidation, Liquidity}.*

A bank willing to maximize expected welfare by choosing the pecking order on date 1 (i.e., after its portfolio and RA's suspension decisions) should pick the one that minimizes depositors' incentives to run. Then, Lemma 5 implies that the equilibrium run threshold without recovery planning is the one that solves $\mathbb{E}[v_2(\sigma,n)|\sigma_2^*]=0$, i.e.,

$$\sigma^*(L)=\sigma_2^*(L)=\frac{n^{**}-\lambda-\int_\lambda^{n_2^*}\frac{L-n}{1-n}dn+\int_{n^{**}}^1\frac{r(1-L)+L}{n}dn}{\int_\lambda^{n_2^*}\frac{R(1-L)}{1-n}dn+\int_{n_2^*}^{n^{**}}\frac{R\left(1-L-\frac{n-L}{r}\right)}{1-n}dn}. \tag{57}$$

By backward induction, we solve for the equilibrium bank asset portfolio in the following:

$$\max_L \int_{r/R}^{\sigma^*(L)}\big[L+r(1-L)\big]dp+\int_{\sigma^*(L)}^1\left[\lambda+(1-\lambda)\left[p\frac{R(1-L)+L-\lambda}{1-\lambda}+(1-p)\frac{L-\lambda}{1-\lambda}\right]\right]dp, \tag{58}$$

subject to $\lambda\le L\le 1$. Define the difference between the utility in the no-run case and the utility in the case of a run as

$$\Delta U=L+\sigma^*(L)R(1-L)-L-r(1-L)=(\sigma^*(L)R-r)(1-L). \tag{59}$$

Then, the first-order condition of the optimization problem with respect to L is

$$\left[\sigma^*(L)-\frac{r}{R}\right](1-r)+\int_{\sigma^*(L)}^1\big[-pR+1\big]dp-\frac{\partial\sigma^*}{\partial L}\Delta U+\xi-\chi=0, \tag{60}$$

where ξ and χ are the respective Lagrange multipliers on the two constraints.

C.2 Equilibrium with recovery planning

As in the main text, to characterize the equilibrium pecking order, we first need to characterize the run threshold $\sigma_1^*(L)$ from $\mathbb{E}[v_1(\sigma,n)|\sigma_1^*]=0$:

$$\sigma_1^*(L)=\frac{n^{**}-\lambda-\int_\lambda^{n_1^*}\frac{L-\lambda}{1-n}dn-\int_{n_1^*}^{n^{**}}\frac{L+r(1-L)+L-n}{1-n}dn+\int_{n^{**}}^1\frac{r(1-L)+L}{n}dn}{\int_\lambda^{n_1^*}\frac{R\left(1-L-\frac{n-\lambda}{r}\right)}{1-n}dn} \tag{61}$$

The banking problem is the same as in (58) with a different run threshold and yields a similar first-order condition as in (60) for the choice of liquidity. The numerical characterization of the equilibrium without resolution plan is reported in Table 3 in the main text.

D Resolution with partial deposit insurance

In the real world, resolution authorities often create good banks and make different payments based on whether depositors are insured versus uninsured, irrespective of their liquidity needs. The aim of this appendix is to show the equivalence of the resolution regime that we model in the paper (with a good bank that repays early depositors in full and rebates the remaining proceeds to the remaining late depositors) to one with partial deposit insurance. To this end, differently from the main text, assume that the good bank created by the RA pays a fraction χ of the initial endowments to all the $1-\phi$ depositors still not served, and rebates the remaining proceeds to the remaining late consumers.

In this new framework, under the pecking order {Liquidation, Liquidity} the RA maximizes depositors' expected welfare:

$$W_1(L_1,\phi_1) = \int_{r/R}^{\sigma_1^*(L_1,\phi_1)} \left[\phi_1 + (1-\phi_1)\left[\chi + (1-\lambda)\left[p\frac{R\left(1-L_1-\frac{\phi_1-\lambda}{r}\right)}{(1-\phi_1)(1-\lambda)} + \frac{L_1-\lambda-(1-\phi_1)\chi}{(1-\phi_1)(1-\lambda)}\right]\right] - \psi(\phi_1)\right] dp + \int_{\sigma_1^*(L_1,\phi_1)}^{1} \left[\lambda + (1-\lambda)\left[p\frac{R(1-L_1)+L_1-\lambda}{1-\lambda} + (1-p)\frac{L_1-\lambda}{1-\lambda}\right]\right] dp. \tag{62}$$

If $p \in \left[\frac{r}{R}, \sigma_1^*\right]$, a run occurs and suspension takes place: ϕ depositors fully retrieve their deposits; all the $(1-\phi)$ depositors served by the good bank obtain a fraction χ of their initial deposits, and the remaining $1-\lambda$ late consumers among them eventually receive an equal share of the available resources on date 2. Notice that this expression is equivalent to (16) in the main text if $\chi = \lambda$.

Under the pecking order {Liquidity, Liquidation} instead, depositors' expected welfare reads:

$$W_2(L,\phi) = \int_{r/R}^{\sigma_2^*(L,\phi)} \left[\phi + (1-\phi)\left[\chi + (1-\lambda)p\frac{R\left(1-L-\frac{\phi-L}{r}-\frac{(1-\phi)\chi}{r}\right)}{(1-\lambda)(1-\phi)}\right] - \psi(\phi)\right] dp +$$
$$+ \int_{\sigma_2^*(L,\phi)}^{1} \left[\lambda + (1-\lambda)\left[p\frac{R(1-L)+L-\lambda}{1-\lambda} + (1-p)\frac{L-\lambda}{1-\lambda}\right]\right] dp. \qquad (63)$$

As for the first pecking order, this expression is equivalent to (11) in the main text if $\chi = \lambda$.

Bank Recovery and Resolution Planning, Liquidity Management and Fragility*

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Abstract

We study how regulation shapes the interaction between financial fragility and bank liquidity management, and propose a rationale for the complementarity between bank recovery and resolution planning. To this end, we analyze an economy in which a resolution authority arranges a bank resolution plan to suspend deposit withdrawals and create a "good bank" at a cost in the event of a depositors' run. In such a framework, banks find it optimal to establish recovery plans in advance, specifying how how to manage liquidity during runs. However, such plans are time inconsistent, and resolution authorities need powers to force their implementation at times of financial fragility.

Keywords: banks, liquidity, financial fragility, financial regulation, resolution.
JEL codes: G01, G21, G28

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