The Architecture of Bank Liquidity: Balancing Assets, Bail-ins and State Support*

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Abstract: This paper develops a unified theoretical framework for bank liquidity regulation, integrating asset-side market liquidity and liability-side bail-inability. It proposes a Liquidity-Weighted Buffer (LWB) requirement that accounts for both haircut-adjusted assets and bail-inable claims. The model shows that optimal liquidity buffers should absorb ordinary shocks, with state support reserved for tail events. We extend the analysis to settings with limited asset supply, fire sale risks, liquidity pooling, and rollover shocks. The framework critiques current regulatory inconsistencies, particularly around de facto insured deposits, and offers policy guidance that preserves maturity transformation while mitigating systemic risk.

Keywords: Liquidity weighted buffer (LWB), prudential regulation, bailouts, bail-ins.

JEL numbers: D82, G21, M48.

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1 Introduction

Bank liquidity shortfalls remain a critical threat to financial stability. From classic bank runs to fire sales, from interbank contagion to government bailouts, inadequate liquidity hoarding by banks has been a recurring source of systemic crises. In response to the 2008 global financial crisis, regulators introduced liquidity requirements such as Basel III's Liquidity Coverage Ratio (LCR), which specify minimum holdings of high-quality liquid assets (HQLAs) against potential short-term outflows. Yet despite significant regulatory progress, key questions remain unanswered: How should liquidity requirements be optimally structured? What is the role of bail-inable liabilities in liquidity planning? And how should regulation account for both the asset and liability sides of the balance sheet?

This paper builds a theoretical framework to address these questions. Section 2 proposes a model in which banks face liquidity shocks and must respond by mobilizing market liquidity (via asset sales) or funding liquidity (via liability-side bail-ins). The framework generalizes prudential regulation through the concept of Liquidity-Weighted Buffer (LWB)[1], which reflects both the discounted liquidation value of assets and the bail-inability of various liabilities. The theoretical benchmark thus blends (modified versions of) LCR and TLAC.[2] We show that liquidity buffers should be structured to absorb "normal" liquidity shocks, with the State stepping in only in extreme tail events. In this setting, bail-inable instruments act as complementary sources of liquidity, and regulatory design requires aligning the structure and level of liquid assets with the composition of liabilities.

Analogous to the dispatching of optimal power plant investment portfolios in a world of uncertain demand, banks optimally hoard a liquid-assets portfolio composed of various types of assets ranging from "base-load" to "peak-load" liquidity. Base-load liquidity consists of low-yield, high-liquidity assets that are used frequently for liquidity coverage. Peak-load liquidity needs are covered through higher-yield, higher-haircut assets; these assets constitute idle liquidity in normal times, but bring a liquidity service in rougher times. The same logic (and again analogous to electricity markets) applies on the liability side: different classes of investors, with different risk appetites, should be offered claims that obey a priority-of-service order and are explicitly bail-inable under prespecified circumstances. In contrast, some other liabilities, "insured deposits", are safe (never bailed in). We show that in the absence of fire-sale externalities, the selection of the liquidity

[1] This terminology is inspired by the notion of RWA (risk-weighted assets) operative in the prudential regulation of solvency since Basel I (1988). We use "LWB" rather than "LWA" because "liquidity-weighted assets" is, as we show, too narrow a concept to meet liquidity shocks at the optimal regulatory scheme.

[2] Total Loss-Absorbing Capacity (TLAC) is a regulatory requirement for global systemically important banks to maintain a certain level of loss-absorbing capacity/bail-inable claims. Unlike TLAC, though, our liability-side liquidity instruments do not apply only in resolution, and can be broader than just long-term debt and equity (but they cannot be so short-term that their holders can run before being put to contribution).

structure on both sides of the balance sheet can be delegated to the bank: the conflict between the bank's and regulator's objectives arises only regarding the *level* of liquidity, not its *structure*.

Section 3 extends the mechanism-design analysis in several policy-relevant directions. First, relaxing the assumption that liquidity supply is available in unlimited quantities (perhaps thanks to unlimited access to an international market), we show how a limited domestic supply of highly liquid assets affects both the level and structure of liquidity. Second, we demonstrate that regulatory LWB mandates should be complemented (as the LCR is) with minimum requirements for base-load liquidity when fire sale externalities are significant. Third, we evaluate how liquidity pooling affects regulatory design. Fourth, we zero in on a specific liquidity shock, the possible difficulty encountered when rolling over cheap deposits. These extensions provide a richer understanding of how liquidity requirements interact with macroeconomic conditions, capital markets, and interbank relationships.

Section 4 draws the policy implications. First, we argue that current regulation suffers from internal inconsistencies. Notably, deposits held by formally-uninsured corporate customers are effectively insured as the threat of runs triggers government support. This allows banks to underprice liquidity risk and fund risky assets with cheaply priced liabilities, a misalignment that was visible in the failures of Silicon Valley Bank and other institutions in 2023. Our model advocates for equal treatment across all de facto insured deposits. Second, the model highlights the shortcomings of relying solely on an outflow-rate logic (as Basel III does): insuring deposits requires that an increase in the liquidity shock be met by tapping one of three sources: (i) resale of sufficiently liquid assets, (ii) bail-in of other liabilities, or (iii) bailout by authorities. Basel III applies this logic only for wholesale deposits held by other financial institutions, for which it privileges approach (i). We also show that, despite our recommendation that liquidity coverage be extended to all de facto insured deposits, the optimal regulatory policy should not resemble narrow banking, which eliminates risk transformation.[3]

Section 5 reviews the relevant literature. Our paper focuses on the optimal liquidity *structure*, taking into account the contributions of financial assets on both sides of the balance sheet, while the literature typically centers on banks holding two assets (loans and liquid assets) and funded by equity and one category of deposits. Moreover, our implementation of the optimal liquidity structure assumes that authorities bail out short-term deposits in order to avoid bank runs, and draws the consequences. It is therefore

[3]Equal treatment is perfectly consistent with the traditional view that banks optimally invest in risky assets and engage in maturity transformation. It demands only that at the margin one more $ of short-term deposit, whether formally insured or uninsured, be matched with one more $ of liquid assets. Our theoretical framework indeed features risky investments in assets with delayed payoffs on the asset side, and dilutable claims on this future equity-like income and bail-inable securities on the liability side, all within the same roof.

complementary to Kashyap et al. (2024), in which there is no deposit insurance and runs help discipline the bank and happen with positive probability at the optimum.

Finally, Section 6 concludes with a brief summary and avenues for future research. Omitted proofs can be found in the Appendix.

By offering a holistic view of liquidity management and its regulatory implications, this paper aims to inform ongoing debates on financial stability, crisis prevention, and the appropriate use of public funds in banking systems.

2 Optimal liquidity structure

This Section develops the model and solves for the optimal prudential regulation. The exercise is one in mechanism design. Its policy implications (implementation) are drawn in Section 4.

2.1 Model

There are three dates, $t = 0, 1, 2$, and no discounting between the periods. Consumers/investors have intertemporal utility $\sum_{t=0}^{t=2} c_t$ from flow consumptions $\{c_t\}_{t=0}^{t=2}$.

Banks. There is a mass 1 of banks. A representative bank (run by a banking entrepreneur) has endowment $A > 0$ at date 0 (and no future endowments). The bank invests i at that date. At date 1, the bank faces a publicly observable liquidity need, ρ per unit of investment, distributed at date 0 according to density $f(\rho)$ and cumulative distribution $F(\rho)$, with mean $\bar{\rho}$ and full support on $[\rho_{\min}, \rho_{\max}]$.[4] The shock ρ should be thought of as a liquidity shock net of the date-1 bank revenue. Thus, the support of shocks can have net revenues ($\rho_{\min} < 0$). Next, we posit a macroeconomic shock; with only idiosyncratic shocks banks could share risk and thereby incur no risk. For simplicity, we assume that the shock ρ is the same for all banks, which rules out any risk sharing among them.[5] To pursue the project at scale $j \in [0, i]$, the bank must find cash ρj (if positive). Only the banking entrepreneur can pursue the project.[6]

[4]The shock ρ captures non-performing loans, legacy assets that have lost market value, guarantees granted to firms or other institutions that are called upon, or new investments (say in Fintech) that are required. As will be shown in Section 3.4, liquidity shocks may alternatively arise from difficulties encountered in rolling over cheap liabilities.

[5]See Section 3.3 for an extension to imperfectly correlated shocks and cross-exposures.

[6]The assumption that the banking entrepreneurs are indispensable implies that they does not lose their job in case of bailout or bail-in. The indispensability assumption is convenient, but is not needed for the results. First, disposing of incumbent management will necessarily deprive the banking entrepreneur from the private benefits attached with managing the asset; it thus makes it more difficult for the state to ex ante ensure participation. Second, even in the absence of indispensability, managerial turnover costs would make firing the banking entrepreneur time-inconsistent given the absence of adverse selection in the model. Finally, the banking entrepreneur's removal would not prevent the bank from under-hoarding liquidity in the absence of regulation.

"Date 2" represents the future. In particular, meeting the date-1 liquidity shock, can be interpreted as "restarting the bank in a healthy, although perhaps downsized state". At date 2, the bank receives expected non-pledgeable benefit bj from the project (this could correspond either to an incentive payment to counter moral hazard or to a pure private benefit). The banking entrepreneur is risk neutral and has payoff $E[\sum_{t=0}^{t=2} c_t + bj]$, where c_t is their date-t consumption. To simplify the presentation, and as is customary in these models, the benefit b will be assumed sufficiently large that the banking entrepreneur wishes to be paid in date-1 continuation.

Sources of liquidity. There are three sources of liquidity. We start with market and funding liquidity, and later describe public liquidity assistance.

(i) *Market liquidity.* The bank hoards at date 0 a quantity $\ell_a \geq 0$ of each asset a in a class $\mathcal{A}$ of assets indexed from 1 through n. One unit of asset a costs 1 at date 0 and delivers $r_a < 1$ if held to maturity, i.e. to date 2: Liquid assets have a yield below the consumers' intertemporal marginal rate of substitution (equal to 1), and so holding them can only be rationalized by liquidity management. While r_a is the rate of return obtained when holding the asset to maturity, if sold at date 1, asset a delivers only $\theta_a r_a$, where $\theta_a < 1$. This captures the idea that assets yield a higher return to the bank if held to maturity.[7] We rank assets by increasing date-2 return: $r_1 < r_2 < ... < r_n < 1$. Also without loss of generality, we assume that no asset is dominated: $\theta_1 r_1 > \theta_2 r_2 > ... > \theta_n r_n$. [For instance, when $n = 2$, a relatively safe asset ("level-1 liquidity") yields a good return even if sold at date 1, while a higher-yield asset ("level-2 liquidity") incurs a larger discount if disposed of before its maturity.] The bank selects amounts $\{\ell_a\}_{a\in\mathcal{A}}$ of the various liquid assets.

(ii) *Funding liquidity.* Funding liquidity stems from the dilution of claims on the incomes created by the initial investments. Let $\rho^0 j$ denote the pledgeable income at date 1, proportional to maintained investment (so $(b + \rho^0)j$ is the total private value associated with the continuation of the banking activity). Reselling these claims yields $\theta^0\rho^0 j$, where $\rho^0 < 1$ and $\theta^0 \leq 1$ (so reinvestment is not self-financing). The term $\rho^0 j$ will be interpreted as the value of the bank's outside equity.

We decompose investors into "ordinary investors" and "depositors". Date-0 ordinary investors have no liquidity need and have utility $E[\Sigma_{t=0}^{t=2} c_t]$. Depositors have a demand for date-1 liquidity: There is a mass $\bar{\ell}^d$ of date-0 depositors of type d, where classes of depositors, $d \in \mathcal{D}$, are indexed from 1 through m. These depositors have a preference for withdrawing at date 1 and are willing to pay $1/\theta^d$ for obtaining 1 unit of cash at date 1, where $1 > \theta^1 > \cdots > \theta^m$. Depositors are local and therefore captive of the bank:

[7] For instance, managing the asset between dates 1 and 2 generates a private benefit $b_a = 1 - \theta_a$, and potential managers of the assets are cashless (and so cannot pay for their subsequent private benefit). Alternatively, assets could be subject to an adverse-selection discount when resold at date 1. Note also that the fact that all r_a's and all θ_a's are smaller than 1 (liquid assets have a low return) needs not make narrow banking (the backing of deposits by an equivalent amount of safe liquid assets) unprofitable; for, there is a demand for consumer liquidity (what we call "depositors"). Indeed, in the absence of productive investment and of government funds, banks would still hold liquid assets (and then be narrow banks).

For expositional simplicity, the bank observes the type (θ^d) of its depositors and so is able to extract the gains from trade in their relationship. More generally, our analysis of deposits requires banking competition to be imperfect, so that deposits are viewed by banks as "cheap funding". Deposits would also be cheap if either the bank did not observe perfectly the depositors' types[8] or if banks waged imperfect competition.

Interpretation. One may have in mind that type-d investors have a date-1 project that they value at $1/\theta^d$ and can be undertaken only if they have 1 unit of cash at date 1. While formally risk neutral and, like ordinary depositors, having utility $E\left[\Sigma_{t=0}^{t=2} c_t\right]$, they behave like risk-averse depositors who are particularly eager to receive their repayment. An "investor" thus in general will have two incarnations: as a type-d depositor for the first unit(s) of date-1 income and an ordinary investor for the income beyond one unit: See Figure 1. The representative bank can issue liabilities that are subscribed by type-d investors in an amount $\ell^d \in [0, \bar{\ell}^d]$. The funding is cheaper for the bank, the lower the d.

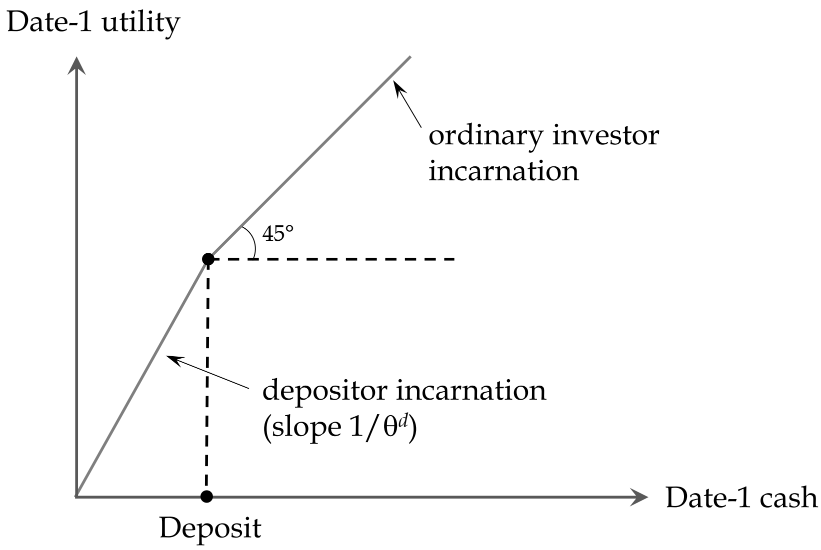

Figure 1: Investors as depositors and ordinary investors

Date-1 investors are all ordinary risk-neutral investors, willing to pay 1 at date 1 for 1 unit of expected date-2 income (thus have utility $E\left[\Sigma_{t=1}^{2} c_t\right]$). [See Section 3.4 on rollover risk for a relaxation of this assumption, capturing the potential shortage of cheap deposits at date 1.] An implication of risk neutrality is that it does not matter for instance whether the pledgeable income ρ^0 is non-risky or rather is just an expectation of a random payoff.

[8]The menu of offers of deposits with different degrees of security would then maximize the bank's utility in the second-, rather than third-degree price discrimination fashion.

State. The State/regulator[9] puts no weight on the banks' welfare,[10] and attaches equal weight on all depositors/taxpayers. It can provide open bank assistance at date 1. The cost for the State of a date-t deficit G_t (or surplus if negative) vis-à-vis the banks is $G_0 + C(G_1) + G_2$. The date-0 deficit G_0 is endogenous and is equal to the difference between the bank's date-0 expenditures (investment in liquid and illiquid assets) and its available cash at that date (endowment and liabilities issuance). One can think of the date-1 cost of liquidity assistance as a political cost of a bailout. Alternatively, it may reflect a shadow cost of public funds (the economic cost might then be an increase in the marginal cost of collecting funds or in the spread in sovereign borrowing).[11] That is, a \$1 emergency support requires using distortionary taxation and imposes a cost on the rest of society. By contrast, redeeming cash to consumers at date 1 has no specific value (is valued one-for-one).[12] The key assumption more broadly is that public money is more valuable under adverse macroeconomic shocks. For simplicity, we will thus assume that

$$C(G_1) = \begin{cases} G_1 & \text{for } G_1 \leq 0 \\ (1+\lambda)G_1 & \text{for } G_1 \geq 0. \end{cases}$$

As everything unfolds without any decision to take in period 2, we can (and will) take $G_2 = 0$ without loss of generality. Note also that we can focus on liquid assets such that $\theta_a > 1/(1+\lambda)$. Other liquid assets would never be used, and their negative return would imply that they would be never be hoarded in the first place.

The State has a stake in the bank's continuation. While it does not directly internalize the bank's welfare, a lower continuation scale translates into a credit crunch, lower activity and unemployment. The State values continuation scale j at βj.[13] That the company may be illiquid and that the State cares sufficiently about continuation as to then grant a bailout is what makes the company a "bank" in this model.[14] We make an assumption that will guarantee that the State always rescues the banks when there is a shortage of liquidity at date 1 (so $j(\rho) = i$ for all ρ):

$$\beta > (1+\lambda)(\rho_{\max} - \theta^0\rho^0). \tag{1}$$

[9] In this paper, we will view the State as a consolidated player. This simplifying assumption will resurface when we discuss liquidity assistance and bailouts. According to the official doctrine, bailouts come from the Treasury while the central bank supplies liquidity without incurring losses (the Bagehot doctrine). In practice, the distinction is murkier, especially as central banks have ventured into non-conventional policies and assumed potentially important risks (perhaps for political economy reasons as central banks are independent: they can decide rapidly and their actions receive a bit less media attention).

[10] More generally, the State could value the bankers' welfare as long as it puts a lower weight on them than on the rest of society.

[11] For a discussion of this assumption, see chapter 5 in Holmström-Tirole (2011).

[12] More generally, the shadow cost of public funds could be increasing in net government outlay, generating a positive correlation between this shadow cost and the macroeconomic shock.

[13] See e.g. Farhi-Tirole (2012) for micro-foundations for this reduced-form internalization.

[14] Some non-financial players may also satisfy those criteria, but the overwhelming share of enterprise bailouts combined with regulation are located in the financial intermediation sector.

Namely, $\rho_{\max} - \theta^0 \rho^0$ is the per-unit net reinvestment need in the absence of sources of liquidity other than the dilution of pledgeable income. We will later add a condition guaranteeing that the State nonetheless does not want to subsidize the bank's investment at date 0: See Proposition 1 and the Appendix.

Regulation. A regulatory contract comprises:

(a) a banking choice $\{i, \{\ell_a\}_{a \in \mathcal{A}}, \{\ell^d\}_{d \in \mathcal{D}}\}$, as well as a (positive or negative) transfer G_0 at date 0;

(b) as functions of the realized shock ρ, a transfer G_1 to the bank,[15] the resale fractions $\{x_a\}_{a \in \mathcal{A}}$ of liquid asset holdings, the dilution level x^0 of claims to pledgeable income, the fractions x^d of non-honored deposit claims of type $d \in \mathcal{D}$. Dilution levels for sources of liquidity, x_a, x^0, and x^d, belong to $[0, 1]$. Whether liquid assets and pledgeable income are sold at date 1 to the private sector or to the State does not matter as the haircuts (i.e., $1 - \theta_a$ and $1 - \theta^0$) are the same in both cases. The extent of involvement of the liquidity sources (including public funds) determines the continuation scale j.

Because condition (1) implies that continuation is a foregone conclusion ($j(\rho) = i$ for all ρ), and, because b is large enough, the banking entrepreneur is best rewarded through continuation and therefore through investment (his utility is $U = bi$), then for any reservation utility $\underline{U}$,[16] the regulator offers investment $i = \underline{U}/b$, and no more, provided that the State does not want to leave rents to banks. Figure 2 summarizes the timing.

Definition (bailinability). At the optimal policy

(i) A type of deposit d is "insured" or "non-bailinable" if $x^d(\rho) = 0$ for all ρ.

(ii) A type of deposit d is "bailinable" if $x^d(\rho) \in [0, 1]$ is a weakly increasing function of ρ taking values in $[0, 1]$.

The combined expected welfare of investors is the value of deposits plus that of non-resold assets:

$$E_\rho \Big[\Sigma_d \frac{[1 - x^d(\rho)]\ell^d}{\theta^d} \Big] + E_\rho \big[[1 - x^0(\rho)]\rho^0 i \big] + E_\rho \big[\Sigma_a [1 - x_a(\rho)] r_a \ell_a \big].$$

[15]The transfer $G_1(\rho)$ needs not be contracted for as condition (1) guarantees that the State, if anything, will be eager ex post to rescue the bank. In contrast, it is important that the State be able to make use of the various sources of liquidity specified by the resale fractions and the bailinability of certain types of liabilities.

[16]Banking entrepreneurs might instead operate in the shadow banking sector, move abroad, run a non-bank company, consume A, whatever is their best outside option. The level of i is thus determined by (i) its initial equity (A), (ii) the bank's outside option, and (iii) costly liquidity requirements (liquid asset hoarding and bailinability). See, e.g., Remark 4 in Section 3.2.

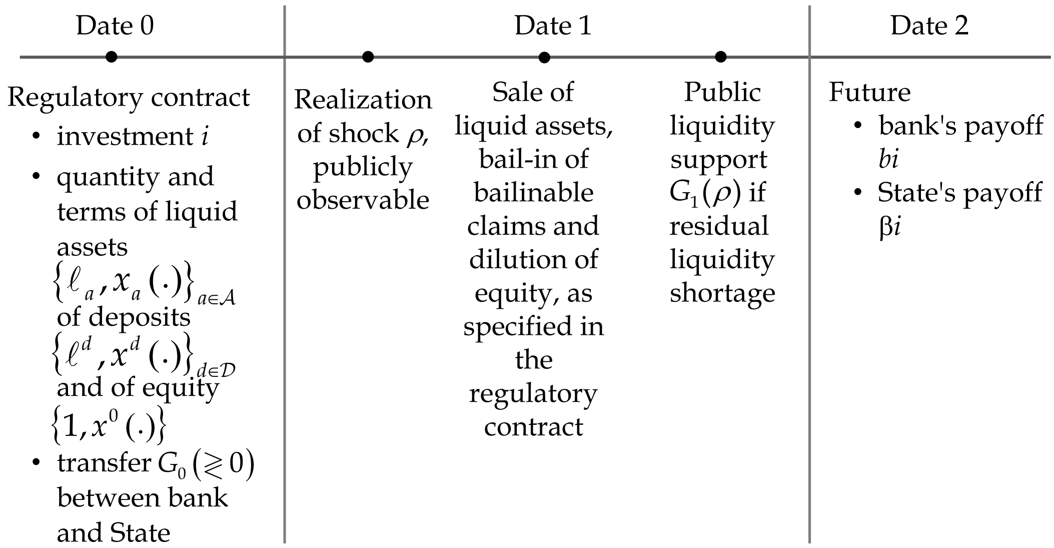

Figure 2: Timing

Assuming this welfare is internalized by the regulator while the bankers' welfare is not, the regulator's objective function writes:

$$W \equiv \Big[A + E_\rho\big[\sum_d [1 - x^d(\rho)]\ell^d/\theta^d\big] - (i + \sum_a \ell_a)\Big]$$
$$+\Big[E_\rho\big[[1 - x^0(\rho)]\rho^0 i + \sum_a [1 - x_a(\rho)] r_a \ell_a - C(G_1(\rho))\big]\Big] + \beta i \qquad (2)$$

as long as $bi \geq \underline{U}$, where the liquidity support, together with the resold shares and liquid assets must cover the liquidity shock plus the part of deposits that are honored:

$$G_1(\rho) = \rho i + \sum_d [1 - x^d(\rho)]\ell^d - [x^0(\rho)\theta^0\rho^0 i + \sum_a x_a(\rho)\theta_a r_a \ell_a] \qquad (3)$$

To understand the expression of social welfare (2), start with date 0. The bank has two date-0 resources, A and the value of the deposits $E_\rho[\sum_d [1 - x^d(\rho)]\ell^d/\theta^d]$, and two date-0 outflows, the investment i together with the purchase of liquid assets, $\sum_a \ell_a$. The difference between the date-0 resources and expenditures is equal to $-G_0$. Next consider date 1. The term $E_\rho\big[[1 - x^0(\rho)]\rho^0 i + \sum_a [1 - x_a(\rho)] r_a \ell_a\big]$ is the expected value of the bank's non-diluted assets; the social cost of a potential bailout corresponds to $E_\rho[C(G_1(\rho))]$. Finally, the date-2 social payoff corresponds to the long-term social payoff of investment βi.

To understand liquidity accounting (3) for an arbitrary shock ρ, a bailout, if any, must cover the liquidity shock, ρi, together with the honored deposit repayment, $\sum_d [1 - x^d(\rho)]\ell^d$. To defray this amount, the planner can dilute equity in the bank to obtain $x^0(\rho)\theta^0\rho^0 i$, and resell liquid assets against payment $\sum_a x_a(\rho)\theta_a r_a \ell_a$.

In practice, the date-0 net transfer made by the State to the bank, G_0, encompasses payments by the bank for lender-of-last-resort services and deposit insurance and/or a subsidy from the State to the bank for abiding by regulatory constraints or installing its headquarters in the country (this subsidy may for example take the form of underpricing of the insurance services).[17]

We will let

$$\bar{\Theta} \equiv \left\{ \{\theta_a\}_{a \in \mathcal{A}}, \theta^0, \{\theta^d\}_{d \in \mathcal{D}}, \frac{1}{1+\lambda} \right\}$$

denote the vector of (inverse) opportunity costs of cash at date 1, with generic element θ.[18] This will be a superset of the set Θ of actively used sources of liquidity.

To reduce the number of configurations under consideration, we will make the reasonable assumption that diluting shareholders is cheaper than using public funds:[19]

$$(1+\lambda)\theta^0 > 1. \tag{4}$$

Laissez-faire. By "laissez-faire", we mean the absence of regulation, i.e., a situation in which the State does not interact at date 0 with the bank, but may intervene to rescue it when push comes to shove at date 1. This situation is similar to that of investment banks and AIG prior to 2008 ("date 0") and in 2008 ("date 1"). Under laissez-faire, $G_0 = 0$. The State, which observes at date 1 the realization ρ of the liquidity shock, the liabilities to depositors, the level i of past investment, and the liquid assets held by the bank, offers support G_1 to the bank in a time-consistent way.

To illustrate the problem with laissez-faire, suppose that there is no pledgeable income: $\rho^0 = 0$. The representative bank chooses at date 0 its liquidity $\left\{ \{\ell_a\}_{a \in \mathcal{A}}, \{\ell^d\}^{d \in \mathcal{D}} \right\}$. Because hoarding of liquid assets is costly and substitutes for the bailout, the bank hoards no liquid asset ($\ell_a = 0$ for all $a \in \mathcal{A}$). Condition (1) ensures that a bailout ($G_1 = \rho i$) will refinance the bank at date 1. The bank further issues deposits $\mathcal{D} = \mathcal{D}^2 \equiv \left\{ d | \theta^d(1+\lambda) < 1 \right\}$. The bank can then invest

$$i = A + \Sigma_{d \in \mathcal{D}^2} \frac{\bar{\ell}^d}{\theta^d},$$

as depositors for which the cost of public funds, $1 + \lambda$, is smaller from the utility from receiving cash, $1/\theta^d$, are expected to be rescued by the State. The big picture therefore

[17]The sign of G_0 (deficit or surplus) depends both on the allocation of surpluses $G_1(\rho) < 0$ (as the consumers' and State's marginal rates of substitution are then both equal to 1), and on $\underline{U}$, i.e., the bank's outside options (e.g., can it operate in the shadow banking sector? Can it move to another country?).

[18]$1 + \lambda$ is the opportunity cost of public funds when relevant, i.e. when the State supports the bank ($G_1(\rho) > 0$).

[19]Were condition (4) not satisfied, our analysis would imply that shareholders would be insured (non-bailinable); while the condition technically is not needed, the implication that shareholders are not diluted in its absence would be unreasonable.

is that under laissez-faire the bank hoards no liquid assets and issues all deposits that are politically sensitive enough so as to be, like investment itself, rescued by the State.

2.2 Optimal liquidity

This paper's central result characterizes the optimal regulatory contract, that maximizes W subject to $i \geq \underline{U}/b$, the bank's participation constraint.

Proposition 1 *(optimal prudential regulation)*

There exists $\bar{\beta} > (1+\lambda)(\rho_{\max} - \theta^0\rho^0)$ such that for $\beta \leq \bar{\beta}$, the State does not want to subsidize the bank at date 0 and gives it its reservation utility $\underline{U}$. The optimal regulatory scheme involves investment $i = \underline{U}/b$ and exhibits the following features:

(i) Bailinability. Liabilities targeted to type-d investors are bailinable if $d \in \mathcal{D}^1$ and non-bailinable (insured) if $d \in \mathcal{D}^2$, where

$$\mathcal{D}^1 \equiv \{d|\theta^d(1+\lambda) > 1\} \text{ and } \mathcal{D}^2 \equiv \mathcal{D}\backslash\mathcal{D}^1.$$

There is no rationing of such liabilities: $\ell^d = \bar{\ell}^d$.

(ii) Pecking order. Liquid assets are resold and liabilities bailed in according to their value of θ. As ρ grows above 0, the highest-θ item in Θ (whether a liquid asset or a bailinable liability) is used to cover small net liquidity shocks, the next-to-highest θ steps in when the most liquid source is exhausted, and so forth until some $\rho^* < \rho_{\max}$ beyond which all bailinable liabilities are wiped out and all liquid assets are sold. The shortfall in liquidity is then made up through public funds (public money is used only in tail events).

So, overall, letting $\rho^* < \rho_{max}$ denote the cutoff such that shocks beyond ρ^* are covered through a bailout, a pecking order is followed for $\rho \in [0, \rho^*]$ on each side of the balance sheet, from the most liquid to the most illiquid on the asset side, and from the lowest-liquidity-demand depositors to the highest-liquidity-demand ones in $\mathcal{D}^1$ on the liability side.

(iii) Delegation. The optimum can be decentralized through a Liquidity-Weighted Buffer (LWB) requirement, in which liquid assets' and equity's weights reflect their haircuts and non-bailinable securities receive weight 1:

$$\sum_a \theta_a r_a \ell_a + \theta^0 \rho^0 i \geq \rho^* i + \sum_{d \in \mathcal{D}^2} \bar{\ell}^d$$

where $\mathcal{D}^2$ denotes the set of liabilities that cannot be bailed in according to part (i). Monitoring the bank's liquidity <u>structure</u> is not necessary as long as a liquidity <u>level</u>

is mandated and all assets and claims, except non-bailinable claims, can be employed (the bank is free to use whatever means it wants to meet a particular shock $\rho < \rho^*$).

(iv) Reserve requirements for insured deposits. Therefore, any increase in insured deposits ($\sum_{d\in\mathcal{D}^2} \ell^d$) must be met, for a given investment level, one-for-one by an increase in haircut-adjusted liquidity.

Proposition 1 (i) is reminiscent of "priority servicing" in electricity retail markets (Wilson 1993). Bailing in liabilities involves no free lunch. As long as holders of liability d care about the certainty of being paid back ($\theta^d < 1$), bailing in the security creates a deadweight loss, that needs to be compared with the concomitant reduction in liquid assets or the reduced likelihood of a bailout.[20]

Part (ii) also finds a perfect analogy in power markets, but on the supply side. A basic dispatching rule states that base-load plants with high fixed cost and low marginal cost are used most of the time, while peak-load plants with low fixed cost and high marginal cost are used occasionally (Boiteux 1949).

To understand part (iii), the available liquidity must guarantee that no public money is required as long as $\rho \leq \rho^*$. Put differently, this liquidity must cover the reinvestment need $\rho^* i$, plus the payment on the non-bailinable claims $\sum_{d\in\mathcal{D}^2} \bar{\ell}^d$. What can be obtained by reselling assets and claims on the pledgeable income is equal to $\sum_a \theta_a r_a \ell_a + \theta^0 \rho^0 i$. Part (iii) states that, given the required amount of liquidity, the bank has the right incentives for the choice of structure of liquidity: It minimizes the expected cost of supplying this total liquidity.

Proof of Proposition 1

(i) and (ii) We maximize W subject to constraint (3), with respect to the various choice parameters:

$$\max_{\{\{\ell_a, x_a\}_{a\in\mathcal{A}}, \{\ell^d, x^d\}_{d\in\mathcal{D}}, x^0, i\}} W$$

Let $\mu(\rho)$ denote the shadow price of \$1 of money available to the bank, i.e. the shadow price of constraint (3). So, $\mu(\rho) = 1 + \lambda$ when $G_1(\rho) > 0$; $\mu(\rho) = 1$ when $G_1(\rho) < 0$; and $\mu(\rho) \in [1, 1+\lambda]$ otherwise. The FOC with respect to the three sources of liquidity are: $\frac{\partial W}{\partial x_a(\rho)} = r_a \ell_a[-1 + \mu(\rho)\theta_a]$, $\frac{\partial W}{\partial x^d(\rho)} = \frac{\ell^d}{\theta^d}[-1 + \mu(\rho)\theta^d]$, and $\frac{\partial W}{\partial x^0(\rho)} = \rho^0 i[-1 + \mu(\rho)\theta^0]$.

- Claims $d \in \mathcal{D}^2$ are by definition such that $(1+\lambda)\theta^d < 1$. And so $x^d(\rho) = 0$ for all ρ: these claims are fully insured. Let $\mid \Theta \mid \subseteq \mid \bar{\Theta} \mid / \mathcal{D}^2$.
- If $\mu(\rho) = 1$, all x's are equal to 0, and $G_1(\rho) = \rho i + \Sigma_d \ell^d \leq 0$; thus, net shocks must be negative, or put differently reinvestment (plus the repayment of deposits) is financed by the date-1 revenue. This may happen only if $\rho_{min} < 0$.

[20] The counterpart of a bailout in the electricity sector corresponds to expensive power purchases abroad by the State.

- Defining $\mathcal{D}^1$ as in Proposition 1, public funds are not employed unless all sources of liquidity (except for the insured claims, $d \in \mathcal{D}^2$) are depleted: $G_1(\rho) > 0$ requires $\mu(\rho) = 1 + \lambda$ and so, for all $a \in \mathcal{A}$, for all $d \in \mathcal{D}^1$, $x_a(\rho) = x^d(\rho) = x^0(\rho) = 1$.

Let ρ^* be equal to total available liquidity (again, aside from $d \in \mathcal{D}^2$) per unit of investment:

$$\rho^* i \equiv \sum_a \theta_a r_a \ell_a + \theta^0 \rho^0 i - \sum_{d \in \mathcal{D}^2} \ell^d$$

For $\rho_{\min} \leq \rho \leq \rho^*$, $G_1(\rho) \leq 0$. The shadow price $\mu(\rho)$ is weakly increasing in ρ, as the bank first pays deposits from date-1 net revenue (low ρ's), and then uses its liquidity options according to the pecking order given by the FOC ($G_1(\rho) = 0$ in this case): use the highest θ coefficient first and when this source of liquidity is exhausted, move on the the next best source, i.e., use the next source in terms of liquidity, etc. Finally, we note that W is increasing in ℓ^d and so $\ell^d = \bar{\ell}^d$, for all $d \in \mathcal{D}$.

More precisely, the pecking order goes as follows for $\rho i + \Sigma_d \ell^d > 0$ where $\Sigma_d \ell^d$ is the total volume of deposits (there is no need for liquidity for $\rho i + \Sigma_d \ell^d \leq 0$) and $\mu(\rho) > 1$: rank sources of liquidity on both sides of the balance sheet by index z such that $\theta(z)$ is decreasing, and let $L(z)$ the corresponding quantity. The index z can refer to a liquid asset $a \in \mathcal{A}$, a bailinable claim $d \in \mathcal{D}^1$, or the pledgeable income (which is also bailinable at the optimum). So, $L(z) = \theta_a r_a \ell_a$ if $z = a$, $L(z) = \ell^d$ for $z = d$, and $L(z) = \theta^0 \rho^0 i$ when z refers to the pledgeable income.

Similarly, define cutoffs $\rho^*(z)$ for $z \in \{0, 1, ..., |\Theta|\}$, with $\rho^*(0) = -\Sigma_d \ell^d / i$, and $\rho^*(z)$ increasing in z: Given distribution $F(\rho)$,

- shocks in $(\rho^*(0), \rho^*(1)]$ are met using source of liquidity 1: $[\rho^*(1) - \rho^*(0)]i \equiv L(1)$.
- shocks in $(\rho^*(1), \rho^*(2))$ are met with sources of liquidity 1 and (at the margin) 2: $[\rho^*(2) - \rho^*(1)]i \equiv L(2)$; etc, until $\rho^*(|\Theta|)) = \rho^*$.

The maximization of W is with respect to the pecking order and the structure of liquid assets ($a \in \mathcal{A}$); for claims on the liability side, the volume of liquidity is exdogenously given and the only question is their rank in the pecking order. For given sources of liquidity, the pecking order is given by:

$$\max \sum_{z=1}^{z=|\Theta|} [\int_{\rho^*(z-1)}^{\rho^*(z)} \frac{[\rho^*(z) - \rho]i}{\theta(z)} dF(\rho) + [1 - F(\rho^*(z)] \frac{L(z)}{\theta(z)}].$$

Take two sources of liquidity with ranks $z < z'$. One can permute and supply amount of liquidity $L(z)$ with the liquid asset z', and conversely amount of liquidity $L(z')$ with source z. Because the initial pecking order has $\theta(z) > \theta(z')$, the maximand is reduced by the permutation; the optimum keeps high return/high haircut assets for high shocks.

Finally, we return to the date-0 investment scale i. We know that $i \geq \underline{U}/b$. Would the State want to increase the bank's scale to benefit from more activity, a possibility that would happen for β very large? To guarantee this is not the case, let us maximize W with respect to i . Using the envelope theorem, the condition is thus:

$$\frac{\partial W}{\partial i} = \beta - 1 - E_{\rho}[\mu(\rho)\rho] + E_{\rho}[[\mu(\rho)\theta^0 x^0(\rho) + [1 - x^0(\rho)]]\rho^0] \leq 0 \tag{5}$$

Because the technology is assumed linear,[21] there must be a bound on the State's demand for investment (otherwise the State would subsidize an unbounded investment). This defines a condition $\beta \leq \bar{\beta}$, with $\bar{\beta} > (1+\lambda)[\rho_{max} - \theta^0\rho^0]$. The analysis can be generalized without qualitative difference if (1) is not satisfied (there may just be no bailout for ρ very large: See Appendix A.1) or if (5) fails (in which case the State may subsidize the banks, but decreasing returns to scale must be introduced to keep its size bounded).

(iii) and (iv). Define the bank's net cost of procuring liquidity $\rho^* i$ under investment i as

$$\mathcal{C} \equiv \min_{\{\{\ell_a, x_a\}_{a\in\mathcal{A}}, \{\ell^d, x^d\}_{d\in\mathcal{D}}, x^0\}} \{A + \sum_a \ell_a - E_\rho[\sum_d [1 - x^d(\rho)]\ell^d/\theta^d + [1 - x^0(\rho)]\rho^0 i + \sum_a [1 - x_a(\rho)] r_a \ell_a]\}$$

subject to (3) and

$$\sum_a \theta_a r_a \ell_a + \theta^0\rho^0 i - \sum_{d\in\mathcal{D}^2} \ell^d \geq \rho^* i$$

This minimization program is a subprogram of the W-maximization program above. Thus, if delegated the choice of the liquidity *structure* and only instructed to reach some liquidity *level*, while declaring a subset of liability $d \in \mathcal{D}^2$ non-bailinable, the bank selects the right structure. Intuitively, the externality exerted by the bank in its liquidity choice occurs only for high shocks ($\rho > \rho^*$); the bank internalizes what happens for lower shocks. ■

2.3 Discussion: Sources of liquidity

Our model encompasses the four main sources of liquidity for banks. First, they can hoard assets with various degrees of liquidity (Treasury bonds, municipal bonds...), that they can resell when needing cash. These correspond to assets $\{\ell_a\}_{a\in\mathcal{A}}$. Second, they can dilute "equity", $\rho^0 j$, namely the rights on the date-2 pledgeable income on past, safeguarded investments. Third, they can bail-in non-guaranteed deposits and non-secured liabilities, $\{\ell^d\}_{d\in D^1}$. In each of these cases, there can be a haircut: The bank does not receive the full amount because of a second-best use or a bid-ask spread perhaps due to adverse selection: Only the fraction $\theta_{.}$ is cashed by the bank. Fourth, invisible in the balance

[21] The limited availability of cheap deposits $\{\bar{\ell}^d\}_{d\in\mathcal{D}}$ is in itself a source of non-linearity. Because we want a finite investment in all cases, we make a conservative assumption.

sheet, but very visible in public policy, are bailouts, namely a government support equal to G_1.[22]

Remark 1 (state-contingent liquidity intensity). The θs may be shock dependent (for example, the haircut $1 - \theta^0(\rho)$ might increase with the macroeconomic hardship). As long as the θs weakly decrease in ρ, a reasonable assumption, the net liquidity needs a fortiori grow with ρ and the analysis carries through. Haircuts that increase with the macroeconomic shock create a multiplier effect, but do not affect the characterization in Proposition 1.

Remark 2 (solvency and number of regulatory ratios). At this stage, there are two ratios, a liquidity ratio and a solvency ratio. The latter ($i \leq \underline{U}/b$) is of limited interest in our context because our assumptions do not really allow the bank to downsize (or to surrender control rights, in a broader model). Appendix A offers a more interesting description of the solvency ratio (even though our focus is on liquidity structure). First, it relaxes the no-downsizing-outcome assumption (1). This implies that the banker's reward, although still in continuation (if b is sufficiently large), depends both on scale (i) and on the state-contingent pattern of downsizing ($j(\rho)$). Put less abstractly, there is a trade-off between solvency and liquidity.[23] Second, it shows how to think about taxes on banking liquidity (or deposit insurance premia) in a world of heterogenous banks.

More broadly, there are at least two reasons why theory commands more than two ratios. First, there are in practice more than one "period" in which the bank may need cash; namely as $t \in \{0, 1, .., T\}$, the regulator needs to impose T ratios in the optimal scheme (the date-0 ratio can be viewed as the solvency ratio). In practice, Basel III instituted two liquidity ratios: the Liquidity Coverage Ratio, with a one-month horizon and the Net Stable Funding Ratio, with a one-year horizon. The second reason why more ratios may be needed is that the bank here exerts a single externality under laissez-faire, namely on public finances. The bank may exert other externalities, such as fire-sales externalities; as we will see in Section 3.2, additional externalities require additional instruments, and therefore possibly more ratios.

Remark 3 (complexity). Our LWB requirement not only defines a pecking order among the liquid assets and a hierarchy of claims on the liability side (as do, respectively, the

[22] As in Holmström-Tirole (1998, 2011), the answer to the question "What is it that the State can do that the private sector cannot do?" rests on the assumption that the State has a unique ability to tax private-sector income in the future, and thereby to issue debt implicitly backed by this private fiscal collateral. Similarly, the use of foreign liquidity is limited by the limited pledgeable income of the country itself. While foreign debt is feasible (and indeed used in case of wars or earthquakes, or issued by smoothing or prodigal governments), the possibility of default imposes limits on the resort to foreign liquidity. Note that, like the rest of the literature, we do not allow the government to bring liquidity assistance against taking ownership of liquid assets. Such transfers of ownership might avoid liquidity discounts $\{(1-\theta_a)l_a\}_{a\in A}$ when putting the assets in the market at date 1. This reduced-form assumption may reflect asymmetric information, inferior ability to manage the liquid-asset portfolio, or an increase in the spread paid on sovereign borrowing, as this transaction temporarily increases government debt.

[23] For a general discussion of this trade-off between liquidity and scale, see, e.g., Tirole (2006, chapters 5 and 15) or Farhi-Tirole (2012).

LCR and TLAC), but it blends them. Although it does not add much complexity relative to existing institutions, it may be perceived as straining the institutional capacity of the supervisors. This is where our delegation result comes in handy: while the supervisor and the bank are in a frontal conflict over the level of liquidity, they are aligned with respect to liquidity structure. A second, here unmodelled, benefit from delegation is that it allows banks to tailor their liquidity structure to their own funding circumstances. In the end what matters is that banks internalize their externalities on the rest of society.

3 Policy-relevant extensions

This section analyzes four important policy questions that arose during the conception of the new liquidity regulation: (1) Do optimal liquidity requirements depend on the supply of liquid assets, and how? (2) Does the possibility of fire sales affect the design of the liquidity requirement? (3) What is the optimal treatment for wholesale deposits? (4) Does the model capture rollover shocks?

For conciseness only, we study these in the following simplified context:

- *Two liquid assets.* "Level-1 assets" are perfectly liquid; indeed $\theta_1 = 1$. They yield $r_1 < 1$ (at date 1 or 2) for a price of 1 at date 0. "Level-2 assets" pay more at date 2 ($1 > r_2 > r_1$), but are less liquid and deliver only $\theta_2 r_2 < r_1$ if liquidated at date 1. Level-2 liquidity satisfies $\theta_2(1+\lambda) > 1$ (otherwise it would never be used).

- *No cheap liquidity.* There are no cheap deposits ($\mathcal{D} = \emptyset$). We further normalize the pledgeable income to be equal to 0: $\rho^0 = 0$.

- *Fixed investment.* Because the questions we pose are orthogonal to bank size/solvency, we also normalize the investment size: $i = 1$.

- *Positive shocks.* Liquidity shocks lie in $[0, \rho_{\max}]$.

Again our insights do not hinge on these expositional choices.

Before pursuing key extensions, let us familiarize ourselves with this version of the model. Suppose that θ_2 is not too small, so that the representative bank hoards the two types of liquid assets at the optimal regulatory scheme (see below). Program (2) can be expressed as a maximization either over liquid assets $\{\ell_1, \ell_2\}$ or over cutoffs $\{\hat{\rho}, \rho^*\}$ at which the level-1 assets and the level-2 assets are exhausted. Let us solve for the representative bank's liquidity structure:

$$\max_{\{\rho^* \geq \widehat{\rho}\}} \Bigg\{ -\frac{\widehat{\rho}}{r_1} - \frac{\rho^* - \widehat{\rho}}{\theta_2 r_2} + \int_0^{\widehat{\rho}} \left[\widehat{\rho} - \rho + \frac{\rho^* - \widehat{\rho}}{\theta_2}\right] dF(\rho) + \int_{\widehat{\rho}}^{\rho^*} \left[\frac{\rho^* - \rho}{\theta_2}\right] dF(\rho)$$
$$- \int_{\rho^*}^{\bar{\rho}} (1+\lambda)(\rho - \rho^*) dF(\rho) \Bigg\}. \quad (6)$$

Provided that r_1 is not too small, the optimal regulatory contract always induces hoarding of level-1 liquidity ($\hat{\rho} > 0$). Hoarding of level-2 liquidity ($\rho^* > \hat{\rho}$) occurs if and only if θ_2 exceeds some threshold θ_2^*.[24] Level-1 liquidity then satisfies:

$$\frac{1-\theta_2}{\theta_2} F(\hat{\rho}) = \frac{1}{\theta_2 r_2} - \frac{1}{r_1}, \tag{7}$$

while level-2 liquidity is given by:

$$F(\rho^*) + [1 - F(\rho^*)](1+\lambda)\theta_2 = \frac{1}{r_2}. \tag{8}$$

To understand condition (8), suppose that the bank hoards $1/\theta_2 r_2$ units of level-2 asset more, yielding \$1 more at date 1. With probability $1 - F(\rho^*)$, the bailout if reduced, and with probability $F(\rho^*)$, the extra unit is returned to investors, yielding $r_2/\theta_2 r_2$. Comparing this with the date-0 cost of purchase, $1/\theta_2 r_2$, yields (8).

Asset substitution. How do risk taking and larger shocks affect optimal liquidity management? Consider first a first-order-stochastic-dominance shift in the distribution of liquidity shocks $F(\rho; \gamma)$ with $F_\gamma < 0$. Then date-1 level-1 and overall liquidity, $\hat{\rho}$ and ρ^*, increase, while the impact on level-2 liquidity $\rho^* - \hat{\rho}$ is in general ambiguous. A uniform upward shift γ in the distribution of shocks, $F(\rho - \gamma)$, requires an increase in level-1 liquidity of the same magnitude, and no change in level-2 liquidity.

Suppose next a second-order stochastic dominance shift in the form of a rotation.[25] An inspection of the optimality conditions shows that the amount of level-1 liquidity $\hat{\rho}$ increases (decreases) with risk taking if and only if it exceeds (is smaller than) the rotation point ($\hat{\rho} \gtrless \rho_\gamma$). In particular, it decreases if liquidity shocks are tail shocks, i.e. infrequent, but large. The same holds for LWB, ρ^*. It may seem surprising that risk-taking leads to lower liquidity when tail-risk is involved. But tail risk implies that liquidity is rarely used and therefore very costly. Our model then predicts that *"tail risk-taking" should go together with a sharp increase in the tax on banking activity* ($-G_0$) *(or in the deposit insurance premium) rather than an increase in liquid assets.*

3.1 Impact of the supply of safe assets on prudential supervision

We have so far assumed that liquid assets are available in unlimited quantities, so their return does not depend on regulatory demand. However, there may be a scarcity of such assets either at the world level (especially if regulatory rules for banks, insurance companies and pension funds all encourage their use by regulated institutions), or, as is often the case, at the country level if there is a home bias in the banks' portfolio.

[24] If $\theta_2 < \theta_2^*$, only level-1 liquidity is hoarded, and is given by $F(\rho^*) + [1 - F(\rho^*)](1+\lambda) = \frac{1}{r_1}$.

[25] A parameter γ of distribution $F(\rho;\gamma)$ is a rotation parameter if there exists a "rotation point" ρ_γ such that $F_\rho \geq 0$ for $\rho \leq \rho_\gamma$ and $F_\rho \leq 0$ for $\rho \geq \rho_\gamma$.

Level-1 liquidity is in practice mostly covered by Sovereign bonds or similar securities. The design of the Liquidity Coverage Ratio by the Basel Committee raised the issue of whether a one-size-fits-all approach makes sense in a world in which Switzerland, Norway, or Australia's debt-to-GDP ratio lies between 20 and 40% and Japan's at 220%.[26] Does our model shed light on this debate? Of course, this debate is meaningful only if cross-country diversification is not perfect (Australian banks do not hoard substantial amounts of Japanese bonds and hedge against the Yen/A$ exchange rate fluctuations), and so domestic liquidity matters. We will take the fact that banks hoard primarily domestic bonds for granted and will not investigate its causes.

Suppose that there is a fixed supply L_1 of level-1 assets in the economy, and that the price $p_1 = 1/r_1 > 1$ of these assets embodies a liquidity premium and is an increasing function of banks' demand ℓ_1 for this asset:[27] $p_1 = P_1(L_1 - \ell_1) = P_1(L_1 - (\widehat{\rho}/r_1))$ with $P_1' < 0$ and $P_1(+\infty) = 1/r_2$ where $\widehat{\rho} = r_1\ell_1$ denotes the maximum shock that is covered solely by level-1 liquidity (recall the notational simplification $\theta_1 = 1$). One may have in mind that (a) L_1 is driven exogenously by the supply of public goods and the public deficit and (b) banks compete with other parties for safe assets.[28] We further assume that $P_1'' \geq 0$, and that there is an infinitely elastic supply of level-2 assets, although this assumption could be relaxed.

Proposition 2 *(supply of safe, liquid assets)*

There exists a threshold $\bar{L}_1$ such that:

(i) $L_1 < \bar{L}_1$: If the supply of level-1 liquid assets is not so abundant that level-2 liquid assets are no longer used for prudential purposes, the amount of level-1 assets at the optimal prudential regulation grows with the supply of the assets $\partial\ell_1/\partial L_1 > 0$. Total haircut-adjusted liquidity (LWB), $r_1\ell_1 + \theta_2 r_2 \ell_2 = \rho^*$ (normalizing $\theta_1 = 1$), is invariant to the supply of level-1 assets, which means that level-1 and level-2 assets (discount-weighted) substitute one-for-one for each other as level-1 liquidity adjusts to the supply.

(ii) $L_1 \geq \bar{L}_1$: A country with abundant net supply uses only level-1 liquid assets; total liquidity then expands with the supply.

Proof of Proposition 2

[26] Specifically, banks from countries with low sovereign debt levels are allowed to fill part of their level-1 buffer with "Committed Liquidity Facilities" (CLF) obtained from their Central Bank at "market rates".

[27] We assume that higher level-1 liquidity requirements reduce the net supply of such assets and thus raise their price. When the Sovereign's solvency is a concern, a doom-loop mechanism could also be at play, as in e.g. Farhi-Tirole (2018).

[28] For simplicity, we will not incorporate the utility of these third parties into social welfare. Note also that we assume that L_1 is a legacy stock of liquid assets. It would be straightforward to extend the model to allow for date-0 issuance of public debt. The analysis would then incorporate the public sector's endogenous cost of issuing debt.

Suppose that the bank uses the two liquid assets. Let shocks in $[0, \hat{\rho}]$ be covered by liquid asset 1, and those in $[\hat{\rho}, \rho^*]$ by (at the margin) liquid asset 2. So, given that we set $\theta_1 = 1$,

$$\hat{\rho} = r_1 \ell_1 \quad \text{and} \quad \rho^* = \hat{\rho} + \theta_2 r_2 \ell_2.$$

The cost of purchasing liquid assets in the maximand writes: $-P_1(L_1 - \ell_1)\ell_1 = -P_1(L_1 - (\widehat{\rho}/r_1))\widehat{\rho}/r_1$. The cost-minimization program (which generalizes (6) to P_1 elastic to the supply) solves

$$\begin{aligned} \min_{\{\hat{\rho},\rho^*\}} \Big\{ & P_1\Big(L_1 - \frac{\hat{\rho}}{r_1}\Big)\frac{\hat{\rho}}{r_1} + \frac{\rho^* - \hat{\rho}}{\theta_2 r_2} \\ & - \int_0^{\hat{\rho}} \Big[(\hat{\rho} - \rho) + \frac{\rho^* - \hat{\rho}}{\theta_2}\Big] dF(\rho) - \int_{\hat{\rho}}^{\rho^*} \frac{\rho^* - \rho}{\theta_2} dF(\rho) \\ & -(1+\lambda) \int_{\rho^*}^{\rho_{\max}} (\rho - \rho^*) dF(\rho) \Big\}. \end{aligned} \tag{9}$$

A standard revealed-preference argument implies that $\hat{\rho}$ increases with L_1. Next, this cost-minimization program is quasi-convex in ρ^* given that $1 + \lambda > 1/\theta_2$. The FOC with respect to ρ^* yields condition (8):

$$F(\rho^*) + (1+\lambda)[1 - F(\rho^*)]\theta_2 = \frac{1}{r_2}.$$

This condition implies that $\rho^* < \rho_{\max}$: As we already noted in the general model, it is not optimal to hoard costly liquidity that one will never use. Because $\hat{\rho}$ is increasing in L_1, there exists $\bar{L}_1$ such that this two-liquidity-sources outcome obtains if and only if $L_1 < \bar{L}_1$. The case with $L_1 \geq \bar{L}_1$ implies an exclusive use of level-1 liquidity and is straightforward (set $\hat{\rho} = \rho^*$ in the program above). ■

A few comments are in order:

Single capital market. Suppose that banks invest in international liquidity rather than just domestic liquidity, while they are still domestic in their operations.[29] What are the implications? Total liquidity is now $L_1 = \Sigma_k L_1^k$, where L_1^k is country k's level-1 liquidity. Low-supply/low-interest-rate countries benefit from the relative expansion of level-1 liquidity and hoard less level-2 liquidity than under autarky; the reverse holds for high-supply/high-interest-rate countries. Again, an analogy with electricity markets can be illuminating. Consumers and industrial users located in cheap electricity regions usually oppose the construction of new transmission lines connecting regions or countries with more expensive electricity, as they know that the price of electricity will rise in their own region or country. Here, banks in high level-1 supply countries will be hurt if banks in other countries start diversifying.

[29] International diversification of banking investment raises the question of which country has the most incentive to rescue illiquid banks (Farhi-Tirole 2025).

Safe sovereign debt? Finally, we have assumed that Sovereign bonds remain safe as their supply expands. The possibility that this is not the case has received substantial attention in the international finance literature, and there is no point rehashing the latter's insights. Let us just qualify Proposition 2 by noting that it holds only as long as an increase in the supply does not substantially affect the probability of Sovereign default.

3.2 Shallow markets and macroprudential aspects

Let us now assume that the date-1 market for liquid asset 2 has limited absorption capacity.[30] Namely, let l_2 denote the hoarded amount of level-2 liquidity, and $x_2(\rho)$ the fraction of these assets that are put on the market in state of nature ρ. We will assume that the liquidity parameters of level-2 assets is $\theta_2 = \theta_H$ if sales lie below some threshold α, that is if $l_2 x_2(\rho) \leq \alpha$, and $\theta_2 = \theta_L < \theta_H$ (fire sales) otherwise. Micro-foundations can be provided in which a mass α of "natural buyers" of the asset can buy and manage one unit of the asset each, so the marginal buyer has a lower willingness to pay when a high volume is put on the market.[31] The no-fire-sales model is a special case of this model, with α sufficiently large ($\alpha \geq \ell_2^*$) and $\theta_2 \equiv \theta_H$. We normalize $r_2 = 1$ for notational simplicity.

The buyers' profit is higher in the high-discount situation than in the low-discount one. This raises the issue of how the buyers' welfare is weighted in the social welfare function. For notational simplicity, we assume that the social planner puts no weight on buyer welfare.[32]

[30]It may be that the marginal buyer has a decreasing valuation for the asset (Shleifer-Vishny 1992, Lorenzoni 2008, Stein 2012), that potential buyers have limited cash (Allen-Gale 1994), or that buyers with lower ability to distinguish assets and therefore more concerned about adversely-selected purchases become the marginal buyers (Kurlat 2016). What matters for what follows is a) the existence of a resale discount, and b) the dependence of this discount on the volume of securitized assets.

[31]To provide limited-cash micro-foundations for the depth of markets, suppose that asset 2 can be managed by alternative buyers with private benefit b_2. Each buyer can manage one asset (one unit of level-2 liquidity). Outside investors stand ready to buy the rest of the claims. A mass α of potential buyers has wealth w_H each at date 1, while there is an unbounded number of buyers who have no wealth: $w_L = 0$. To guarantee the existence of haircuts (illiquidity), we assume that $w_H < b_2$, where b_2, recall, is the haircut when selling a level-2 asset to a cashless buyer (in particular, $b_2 = 1$ if one imposes $\rho^0 = 0$, which is not necessary here). A bidder with wealth w can bid up to $w + (1 - b_2)$; that is, he can bring equity w and lever up by pledging the liquid asset's pledgeable income $1 - b_2$. Let $x_2(\rho)$ denote the fraction of type-2 assets that are put up for sale in state of nature ρ. Because the pledgeable income can always serve to finance the purchase (by leveraging up) but does not exhaust total value, then the resale price depends on whether the marginal buyer has low or high net wealth, and is equal to $\theta_k \equiv 1 - (b_2 - w_k)$, where $k = H$ if $\ell_2 x_2(\rho) \leq \alpha$ and $k = L$ if $\ell_2 x_2(\rho) > \alpha$. So, regardless of how much is offered for sale, there is a discount as potential buyers do not have enough wealth to pay for the non-pledgeable income; but this discount can be high or low depending on how much is put up for sale. And while the asset sells at a discount, it reaches its highest value (strictly or weakly) in private hands.

[32]This assumption is much stronger than needed: Even if buyers received the same weight as consumers, their obtaining a higher discount forces banks to hoard more of the costly liquidity, altering the net transfer to the State and generating a social loss.

The Bagehot doctrine. In the absence of public intervention there can be multiple equilibria for a given amount of liquidity (ℓ_1, ℓ_2). This occurs whenever the banks are keen on continuing even if that means selling at a big discount, but the shock is not so high as to preclude a low-discount equilibrium:

$$\theta_L \alpha \leq \rho - r_1 \ell_1 \leq \theta_H \alpha. \tag{10}$$

In this case, the State can enforce the "good equilibrium" (the low-discount one), by setting a floor, i.e. by standing ready to purchase assets at yield (slightly smaller than) θ_H. In equilibrium the State purchases no assets, but it prevents fire sales through the backstop. This can be viewed as an illustration of the Bagehot doctrine, that directs central banks to bring liquidity without incurring losses. The State can enforce the preferred equilibrium by standing ready to purchase liquid assets at a price floor (making these assets "central-bank eligible"). In the following, we will assume that the low-discount equilibrium prevails when (10) is satisfied; so coordination failures are not the rationale for regulation in the remainder of this section.

Implications of fire sales for liquidity regulation. It is well-known that fire sales externalities imply that banks may hoard insufficient liquidity. The new point here is that they may also hold the *wrong kind of liquidity.*

Let (ℓ_1^*, ℓ_2^*) denote the optimal liquidity management (solving Program (9) with $P_1 = 1/r_1$) when $\theta_2 = \theta_H$. The following proposition is demonstrated in Appendix B. Its main insight is that imposing a minimum level of overall liquidity (a LWB requirement) no longer suffices. When arbitraging between level 1 and 2 liquidity supports, the bank does not internalize the impact of its choice on fire sales and so on the liquidity position of other banks. Thus, the fire sales externality exists both in the level and structure dimensions. It is interesting to note that recent regulations impose not only a minimum liquidity requirement, but also a minimum level-1 liquidity requirement (and so, implicitly, a cap on level-2 liquidity).

Proposition 3 *(minimum level-1 liquidity) Normalizing $\theta_1 = 1$ and $r_2 = 1$ for notational simplicity:*

(i) If the resale market for level-2 liquidity is deep in the sense that $r_1 \ell_1^* + \theta_H \alpha \geq \rho^*$, there are no fire-sales externalities if the Bagehot doctrine is applied. The decision concerning the composition of the liquidity portfolio can be delegated to the bank through a LWB requirement: No minimum level-1-liquidity requirement needs to be imposed.

(ii) If the resale market for level-2 liquidity is shallow ($r_1 \ell_1^* + \theta_H \alpha < \rho^*$), there exists $\underline{\theta}_L > 1/(1+\lambda)$ such that

(a) if $\theta_L \leq \underline{\theta}_L$, then again there are no fire-sales. The optimal liquidity portfolio (ℓ_1, ℓ_2) satisfies $\hat{\ell}_1 > \ell_1^*$ and $\hat{\ell}_2 = \alpha < \ell_2^*$. Bailouts are more frequent than

when the market for level-2 liquidity is deep. In contrast with the case of a deep market, a LWB requirement does not suffice: individual LWB-constrained banks would select too little baseload liquidity ($\ell_1 = \ell_1^*$) and too much peak-load liquidity ($\ell_2 > \alpha$), generating fire sales. The two wedges between private and social interests (involuntary bailouts and fire sales) require two instruments: a LWB requirement and a minimum-level-1-liquidity requirement.

(b) *If $\theta_L > \underline{\theta}_L$, then the social optimum involves some fire sales as well as the use of public funds. There exist $\widehat{\rho} \leq \rho^* \leq \mathring{\rho}$ such that the pecking order for liquidity use is level-1 liquidity for $\rho \in [0, \widehat{\rho})$, complemented by level-2 liquidity with a low discount on $[\widehat{\rho}, \rho^*]$ and high discount on $[\rho^*, \mathring{\rho}]$. A LWB requirement based on the worst-case scenario ($\ell_1 + \ell_2\theta_L \geq \mathring{\rho}$) does not suffice to implement the social optimum given that the latter involves fire sales: The structure, and not only the level of liquidity must again be monitored.*

Let us note the different nature of the government's intervention relative to the regulation of liquidity in Section 2. In Section 2, the banks exerted a negative externality on public finances, and regulation (together with a transfer) achieved a Pareto improvement among banks and the State. Here there is also an externality among banks; their welfare is reduced by an inappropriate composition of liquidity. Like Kashyap et al (2024), this Proposition has a Tinbergenian flavor, an additional distortion requiring an additional instrument.

Stress periods and the stabilization function of central bank eligibility. Suppose next that the depth of the resale market is ex ante unknown, and so is the future haircut. Intuitively, the State can in case of stress in the resale market stabilize the price of level-2 assets by offering to take a fraction of level-2 liquidity out of the market. The State will thereby incur a loss, but this loss is still preferable to either not using level-2 assets at all or tolerating a fire sale. We provide an informal treatment of this idea.

With probability s ("s" for "stress"), the resale market for level-2 assets is shallow in that $\alpha = \alpha_-$, while with probability $1 - s$, it is deep: $\alpha = \alpha_+ > \alpha_-$. Which obtains is revealed only at date 1. For computational simplicity let us assume that s is arbitrarily close to 0 (the analysis holds more generally if s lies below a threshold). Letting ℓ_1^* and ρ^* denote the level-1 liquidity and the cutoff that prevail when it is known that the resale market for level-2 assets is deep (i.e. $r_1\ell_1^* + \alpha_+\theta_H \geq \rho^*$), then this policy is still (approximately) optimal when the probability of stress is arbitrarily close to 0. However if $r_1\ell_1^* + \alpha_-\theta_H < \rho^*$, the liquidation of level-2 assets in a situation of stress (i.e. $r_1\ell_1^* + \alpha_-\theta_H < \rho$) creates fire sales. Assuming that the cost of such fire sales exceeds that of public funds (in that $1 + \lambda < 1/\theta_L$), the optimal policy in case of stress involves making level-2 assets central bank eligible (CBE) with a low haircut $1 - \theta_H$, so that an amount α_- of level-2 assets be resold in the marketplace at low haircut as well. The rest is supported by the central bank, which accepts level-2 assets at a loss since its own valuation for them is θ_L.[33]

Proposition 4 *(stabilization through CBE assets)*

Suppose that fire sales are not a concern when the depth of the market is known at date 0. Introduce a small probability of a stress situation in which level-2 liquidity would be sold at fire-sale prices for a range of liquidity shocks. Then the optimal policy in the stress scenario when $1 + \lambda < 1/\theta_L$ *consists in making level-2 assets central bank eligible, so as to keep the haircut at its no-stress level,* $1 - \theta_H$.

We here encounter a rationale for central bank eligibility, which is to prevent fire sales in a state-contingent manner (this of course provides the central bank with some discretion). While the distinguishing feature of real-world CBEA interventions is their exceptional and temporary nature, the theory envisions two possibilities. The first, and the one developed above, is that the central bank exceptionally brings price support for liquid assets counting toward the LWB requirement; the goal is then just to prevent fire sales. The second possibility is to make eligible assets that are not ex ante counted by the regulator as part of the LWB requirement. This can be the case if the central bank's support for these assets crowds out the sale of level-2 assets to meet the liquidity shock, again preventing fire sales (in the model, the bank would have no incentive to hoard such assets, as it is certain to be bailed out; but as we noted the extension to accommodate states of nature without bailout is straightforward). Note, finally, that, unlike in the case where the central bank pledges liquidity support so as to eliminate the poor-coordination equilibrium, the Bagehot doctrine no longer applies: The State accepts an expected loss in order to avoid fire sales.

3.3 Treatment of liquidity pooling

Banks share liquidity in multiple ways: derivatives, credit default swaps, interbank loans,[34] etc. Should this shared liquidity be counted towards meeting the liquidity coverage requirement?

An imperfect correlation of liquidity shocks across banks creates scope for liquidity sharing. In this section, we take the best case for such pooling: We assume that banking cross-exposures are legitimate in that they are used for hedging rather than gambling. The case for a favorable regulatory treatment of interbank exposures is much weaker

[33] Assuming authorities cannot manage the asset themselves and have to hire a professional manager.

[34] Donaldson and Piacentino (2018) argue that the desire to share liquidity may explain why banks maintain off-setting long term debts without netting them. Their idea is that the absence of netting may be a mutual insurance device. If one bank is short of cash to meet a liquidity shock, it can sell its claim on the other bank and simultaneously issue senior debt, which de facto dilutes the other bank in case of default (which is not the case for the cash-rich bank).

when the supervisor is unable to assess the directionality of risk taking in interbank arrangements (as in Farhi-Tirole 2021).

To study liquidity pooling while allowing for macroeconomic shocks, we generalize the model in the following way. There is an even number of ex-ante identical banks. Each bank's liquidity shock is drawn from the same distribution $F(\rho)$ on $[0, \rho_{\max}]$ as earlier. For expositional simplicity, we assume that the distribution $F(\rho)$ is symmetrical around $\rho_{\max}/2$.

What differs is that the banks are no longer perfectly correlated. With probability χ, banks face a common shock ρ (so $\chi = 1$ in the model of Section 2); with probability $1 - \chi$, even-numbered banks face liquidity shock ρ while odd-numbered face liquidity shock $\rho_{\max} - \rho$. The symmetry assumption implies that the distribution before hedging is unchanged: $\frac{1}{2}F(\rho) + \frac{1}{2}[1 - F(\rho_{\max} - \rho)] = F(\rho)$. The post-hedging per-bank distribution however is $F(\rho)$ with probability χ and a spike at $\rho_{\max}/2$ with probability $1 - \chi$.

In the absence of liquidity pooling, the optimal regulation specifies the same pair $\{\ell_1^*, \ell_2^*\}$ given by condition (8) and (9), the former for a fully elastic supply at $P_1 = 1/r_1$, regardless of χ. For a given correlation χ of liquidity shocks, let $\rho^*(\chi)$ denote the optimal LWB liquidity level when even-numbered banks pool their liquidity with odd-numbered banks, so liquidity pooling is indeed used for hedging purposes. The following proposition is proved in Appendix C.

Proposition 5 *(prudential treatment of interbank exposures)*

Provided that liquidity pooling is used to provide hedges,

(i) Liquidity requirements should be relaxed: $\rho^*(\chi)$ is an increasing function of the correlation χ.

(ii) The liquidity requirement can be decentralized through an LWB requirement.

Intuitively, cross-exposures make it more likely that baseload liquidity will be employed, raising its attractiveness. Peak liquidity by contrast is less useful, as some of the high shocks are covered through the mutual insurance arrangement.[35]

The regulatory implication of our analysis is that regulators can lower the liquidity requirement if they can certify that the banks' shocks will be uncorrelated or, even better, negatively correlated. This is a very strong informational requirement, all the more that banks have incentives either to correlate their positions or to select wholesale-market partners with whom are correlated (Farhi-Tirole 2012, 2021). Overall, caution suggests not lowering liquidity requirements absent such information.

[35] These two results may be viewed as a collective version of Diamond (1984)'s "cross-pledgeability" theory. Diamond argued that a firm whose activities are not perfectly correlated needs less capital than the set of single-product-line firms.

3.4 Rollover shocks

So far the shock ρ was assumed to stand for non-performing loans, legacy assets that have lost market value, guarantees granted to firms or other institutions that are called upon, or new investments (say in Fintech) that are required. However, liquidity shocks may also arise from the difficulty in rolling over liabilities.

We here content ourselves with an illustrative example that captures the essence of the rollover shock and makes it clear how to generalize the insight (at the cost of notational complexity) to less special environments. This example builds on a simple funding liquidity risk version of Section 3.1, but with a different assumption on date-1 depositors, and we reintroduce the pledgeable income for reasons that will become apparent.[36]

Suppose again that there are overlapping generations of investors.[37] Date-0 investors are all ordinary investors with utilities $c_0 + c_1$ (this feature is irrelevant). They invest at date 0 and consume at date 1; date-1 investors invest at date 1 and consume at date 2. Both at dates 0 and 1, there is an infinite amount of ordinary investors with $\theta^1 = 1$. At date 1, there is furthermore a limited amount $\bar{\ell}^2$ of captive risk-averse investors with $\theta^2 < 1$ (so "1" and "2" now stand for the generations of depositors rather than for the category of initial period depositors). Importantly, $\bar{\ell}^2$ is random and is drawn at date 1 from distribution $G(\bar{\ell}^2|\rho)$ on $[\bar{\ell}^2_{\min}, \bar{\ell}^2_{\max}]$. A representative bank as earlier faces a random date-1 shock ρ drawn from distribution F and has pledgeable income ρ^0 that accrues at date 2. We assume that $\rho^0 \geq \bar{\ell}^2_{\max}$, so the pledgeable income always suffices to pay back at date 2 date-1 depositors.

Then, for any realization of $\bar{\ell}^2$, the bank must allocate date-2 income $\bar{\ell}^2$ out of its pledgeable income ρ^0. The net shock for the bank is therefore

$$\rho' = \rho - \left(\frac{1}{\theta_2} - 1\right)\bar{\ell}^2.$$

The distribution of ρ' is computed from $F(\rho)$ and $G(\bar{\ell}^2|\rho)$. A low demand by "risk-averse" investors creates a second liquidity shock that must be factored into the overall shock. *In that sense, our model also covers shocks that arise from difficulties in rolling over deposits on the liability side.*

[36] In that, we follow Diamond-Rajan (2012) which introduces uncertainty about future household endowments. In their model, current adversity or anticipated future prosperity creates a demand for smoothing income through reduced savings.

[37] Alternatively we could consider a Diamond-Dybvig (1983) model with aggregate uncertainty about date-1 preferences.

4 Assessing regulation

4.1 Overview of some key post-GFC regulatory reforms

Basel III introduced two liquidity ratios: a short-term ratio, the Liquidity Coverage Ratio (LCR), looking at a one-month horizon, and a longer-term ratio, the Net Stable Funding Ratio (NSFR), looking at a one-year horizon.[38] We concentrate here on the LCR, which tries "*to ensure that a bank has an adequate stock of unencumbered high quality liquid assets (HQLAs) which consists of cash or assets that can be converted into cash at little or no loss of value in private markets to meet its liquidity needs for a 30-calendar-day liquidity stress scenario*".[39] The LCR is the ratio of the value of the stock of HQLAs divided by the total net cash outflows, over the next 30 calendar days and should exceed 1.

The numerator of the LCR is the stock of HQLAs. These assets should be liquid in markets during a time of stress. They are comprised of "level-1" and "level-2" assets. The former include cash, central bank reserves, and certain marketable securities backed by sovereigns and central banks, among others. They are considered as the most liquid and can in principle constitute the whole HQLA stock. Level-2 assets are comprised of level-2A assets (certain government securities, covered bonds and corporate debt securities) and level-2B assets (lower rated corporate bonds, residential mortgage backed securities and some equities). Level-2 assets may not account for more than 40% of a bank's HQLA stock, and level-2B assets may not account for more than 15% of this stock.

The denominator of the LCR is the total net cash outflows (outflows minus inflows, which are capped at 75% of total outflows) in the specified stress scenario for the subsequent 30 calendar days. Outflows (resp. inflows) are calculated by multiplying the outstanding balances of various categories or types of liabilities and off-balance sheet commitments (resp. contractual receivables) by the rates at which they are expected to run off or be drawn down (resp. flow in). For liabilities without fixed horizons, evidence from the 2007-2008 financial crisis led the Basel Committee to choose much higher outflow parameters for wholesale deposits (up to 100%, for financial institutions) than for retail deposits (as low as 3%, for those covered by the "best" insurance schemes).

Besides liquidity ratios, Basel III strengthened the Basel II solvency requirements. It focused on the "quality of capital", namely "common equity tier 1" which was significantly raised while the rest of tier-1, as well as tier-2 capital, was left as in Basel II. This choice reflected the fact that in the crisis, after the Lehman bankruptcy and out of fears for financial instability, public authorities inflicted losses almost exclusively on common equity-holders. Before Basel III was finalized, in order to better protect taxpayers, the Financial Stability Board further introduced (for the biggest banks worldwide, G-SIB's

[38] Our simple model, with a single liquidity shock, cannot distinguish between the two horizons.

[39] For more details, see Basel Committee on Banking Supervision (2013).

or Global Systemically Important Banks) additional loss-absorbency to existing Basel III solvency requirements. In effect, this meant coming back to a kind of tier-2 capital, while being much more explicit about "bail-inability", i.e. the loss-absorbency, of these claims: They contribute to TLAC, for Total Loss Absorbing Capacity (the EU has decided to extend the idea to all its banks and not only G-SIB's, under the acronym MREL, for Minimum Requirement on own funds and Eligible Liabilities).

4.2 Bank runs

Our model ignores the monitoring of the bank. While the model can easily be extended to accommodate such monitoring by, say, the banking supervisor,[40] our implementation stresses the absence of bank runs, whether due to coordination failures or to "fundamental" insolvency problems. Some of the banking literature justifies runs as a monitoring tool, creating discipline on the bank.[41]

While banks' combination of liquidity provision to depositors and investment in risky projects creates an important threat of runs, our assumption reflects the fact that public authorities in rich countries have overwhelmingly avoided bank runs since the mid-1930s (for a brief summary of this issue until the early 2010s, see Dewatripont 2014a): Faced with the fait accompli of failed supervision or misfortune, they have viewed the economic and political cost of financial instability that runs provoke as vastly larger than the economic and political cost of bailouts.

From the mid-1930s to the early 1970s, the franchise value associated with a heavily regulated and non-competitive banking sector (caps on interest on deposits to prevent "gambling for resurrection" by insolvent banks, significant barriers to entry and limits on size and scope of banks, deposit insurance) led to an inefficient but safe banking sector. The later relaxation of regulation was accompanied with a significant number of banking crises (Laeven-Valencia 2013), many of which led to large bailouts (for example in the US – the S&L crisis-, Japan, and Scandinavia), and still no bank runs: In particular, authorities guaranteed financial and non-financial corporate deposits, and not only those formally protected by deposit insurance.

[40] For example, we could assume that the distribution of net liquidity shocks depends on the bank's effort e (it is $F(\rho + e)$, say). Supervision then could take the form of limiting moral hazard (as for example in Holmström-Tirole 1997).

[41] In our 1994 book Dewatripont-Tirole (1994b), we expressed our skepticism about short-term depositors' capability to "discipline" banks: Small and large, retail and corporate depositors lack the expertise, information and incentives to monitor their bank. In practice, and unless they are not already insured, they rationally run when they hear rumors of possible bank distress. Furthermore, digital banking (one-click transfers) and social media have substantially increased their ability to run in time; for example, uninsured deposits' withdrawal rates were very high during the 2023 low-interest-rate dependence crisis.

Lehman Brothers' 2008 bankruptcy was of course the big exception to this policy.[42] This event, which was only the application of the law (Lehman Brothers was a non-FDIC-insured investment bank), triggered massive bank runs and had major consequences across the world. Runs stopped when authorities signaled a return to a de-facto unlimited deposit insurance. In fact, except for Lehman depositors, no bank creditor, not even subordinated debtholders (who were unable to take their money out of the banks), lost money in the Great Financial Crisis in countries where the State was able to bail them out –only shareholders did.[43] Basel III therefore subsequently raised the required quantity and quality of capital (i.e. core equity tier 1).

Despite latter shocks (Eurozone sovereign crisis, zero-lower-bound challenge, Ukraine invasion), the threat of runs subsided until in 2023 nervousness caused by rising interest rates resurfaced, in the US with three large regional banks (Silicon Valley Bank, Signature Bank and First Republic Bank) and in Switzerland with "global systemically important" Crédit Suisse. These episodes indicate that the current regulatory and supervision ecosystem is still unfinished business: The set of US banks that fall under Basel III failed to include midsize regional banks; and prompter corrective action would have been useful for a mega-bank like Crédit Suisse. But in either case, runs were stopped from spreading: US authorities preferred bailouts to financial instability caused by losses on uninsured depositors: (Silicon Valley Bank and Signature Bank failed, and First Republic was sold to JP Morgan, but in all three cases even uninsured depositors were fully protected, including some very big ones). As for the bail-in of Crédit Suisse, the wiping out of non-equity "Alternative Tier 1" (AT1) was decisive to avoid a (potentially quite large) public bailout.

Figure 3 illustrates the current regulation of liquidity for the bank. As the shock ρ grows, the balance sheet's liquidity contribution to meeting ρ follows the pecking order. For example, level-1 liquid assets may be depleted first, then there may be some recapitalization (bail-in of equity), then a use of level-2 liquidity, etc... The actual pecking order is determined by the rank (θ) of the various resources, whether on the asset or the liability side of the balance sheet.

In sum, policy interventions make runs broadly off the table. The most "relevant" policy issue today is thus not whether deposit insurance is limited (it is not), but which combination of instruments, in terms of the hoarding of high-quality assets and the bail-in of pre-specified securities with sufficient residual maturities (whose owners can therefore not run), is constrained-optimal. Therefore, this paper studies the tradeoff between the

[42] The exception to the "Lehman exception" was Iceland, whose banks were much too big to be saved by the State. Another "anomaly" was the Northern Rock 2008 bank run (oddly enough, the UK deposit insurance was at the time only partial from the first pound on).

[43] A subsequent exception to the Lehman exception was the bail-in of uninsured deposits at the two biggest Cypriot banks. Cyprus was, like Iceland, a country whose banks were very big and could not be saved by the State. There, the whole banking sector was closed (on March 18, 2013, for a week) and only reopened once the "cleanup" had been implemented. Such a scenario can of course only be envisaged in extreme macroeconomic circumstances.

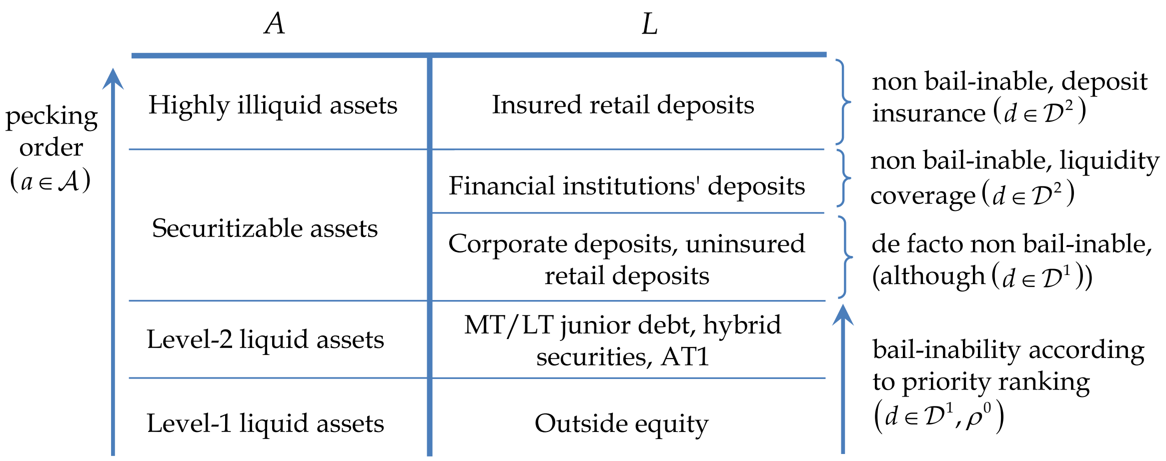

Figure 3: Current regulation of funding and market liquidity

safety of the banking sector and its ability to serve the needs of the real economy and its constituencies under a no-run constraint.

4.3 Comparison with Proposition 1

Proposition 1, our central result, indicates that the LCR design fits well with the theory on the asset side, by introducing a hierarchy of HQLA assets weighted by their liquidity discounts. The fit with the theory is much weaker on the liability side. To see why let us compare the theoretical recommendation:

$$\Sigma_{a \in A} \theta_a r_a \ell_a + \theta^0 \rho^0 i \geq \rho^* i + \sum_{d \in D^2} \ell^d$$

with the formulation of the LCR:

$$\Sigma_{a \in A} \theta_a r_a \ell_a \geq \Sigma_{d \in D} O^d \ell^d$$

where $O^d \in [0,1]$ is the LCR outflow factor.

Simplifying, suppose that there are three types of liabilities: Insured retail deposits, de jure although not de facto bail-inable wholesale deposits, and bail-inable liabilities.[44] Assume further that (insured and uninsured) retail deposits ℓ^r as well as bail-inable liabilities ℓ^b are assumed fully stable (outflow rates O^r and $O^b \approx 0$), while wholesale deposits ℓ^w are fully unstable ($O^w = 1$). The LCR requirement writes:

$$\Sigma_{a \in A} \theta_a r_a \ell_a \geq \ell^w,$$

[44] Wholesale deposits are theoretically bail-inable, but their quick-exit option, as we observed, de facto makes them unbail-inable. Non bail-inable liabilities can be lumped together with wholesale deposits.

while the formula in Proposition 1 implies that

$$\Sigma_{a\in A}\theta_a r_a \ell_a \geq [\rho^* - \theta^0\rho^0]i + [\ell^r + \ell^w].$$

This comparison illustrates both the strength and the incompleteness of the theoretical approach. Theory says little about the actual value of the wedge $(\rho^* - \theta^0\rho^0)i$ on the right-hand side of the last inequality. In fact, this wedge (logically) depends on the distribution F of the shock, on the cost and haircut of level-2 liquidity, and on the cost of bailing out banks. It is hard to calibrate this wedge without stress tests.

By contrast, theory indicates that treating retail and wholesale deposits in diametrically opposite ways is not warranted. Retail and wholesale deposits share the property that one cannot count on diluting them to meet liquidity shocks that cannot be met through HQLA sales, as they are explicitly or implicitly insured.

The narrative behind the LCR logic is instead based on run-off/outflow rates. The idea is that even a small concern about the bank's health will induce a run by legally uninsured short-term wholesale deposits. This run will create difficulties for the bank if it cannot find alternative funding liquidity; the concomitant liquidation of illiquid assets will lead to losses for the bank. By contrast, retail deposits are stable.

Basel III embodies a fundamental tension between the (understandable) unwillingness to insure large depositors and the fact that, to consent to low rates, these depositors insist on highly liquid deposits, giving them the option to run fast if they are worried and making them de facto insured. In contrast, our analysis concurs with the LCR design on the wholesale-deposits front: Regulation should require banks to be able to handle even a 100% outflow solely by selling haircut-adjusted liquid assets.

But what about insured retail deposits, where the LCR view is that there will not be massive outflows, because of deposit insurance? When the bank faces disappointing net cash inflows, it has to obtain the money from liquid asset sales, bail-ins or bailouts. Our key point is that, since neither insured retail deposits nor short-term wholesale deposits can credibly be bailed in, the regulator's choice should be identical for both.

We have already stressed the (straightforward) point that pretending that some deposits are uninsured, and thus exempting them from deposit insurance fees, while insuring them ex post is distortive. Here we add that : (1) One way to resolve this contradiction is to back a one-$ increase in insured deposits by a one-$ increase in haircut-adjusted liquid assets. Since deposits held by financial institutions face 100% outflow rates, no level of withdrawals of these deposits will ever require bailouts. (2) Instead, for all the other deposits, which benefit from lower LCR outflow rates, the Basel framework struggles with the contradiction of deposit insurance: Why should outflow rates be stable? They will depend on depositors' degree of nervousness. And, for a given ρi, all short-term deposits will be insured anyway, thereby validating our Proposition 1.

4.4 How narrow a bank?

Narrow banking requires banks to hold highly liquid and safe assets (government bonds, reserves at the Central Bank) against depositor's money. Such banks cannot fail unless the Treasury or the Central Bank renege on their obligations; they are sometimes viewed as offering security against financial crises (Cochrane 2018). How close does the optimal regulation come to narrow banking? We provide clarifications and highlight differences:

1) Public funds should cover tail shocks. Safety is a desirable goal. But it should not be provided entirely by accumulating low-yield liquid assets that are inefficiently used for liquidity purposes with vanishingly small probability.

2) Macroeconomic shocks can also be partly met by banks' investors, be they depositors, longer-term investors or other claimholders, who then must be compensated through higher yields. To make such loss-sharing credible, these investors should be unable to run, i.e. to withdraw their money from the bank before being diluted. Conversely, those wanting to be insured against bank distress must pay for this guarantee and receive low yields. The important point is that investors should not get their cake and eat it too: they should not expect de facto insurance through either bailouts or the ability to run before distress is declared, and yet receive more than formally insured depositors. This "equal-treatment" condition does not presume how the insurance should be provided.

3) A diversity of liquid assets is optimal. In the same way a power system, as demand increases, dispatches plants according to the merit order, from low to high marginal cost, a bank should sell the most liquid, low-yield assets first and then more illiquid ones as it must meet larger shocks.

These remarks can be summarized by rewriting the liquidity coverage equation (3) as;

$$\overbrace{\sum_d \ell^d - \sum_a \theta_a r_a \ell_a}^{\substack{\text{for a narrow bank} \\ \text{would be 0, with} \\ \text{only one asset in } \mathcal{A}}} = \underbrace{G_1(\rho)}_{\substack{\text{provision of} \\ \text{public funds}}} \overbrace{-\rho i}^{\substack{\text{shock} \\ \text{on risky} \\ \text{assets}}} + \underbrace{[x^0(\rho)\theta^0\rho^0 i + \sum_d x^d(\rho)\ell^d]}_{\substack{\text{dilution of} \\ \text{liability-side claims}}} - \underbrace{\sum_a [1 - x_a(\rho)]\theta_a r_a \ell_a}_{\text{unused liquid assets}}$$

The LHS is the difference between the payment owed to depositors and the value of liquid assets if resold at date 1; the equalization of this LHS to 0 would capture a narrow bank. There are two essential and related indications that the optimal bank is not a narrow bank. First, in the absence of risk there would be a single liquid asset - namely the most liquid one in $\mathcal{A}$, rather than a pecking order of multiple liquid assets. Second, there is at the optimum an imbalance between the two terms on the LHS, captured on the RHS: the provision of public funds $G_1(\rho)$, positive in high-shock states, and the dilution of liability-side claims on the bank $x^0(\rho)\theta^0\rho^0 i + \sum_d x^d(\rho)\ell^d$. These is also the shock (or gain) ρi on risky assets plus the value to outsiders of unused liquid assets, $\sum_a [1-x_a(\rho)]\theta_a r_a \ell_a$. Thus, liquidity considerations are naturally deeply intertwined with risk taking and maturity transformation.

Proposition 1 (iv) states that any increase in insured deposits must be met, for a given investment level, one-for-one by an increase in haircut-adjusted liquidity. But how this is accomplished is obtained through an optimization. All de jure or de facto insured deposits (including wholesale, retail, and corporate demand deposits) should be matched through a proper mix of HQLAs, bailinable securities, and public support.

4.5 Other regulatory provisons

Section 3 developed policy-relevant extensions of our model in terms of the (limited) availability of safe assets, of macroprudential regulation, and of liquidity pooling by banks.

Basel III jurisdictions that have an insufficient supply of level-1 assets (or both level-1 and level-2 assets) in their domestic currency to meet the aggregate demand of banks may qualify for alternative treatment. Three options are contemplated for the alternative treatment: (i) banks can access contractual committed liquidity facilities (with a maturity over 30 days) provided by the relevant central bank for a fee; (ii) banks can hold HQLAs in a currency that does not match the currency of the associated liquidity risk, (iii) banks that evidence a shortfall of HQLAs in the domestic currency are allowed to hold additional level-2A assets in the stock (these additional assets facing $\theta = 0.80$ instead of 0.85). This fits well with our Proposition 2.

Beyond this, macroprudential provisions constitute a key innovation of Basel III. In particular, the LCR (i) specifies minimal levels of higher-quality liquid assets, and (ii) stipulates that HQLAs (except lowest-quality level-2B assets) should ideally be eligible at central banks for intraday liquidity needs and overnight liquidity facilities, but central bank eligibility does not by itself constitute the basis for the categorization of an asset as HQLA. Propositions 3 and 4 indicate that the LCR design fits well with the theory here.

Finally, Proposition 5 suggests a reduction in liquidity coverage when banks grant each other insurance. No such provision is made under the LCR. This disparity may be associated with a prudent approach in view of the caveat in Proposition 5 that supervisors can check that liquidity pooling is used for hedging purposes.

5 Relationship to the literature

Our paper relates to a growing literature on liquidity regulation. Liquidity requirements are here motivated by an externality on public finances (e.g., Farhi-Tirole 2012) rather than by bank runs (e.g., Diamond-Kashyap 2016, Kashyap et al 2024), a fire-sales externality among banks (e.g., Shleifer-Vishny 1992, Allen-Gale 1994, Lorenzoni

2008, Brunnermeier-Pedersen[45] 2009, Perotti-Suarez 2011, von Thadden 2011, Stein 2012, Guerrieri-Shimer 2014, Kurlat 2016, Clayton-Schaab 2025), or the risk of contagion through cross-exposures within the financial system (e.g., Rochet-Tirole 1996, Kahn-Roberds 1998, Allen-Gale 2000, Acharya et al 2017, Farboodi 2023). All approaches predict a socially insufficient *level* of liquidity under laissez-faire. Our analysis focuses on another key concept for the design of regulation, the liquidity *structure*, when the literature features only a need for a minimum amount of liquidity.[46] Several papers, like us, integrate the asset and liability sides of the bank, though (see (a) and (b) below).

(a) Insufficient level of liquidity (runs)

In Kashyap et al (2024), (explicit or implicit) deposit insurance is assumed away, generating runs,[47] whose probability is determined as the equilibrium of a global game. While the potential for runs makes their analysis quite different from ours, they also endogenize liquidity and risk choices, and assume that loan monitoring by banks requires sufficient profitability. They show that banks, due to their limited liability, tend to be excessively deposit-intensive. On the other hand, their asset portfolio will be more or less liquid, and their level of lending higher or lower, than the ones preferred by public authorities, depending on the latter's preferences for liquidity provision and credit extension. To correct for these distorsions, they argue that a bank credit tax or subsidy is needed next to liquidity and solvency regulation.

Kashyap et al's analysis offers rich insights into the interactions between solvency, liquidity and fragility in a world without deposit insurance and public liquidity support. It is complementary to ours, which relies on the desirability of the protection of some categories of depositors and authorities' ex-post desire to protect all short-term deposits in order to avoid bank runs and their concomitant cost of financial instability. In our model, the bail-inability of some categories of (longer-term) deposits and public liquidity support in last resort emerge as alternatives to runs.

[45] Before us, Brunnermeier and Pedersen (2009), who introduced the market and funding liquidity terminology, integrate the asset and liability sides into an overall design for liquidity surveillance analyze how the funding of asset buyers impacts the volatility of asset prices, and how margins demanded on buyers' positions (which determine their funding liquidity) can vary suddenly and affect market liquidity. So like in our Section 3.2, resale prices are contingent of the financial muscle of buyers. Brunnermeier and Pedersen show that margins increase with market illiquidity when financiers cannot distinguish fundamental shocks from liquidity shocks and fundamentals have time-varying volatility, and that liquidity crises simultaneously affect many securities, mostly risky high-margin securities, resulting in commonality of liquidity and flight to quality.

[46] Note also that the policy debate on prudential reforms has led to various qualitative and quantitative assessments. A cost-benefit analysis of liquidity ratios is more complicated than an equivalent analysis of solvency ratios. This being said, early assessments (see Basel Committee on Banking Supervision 2016) indicate very moderate effects, if any, of an LCR introduction on the level of private lending (the European Banking Authority conducted detailed Quantitative Impact Studies on the subject, see EBA 2013, 2014; it is also consistent with Banerjee-Mio 2018, which looks at the impact of an LCR-like ratio introduced earlier in the UK). Note that our fixed-investment model shuts down this liquidity-lending channel, while our appendix considers it by allowing bank investment to vary in size.

[47] In the tradition of Diamond-Dybvig (1983), Bhattacharya-Gale (1987), Allen-Gale (1997), Ennis-Keister (2006) and Farhi et al (2009).

(b) Insufficient level of liquidity (fire sales)

Kara and Oszoy (2020), like us, assume away bank runs (all deposits are long term) and show the complementarity between solvency and liquidity regulation. Their results are driven by the fact that banks do not take into account fire sale externalities when deciding on the level of their asset-side risk. Capital regulation alone worsens illiquidity, since banks rationally further neglect the need to cover liquidity needs. Walther (2016) also assumes away bank runs (in this case because deposits are secured by assets), and the source of the problem is again fire-sale externalities. Once again, both regulations are needed. Like the rest of the literature and in contrast with our paper, these papers abstract from the optimal structure of liquidity, which we show leads to a modified version of Basel III's LCR.

(c) Analogy with power markets

In the process of studying liquidity regulation, we encountered four perhaps-unexpected links with electricity regulation. Banking and electricity regulations indeed share a number of characteristics. First, uncertain demand (liquidity needs, electricity loads) raises the issue of optimal liquidity management or plant dispatch, with a resulting pecking order (in the power industry, the low-marginal-cost/high-investment-cost plants are dispatched first): see Boiteux (1949) and Léautier (2019) for treatments in the context of the electricity industry. Second, market participants may exert negative externalities among each other. Market integrity is a public good; in power markets, insufficient investments in peakload capacity may lead to network collapses, hurting everyone (Joskow-Tirole 2007); similarly, insufficient liquidity provision may lead to fire sales, to the detriment of the entire banking sector. Third, electricity customers have different demands for the certainty with which they are served, giving rise to priority servicing (Wilson 1993), akin to the priority structure for bail-ins in Proposition 1. Fourth and finally, both industries exhibit ex-post interventions to protect politically sensitive clients (SMEs and retail depositors for banks, retail customers for electricity markets), although these interventions have different characteristics (mostly bailouts for banks and price ceilings in electricity markets).

(d) Equity as a vector of activism or as a buffer?

Finally, our modeling of the liability side adds a new perspective to the vast corporate finance literature. The existing literature exhibits a dichotomy between "inside equity", held by active agents in need of incentives (manager, large block shareholder), and "outside equity", the set of claims held by passive investors and therefore satisfying no incentive purpose, and to which the Modigliani-Miller theorem applies.[48] The corporate finance literature is often criticized for focusing on inside equity and ignoring the

[48] An exception is Dewatripont-Tirole (1994a), in which control rights are exerted by outside investors and so the financial structure serve to discipline the managers (with, optimally, a relative congruence between management and shareholders and a transfer of control to more conservative debtholders when the firm underperforms).

role of outside equity and junior claims as a buffer[49] protecting debtholders. By positing that different classes of investors have different risk preferences and introducing optimal bailinability, this paper addresses this widespread criticism and captures the notion of a buffer as independent of shareholder activism.

6 Conclusion

Liquidity regulation remains one of the most consequential, yet conceptually underdeveloped, pillars of financial oversight. This paper developed a framework to assess post-crisis reforms such as Basel III. This framework unveils a natural analogy with dispatching rules and priority servicing. It provides the conditions under which the management of liquidity can or cannot be delegated to the bank, i.e., when the supervisor can focus on the liquidity level and not its structure.

Rather than pushing for narrow banking or arbitrary buffers, we argue for a calibrated liquidity-weighted buffer requirement that reflects the true economic risks banks pose to the system. When applied consistently across assets and liabilities, and adjusted for country-specific constraints and systemic linkages, this approach strengthens financial stability without impairing banks' core role in maturity transformation.

Post-crisis reforms fall short in addressing a core inconsistency. First, regulators continue to treat some deposits as if they are not guaranteed, while public policy consistently bails them out in practice. This paper proposes a framework that corrects this disconnect. Second, by recognizing that de facto insured liabilities should be backed accordingly, whether by sufficiently liquid assets, bail-inable liabilities, or a bailout by authorities, we offer a liquidity regulation strategy that is more efficient and more resilient.

This paper opens several avenues for further investigation into the design and implementation of liquidity regulation. First, a deeper analysis is needed on cross-border liquidity management. The current framework considers either full international liquidity access or extreme home bias, but in practice banks operate within a mix of domestic and international markets. Future research should explore how regulatory design interacts with the uneven global distribution of safe assets and the potential for countries to contribute to—or benefit from—the provision of global liquidity.

Second, liquidity is a dynamic concept, yet this study relies on a three-period model. Extending the model to a dynamic setting would allow for a better understanding of how liquidity buffers should be built, depleted, and replenished over time. This is particularly important in light of regulatory debates about the extent to which banks should be

[49] We here follow the Basel terminology, whereby buffers are meant to be "used" in time of stress (while "requirements" are not).

allowed to use buffers during crises and the speed at which they need to replenish them (echoing Goodhart's "last taxi" metaphor[50]).

Third, the question of intertemporal mutual insurance among banks merits attention. While this paper examines liquidity pooling across states of nature, future work could analyze how liquidity is shared or hoarded across time, and how that affects optimal regulation. This includes examining the withdrawal speeds of various liabilities and the timing of liquidity pressures.

Finally, the interaction between monetary policy and liquidity regulation remains underexplored. Monetary tools, such as interest rate reductions, may alleviate financial stress[51] and reduce the need for high liquidity buffers. Understanding how monetary and prudential policies complement or substitute for one another—especially in the context of currency unions—could lead to more effective and context-sensitive regulation.

Ultimately, smarter liquidity rules won't eliminate crises—but they can make them rarer, less costly, and more transparent. It is time to align regulation with reality.

[50] Goodhart (2008) argued that liquidity which is never used is wasteful (on this and other potential unintended consequences of liquidity requirements, see also Dewatripont 2014b). There are very few models on the dynamic management of liquidity. In Biais et al (2010), liquidity is constantly replenished through downsizing when facing adverse news.

[51] As in Diamond-Rajan (2012) and Farhi-Tirole (2012)

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Appendix

A Solvency-liquidity trade-off

A.1 State-contingent downsizing and the solvency-liquidity trade-off

We here generalize the model of Section 2 in two ways. The major one is that we assume $\rho_{\max} = +\infty$, so that downsizing will occur at the optimal policy. Second, to avoid corner solutions, we will assume that the date-2 productivity is $h(j)$ with $h' > 0$, $h'' \leq 0$ and $h'(0) = +\infty$ (so for all ρ, j will be positive). The date-2 payoffs for the banker and the social planner are thus $bh(j)$ and $\beta h(j)$.

The program thean generalizes $\{(2),(3)\}$:

$$\max \Big\{A + E_\rho\big[\sum_d [1 - x^d(\rho)]\ell^d/\theta^d - (i + \sum_a \ell_a)\big]\Big\}$$
$$+E_\rho\Big[[1 - x^0(\rho)]\rho^0 h(j(\rho)) + \sum_a [1 - x_a(\rho)]\Big] - C(G_1(\rho)) + \beta h(j(\rho)),$$

subject to

$$G_1(\rho) = \rho j(\rho) + \sum_d [1 - x^d(\rho)]\ell^d - \Big[x^0(\rho)\theta^0\rho^0 h(j(\rho)) + \sum_a x_a(\rho)\theta_a r_a \ell_a\Big] \qquad (\mu(\rho)),$$

$$\int_{\rho_{\min}}^{+\infty} bh(j(\rho))dF(\rho) \geq \bar{U} \qquad (\nu),$$

and $j(\rho) \leq i$ for all ρ.

At the optimum, full-scale continuation occurs whenever $\rho \leq \rho^\dagger$ for some $\rho^\dagger$. Beyond $\rho^\dagger$, $j(\rho) \in (0, i)$. We have

$$(\beta + \nu b)h'(i) = (1 + \lambda)[\rho^\dagger - \theta^0\rho^0 h'(i)].$$

The optimal investment is then given by

$$\int_{\rho_{\min}}^{\rho^\dagger} \big[[1 - x^0(\rho)]\rho^0 h'(i) - \mu(\rho)[\rho - x^0(\rho)\theta^0\rho^0 h'(i) + (\beta + \nu b)h'(i)]\big] dF(\rho) = 1,$$

as the scale of investment matters at date 1 only if no downsizing occurs.

A.2 Tax on banking activity and liquidity ratio

The limited supply of cheap deposits, as captured by the ceilings $\{\bar{\ell}^d\}_{d\in\mathcal{D}}$, creates a non-linearity (actually decreasing returns to scale) in an otherwise constant-returns environment. This non-linearity implies that regulatory ratios necessarily are not invariant to net worth (A in our model). To simplify things, let us therefore, for the sake of this remark, assume that $\bar{\ell}^d = 0$ for all d (the same remarks apply to deposits and the deposit insurance premium, but in a non-linear way). Assume further that the outside option is proportional to net worth

$$\underline{U} = \xi A \;\Rightarrow\; i = \frac{\xi}{b} A.$$

Program (2) and constraint (3) are then homogenous in i and $\{\ell_a\}$. The optimal liquidity requirements are proportional to the level of investment: There exists a vector $\{k_a^*\}_{a\in\mathcal{A}}$ such that

$$\ell_a = k_a^* i \quad \text{for all } a \in \mathcal{A}.$$

Similarly, let $x^{0*}(\rho)$ and $x_a^*(\rho)$ denote the dilution rates of equity and liquid asset a. And let $L \equiv E_\rho\big[[1 - x^{0*}(\rho)]\rho^0 + \Sigma_a[1 - x_a^*(\rho)]r_a k_a^*\big]$ the unit value of non-deposit claims. Let $T_0 \equiv -G_0$ be interpreted as a tax on banking activity

$$A + Li \equiv i + (\Sigma_{a\in\mathcal{A}} k_a^*)i + T_0 \quad \Leftrightarrow \quad T_0 \equiv \Big[\frac{b}{\xi} + L - \Sigma_{a\in\mathcal{A}} k_a^* - 1\Big] i.$$

An increase in the cost of bailouts $(1 + \lambda)$ leads to more liquid-assets hoarding $\Sigma_{a\in\mathcal{A}} k_a^*$ increases. In this case bailouts and the tax on banking activity covary positively. Similarly, consider an extension in which banks are heterogenous with respect to their ability to manage liquid assets.[52] They will therefore differ in their liquidity hoarding. A bank hoarding more liquidity then should pay a lower tax on their banking activity (conversely, a bank taking on more deposits would pay a higher tax).

B Proof of Proposition 3

(i) LWB. Suppose that the regulator requires that $r_1\ell_1 + \theta_H\ell_2 \geq \rho^*$. Then each bank selects the same portfolio (ℓ_1^*, ℓ_2^*) as in Section 2. And there will not be fire sales as $\theta_H\ell_2^* \leq \alpha$.

(ii) Let us now focus on the interesting case in which $r_1\ell_1^* + \theta_H\alpha < \rho^*$ (shallow market). Consider first the date-1 pecking order. The date-1 opportunity cost of 1 unit of liquidity is 1 when using level-1 liquidity, $1 + \lambda$ when using public funds, and $1/\theta_2(\rho)$ when using level-2 liquidity where $\theta_2(\rho) \in \{\theta_L, \theta_H\}$ measures the state-contingent marketability/liquidity of level-2 assets.

[52] They still have the same objective function, bi.

(a) If $1+\lambda < 1/\theta_L$, fire sales are always socially undesirable. And so there is no point hoarding level-2 liquidity $\ell_2 > \alpha/\theta_L$, as excess level-2 liquidity will never be used. The solution is therefore derived as in Section 2, except that the constraint $\ell_2 \leq \alpha$ is binding, and so:

$$r_1\ell_1 + \theta_H\alpha = \rho^*, \tag{A.1}$$

which defines a function $\rho^*(\ell_1)$. We still have

$$\widehat{\rho} \equiv r_1\ell_1. \tag{A.2}$$

The social planner's program is:

$$\max_{\{\ell_1\}}\Bigg\{ -\frac{\widehat{\rho}}{r_1} - \frac{\alpha}{\theta_H} + \int_0^{\widehat{\rho}} [(\widehat{\rho}-\rho)+\alpha]\, dF(\rho) + \int_{\widehat{\rho}}^{\rho^*(\ell_1)} \left[\alpha - \frac{\rho-\widehat{\rho}}{\theta_H}\right] dF(\rho) - \int_{\rho^*(\ell_1)}^{\rho_{\max}} (1+\lambda)\,[\rho-\rho^*(\ell_1)]\, dF(\rho)\Bigg\}.$$

The first-order condition is such that the marginal benefit of level-1 liquidity is equal to the marginal cost:

$$F(\widehat{\rho}) + [F(\rho^*) - F(\widehat{\rho})]\left(\frac{1}{\theta_H}\right) + [1-F(\rho^*)]\,(1+\lambda) = \frac{1}{r_1}. \tag{A.3}$$

Substituting (A.1) and (A.2) into (A.3) yields the optimal level of level-1 liquidity.

Next, we show that $\ell_1 > \ell_1^*$ and $\ell_2 < \ell_2^*$. Suppose, a contrario, that $\ell_1 \leq \ell_1^*$. Condition (A.3), which is also satisfied by the unconstrained solution of Section 2, together with $1+\lambda > 1/\theta_H$, imply that ρ^* is higher than in Section 2 and so

$$\begin{aligned} & r_1\ell_1 + \theta_H\ell_2 \geq r_1\ell_1^* + \theta_H\ell_2^* \\ \Rightarrow \quad & \ell_2 \geq \ell_2^* > \frac{\alpha}{\theta_H}, \end{aligned}$$

a contradiction. So, $\ell_1 > \ell_1^*$ and $\ell_2 < \ell_2^*$. Furthermore, bailouts are more frequent (ρ^* is smaller) than when the level-2-liquidity market is deep.

It is also easy to see that the optimal solution cannot be decentralized through a mere LWB requirement. Otherwise, the representative bank would pick $\ell_1 = \ell_1^*$. A minimum-level-1 requirement in complement of the LWB is needed to achieve the optimum.

(b) Finally, suppose that $(1+\lambda)\theta_L > 1$. The date-1 pecking order is then: (1) level-1 liquidity, (2) level-2 liquidity at a low discount, (3) level-2 liquidity at a high discount, (4) public funds (since $1 < 1/\theta_H < 1/\theta_L < 1+\lambda$). Let the cutoffs be

$\widehat{\rho} < \rho^* < \mathring{\rho}$ with $\widehat{\rho} \equiv r_1\ell_1$, $\rho^* \equiv r_1\ell_1 + \theta_H\alpha$ and $\mathring{\rho} \equiv r_1\ell_1 + \theta_L\ell_2$ (which imply $\ell_2 > \alpha/\theta_L$).

The social planner solves:

$$\max_{\{\ell_1,\ell_2\}} \Bigg\{ -\frac{\widehat{\rho}}{r_1} - \frac{\ell_2}{\theta_H} + \int_0^{\widehat{\rho}} [\ell_1 - \rho + \ell_2] dF(\rho) + \int_{\widehat{\rho}}^{\rho^*} \left[\ell_2 - \frac{\rho - \ell_1}{\theta_H}\right] dF(\rho)$$
$$+ \int_{\rho^*}^{\mathring{\rho}} \left[\ell_2 - \frac{\rho - \ell_1}{\theta_L}\right] dF(\rho) - \int_{\mathring{\rho}}^{\bar{\rho}} (1+\lambda)(\rho - \mathring{\rho}) dF(\rho) \Bigg\}.$$

Assuming $\mathring{\rho} > \rho^*$ (otherwise the solution is the same as in (a)), the maximization with respect to ℓ_2 yields

$$-1 + F(\mathring{\rho}) + \left[1 - F(\mathring{\rho})\right] (1+\lambda)\theta_L = 0.$$

A necessary condition for such a $\mathring{\rho}$ to exist (ignoring the constraint that $\mathring{\rho} \geq \rho^*$) is that $(1+\lambda)\theta_L > 1$, which is stronger than $(1+\lambda)\theta_L > 1$.

Note that the first α units of level-2 liquidity incur a capital loss $\alpha(\theta_H - \theta_L)$ when $\rho > \rho^*$, and so a necessary condition for this regime to be feasible is that $\mathring{\rho} > \rho^*$ or

$$\ell_2 > \frac{\theta_H}{\theta_L}\alpha.$$

■

C Proof of Proposition 5

With probability χ, shocks are identical and the liquidity coverage constraint is, as earlier,

$$\rho - \Sigma_a x_a(\rho)\theta_a r_a \ell_a \geq 0.$$

For conciseness, we will focus on the case in which $\rho^* \geq \rho_{\max}/2$. That is, liquidity coverage ensures that there is probability at least 1/2 (given the symmetry of F) that there is no need for public intervention, a reasonable assumption. This is guaranteed if λ is large enough or liquid assets are not too costly. With probability $1-\chi$, the liquidity coverage constraint is

$$\frac{\rho_{\max}}{2} - \Sigma_a x_a(\rho)\theta_a r_a \ell_a \geq 0.$$

Adapting Program (9):

$$
\begin{aligned}
\max_{\{\hat\rho,\rho^*\}} W = & -\frac{\widehat{\rho}}{r_1} - \frac{\rho^* - \widehat{\rho}}{\theta_2 r_2} \\
& + \chi \Bigg[\int_0^{\widehat{\rho}} \left(\widehat{\rho} - \rho + \frac{\rho^* - \widehat{\rho}}{\theta_2} \right) dF(\rho) + \int_{\widehat{\rho}}^{\rho^*} \left(\frac{\rho^* - \rho}{\theta_2} \right) dF(\rho) \\
& \qquad - \int_{\rho^*}^{\rho_{\max}} (1+\lambda)(\rho - \rho^*) dF(\rho) \Bigg] \\
& + (1-\chi) \begin{cases} \dfrac{\rho^* - \frac{\rho_{\max}}{2}}{\theta_2} & \text{if } \widehat{\rho} \le \dfrac{\rho_{\max}}{2} \quad \text{(case (A))} \\ \widehat{\rho} - \dfrac{\rho_{\max}}{2} + \dfrac{\rho^* - \widehat{\rho}}{\theta_2} & \text{if } \widehat{\rho} \ge \dfrac{\rho_{\max}}{2} \quad \text{(case (B))} \end{cases}
\end{aligned}
$$

Regardless of whether level-1 liquidity suffices to cover the liquidity shock in the insurance state (case (A)) or not (case (B)), total liquidity is given by

$$
\frac{F(\rho^*)}{\theta_2} + [1 - F(\rho^*)](1+\lambda) = \frac{1}{\chi \theta_2 r_2}
$$

and so

$$
\frac{\partial \rho^*}{\partial \chi} > 0.
$$

Level-1 liquidity is driven by

$$
\begin{aligned}
\left.\frac{\partial W}{\partial \widehat{\rho}}\right|_{(A)} &= \chi \left(\frac{1-\theta_2}{\theta_2} \right) F(\widehat{\rho}) - \left(\frac{1}{\theta_2 r_2} - \frac{1}{r_1} \right) \\
&= \left.\frac{\partial W}{\partial \widehat{\rho}}\right|_{(B)} + (1-\chi) \left(\frac{1-\theta_2}{\theta_2} \right).
\end{aligned}
$$

So if

$$
\chi \left(\frac{1-\theta_2}{\theta_2} \right) F\left(\frac{\rho_{\max}}{2} \right) - \left(\frac{1}{\theta_2 r_2} - \frac{1}{r_1} \right) < 0, \text{ then } \widehat{\rho} > \rho_{\max}/2.
$$

Similarly, if

$$
\chi \left(\frac{1-\theta_2}{\theta_2} \right) F\left(\frac{\rho_{\max}}{2} \right) - \left(\frac{1}{\theta_2 r_2} - \frac{1}{r_1} \right) - (1-\chi) \left(\frac{1-\theta_2}{\theta_2} \right) > 0, \text{ then } \widehat{\rho} < \rho_{\max}/2.
$$

Finally, if neither obtains, then $\widehat{\rho} = \rho_{\max}/2$.

Note also that

$$
\left.\frac{\partial^2 W}{\partial \widehat{\rho} \partial \chi}\right|_{(B)} > 0 > \left.\frac{\partial^2 W}{\partial \widehat{\rho} \partial \chi}\right|_{(A)}.
$$

So $\widehat{\rho}$ increases (decreases) with χ in case (B) (case (A)). Intuitively, the liquidity in excess of $\rho_{\max}/2$ is wasted in the insurance state, making the case for the higher-yield level-2 liquidity more compelling.

The decentralization result has the same logic as earlier: The externality on public finances is addressed entirely through the liquidity requirement ρ^*. Given this, the banks will by themselves opt for the least-cost way of generating this level of total liquidity, provided that the supervisor can check that interbank contracts are used for hedging purposes.

$\blacksquare$