Optimal bank resolution*

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Abstract

Recent policy reforms endow financial regulators with broad powers to "bail-in" the creditors of troubled banks, with the aim of avoiding future "bail-outs." We analyze equilibrium bail-in policies during financial crises and study the optimal design of regulatory regimes. We show that such powers, when discretionary, will have limited impact. Regulators with discretion conduct weak interventions in order to avoid revealing adverse private information and triggering bank runs. Optimal resolution regimes allow discretion whenever public news is favorable, but tie the regulator's hands after bad news. The optimal regime can be implemented by supplementing bail-in powers with contingent capital instruments.

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1 Introduction

Few economic policies have enjoyed more universal support than ending the "too big to fail" problem of financial systems. Since the crisis of 2008, this agenda has proceeded along two lines: First, regulators are imposing tougher capital and liquidity requirements on big banks in an attempt to reduce the *probability* that systemically important institutions fail. Second, most developed countries have established new resolution regimes for big banks in order to reduce the *cost* of failure. Regulators can now *bail-in* big banks by imposing losses on their shareholders and creditors without invoking bankruptcy proceedings, and without using taxpayers' money for bail-outs.[1]

Policy-makers appear to have significant faith in bail-ins as a credible alternative to bail-outs.[2] Indeed, the availability of bail-in is frequently cited as an argument *against* tougher capital regulation.[3] This is contentious because bail-ins are mostly untested.[4] As pointed out by Kane (2013) and others, the fact that regulators have the tools at their disposal to undertake desirable write-downs does not necessarily imply that they will use them in a timely fashion, even when they have the best of intentions. Moreover, while recent academic research yields new insights into the consequences of bail-outs for financial fragility (Farhi and Tirole, 2012; Keister, 2016) and into the efficient design of bail-out interventions and prudential regulation (Bianchi, 2016; Chari and Kehoe, 2016), very few papers have formally studied the effectiveness of bail-in and resolution regimes, or whether bail-ins can be expected to replace bail-outs in future. In this paper, we propose a model of bail-in to address these issues.

Our model explains first why even a benevolent regulator with no conflict of interest will have trouble taking actions which are tough enough and early enough to deal most effectively with problem banks; and then shows how a properly designed regulatory environment can mitigate this difficulty. Our insights are complementary to recent work by Bolton and Oehmke (2016), who

[1] In the United States, the resolution of large, complex financial companies is overseen by the FDIC, which has been given the power to impose losses on bank shareholders and creditors under Title II of the Dodd-Frank Act. In the Eurozone, the ECB has been given similar powers under the 2014 Bank Recovery and Resolution Directive.

[2] For example, Treasury Secretary Jack Lew (2013) argues that the Dodd-Frank act "ended 'too big to fail' as a matter of law; tough rules are now in place to make sure banks have the capital to absorb their own losses; monitoring through stress tests is underway; and resolution authorities and plans are in place. There is a growing recognition of these changes, and market analysts are now factoring them into their assumptions. Put simply, the reforms we are putting in place raise the cost for a bank to be large, requiring firms to internalize their risks, and together, with resolution authority and living wills, make clear that shareholders, creditors, and executives—not taxpayers—will be responsible if a large financial institution fails."

[3] Bank of England governor Mark Carney (2016) states that bail-in "will reduce both the likelihood and probable impact of systemic bank failures, leaving the system less reliant on going concern capital to do the heavy lifting".

[4] Admati (2016), for instance, states that "it is unrealistic to expect that regulators will trigger recovery and resolution processes that are complex, costly and untested". Persaud (2013) argues that bail-in securities as "fool's gold" which, unlike equity capital, is unable to prevent systemic distress. Empirical work on bail-in is scarce; Beck et al. (2017) show that the recent bail-in of a major Portuguese bank did not entirely eliminate the adverse real effects of the bank's failure.

show that international coordination of bail-in choices may not be implementable, but maintain the assumption that each national authority can carry out tough policies without any frictions.

The model features a single bank and its benevolent regulator, who has the power to conduct a bail-in policy, that is, to write down long-term debt obligations if the bank's asset values deteriorate. The environment has three key ingredients: First, the bank's shareholders need to be given incentives to manage the bank's choices in a desirable way. As a result, a deterioration in bank capital creates a deadweight loss, because it erodes shareholders' "skin in the game" and weakens their incentives. This friction motivates a timely bail-in which re-capitalizes the bank and improves incentives. Second, the bank faces potential liquidity problems in the spirit of Diamond and Dybvig (1983), and bank runs by short-term creditors can force the bank to liquidate its assets early. Since the bank in question is big, assets cannot be liquidated efficiently, so that runs have the potential to generate further welfare losses. Third, there is asymmetric information between the regulator, who observes the true value of the bank's assets, and creditors, who observe only a noisy public signal.

We begin by assuming that the regulator has discretion to undertake bail-ins when he sees fit. That is, he can choose his policy based on his private information, as current legislation implies. We show that regulators in this regime have a tendency to be weak in a crisis. If the regulator "bails-in" a large portion of the bank's debt, market participants rationally infer that the bank must be under-capitalized. This revelation can trigger costly disruptions such as runs by short-term creditors.[5] Therefore, regulators with bad news have incentives to act as if they had better news. In equilibrium, they conduct excessively weak bail-in policies. This signaling problem becomes particularly costly after bad public news: Recapitalizations are badly needed in order to improve incentives, but at the same time, bank creditors are already on the verge of running, causing the regulator to tread even more carefully. The availability of discretionary bail-ins therefore has only a limited effect on the likelihood of bank failure.

Moreover, if bank failures are socially costly, then the government has incentives to rescue failing banks with public money ex post. The excessive weakness of regulators just outlined then implies that providing regulators with discretionary bail-in powers may be unable to significantly reduce the probability of bail-outs in the way that the politicians that have legislated for these powers have hoped.[6]

As an alternative to the existing discretionary policy, we consider rules that tie the regulator's

[5] In modern banking systems with deposit insurance, runs generally take place in wholesale credit markets, such as repo and commercial paper, rather than on retail deposits. Wholesale runs are discussed in detail by Shin (2009), Gorton and Metrick (2012) and Krishnamurthy et al. (2014).

[6] For example, in supporting the new bank resolution powers in the Dodd-Frank Act, President Obama said, "Never again will the American taxpayer be held hostage to a bank that is too big to fail," (New York Times, January 21, 2010, available at: http://www.nytimes.com/2010/01/22/business/economy/22policy.html?_r=0.

action to publicly observed but noisy signals of the bank's health, for example, banks' book or market values, or measures of leverage such as Tier I capital ratios. We show that because rules eliminate the signaling problem, they can induce tougher bail-in policies and reduce the likelihood of bank failures and bail-outs compared to the discretionary regime. The cost of using rules, however, is that the regulator is unable to fine-tune his bail-in policy to the private information that he has, so that on occasion the regulator is forced to deliberately implement bail-ins which he knows to be excessively and unnecessarily tough.

Given this insight, we characterize the optimal design of resolution regimes which combine rules and discretion. The best regime makes the extent of regulatory discretion contingent on the realization of public signals: After bad public news, when tough bail-in policies are most beneficial, it is optimal to impose rules in order to reduce the temptation to be weak. After good public news, when weakness is less costly, it is optimal to allow the regulator discretion so that he can fine-tune the bail-in policy to his private information. In addition, in most realistic cases, rules become more valuable when transparency improves and public information becomes more accurate. Conversely, although discretion is problematic, it does not pay to tie one's policy to an extremely noisy signal of bank health. There is thus a complementarity between promoting better public disclosure for banks, and greater use of rules based on public information.

We show that the optimal mixture of rules and discretion can be implemented using contingent convertible debt (CoCo) contracts. These contracts mandate debt to be written down contingent on sufficiently negative public signals, thus recapitalizing the bank, and this conversion cannot be reversed by the regulator. By hard-wiring recapitalization contingent on public news, CoCos counteract the regulator's tendency to be weak, and therefore substitute for explicit rules. This result presents a novel rationale for CoCos relative to the existing literature, which has emphasized the impact of contingent contracts on bank, rather than regulatory, incentives (Pennacchi 2011, Martynova and Perotti 2016, Albul et al. 2013).

We consider several extensions to our baseline model. First, we endogenize the timing of bail-in policies. We show that under discretion, regulators intervene both "too little", by reducing early interventions to avoid signaling bad news, and "too late", by tilting their policies towards late interventions which prevent bank failures at the last minute. Using a policy of bail-in rules tied to public signals could improve welfare by forcing an earlier resolution of problematic banks.

Second, we model the interaction between bail-in and other financial policies such as capital and liquidity requirements. We show that tightening liquidity requirements ex ante, while holding capital requirements constant, can relax the constraints which are imposed on bail-in policy as a result of signaling problems. This is because these requirements make short-term creditors less likely to run, thus alleviating the regulator's incentives to be weak in a crisis. We argue that this policy is more effective than tightening capital or liquidity requirement in isolation; the two tools have complementary effects on the effectiveness of bail-in regimes. Therefore, while we do not take a stand on the optimal level of capital and liquidity requirements, we note that the *marginal benefit* of tightening liquidity requirements is higher when (partially discretionary) bail-in policy is in place.

In our final extension, we focus on the distinction between fundamentals-based bank runs and self-fulfilling bank runs. In our model, as in most of the literature following Diamond and Dybvig (1983), there are potentially multiple equilibria: When some creditors decide to withdraw early, they trigger costly liquidations, which can entice others to also withdraw early and lead to a self-fulfilling bank run. This indeterminacy is commonly resolved by focusing on the best incentive-compatible outcome (Allen and Gale, 1998), or by employing techniques from global games to predict equilibrium play given small deviations from common knowledge (Goldstein and Pauzner, 2005; Rochet and Vives, 2004). Effectively, the Allen-Gale approach focuses on bank runs which are driven by *fundamental* concerns about the bank's health, while the global games approach allows for *self-fulfilling* bank runs.

We show that the qualitative trade-off between rules and discretion is the same under both approaches. In both cases, bank runs end up being driven by concerns about the fundamental health of the bank, so that signaling bad news makes runs more likely, giving the regulator an incentive to weaken his bail-in choice. However, the policy conclusions are different if bank runs are driven exclusively by coordination failure. In this case, a central bank can remove bank runs by acting as a "lender of last resort", which in turn removes signaling concerns from the regulator's objective function when choosing a bail-in policy. Therefore, a more generous lender of last resort has the additional marginal benefit of ensuring that bail-in choices are closer to first-best in a crisis.

The trade-off between rules and discretion in our model is distinct from that highlighted in macro-economic policy by Kydland and Prescott (1977) and subsequent literature. In these models, the government moves last, and is tempted to create ex post inflation surprises to boost output. In that literature, it is sub-game perfection which motivates the policy-maker's desire to tie his hands. In our model, bank creditors move *after* the regulator-policy-maker makes his perfectly observable bail-in choice, so the policy maker does not have the opportunity to create any surprises *per se*. The problem is rather that the regulator has private information and that his action choice results in undesirable information leakage. Our setting is therefore closer to models in the spirit of Barro and Gordon (1983), where the central bank has private information about its objective function, and chooses its actions to establish a reputation for being tough on inflation.[7] In our model, however, the regulator has private information about a fundamental state of the economy,

[7] Other papers in this tradition include Backus and Driffill (1985), Cukierman and Meltzer (1986) and, more recently, Stein and Sunderam (2016) and Hansen and McMahon (2017). See Barro (1986) and Blackburn and Christensen (1989) for surveys of the early literature on rules versus discretion in monetary policy.

rather than about his own preferences or ability. This creates a case for rules which tie policies to noisy but informative public signals.

Our results are therefore complementary to those of Bouvard et al. (2015), who show that central banks may refrain from disclosing stress test results in order to avoid signaling bad news, and to Angeletos et al. (2006), who show that signaling concerns in coordination games can lead to self-fulfilling "policy traps". The signaling motive in our paper is similar, but we go further in characterizing the optimal policy response to this issue in terms of rules and discretion, the implementation of optimal policy, and the implications for the timing of intervention.

We further contribute to the literature on contingent capital, which has focused on contract design and its associated problems. Hillion and Vermaelen (2004) and Sundaresan and Wang (2014), for example, argue that market-based triggers in contingent contracts can lead to multiple equilibria in triggering conversion, while Hart and Zingales (2011), Pennacchi et al. (2013) and Bulow and Klemperer (2015) present alternative designs of market triggers to overcome this problem.[8] Our analysis of contingent capital helps to motivate the questions in this literature. We show that the optimal resolution regime can *in principle* be achieved with contingent capital contracts, but only if these contracts can (i) avoid multiple equilibria and "death spirals", and if (ii) their conversion is credibly beyond the regulator's control.

Our model is also related to the literature on contagion and foreclosure of banks. Various authors have been interested in the trade-off regulators face between taking inefficient private actions - that is, forbearance - and efficient public actions - that is, foreclosure. Boot and Thakor (1993) show that a self-interested regulator has incentives to hide his own monitoring failures by forbearing rather than foreclosing a bank. Morrison and White (2013) show that the same incentives affect a benevolent regulator who needs to preserve his own reputation for competence in order to prevent contagion to other, sound, banks. Shapiro and Skeie (2015) examine the case when regulators have private information about their type and need to signal their toughness to banks on the one hand and their willingness to bail-out to depositors on the other. In our paper, the regulator does not have the option of taking a secret action, so his choice is instead between public bail-in or public hesitation. This setting is arguably closer to the political reality faced by, for example, US regulators, given the level of transparency required of the Federal Reserve. In contrast to the foregoing papers, we examine in detail the design of the optimal public policy and in particular how a combination of rules and discretion can bring the regulator as close as possible to the efficient public bail-in action while avoiding adverse signaling consequences.

The paper is structured as follows: Section 2 describes our model. Section 3 describes equi-

[8] CoCos were first proposed by Flannery (2005) as "reverse convertible debentures". Flannery (2013) provides an excellent survey of the existing literature. Duffie (2014) discusses the related issue of resolving central counterparties in financial markets.

libria under rules and discretion, and Section 4 analyzes the optimal resolution regime when commitment is possible and the implementation of optimal regimes with contingent capital contracts. Section 5 considers extensions of the model, including a model with endogenous timing, an analysis of other financial policies, and a discussion of self-fulfilling bank runs that uses tools from global games. Section 6 concludes and elaborates on policy implications. The Appendix contains all proofs not given in the text.

2 Model

Time and agents. There are two dates $t \in \{1,2\}$ and three sets of agents: A single bank, a regulator, and a population of creditors. The regulator is benevolent and maximizes expected total welfare. The bank acts in the interest of its shareholders, who have limited liability. All agents are risk-neutral and nobody discounts the future. We take as given the bank's assets and liabilities which are in place at date 1.[9] Figure 1 illustrates the timing of events.

Bank investments. The bank's assets are long-term risky investments, which pay a random cash flow of $v \in [\underline{v}, \overline{v}]$ dollars per unit if held to maturity at date 2, and a certain but lower cash flow $L < \underline{v}$ if liquidated at date 1. If assets are not liquidated, the bank earns an additional random return $x \in \{0, R\}$ which is independent of v. Between dates 1 and 2, the bank's shareholders choose the probability $q = Pr[x = R]$ of earning the additional return. They incur a private utility cost $c(q)$ per unit of assets, which is increasing and convex and satisfies the technical condition $\frac{c'''(q)}{c''(q)} \geq -\frac{1}{R}$.[10] We call q the "effort" exerted by the bank.

Uncertainty and information. There is asymmetric information about the value of assets in place at date 1. The regulator and the bank privately observe the true asset value v at date 1, but are unable to send verifiable messages about this information. Creditors observe only a noisy public signal $s \in [\underline{s}, \overline{s}]$ of the value of assets v.[11] It is commonly known that the prior distribution of asset values is $F(v)$ with density $f(v)$ and full support on $[\underline{v}, \overline{v}]$, and that the conditional distribution of signals is $G(s|v)$ with density $g(s|v)$ and full support on $[\underline{s}, \overline{s}]$. We assume that signals have the monotone likelihood ratio property, i.e. that $\frac{g(s|v')}{g(s|v)}$ is increasing in s whenever $v' > v$. At date 2, all payoffs are publicly observed.

The bank's balance sheet. We take as given the bank's liabilities, which are short-term demandable debt with face value D, and long-term bonds with face value B. Short-term creditors have

[9]In Section 5.2, we consider policies which alter the bank's balance sheet composition, such as capital and liquidity requirements.

[10]This is satisfied by commonly-used cost functions such as quadratic costs with $c(q) \propto q^2$, or exponential costs with $c(q) \propto e^{\gamma q}$ for $\gamma > 0$.

[11]Under this assumption, regulators have better information about banks' health than creditors. This is motivated by the observation that in practice, regulators collect proprietary information about banks' assets and liabilities for use in supervisory assessments and stress testing.

the option to withdraw early, which entitles them to a claim D at date 1, or to wait, which entitles them to $(1+r)D$ at date 2. We assume $D > L$, so that the bank has a potential liquidity shortage if enough creditors decide to withdraw. Short-term debt is not insured by the government, but enjoys (absolute) priority over long-term bonds in case of insolvency. This is an optimal arrangement: If short-term creditors were to rank *pari passu* with long term debt at date 2, then the bank would be more prone to runs and, according to our arguments below, regulatory actions would be correspondingly less efficient in equilibrium. This observation validates recent regulatory attempts to restructure banks to ensure that short-term debt is structurally senior to most long-term debt.[12] Note that we can remain agnostic as to which violations of the Modigliani and Miller (1958) theorem motivate the bank's capital structure choices; our results below will apply provided that there are reasons why the bank wants to issue some short-term debt, even though this makes it prone to runs.[13]

Regulatory policy. At date 1, the regulator can intervene to increase the bank's equity by writing down long-term bonds with face value $a \in [0, B]$ by paying a cost κa.[14] This cost can be thought of either as a simple administrative cost, or as a short-hand to capture the reasons why writing down bank debt is, other things equal, undesirable - ranging from the problems associated with repudiating private contracts between willing parties, to the externalities associated with reducing the net-worth of the bond-holders. The "bail-in" action is observed by all creditors before they decide whether to withdraw early. We consider two institutional regimes: Policy based on *rules*, where the regulator's action a is pre-determined as a function of public information s, and policy based on *discretion*, where the regulator is free to choose a based on her private information v. We will also consider hybrid regimes, where the regulator is bound by rules after some realizations of s, and has discretion after others.[15] In Section 3.5, we discuss the robustness of our results if a is interpreted as an alternative policy that re-capitalizes the bank, such as the decision to force the bank to raise outside equity.

[12] For an accessible guide to how this structural subordination is to be achieved, and other recent policy changes, see Tucker (2014).

[13] Established reasons why short-term debt can be optimal, even if it induces fragility, include a desire to generate market discipline in the presence of imperfect contracts (Calomiris and Kahn, 1991; Diamond and Rajan, 2000) or a preference among non-bank investors for "money-like" securities which are insensitive to information (Stein, 2012; Dang et al., 2017).

[14] In practice, the regulator can wipe out existing shareholders and convert long-term bonds to equity. This is done to give existing shareholders incentives to avoid failure *ex ante*, and in order to satisfy the legal constraint that long-term creditors must be no worse off than they would be in bankruptcy. Our analysis, which focuses on *ex post* incentives, is unchanged in this case, as long as bondholders exercise their voting rights after conversion, and the bank continues to act in the interest of all shareholders (i.e. old shareholders and converted bondholders).

[15] Implicit in this distinction is an assumption that rules cannot be made contingent on private information. This is true, for example, if the regulator's private information is costly to verify *ex post*. In that scenario, it is impossible to enforce rules which are contingent on private information, because a regulator who deviates from a rule based on private information cannot be held to account or punished for her deviation.

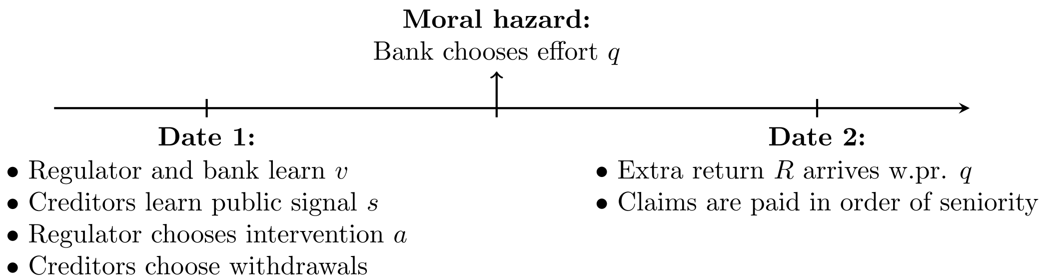

Figure 1: Timeline

2.1 Equilibrium definition

Our solution concept is Perfect Bayesian Equilibrium: The bank, regulator and creditors make decisions to maximize their expected payoffs. Creditors form beliefs $\mu(v|a,s)$ about asset values, conditioning on the public signal and the regulator's action, and these beliefs obey Bayes' rule whenever possible.

We impose the Cho and Kreps (1987) D1 criterion: If the regulator deviates from equilibrium play, creditors' beliefs concentrate on those realizations of v for which the regulator has the most to gain from deviating. This restriction is common in finance applications (e.g. Nachman and Noe, 1994) since it can generate equilibrium predictions in signaling games with more than two types. In particular, it selects equilibria in which the best types select their preferred outcome, and the actions of the remaining types are determined by incentive compatibility, as is assumed in the classical "pecking order" theory of capital structure following Myers and Majluf (1984).

2.2 The analysis of bank runs and multiple equilibria

The game among creditors at date 1 potentially has multiple equilibria: Withdrawals by some creditors, by increasing inefficient liquidations, can increase the value of withdrawing early for others, and trigger self-fulfilling bank runs as in Diamond and Dybvig (1983).

There are two common approaches to this problem in the literature which studies welfare in the presence of bank runs. On one hand, Allen and Gale (1998) focus on the best incentive-compatible outcome. This is equivalent to assuming that creditors have access to a coordination technology: They choose withdrawal strategies at date 1 in order to maximize their joint utility, subject to the restriction that no individual creditor has a unilateral incentive to deviate from the agreement. On the other hand, Goldstein and Pauzner (2005) and Rochet and Vives (2004) use techniques from global games to argue that small deviations from common knowledge can lead to unique equilibrium outcomes, so that creditors run if and only if they receive negative private signals about the bank's prospects.

Our key insights obtain under both approaches. In the baseline model, we will assume for simplicity that creditors can coordinate. In Section 5.3, we allow for coordination failure, introduce deviations from common knowledge, and derive similar qualitative results.

2.3 Parametric assumptions

We impose three restrictions: First, the additional return R at date 2 is always large enough to cover the bank's liabilities:

$$\underline{v}+R \geq (1+r)D+B+c'(0). \tag{1}$$

Assumption (1) is made for technical reasons. It ensures that banks always make positive effort in equilibrium. This guarantees concavity of the social welfare function and facilitates our analysis of the signaling game between the regulator and creditors.

Next, we assume that creditors do not wish to run on the bank based on public information alone:

$$\mathbb{E}\left[\min\{(1+r)D, v+x\}\,|\underline{s}\right] > D, \tag{2}$$

The left-hand side of (2) is the payoff that a creditor receives if she waits, given that everybody else is waiting and given the worst public signal $\underline{s}$. The right-hand side is the certain payoff from withdrawing immediately. Under this condition, public information alone cannot trigger a fundamentals-based bank run.

Finally, the costs of intervention are not too large:

$$\kappa B < \underline{v} - L. \tag{3}$$

If this holds, then cost of a bail-in intervention (which is at most κB) does not outweigh the potential cost of liquidating the bank (which is at least $\underline{v} - L$). Therefore, the regulator would rather intervene than risk liquidation. Assumptions (2) and (3) are made to clarify the exposition. We discuss the robustness of our results to relaxing these conditions in Section 3.5.

3 Equilibrium

3.1 Moral hazard motivates bail-in

We solve the model by backward induction, starting with the bank's incentives to exert effort between dates 1 and 2. Consider first the case where all depositors withdraw late. The bank's equity capital at date 2, if it earns the additional return R, is

$$K = v + R - (B - a) - (1 + r) D. \tag{4}$$

If the bank does not earn R, then its equity is $K - R$. When equity capital is negative, then the bank is insolvent and shareholders receive zero. The expected payoff to shareholders, given that the extra return arrives with probability q, is therefore

$$q \max\{K, 0\} + (1 - q) \max\{K - R, 0\} - c(q). \tag{5}$$

Assumption (1) implies that banks always choose positive effort, and so the first-order condition for maximizing (5) reduces to

$$c'(q) = \min\{K, R\}. \tag{6}$$

By contrast, a social planner would choose q to maximize the Net Present Value $qR - c(q)$, so that socially optimal effort is determined by

$$c'(q) = R. \tag{7}$$

Comparing (6) with (7), it follows that the bank acts in a socially efficient way as long as it is sufficiently well capitalized with $K \geq R$. A badly capitalized bank with $K < R$, however, exerts insufficient effort because it does not internalize losses to creditors if it fails to generate R. This is a version of the debt-overhang problem due to Myers (1977).

To make explicit the dependence of effort on asset values and regulatory intervention, we let $\hat{q}(a, v)$ denote the optimal choice which solves (6), given that (equity) capital is determined by (4). Note, in particular, that effort (weakly) increases whenever asset values v increase or more debt a is written down by regulators.

This moral hazard problem is the primary motivation for regulatory intervention in our paper. If $K < R$, then the regulator can boost capital by writing down more long-term debt, since $dK/da > 0$ in Equation (4), and thus bring effort closer to its efficient level by creating "skin in the game" for bank shareholders. Our technical condition on the third derivative of c further guarantees that welfare is a concave function of bank capital in the region where $K < R$.

We emphasize that our results below do not depend on the specifics of the moral hazard problem. The key assumption is that social welfare is an increasing, single-peaked function of bank capital. In particular, similar conclusions would emerge in a model where the bank has opportunities to extend credit to new firms at date 2, but is unable to finance these loans if K is low. This kind of credit rationing due to insufficient bank capital can be motivated, in principle, by appealing to debt overhang, or to further incentive problems as in Holmstrom and Tirole (1997). In this alternative scenario, the rationale for regulatory intervention would be driven by macroeconomic concerns, namely to raise bank capital in order to reduce the welfare costs associated with credit crunches. In the remainder of the paper, we focus on the above moral hazard model for clarity, but we note that our results on optimal policy apply equally when intervention is motivated by macroeconomic concerns.

3.2 Bank runs

We turn to creditors' optimal choices. Recall that we assume, for now, that creditors coordinate: They choose strategies which maximize their joint utility, subject to the requirement that no individual creditor has an incentive to deviate. The chosen strategy is therefore the best Nash equilibrium of the (sub)game among creditors:

Lemma 1. *All creditors withdraw at date* 1 *if*

$$\mathbb{E}_{\mu}\left[\min\left\{(1+r)D, v+x\right\}\right] < D, \tag{8}$$

where the distribution of x under μ is defined by $Pr_{\mu}[x=R|v,a,s] = \hat{q}(a,v)$, where $\hat{q}(a,v)$ solves the first-order condition (6). If (8) does not hold, then all creditors wait and withdraw at date 2*.*

In equilibrium, each individual creditor trades off the costs and benefits of waiting until date 2 to withdraw. The payoff from waiting is the left-hand side in (8): Short-term creditors receive their full claim $(1+r)D$ when the bank is solvent, and the remaining value of assets $v+x$ otherwise. The payoff from withdrawing early is D, the right-hand side of (8).

If (8) holds, then each individual creditor has a dominant strategy to withdraw early, so the only possible equilibrium is for all creditors to withdraw early. This leads to a *fundamentals-based bank run*. It is important to note, however, that fundamentals-based bank runs are not socially optimal. In a fundamentals-based run, the bank is liquidated because waiting ceases to be incentive compatible, but liquidation is wasteful nonetheless. Moreover, short-term creditors do not internalize the losses which liquidation causes for shareholders and other (junior) debtholders.

If (8) does not hold, then individual creditors are happy to withdraw late, given that nobody else withdraws early. Moreover, in this case the expected shortfall between assets and liabilities is relatively small, so that creditors' utility is maximized if all of them withdraw late. Thus, they will optimally coordinate on withdrawing late.

Lemma 1 links bank runs to creditors' beliefs μ about asset values, and to the "bail-in" intervention a. Pessimistic beliefs about v increase the likelihood of bank runs by increasing the expected value of assets, as well as by weakening shareholders' incentives. By contrast, a more aggressive bail-in (higher a) reduces the likelihood of bank runs because it improves shareholders' incentives and increases the probability that $x = R$ instead of $x = 0$.

However, an increase in a can also render bank runs *more* likely if creditors interpret the regulator's aggressive stance as bad news. We now analyze this signaling problem.

3.3 Discretion leads to excessive weakness

We now consider the regulator's problem, which is to choose his "bail-in" action a to maximize expected social welfare. We start by assuming that the regulator has full discretion when choosing his policy.

Welfare is L if the bank is liquidated at date 1, and equal to $v + qR - c(q) - \kappa a$ if it continues at full scale until date 2. When choosing a, the regulator knows the realization of asset values v and anticipates that the bank will choose the best-response effort level $q = \hat{q}(a, v)$. Thus, welfare if the bank continues is

$$W(a,v) \equiv v + \hat{q}(a,v)R - c(\hat{q}(a,v)) - \kappa a. \tag{9}$$

The regulator considers two effects on welfare: First, writing down more of the bank's long-term liabilities (i.e. increasing a) improves the incentives of bank shareholders and brings the bank's effort $\hat{q}(a,v)$ closer to its efficient level. Second, the intervention itself may be interpreted as a signal of the regulator's private information and lead to a bank run if creditors' beliefs become too pessimistic.

To find equilibria of the signaling game, consider first a hypothetical game where creditors do not have the option to withdraw, so that bank runs are impossible. In this case, the regulator's (first-best) action is

$$a^{\star}(v) = \arg\max_{a \in [0,B]} W(a,v).$$

The first-best action is decreasing in asset values: When asset values increase, banks' incentives improve and effort will be closer to the first-best. Therefore, the marginal value of intervention decreases.

In our model, the regulator also needs to consider that his action may trigger bank runs. It is useful to define $v_0(s)$ as the lowest value v for which the regulator can (i) choose the first-best action $a^{\star}(v)$, (ii) reveal to creditors that asset values are no better than v, and (iii) avoid a bank run, in the sense that beliefs after this revelation are optimistic enough to violate the bank run condition (8).[16] We can now characterize equilibrium play with discretion:

[16]Formally, $v_0(s)$ is the smallest v' satisfying

$$\mathbb{E}\left[\min\{(1+r)D, v+x\} \,|a^{\star}(v'), s, v \leq v'\right] = D,$$

and if such a value does not exist we set $v_0(s) = \infty$.

Proposition 1. *If the public signal s is realized and the regulator has discretion, then the regulator's action in any equilibrium takes the form*

$$\alpha(v,s) = \min\{a^\star(v), a_0\},$$

where $a_0 \leq a^\star(v_0(s))$. The equilibrium which yields the highest welfare is where $a_0 = a^\star(v_0(s))$.

Figure 2 illustrates equilibrium play with discretion, taking as given a public signal s. The solid line shows the first-best action $a^\star(v)$. Two possible equilibria with discretion are the dashed lines. In each case, regulators with bad news play a pooling strategy with $\alpha(v,s) = a_0$ or a_0', and regulators with good news play their first-best strategy.

This characterization follows from incentive compatibility. First, note that there can be no runs in equilibrium. Condition (3) ensures that the regulator would rather conduct a bail-in than risk a bank run, even if this bail-in is not the first-best. Hence, regulators with bad news will always "mimic" better types in order to avoid a run. Second, given that there is no run, welfare in equilibrium is given by $W(a,v)$. Incentive compatibility now requires that the regulator with type v cannot gain by taking the equilibrium action of another type $\alpha(v',s)$. The first-order necessary condition for incentive compatibility is then

$$0 = \left.\frac{\partial W(\alpha(v',s),v)}{\partial v'}\right|_{v'=v} = \frac{\partial W(\alpha(v,s),v)}{\partial a} \times \frac{\partial \alpha(v,s)}{\partial v}. \tag{10}$$

The regulator's equilibrium action is either insensitive to his information, so that $\frac{\partial a}{\partial v} = 0$, or coincides with the first-best action, so that $\frac{\partial W}{\partial a} = 0$. The requirement to avoid runs implies that regulators with bad news must copy better types, implying a region where $\alpha(v,s) = a_0$ for all $v \in [\underline{v}, v_0]$. Beyond this region, the regulator's policy action coincides with first-best actions. The formal proof of Proposition 1 uses our restriction on off-equilibrium beliefs to rule out any other possible strategies.

Moreover, it is clear from Figure 2 that welfare is increasing in the pooling action: The equilibrium with a high pooling action a_0 is everywhere closer to the first-best strategy than the equilibrium with a low pooling action $a_0' < a_0$.

Figure 2 makes it clear that the main shortcoming of discretionary policy is *excessive weakness*. The desire to avoid bank runs leads regulators with bad news to conduct a less aggressive bail-in than they would otherwise prefer. Note that this problem becomes less severe as public beliefs improve: Regulators with bad news at least up to $v = v_0(s)$ must pool to avoid a bank run. When the public signal s improves, creditors become less skeptical about the bank's health, and less sensitive to bad news about the regulator's private information. Therefore, $v_0(s)$ falls, and the equilibrium with discretion becomes more closely aligned with the first-best outcome. It is therefore primarily

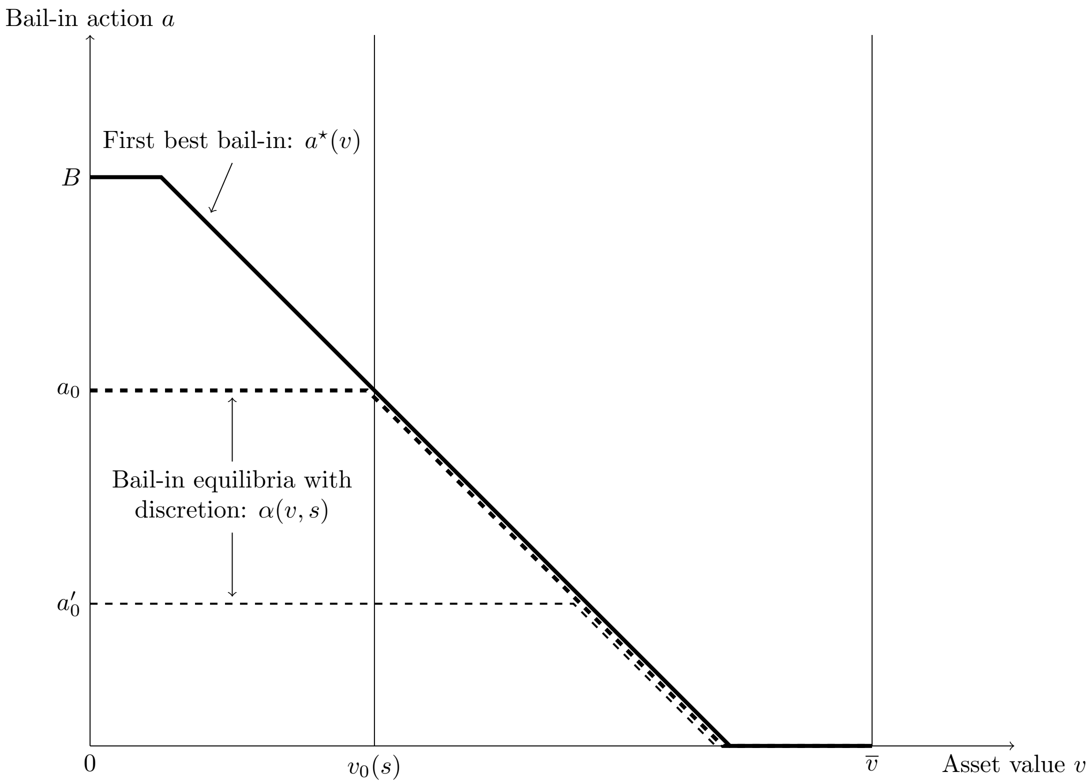

Figure 2: Equilibrium with discretion

in bad states, after bad realizations s of the public signal, that discretion becomes problematic.

3.4 Rules versus discretion: Toughness versus accuracy

If the regulator is bound by *rules*, then he must take a pre-specified action $a = A(s)$ if the public signal s is realized. Thus his response is, by definition, insensitive to his private information. Creditors cannot infer private information from the regulator's action, and their posterior beliefs are formed by Bayesian updating using only the public signal s. Assumption (2) implies that the public signal is sufficiently noisy, so that public information alone cannot trigger a bank run.

Rules can, in principle, overcome excessive weakness. Suppose that the regulator commits to a rule which mandates $a = A(s) > a^\star(v_0(s))$ regardless of the realization of private information. Figure 3 illustrates the bail-in policy associated with this commitment. Note that under this rule, the regulator is bound to conduct a tougher bail-in than he would conduct in *any* equilibrium with discretion.

We first examine the positive implications of discretion and rules for the probability of bank insolvency. The bank is insolvent at date 2, in the absence of a bank run, if its final liabilities exceed assets, or $(1+r)D + B - a > v + x$. Compared to rules, discretion increases the probability

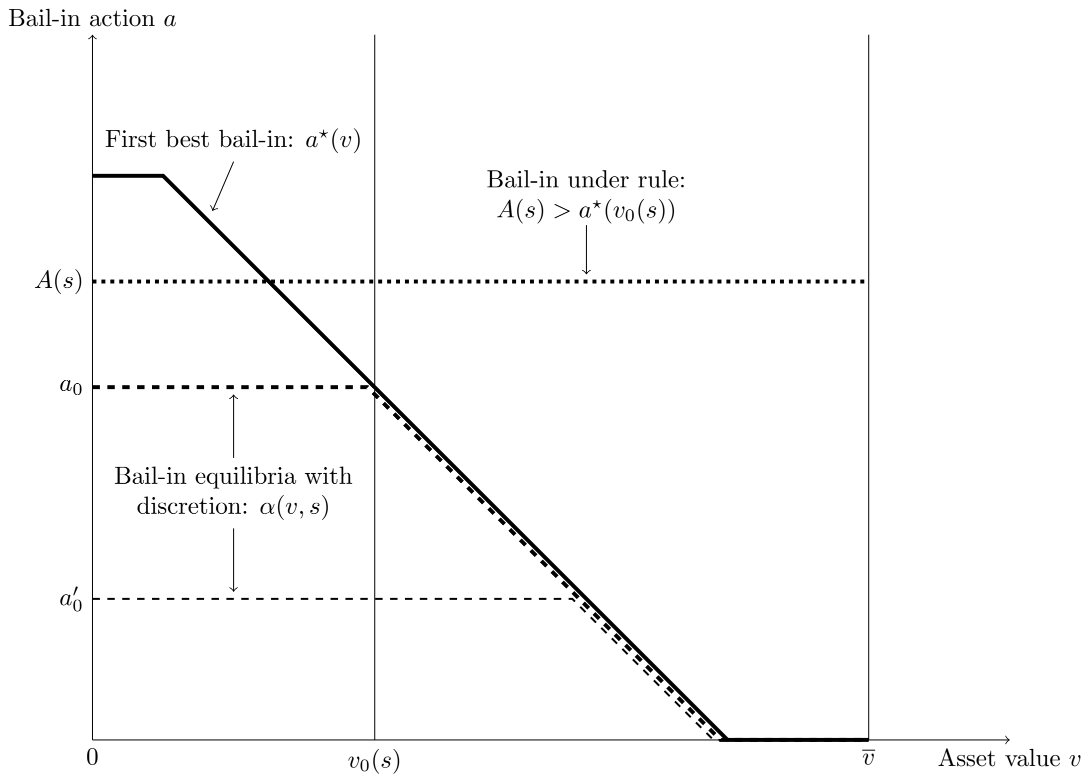

Figure 3: Comparing rules and discretion

of bank insolvency:

Proposition 2. *The probability of bank insolvency is higher under discretion than under a rule with* $A(s) > a^\star(v_0(s))$.

To establish this, note that a decrease in the bail-in action a always decreases shareholder's optimal choice of effort. This is clear because optimal effort is a function of bank capital, which is itself an increasing function of a. Therefore a rule which increases the bail-in action relative to discretion has two beneficial effects on bank solvency. First, it directly decreases long-term liabilities at date 2. Second, it improves shareholder incentives, which increases the probability that $x = R$, and therefore increases the expected value of bank assets. In Section 5.1, we extend this analysis to a model where the government can also intervene ex post (at date 2) to avert insolvency, either by writing down additional long-term debt or by conducting a bail-out with public funds. In that Section, we find, similarly to Proposition 2, that discretion increases the probability of bank insolvency, and we show in addition that the probability of public bail-outs is higher under discretion than under an appropriate rule.

To motivate our normative analysis, we show that rules improve welfare as long as beliefs about asset values v given the public signal s are pessimistic:

Proposition 3. *Expected welfare given public signal s is lower under discretion than under a rule with $A(s) > a^\star(v_0(s))$, as long as the distribution of v given s places sufficient weight on low realizations of v.*

This result is immediate from Figure 3, which highlights that the trade-off between rules and discretion is one between *toughness* and *accuracy.* If asset values v turn out to be low, then the regulator takes an excessively weak action under discretion because of signaling concern. A rule $A(s) > a^\star(v_0(s))$ brings policy close to the first best action for these realizations of v. The welfare benefit of rules is the ability to commit to be tough in bad times.

If asset values v turn out to be high, then the rule binds the regulator to an excessive intervention, while under discretion, he is not affected by signaling concerns and reduces bail-in to its first best level. The welfare benefit of discretion is therefore the ability to conduct more accurate policy in good times. If, given a public signal s, low realizations of v are relatively more likely, then toughness is more valuable than accuracy, and rules can improve welfare.

We discuss welfare properties in much more detail in Section 4, where we characterize the optimal choice between rules and discretion and allow the existence and design of rules to be made contingent on public signals. To conclude this Section, we discuss the sensitivity of the key trade-offs to our assumptions.

3.5 Discussion of assumptions

Assumption (1) imposes that the additional return R which the bank can earn by making effort is high enough to guarantee positive levels of effort in any equilibrium. If this is relaxed, the regulator's incentive to conduct a bail-in becomes non-monotonic: Regulators with very bad news are fatalistic and refrain from bail-ins, because they know that the bank is likely to make zero effort regardless of the policy. Regulators with mediocre news want to conduct bail-ins to sharpen incentives, and regulators with very good news consider bail-ins unnecessary because they know that the bank is already well-capitalized. This setup violates the standard Spence-Mirlees single-crossing condition and is therefore harder to analyze, but our basic point remains valid: Giving discretion to the regulator creates an incentive for mediocre types to conduct excessively weak (but not zero) bail-ins in order to pool with better types.

We impose Assumption (2) to ensure that public information alone cannot trigger a fundamentals-based bank run. We make this assumption mainly to restrict attention to situation where regulatory policy can have an impact, and thus to reduce the number of cases to analyze. Suppose instead that there is a bad realization of the public signal s which would trigger a run even if the regulator revealed no further information about v. In this case, there must be a run in equilibrium, regardless of whether the regulator operates under discretion or rules: The only alternative would be for the regulator to take a discretionary action to reveal that v is good enough to improve creditors' beliefs. But in this case, regulators with worse news would copy that action in order to avoid a run themselves, so that the action would again become uninformative. Hence, welfare after such a public signal is independent of the institutional design, and the bank is sure to be liquidated at date 1.

Finally, Assumption (3) states that the regulator would rather intervene by writing down debt than risk liquidation of the bank. This assumption can be relaxed, and in that case, we would find that regulators with very bad news about v would be unwilling to distort their action in order to ensure the bank's survival. In an equilibrium with discretion, we would see (i) regulators with good news taking their first-best action, (ii) regulators with intermediate news pooling on a weaker action than first-best, and (iii) regulators with very bad news revealing their news by taking their first best action, leading to immediate liquidation of the bank through a bank run. In this case, point (ii) still generates excessive weakness from discretion, and therefore, as long as intermediate news arrives with sufficient probability, rules continue to be preferable to discretion.

For concreteness, we have modeled the action that the regulator takes to create equity as a bail-in of long term debt, in line with current policy. However, the same logic would apply to a model in which bail-in is not available and the regulator is obliged to create equity by forcing the bank to issue new equity at date 1. In this case, the model would suggest that tough rules concerning re-capitalizations in the face of negative public news would be valuable, because under discretion fear of runs will prevent the regulator from imposing as large a recapitalization as would be desirable. Tight capital requirements could potentially fulfill this role. In addition, the problems of discretion are likely to be magnified when the regulator's only tool is to enforce equity issuance rather than to undertake bail-ins. The reason is that with the ability to bail-in, the regulator is concerned only about runs; and not directly about the impact on the bank's stock price. Whereas with equity-issuance and re-capitalizations, the regulator also fears the impact of information on the bank's stock price and its ability to issue equity to recapitalize. In this sense, we conjecture that the ability to bail-in may help the regulator to commit to tougher actions than when he must resort to insisting on re-capitalizations.

4 Optimal resolution regimes

A resolution regime lays out (i) for which realizations s of the public signal the regulator will be bound by rules, and (ii) which action $A(s)$ he will commit to for each realization where he is bound by rules. The optimal resolution regime is one which maximizes welfare from an *ex ante* perspective. We find that it is optimal to commit after sufficiently bad realizations of the public signal:

Proposition 4. *There is a critical level of the public signal $s^\star$, such that the optimal resolution regime is as follows:*

1. *If the public is below $s^\star$, then the regulator is bound by rules and must take action $a = A(s)$. The mandated action $A(s)$ is a decreasing function of s, and it is always higher than the highest action that would be played if the regulator had discretion in state s, that is, $A(s) > a^\star(v_0(s))$.*

2. *If the public signal is above $s^\star$, then the regulator has discretion.*

This result builds on the trade-off between rules and discretion that we explored in Proposition 3. The benefit of commitment is the ability to be tough when asset values are low, while the costs of rules are a loss in accuracy and the fact that rules may force the regulator to conduct unnecessary bail-ins when asset values are high.

When the economic outlook based on public news is poor, it is rational to anticipate low asset values, and therefore a greater need for tough bail-in policies. In this case, the benefits of commitment outweigh the costs. Conversely, when public news suggests that the economic outlook is good, we anticipate high asset values. In this case, the costs of commitment outweigh its benefits. The threat of runs is remote, and the excessive weakness induced by discretion is unlikely to affect the regulator. As a result, the regulator optimally writes rules which tie his hands whenever the economic outlook, as measured by public news, falls below a threshold $s^\star$, and retains discretion when news are above the threshold.

4.1 Implementing the optimal policy using contingent capital

In this Section, we assume that explicit rules are unavailable, but that that some of the bank's long-term bonds can be replaced with contingent capital. The bank writes binding contracts with its investors which specify that some long-term bonds will be written down, or converted to equity, contingent on the realization of public news s.[17] The regulator has discretion to write down additional long-term debt, but cannot undo contractually mandated write-downs. We show that this constraint provides sufficient commitment to implement the optimal regime.

Proposition 5. *The optimal resolution regime can be implemented, when explicit rules are unavailable, by modifying the bank's capital structure as follows:*

[17] Avdjiev et al. (2013) show that conversion-based contracts dominated the initial wave of issuance in 2009, but that more recently, the split between conversion and principal write-down CoCos has been roughly half-half. Since in our model the conversion happens before the bank undertakes its moral hazard action, it is immaterial whether the long term debt is simply written down or converted into equity. This distinction can, however, be of crucial importance in other models of contingent convertibles: see Pennacchi (2011); Martynova and Perotti (2016); Albul et al. (2013), and Flannery (2013) for a survey.

- *A subset of long-term debt is replaced with contingent convertible debt contracts. Each contingent debt contract has a trigger τ, and is written down whenever the public signal falls below the trigger so that $s \leq \tau$.*
- *The triggers of the contingent debt contracts are chosen such that the face value of contracts with trigger s or higher is equal to $A(s)$ for $s \leq s^{\star}$, and no contracts have a trigger above $s^{\star}$.*

This illustrates a novel role for contingent capital in financial policy. Contingent capital hard-wires the conversion of debt upon bad public news. This ties the regulator's hands in a helpful way. When public news is bad, commitment to tough bail-in actions is valuable, since the threat of runs and the excessive weakness associated with discretion are imminent. In these states, the conversion of contingent debt provides quasi-commitment by mandating a tough bail-in policy beyond the regulator's control. When public news is good, discretion is preferable. Since contingent capital does not convert in these states, discretion is preserved exactly when it is most valuable.

In our implementation, the regulator has the option to take the bank into resolution and conduct further bail-ins ($a > A(s)$), even when some conversion of the contingent debt has been mandated. Contingent debt contracts in practice often have this feature: There is a trigger based on market or accounting information, but the regulator always has the option to intervene, even when the trigger has not been hit. It is interesting to note that in our implementation, this additional "regulatory trigger" is not used in equilibrium. The regulator would only want to conduct an additional bail-in when he has very bad news. But doing so would reveal bad news to the public, triggering a run.[18]

Our results show that it can be desirable for banks to have a contingent capital structure designed according to the *regulator's* tastes. If there are externalities associated with bank distress, this structure will differ from banks' private preference. In the Basel III framework, steps have been taken towards aligning the incentives of banks and regulators by having contingent debt count towards regulatory capital requirements (Avdjiev et al., 2013). However, there is no reason to suppose that this measure alone will align incentives exactly. Thus, the right type of commitment may require a combination of (i) a policy which allows contingent debt to count towards capital requirements, and (ii) hard-wired rules which constrain bail-in policy based on public signals.

By specifying contingent capital in this way, we are making some implicit assumptions. First, we have treated the distribution of the public signal s, which plays the role of a trigger, as exogenous. In the case of a market price-based trigger, this is a bad approximation in situations where conversion itself strongly affects prices. In other words, we assume that contingent debt

[18] I a richer model, regulatory triggers might still be valuable. For example, consider a setting where the public signal s is observable, but only a noisier version $\hat{s}$ is privately contractible. Then commitment via contingent capital contracts is only possible based on $\hat{s}$. However, the regulator will wish to react by using additional regulatory triggers when the public news s is worse than its contractible part $\hat{s}$. Moreover, he will not hesitate to do so, because s is publicly known and so acting upon it will not trigger runs because it does not provide any further information beyond what creditors already have.

is designed to prevent the strong feedback effects or "death spirals" discussed by Sundaresan and Wang (2014). Second, we assume that the regulator has no direct influence over the realization of s. This is not guaranteed. For example, Bulow and Klemperer (2015) argue that the conversion of contingent convertibles with *regulatory capital* (i.e. book equity) triggers may not be credible, since regulators can affect measured regulatory capital by deciding when to require banks to write down non-performing assets.

Our recommendations in Proposition 5 therefore apply if the design of contingent capital is such that these contracts (i) do not lead to strong feedback effects and (ii) are based on triggers which are credibly beyond the regulator's control. Proposals for such designs are given by Hart and Zingales (2011), Bulow and Klemperer (2015), and Pennacchi et al. (2013), among others. Moreover, anticipating Proposition 6 below, triggers should not be too noisy. This implies a potential trade-off between the use of market and book values in contingent capital design: Market values are more credibly beyond the control of the regulator than book values, but might also be considered noisier.

Note, in addition, that a further advantage of CoCos cited by practitioners is that they offer investors a way to avoid the risks associated with regulatory discretion over bail-ins. If investors are uncertain about the regulator's preferences, this can introduce additional risk for the buyers of bonds which may be deemed "bail-inable". In our model, regulators' preferences are known and benevolent, but there will nevertheless be uncertainty associated with discretion because investors are not privy to the regulator's private information. Commitment has the virtue of avoiding not only excessive weakness, but also the risk associated with predicting the regulator's signal on the basis of public information.

4.2 Are rules more valuable when public signals are more precise?

The value of commitment depends on the quality of public information. When the regulator gives up discretion, he is forced to ignore his private information and acts only on public signals. At first glance, a noisy public signal should therefore reduce the value of commitment by decreasing the accuracy of bail-in policies. Suppose, for example, that public information improves due to an increase in mandated information disclosure by banks - does this increase the set of signals for which it is optimal to employ rules or automatically convert contingent capital?

We model a deterioration in the quality of public information as follows: Suppose that instead of s, the public observe a signal $\hat{s} \in [\underline{s}, \overline{s}]$ which is less informative than s in the sense of Blackwell (1953), that is, it is drawn from a conditional distribution $G(\hat{s}|s)$ which is non-degenerate and independent of asset values v. Intuitively, such a signal $\hat{s}$ is a "garbled" version of the original signal s. We show that the above intuition is true in a practically relevant region of the parameter space, but that the general effect is more nuanced.

Proposition 6. *If creditors observe the less informative signal $\hat{s}$ instead of s, then the critical public signal $s^\star$ below which rules are optimal decreases, as long as the initial threshold is sufficiently close to the worst signal $\underline{s}$.*

Recall that commitment to tough actions benefits the regulator when he has bad news (low v) and hurts him if he faces good news (high v). First, consider a low realization of the public signal, close to $\underline{s}$. Noisy bad news is less meaningful than precise bad news, so the distribution of v given $\hat{s}$ is more *optimistic* than its distribution given s. Hence, the noise shifts probability mostly towards high v, where commitment is harmful, and the value of commitment falls. Second, consider a high realization of the public signal, close to $\overline{s}$. In this case, noise makes the conditional distribution more *pessimistic*, probability shifts mostly towards low v, and commitment becomes more valuable.

In reality, regulators would want to execute tough resolution policies only when banks are close to failure. Hence, the empirically relevant case is perhaps where $s^\star$ is close to $\underline{s}$. In this scenario, Proposition 6 shows that when the quality of public information deteriorates, a more cautious approach to rules-based resolution is warranted. By contrast, an improvement in the quality of public information about banks' financial condition would allow greater use of rules-based policy.

5 Extensions

5.1 The timing of intervention

In this section, we allow the regulator to choose the timing, as well as the extent, of intervention. As before, he can write down a portion $a_1 \in [0,B]$ of the bank's long-term debt at a cost of κ_1 per unit at date 1. But now, we allow the regulator a chance to intervene at date 2, by bailing in another $a_2 \in [0, B - a_1]$ of long-term debt at a cost of κ_2 per unit. To motivate late intervention we assume that bank insolvency at date 2 creates a deadweight social cost equal to χ times the shortfall of assets from liabilities, that is:

$$\chi \times \max\left\{(1+r)D + B - \sum_{t=1}^{2} a_t - v - x, 0\right\}. \tag{11}$$

We assume $\chi > \kappa_2$, so that the government's best response ex post is to intervene in order to minimize shortfalls at date 2. By Assumption (1), a shortfall can arise only if the additional return

$x = 0$. In this case, the optimal late intervention is $a_2 = \hat{a}_2(v, a_1)$, where

$$\hat{a}_2(v,a_1) \equiv \begin{cases} 0, & \text{if } v \geq (1+r)D + B - a_1, \\ D + B - a_1 - v, & \text{if } (1+r)D + B - a_1 > v \geq (1+r)D, \\ B - a_1, & \text{if } v < (1+r)D. \end{cases}$$

Substituting into (11), the resulting deadweight loss is $\chi \times \max\{(1+r)D - v, 0\}$. In response to the regulator's policy (both the realized early action a_1 and the anticipated late action $\hat{a}_2(v,a_1)$), the bank chooses an optimal effort level $\hat{q}(v,a_1)$. Therefore, welfare from the perspective of date 1 is

$$W(v,a_1) = v + \hat{q}(v,a_1)R - c(\hat{q}(v,a_1)) - \kappa_1 a_1 - \kappa_2 \hat{a}_2(v,a_1) \\ - \chi(1 - \hat{q}(v,a_1)) \max\{(1+r)D - v, 0\}.$$

If creditors did not have the option to run on the bank, the regulator would choose the first-best early action

$$a_1^\star(v) = \arg\max_a W(v,a_1).$$

In this version of our model, the first-best action optimally trades off the incentive benefits of early intervention against the option value of waiting: Early intervention boosts bank capital and improves the incentives of bank shareholders. The option value of waiting arises because, if the regulator does not intervene at date 1, there is still a positive probability q that the bank will earn $x = R$, in which case solvency is guaranteed and the regulator can save the costs of intervention. Indeed, it is easy to show that if the regulator did not have the option to move at date 2, he would choose a strictly *higher* action that $a_1^\star(v)$ ex ante; the difference between this action and $a_1^\star(v)$ is explained by the option value of waiting.

We can characterize equilibrium play under discretion and rules by analogy to Propositions 1 and 2:

Proposition 7. *If the public signal s is realized and the regulator has discretion, then the regulator's date* 1 *action in any equilibrium takes the form*

$$\alpha_1(v,s) = \min\{a^\star(v), a_0\},$$

where $a_0 \leq a^\star(v_0(s))$, with $v_0(s)$ defined as the lowest v' for which the regulator can play $a_1^\star(v')$, reveal that $v \leq v'$ and avoid a bank run. The probability of bank insolvency, and the expected late intervention $\mathbb{E}[a_2|s]$, are weakly higher under discretion than under a rule with $A(s) > a^\star(v_0(s))$.

As before, the regulator takes excessively weak actions at date 1, compared to the first best case, in order to avoid signaling bad news to creditors. As a result, bank incentives are weakened and the probability of bank insolvency increases.

The new result in Proposition 7 concerns the timing of intervention. Compared to rules, discretion leads to weaker interventions at date 1 but to *stronger* interventions, on average, at date 2. This is because discretion weakens bank shareholders' incentives, and therefore reduces the probability that the bank survives ex post. Therefore, discretion increases the average late intervention that is needed to prevent socially costly failure at date 2. In summary, this extension reveals that discretion leads the regulator to intervene not only "too little," but also "too late".

An interesting thought experiment in this context is to consider the link between bail-ins and bail-outs. For this purpose, we add to our model a fiscal authority which can bail out banks at date 2. In particular, assume that there is a benevolent Treasury which can conduct a cash transfer T from households to the bank's shareholders (i.e. a bail-out) at date 2, in addition to the bail-in a_2 conducted by the regulator. This transfer results in a social deadweight cost of $\tau \times T$, where $\tau > 0$ represents the welfare cost of distortionary taxation. We assume that the fiscal authority and the regulator choose a_2 and T jointly to maximize welfare at date 2, and that $\kappa_2 < \tau$, which makes bail-ins less costly than bail-outs. Under these conditions, the government will optimally use bail-outs only if the bail-in option has been exhausted (i.e. when $a_1 + a_2 = B$) but the bank is still facing insolvency.

In this extension, we can show that rules can offer a more credible way to prevent bail-outs.

Proposition 8. *If the ratio χ/τ of bankruptcy costs to taxation costs is sufficiently large, then the expected value of the bail-out $\mathbb{E}[T|s]$ is higher under discretion than under then a rule with $A(s) > a^{\star}(v_0(s))$.*

If the government can provide bail-outs to prevent failures, and if the ratio χ/τ of the cost of failure to the cost of bail-outs is sufficiently high (the bank is "too big to fail"), then it will be profitable ex post to save the bank whenever it faces failure. By Proposition 2, discretionary policy increases the likelihood of failure, and therefore increases the likelihood that a bail-out becomes necessary.

We omit a formal analysis of the optimal resolution regime when the regulator can choose the timing of his bail-in actions. The result, however, is the same as in the baseline model: It is optimal to commit to tough early action whenever public signals are sufficiently negative, because after these realizations, the tough early interventions which rules permit dominate the weak but fine-tuned policies which arise under discretion.

5.2 Balance sheet policy

So far, we have taken the bank's balance sheet as a primitive, determined exogenously at some prior date (date 0, say). In this section, we will continue to be agnostic regarding the particular violations of the Modigliani and Miller (1958) conditions that determine the bank's capital structure choices, but we offer some observations on how these choices affect the operation of bail-in policy. Or, looking at it another way, what changes would a regulator like to see in the date 0 balance sheet, considering how this balance sheet will affect the problems associated with discretion and the optimal rule later on? This exercise will point to ex ante policies, such as tighter liquidity and capital regulation at date 0, which allow bail-in policy to become more effective. Hence, we show that Basel III's ex ante liquidity and capital requirements can be seen as *complements* rather than substitutes to the design of ex post resolution regimes.

The parameters of the bank's balance sheet in the baseline model are its short-term debt D, and its long-term bonds B. We can think of these quantities as defined *per unit* of risky assets; since technologies in our model exhibit constant returns to scale, our analysis would be the same for a bank who held debt ηD and ηB as well as risky assets yielding $\eta(v+x)$ for some scaling factor $\eta > 0$.

It is useful to define $\mathscr{A} \equiv \{v, s | v < v_0(s) \text{ and } s > s^\star\}$ as the set of states in which the regulator has discretion (since the public signal is above the threshold $s^\star$ – defined in Proposition 4 – where rules become optimal), but ends up taking an excessively weak action (since private information s is below the threshold $v_0(s)$ where the regulator begins to worry about bank runs). To clarify the exposition in this Section, we will assume that the regulator's action in equilibrium is always interior with $a \in (0, B)$, and that the critical value below which the regulator acts weakly is interior with $v_0(s) \in (\underline{v}, \overline{v})$.

Proposition 9. *Suppose that regulators implement the optimal mix of rules and discretion derived in Proposition 4, after observing the bank's balance sheet (D, B). The welfare gain from reducing the bank's short-term debt obligations $(1+r)D$ by a marginal unit is*

$$\left|\frac{dW^\star}{d(1+r)D}\right| = \kappa + Pr[\mathscr{A}]\,\mathbb{E}\left[\left.\frac{\partial W(a,v)}{\partial a}\right|_{a=a^\star(v_0(s))}\left(1 - \frac{\partial a^\star(v_0(s))}{\partial v} \times \frac{dv_0(s)}{d(1+r)D}\right)\right] \tag{12}$$

Similarly, the gain from lowering the bank's long-term debt B by a marginal unit is

$$\left|\frac{dW^\star}{dB}\right| = \kappa + Pr[\mathscr{A}]\,\mathbb{E}\left[\left.\frac{\partial W(a,v)}{\partial a}\right|_{a=a^\star(v_0(s))}\left(1 - \frac{\partial a^\star(v_0(s))}{\partial v} \times \frac{dv_0(s)}{dB}\right)\right] \tag{13}$$

Moreover, reducing short-term debt is more valuable than reducing long-term debt:

$$\left|\frac{dW^\star}{d(1+r)D}\right| > \left|\frac{dW^\star}{dB}\right|.$$

Proposition 9 follows by applying the envelope theorem to the optimal rule. Lowering the bank's liabilities, either by lowering short-term debt $(1+r)D$ or by lowering long-term debt B, improves welfare through two effects. First, a reduction in debt has a direct effect on shareholders' incentives. The marginal incentive benefit of lowering the debt burden is the same as the marginal benefit of a bail-in. This is because both interventions improve the bank's capital, which determines effort via the first-order condition (6), by a marginal unit. In states where the regulator's date 1 bail-in is chosen optimally (either via an optimal rule or under discretion when the regulator has good news), the direct marginal benefit of incentives is set equal to the social cost κ of bail-in. In states $\mathscr{A}$ where the regulator has discretion and takes an excessively weak action, the direct marginal benefit of incentives is stronger, and given by $\kappa + \frac{\partial W}{\partial a} > \kappa$. (This follows because excessively weak actions imply that overall welfare can be improved by raising a, that is, $\frac{\partial W}{\partial a} > 0$.)

Second, a reduction in debt creates an indirect welfare benefit by reducing incentives for short-term creditors to run on the bank. Indeed, for every realization s of the public signal, reducing D lowers the threshold $v_0(s)$ and allows the regulator to avoid a run – while conducting the first-best policy – more frequently. This is captured by the final terms in (12) and (13), which take into account the change in the threshold $v_0(s)$.

The final result in Proposition 9 states that reducing short-term debt is more valuable than reducing short-term debt. This follows because the indirect welfare benefit, that is the effect of relaxing the "runs" constraint, is stronger when short-term debt is cut. In particular, individual short-term creditors are less likely to run on the bank in equilibrium when $(1+r)D$ is reduced: This reduction implies that assets are shared among fewer senior creditors in case of insolvency at date 2, an effect that is absent when only long-term debt B is reduced.

In summary, reducing debt burdens is especially valuable when there are binding constraints on bail-in policy, that is, when the excessive weakness problem applies in a non-negligible set of states $\mathscr{A}$.

In terms of real-world regulations, *liquidity requirements* constrain the use of short-term, "runnable" liabilities per unit of risky assets. A binding liquidity requirement in our model takes the shape $(1+r)D = A_1$, where A_1 is chosen by the regulator. *Capital requirements* bound total debt per unit of risky assets and take the shape $(1+r)D + B = A_0$.

A particularly effective way to increase the effectiveness of bail-in is to tighten the liquidity requirement by lowering A_1 *ex ante*, while holding the capital requirement A_0 constant. Tightening A_1 yields an additional marginal benefit $\left|\frac{dW^\star}{d(1+r)D}\right| > 0$, because doing so allows the regulator to avoid excessive weakness *ex post*. Holding A_0 constant prevents banks from substituting long-term debt for short-term debt, which would mitigate the welfare improvement.

Proposition 9 therefore implies that, in the presence of an optimally designed bail-in regime, liquidity and capital requirements are complementary. Tightening the liquidity requirement without a binding capital requirement may trigger substitution to long-term debt $\frac{dB}{dA_1} > 0$, which would reduce the welfare benefit. Moreover, tightening a capital requirement without a liquidity requirement is a blunter instrument, since banks may respond by cutting either long-term or short-term debt, and the former has a weaker welfare effect (according to the last inequality in Proposition 9). Intuitively, liquidity requirements have a more direct impact on the effectiveness of bail-in regimes because they directly constraint short-term debt, which significantly relaxes the "bank run constraint" faced by regulators. Capital requirements only mandate a reduction in total debt burdens, and therefore fail to achieve the same relaxation of regulatory constraints.

Our analysis suggests that balance sheet policy is a natural complement to bail-in because it alleviates concerns about runs and moral hazard and mitigates the welfare losses in the second-best bail-in regime. Moreover, in achieving this goal, capital and liquidity regulation are complementary to each other.

5.3 Self-fulfilling bank runs and the lender of last resort

In this Section, we remove the assumption that the bank's creditors can co-ordinate. We use the global games approach to bank runs to obtain equilibrium predictions.

The bank's performance is now partly determined by the realization of a shock $\theta \sim U[0,1]$ which is independent of v, x and s.[19] With probability $p(\theta)$, where $p(\theta)$ is increasing in θ, the bank survives until date 2 and acts as in the baseline model. With probability $1-p(\theta)$, the bank loses all its assets before date 2. At date 1, each creditor receives a private signal $\theta_i = \theta + u_i$, where $u_i \sim U[-\varepsilon, \varepsilon]$ is independent of all other variables and independent across creditors.

We make two assumptions which are adapted from Goldstein and Pauzner (2005): First, the probability of survival is $p(\theta) = 0$ for $\theta < \underline{\theta}$, where $\underline{\theta} > 2\varepsilon$. This generates generates a "lower dominance region": If $\theta \simeq 0$ is realized, then all creditors receive signals $\theta_i < \underline{\theta} - \varepsilon$, it becomes common knowledge that the bank is sure to fail, and all creditors withdraw with probability 1. Second, we assume that $p(\theta) = 1$ for all $\theta \geq \overline{\theta}$, where $\bar{\theta} < 1 - 2\varepsilon$, and that all the bank's asset value v is realized and paid out at date 1 whenever $\theta \geq \bar{\theta}$. This assumption generates an "upper dominance region": If $\theta \simeq 1$, then all depositors wait, because it is common knowledge that cash arrives at date 1. Since we are interested in self-fulfilling bank runs, we assume for clarity that

[19] This independence assumption allows us to obtain equilibrium predictions even when creditors observe public information about v (i.e. the public signal s and the signal that is implicit in the regulator's action a in equilibrium). See Bouvard et al. (2015) for a similar approach and further discussion.

creditors have no fundamental incentive to withdraw early:

$$v \geq (1+r)D \text{ with probability } 1. \tag{14}$$

We analyze the "noiseless limit" where this model converges to our baseline setup. This happens when noise and the dominance regions become small ($\varepsilon \to 0$, $\bar{\theta} \to 1$ and $\underline{\theta} \to 0$), and where outside the dominance regions we have $p(\theta) \to 1$.[20]

Proposition 10. *In the noiseless limit, all creditors withdraw early if*

$$\int_0^1 \left(\mathbb{E}_\mu \left[\min\left\{ (1+r)D, \frac{1-nD/L}{1-n}(v+x) \right\} \right] - \min\left\{ D, \frac{L}{n} \right\} \right) dn < 0, \tag{15}$$

and all creditors wait otherwise.

Proposition 10 applies two insights from Goldstein and Pauzner (2005) to our setting: First, the known behavior of creditors in the upper and lower dominance region gives rise to a unique threshold equilibrium, where creditors with private signals $\theta_i < \theta^\star$ withdraw early and creditors with $\theta_i > \theta^\star$ wait. Second, in the absence of common knowledge, each individual creditor knows that the mass n of others who withdraw is uniformly distributed on $[0,1]$.[21] Condition (15) is derived by integrating the net payoff from waiting, given that n others withdraw.

This solution ties bank runs to fundamentals even when they are driven by coordination problems. Indeed, the left-hand side of (15) is increasing in the expected payoff $\mathbb{E}_\mu \left[\min\left\{ (1+r)D, \frac{1-nD/L}{1-n}(v+x) \right\} \right]$ which creditors receive if they wait. It is easy to see that this term increases, thus making bank runs less likely, whenever (i) beliefs μ about asset values become more optimistic, or (ii) the regulator conducts a larger bail-in a which sharpens incentives and therefore improves the distribution of x.

The key point to note is that these comparative statics are qualitatively the same as in the case of fundamentals-based bank runs. In the baseline model, we showed using Equation (8) that fundamentals-based runs become less likely whenever a increases or μ becomes more optimistic. The same is true of self-fulfilling bank runs and Equation (15), given small deviations from common knowledge.

As a result, our analysis of bail-in policy under rules and discretion applies to the setup with self-fulfilling bank runs. The only thing that needs to change is the definition of the critical type $v_0(s)$, below which the regulators pool on a weaker action than first-best: This is still the lowest

[20] For an example of how to construct a sequence of functions $p(\theta)$ with this limit, for given $\underline{\theta}$ and $\overline{\theta}$, take any smooth increasing function $J(\theta)$ with $J(\underline{\theta}) = 0$ and $J(\overline{\theta}) = 1$, set $p(\theta) = J(\frac{\theta}{k})$ for $\theta \in (\underline{\theta}, \overline{\theta})$, and let $k \to 0$.

[21] This property, also known as a Laplacian belief, holds in an approximate sense in a large class of global games – see Morris and Shin (2003).

type v' who can reveal that $v \leq v'$, take his first-best bail-in action, and avoid a run; but the "no run" requirement is evaluated in the sense of our new condition (15). Modulo this change of definition, Propositions 1 to 5 go through. Discretion can induce excessive weakness and increases the likelihood of failures and bail-outs, rules should bind after bad public news, and the optimal regime can be implemented with CoCo bonds.

An interesting corollary of this extension concerns central bank lending policies. When depositors' incentives to run are primarily due to co-ordination failure, then it is well known that bank runs can be eliminated by a sufficiently lenient "lender of last resort". In particular, when Assumption (14) holds and depositors choose to run on the bank, the central bank can provide a loan D to banks at date 1, and the bank can promise a guaranteed repayment $(1+r)D$ at date 2 by posting its projects as collateral. It is clear that this "lender of last resort" policy removes the bank run problem. Therefore, the regulator will not worry about bank runs or signaling, and first-best bail-in policies become possible. In summary, if bank runs are primarily a self-fulfilling problem, a sufficiently generous lender of last resort can insure that bail-in works without any frictions.

6 Conclusion

The design of bank resolution schemes is of central importance in the plan to end the practice of "too big to fail" among large banks. If banks can be resolved quickly and with minimal disruption when necessary, then regulators will be more willing to restructure banks' debts by "bailing in" and will be less likely to "bail out" bank creditors, imposing expenses on the taxpayer. In this paper, we have highlighted a problem which limits bank regulators' ability to act effectively in this regard, even when equipped with the best of intentions, information, powers and tools. In order to stave off problems, the regulator must act before creditors are fully aware of the seriousness of the bank's problems. But then, the fact that the regulator acts becomes a signal to creditors that problems at the bank are worse than they had anticipated, and could precipitate a run. The damage that such a run will likely cause then discourages the regulator from acting as early, or as strongly, as he should. We show that when the regulator has full discretion to act upon his own, accurate, private information about the value of bank assets (and liabilities), he has a tendency to act both too little and too late in the most serious situations.

We then outlined a mechanism that could be used to ameliorate this problem. In particular, we showed that committing to the regulator to acting on a rule, which mandates action based on publicly available information, can be preferable to giving the regulator full discretion to act on the basis of his superior information. The key here is that because the regulator's action is now tied to public information, the regulator's action provides no further information to the market than what is already available, and thus generates no runs. The disadvantage of the rule is that costly action may be taken when the regulator's private information suggests that this action is not necessary because public information is unduly pessimistic; but this cost is traded-off against the unduly soft actions the regulator otherwise takes when public information is too optimistic. We showed that the optimal arrangement is a combination of rules and discretion: discretion when public information is relatively benign, and rules when public information is more negative. We discussed how a mechanism of this kind could be implemented by forcing banks to issue appropriate denominations of contingent-convertible ("CoCo") bonds with carefully chosen triggers at which the bonds convert to equity or are written down.

We explored the comparative statics of our mechanism; showing that if – as seems realistic – the use of rules is confined to states where public information is quite negative, then an increase in transparency and the accuracy of public information should expand the use of rules; the converse is true if the quality of public information deteriorates. We also explained how new rules on liquidity ratios; and tighter capital regulation, can help improve the efficacy of bank resolution by making the bank less prone to runs, thus allowing the regulator to act earlier and more toughly. Finally, we examined a global-games model where non-fundamental runs can occur (that is, runs on solvent banks), and showed how an effective lender of last resort policy is also complementary to bank resolution by reducing the impact of fear of runs regulator's choices.

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A Proofs

Lemma 1

Proof. We first find equilibria of the subgame among creditors. The net benefit of waiting until date 2 to withdraw, if a mass n of other creditors withdraw, is

$$u(n) \equiv \mathbb{E}_\mu \left[\min\left\{ (1+r)D, \frac{1-nD/L}{1-n}(v+x) \right\} \right] - \min\left\{ D, \frac{L}{n} \right\}.$$

It is easy to see that $u(n)$ is decreasing in n for $n \leq L/D$, increasing but strictly negative for $n > L/D$, and has single crossings in n (i.e. if $n' > n$ and $u(n) \leq 0$ then $u(n') < 0$).

If condition (8) holds we have $u(0) < 0$, so that $u(n) < 0$ for all n. Creditors then choose to all withdraw ($n = 1$) because no other strategy is incentive compatible. If (8) does not hold we have $u(0) \geq 0$, and the set of incentive compatible strategies (i.e. equilibria of the subgame among creditors) is $n \in \{0, \bar{n}, 1\}$, where $\bar{n}$ is the unique solution of $u(n) = 0$. If $n = 0$ is chosen, creditors' utility equals the left-hand side of (8). We complete the proof by arguing that this strategy will be chosen, because for the other incentive compatible options $n \in \{\bar{n}, 1\}$ creditors' utility is at most D, which by assumption is less than the payoff when $n = 0$: If $n = 1$, then the bank is liquidated and each creditor receives $L \leq D$; if $n = \bar{n}$, then creditors are indifferent between withdrawing early and late, and so the utility of each creditor is D. □

Proposition 1

Proof. Using (9), and the characterization of optimal effort in (4) and (6), we can write welfare in the absence of a run as $W(a, v) = v - \kappa a + U(v + a - B - (1+r)D)$ for some function U of bank capital. It is straightforward to check that, under the technical condition $c'''/c'' > -\frac{1}{R}$, $U(K)$ is increasing and concave in K.

It follows that welfare is submodular in (a,v): $\frac{\partial^2 W}{\partial a \partial v} \leq 0$. This single-crossing condition, along with the observation that there are no runs in equilibrium, ensures that the regulator's equilibrium action $\alpha(v,s)$ is decreasing in his information v. Suppose not, so that $v' > v$ and $\alpha(v',s) = a' > \alpha(v,s) = a$. Then incentive compatibility requires that type v' has no incentive to mimic type v and vice versa, i.e.

$$W(a',v') - W(a,v') \geq 0 \geq W(a',v) - W(a,v),$$

but submodularity implies that $W(a',v) - W(a,v)$ is strictly decreasing in v, a contradiction. Therefore, $\alpha(v,s)$ is decreasing, hence differentiable for almost all v, and the incentive compatibility condition (10) holds at every point of differentiability.

The D1 refinement gives additional structure:

Lemma. *The equilibrium action $\alpha(v,s)$ is continuous in v, and satisfies $\alpha(\bar{v},s) \leq a^\star(v)$.*

Proof. First, suppose that there is a jump in $\alpha(v,s)$ at v'; then type v' must be indifferent between $a_- = \lim_{v \uparrow v'} \alpha(v,s)$ and $a_+ = \lim_{v \downarrow v'} \alpha(v,s)$. It follows that a_- lies above, and result a_- above, the preferred action of type v' . Then, type v' has the strongest incentive to deviate to an off-equilibrium action $a_+ + \varepsilon$ for small enough ε. Therefore, creditors must place support on types close to v' following this action. Since the pool of types $\mathscr{V}_- = \{v | \alpha(v,s) = a_-\}$ does not face a run in equilibrium, and noting that $v' = \sup \mathscr{V}_-$, we see that v' does not face a run in equilibrium when deviating to $a_+ + \varepsilon$. Therefore v' prefers to deviate, contradicting equilibrium. Second, suppose that $\alpha(\bar{v},s) > a^\star(v)$. Then type $\bar{v}$ has the strongest incentives to deviate to the off-equilibrium action $a^\star(v)$, so that creditors beliefs must be supported on $\bar{v}$ alone following this action. $\bar{v}$ can deviate his first-best action and avoid a run, contradicting equilibrium. □

Combining this Lemma with the incentive compatibility condition, we can integrate

$$\begin{aligned}
\alpha(v,s) &= \alpha(\bar{v},s) - \int_{v}^{\bar{v}} \frac{\partial \alpha(v',s)}{\partial v} dv \\
&= \min \{a^\star(v), a_0\},
\end{aligned}$$

where $a_0 = \alpha(v_0,s)$, with $v_0 = \inf \{v | \alpha(v,s) = a^\star(v)\}$. Moreover, since there can be no runs in equilibrium, we have $v_0 \geq v_0(s)$, and by continuity, $a_0 = a^\star(v_0) \leq a^\star(v_0(s))$. The fact that equilibrium welfare is increasing in a_0 is immediate from Figure 2.

Finally, we must check existence, i.e. that the proposed equilibrium is compatible with no runs. This requires that for all $v > v_0(s)$, Equation (8) holds if (i) the regulator takes her preferred action $a^{\star}(v)$, and (ii) creditors learn that the private signal perfectly. Letting $a_{rev}(v)$ be the lowest action such that the regulator can reveal v and avoid a fundamental run, we need to show that $a_{rev}(v) \leq a^{\star}(v)$ for all $v \geq v_0(s)$. This is true by construction for type $v_0(s)$, because revealing $v = v_0(s)$ is better news than revealing $v \leq v_{pool}(y)$, and the latter revelation is sufficient to avoid a run.

If $v_0(s) > (1+r)D$, then $a_{rev}(v) = 0$ for all $v \geq v_0(s)$, since depositors are paid in full regardless of effort choice, and we are done. Otherwise, since both $a_{rev}(v)$ and $a^{\star}(v)$ are differentiable almost everywhere, it suffices to show that at every point of differentiability $v \in \big(v_{pool}(y), (1+r)D\big)$, we have

$$\frac{\partial a^{\star}(v)}{\partial v} \geq \frac{\partial a_{rev}(v)}{\partial v}.$$

Note that in this region, $a_{rev}(v)$ is the solution to

$$q^{\star}(a,v)(1+r)D + (1-q^{\star}(a,v))v = D,$$

while $a^{\star}(v)$ is the solution to $\frac{\partial \hat{q}}{\partial a}[R - c'(\hat{q})] = \kappa$, or, substituting the FOC of the bank:

$$\frac{\partial \hat{q}}{\partial a}[(1+r)D + B - a - v] = \kappa$$

We can further note that $\hat{q}$ depends only on the sum of $v+a$, so that $\frac{\partial \hat{q}}{\partial a} = \frac{\partial \hat{q}}{\partial v}$ and $\frac{\partial^2 \hat{q}}{\partial a^2} = \frac{\partial^2 \hat{q}}{\partial a \partial v}$. so totally differentiating both conditions gives

$$[da^{\star} + dv] \times \left\{ \frac{\partial^2 \hat{q}}{\partial a^2}[(1+r)D + B - a^{\star} - v] - \frac{\partial \hat{q}}{\partial a} \right\} = 0$$
$$[da^{rev} + dv]\frac{\partial \hat{q}}{\partial a}[(1+r)D - v] + (1-\hat{q})dv = 0$$

Our technical condition guarantees that $\frac{\partial^2 \hat{q}}{\partial a^2} < 0$, so we can write these as

$$da^{\star} = -dv$$
$$da^{rev} = -dv - \frac{(1-\hat{q})dv}{\frac{\partial \hat{q}}{\partial a}[(1+r)D - v]} \leq da^{\star},$$

which completes the proof. result □

Proposition 4

Proof. Welfare under rules, after public signal s, is

$$W_r(s) = \max_a \mathbb{E}\left[W(a,v)|s\right].$$

Since $W(a,v)$ has a single-crossing property (see the proof of Proposition 1), and the distribution of signals has the monotone likelihood ratio property, standard comparative statics (Athey, 2002) results imply that the maximizer $A(s)$ which achieves $W_r(s)$ is decreasing in s. We need to show that $W_r(s)$ can dominate discretion only if public signals are low. Discretion in state s achieves welfare of at most

$$W_d(s) = \mathbb{E}\left[W\left(\min\left\{a^\star(v), a^\star(v_0(s))\right\}, v\right)|s\right].$$

To complete the proof, we only need to establish that $W_r(s) - W_d(s)$ is decreasing in s whenever it is positive. We have

$$W_r(s) - W_d(s) = \max_a \int_{\underline{v}}^{\overline{v}} W(a,v) - W\left(\min\left\{a^\star(v), a^\star(v_0(s))\right\}, v\right) dF(v|s)$$

Note first that the integral must be negative whenever $a \leq a^\star(v_0(s))$. Second, for all $a > a^\star(v_0(s))$, the integrand is decreasing in s (because an increase in s implies a decrease in $v_0(s)$, which improves welfare under discretion) and decreasing in v (using single crossings). From the monotone likelihood ratio property of signals, it follows that the integral for a given $a > v(s)$ is increasing in s. Then, whenever $W_r(s) - W_d(s)$ is positive, it is equal to the maximum of decreasing functions of s, and therefore decreasing in s. □

Proposition 5

Proof. Under the proposed contingent capital structure, bonds with face value $A(s)$ convert for $s \leq s^\star$ and no bonds convert for $s > s^\star$. It follows immediately that equilibrium play for $s > s^\star$ coincides with full discretion, as is the case in the optimal rule.

For $s \leq s^\star$, the regulator has discretion to bail-in an additional $a \in [0, B - A(s)]$ of the remaining bonds. We show that $a = 0$ in equilibrium, so that equilibrium play again coincides with the optimal rule. The first-best action is $a = 0$ for all $v > v_1(s) \equiv \inf\{v|A(s) \geq a^\star(s)\}$. By the argument of Proposition 4, any welfare-improving rule must lead to tougher interventions than discretion, so that $A(s) > a^\star(v_0(s))$, implying $v_1(s) < v_0(s)$. Now suppose that some types play $a > 0$ in equilibrium. By analogy to the proof of Proposition 1, we can use incentive compatibility and the D1 refinement to show that all types above $v_1(s)$ play their preferred action $a = 0$. Then, all types below $v_1(s)$ must also play $a = 0$ because otherwise, a run would be triggered for a subset of them. □

Proposition 6

Proof. If the garbled signal $\hat{s} = \underline{s}$, then Bayes' rule implies that beliefs about v given $\hat{s}$ are a weighted average of beliefs given possible realizations of s, including realizations $s > \underline{s}$ (because of full support of the garbling density). Therefore, beliefs given $\hat{s} = s$ first-order stochastically dominate beliefs given $s = \underline{s}$. By continuity, for signals sufficiently close to $\underline{s}$, the shift from the original signal s to the garbled signal $\hat{s}$ amounts to a first-order improvement in public information. In the proof of Proposition 4, we establish that such an improvement reduces the net value of rules. By analogy, when s is replaced with $\hat{s}$, the value of rules falls for realizations near $\underline{s}$. If the critical signal falls into this region, the point of indifference between rules of discretion must shift down. □

Proposition 7

Proof. The characterization of equilibrium and insolvency probabilities is identical to Propositions 1 and 2. To establish the result about $\mathbb{E}[a_2|s]$, we examine what happens to the late intervention a_2 when the early intervention a_1 is reduced in a subset of states v. In equilibrium, late intervention occurs only if $x = 0$, so that

$$\mathbb{E}[a_2|s] = \mathbb{E}[(1 - \hat{q}(a_1, v))\,\hat{a}_2(a_1, v)]\,.$$

Under discretion, a_1 is weakly lower than under rules.Therefore, the probability $1 - \hat{q}(a_1, v)$ of failure is higher for all v and the ex post intervention $\hat{a}_2(v, a_1)$ is larger for all v. It follows that $\mathbb{E}[a_2|s]$ is larger under discretion, as required. □

Proposition 9

Proof. Under the optimal rule, welfare is

$$W^\star = \int_{\underline{s}}^{s^\star} \mathbb{E}[W(A(s), v)|s]\,dG + \int_{s^\star}^{\bar{s}} \int_{\underline{v}}^{\bar{v}} W(\alpha(v, s), v)dF, \tag{16}$$

where $\alpha(v, s) = \min\{a^\star(v), a^\star(v_0(s))\}$ is the action corresponding to the best equilibrium with discretion. Using (9), and the characterization of optimal effort in (6), we can write $W(a, v) =$

$v-\kappa a+U\left(v+a-B-(1+r)D\right)$ for some function U.

When $s<s^\star$, the commitment action is chosen such that $W(A(s),v)=\max_a \mathbb{E}\left[W(a,v)|s\right]$, with first-order condition $\kappa=\mathbb{E}\left[U'(v+A(s)-B-(1+r)D)|s\right]$. The envelope theorem gives

$$\frac{dW(A(s),v)}{d(1+r)D}=-\mathbb{E}\left[U'(v+A(s)-B-(1+r)D)|s\right]=-\kappa,\text{ if } s<s^\star.$$

When $s>s^\star$ and $v>v_0(s)$, then the equilibrium action is chosen such that $W(a^\star(v),v)=\max_a W(a,v)$, with first-order condition $\kappa=U'(v+a^\star(v)-B-(1+r)D)$. Applying the envelope theorem we get

$$\frac{dW(\alpha(v,s),v)}{d(1+r)D}=-U'(v+a^\star(v)-B-(1+r)D)=-\kappa,\text{ if } s>s^\star, v>v_0(s).$$

Finally, when $s>s^\star$ and $v<v_0(s)$, the equilibrium action is simply $a^\star(v_0(s))$. Then we have

$$\begin{aligned}\frac{dW(\alpha(v,s),v)}{d(1+r)D}&=-U'(v+a^\star(v_0(s))-B-(1+r)D)\\&\quad+\left[U'(v+a^\star(v_0(s))-B-(1+r)D)-\kappa\right]\frac{da^\star(v_0(s))}{d(1+r)D}\\&=-\kappa-\frac{\partial W\left(\alpha(v,s),v\right)}{\partial a}\left(1-\frac{\partial a^\star(v_0(s))}{\partial v}\frac{\partial v_0(s)}{\partial(1+r)D}\right),\text{ if } s>s^\star, v<v_0(s),\end{aligned}$$

where the last line follows by noting that $\frac{\partial W(a,v)}{\partial a}=U'(.)-\kappa>0$. Differentiating under the integral in (16) and substituting the last three equations we obtain

$$\frac{dW^\star}{d(1+r)D}=-\kappa-Pr\left[\mathscr{A}\right]\mathbb{E}\left[\frac{\partial W\left(\alpha(v,s),v\right)}{\partial a}\left(1-\frac{\partial a^\star(v_0(s))}{\partial v}\frac{\partial v_0(s)}{\partial(1+r)D}\right)|\mathscr{A}\right]<0,$$

where the inequality follows from the facts that $\frac{\partial a^\star}{\partial v}<0$ and $\frac{\partial v_0(s)}{\partial(1+r)D}>0$ (we show the second fact below). This gives expression (12). A parallel argument establishes (13). Finally, note that

$$\left|\frac{dW^\star}{d(1+r)D}\right|-\left|\frac{dW^\star}{d(1+r)B}\right|=Pr\left[\mathscr{A}\right]\mathbb{E}\left[\frac{\partial W\left(\alpha(v,s),v\right)}{\partial a}\left(-\frac{\partial a^\star(v_0(s))}{\partial v}\right)\left(\frac{\partial v_0(s)}{\partial(1+r)D}-\frac{\partial v_0(s)}{\partial B}\right)\right].$$

To complete the proof we need to show that

$$\frac{\partial v_0(s)}{\partial(1+r)D}>\frac{\partial v_0(s)}{\partial B}.$$

Since $v_0(s)$ exists, it is the smallest v' such that

$$\mathbb{E}\left[\min\left\{(1+r)D,x+v\right\}|s,v\leq v',a^\star(v')\right]\geq D.$$

By assumption (1), the bank is always solvent when $x = R$, so we can write this inequality as

$$Z\left(v',(1+r)D,B\right) \equiv \int_{\underline{v}}^{v'} \left(\hat{q}(a^{\star}(v'),v)+(1-\hat{q}(a^{\star}(v'),v))\min\left\{1,\frac{v}{(1+r)D}\right\}\right)\frac{dF(v|s)}{F(v'|s)}-\frac{1}{1+r},$$
$$\geq 0$$

where the dependence on B is implicit through the optimal effort choice $\hat{q}(a,v)$, which is decreasing in B. Since $v_0(s)$ is interior, Z must cross zero from below, so that $\frac{\partial Z}{\partial v'} > 0$ when $v' = v_0(s)$. Then the implicit function theorem gives us

$$\frac{\partial v_0(s)}{\partial(1+r)D}-\frac{\partial v_0(s)}{\partial B} = -\frac{1}{\partial Z/\partial v'}\times\left(\frac{\partial Z}{\partial\left(1+r\right)D}-\frac{\partial Z}{\partial B}\right).$$

We still need to show that $\frac{\partial Z}{\partial(1+r)D}-\frac{\partial Z}{\partial B} < 0$. Differentiating in the definition of Z,

$$\frac{\partial Z}{\partial(1+r)D} = \int_{\underline{v}}^{\min\{(1+r)D,v'\}}\left(-\frac{v}{(1+r)^2D^2}+\left(1-\frac{v}{(1+r)D}\right)\frac{\partial\hat{q}}{\partial\left(1+r\right)D}\right)\frac{dF(v|s)}{F(v'|s)}$$
$$\frac{\partial Z}{\partial B} = \int_{\underline{v}}^{\min\{(1+r)D,v'\}}\left(1-\frac{v}{(1+r)D}\right)\frac{\partial\hat{q}}{\partial B}\frac{dF(v|s)}{F(v'|s)}.$$

Finally noting that $\frac{\partial\hat{q}}{\partial B} = \frac{\partial\hat{q}}{\partial(1+r)D} < 0$ gives

$$\frac{\partial Z}{\partial(1+r)D}-\frac{\partial Z}{\partial B} = -\int_{\underline{v}}^{\min\{(1+r)D,v'\}}\frac{v}{(1+r)^2D^2}\frac{dF(v|s)}{F(v'|s)} < 0$$

as required. □

Proposition 10

Proof. The net payoff from waiting until date 2 to withdraw in our model, given that state θ realizes and n creditors withdraw early, is

$$u(\theta,n) \equiv p(\theta)\,\mathbb{E}_{\mu}\left[\min\left\{(1+r)D,\frac{1-nD/L}{1-n}(v+x)\right\}\right]-\min\left\{D,\frac{L}{n}\right\}.$$

Clearly, u is increasing in θ. Moreover, u has one-sided strategic complementarities: Whenever $u(\theta,n)$ is positive, it is monotonically decreasing in n. Indeed, $u(\theta,n)$ is strictly decreasing unless

$n > D/L$, in which case the bank fails at date 1 and we have $u(\theta, n) = -L/n < 0$. It follows also that v has single crossings with zero: If $n' > n$ and $u(\theta, n) \leq 0$, then $u(\theta, n') < 0$.

Given one-sided strategic complementarities and dominance regions, we can directly apply the results of Goldstein and Pauzner (2005). Using their Theorem 1 and Equation (5):

Lemma. (Goldstein-Pauzner) *In any equilibrium, creditor i withdraws early if he observes a private signal below $\theta^\star$ and withdraws late otherwise. In the limit as $\varepsilon \to 0$, $\theta^\star$ converges to the solution to*

$$\int_0^1 u(\theta^\star, n) dn = 0$$

Given a realization of θ, each creditor's signal is approximately $\theta_i = \theta$ in the limit, and therefore all creditors withdraw if and only if $\theta > \theta^\star$, which is equivalent to our proposed condition when $p(\theta) \simeq 1$. □