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Interplay between Accounting and Prudential Regulation

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ABSTRACT: We develop a model in which accounting information and prudential regulation interact to affect banks' incentives to originate loans. Prudential regulators impose capital requirements to prevent banks from taking excessive risk. However, regulators cannot commit to *ex ante* efficient intervention and, instead, respond to *ex post* accounting information. We show that capital requirements and accounting measurement are substitutes when considered separately. By contrast, when considered jointly, accounting measurement and capital requirements are complementary tools that affect the level and efficiency of credit decisions. Comparative statics link capital requirements, quality of accounting information, and regulatory intervention to credit market conditions. An upshot of our analysis is that by appropriately optimizing the information from expected loss models, prudential regulators may design looser capital requirements to spur more bank lending.

JEL Classifications: G21; G28; M41; M48.

Keywords: accounting standards; prudential regulation; capital requirements; expected loss models; loan loss provisioning rules.

I. INTRODUCTION

Prudential regulation relies on inputs from accounting numbers. However, prudential regulators and accounting standard setters do not implement policies based on an explicit articulation of their joint mission statements.[1] In this paper, we provide a framework in which prudential regulators learn from banks' accounting systems.

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Supplemental material can be accessed by clicking the link in Appendix B.

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[1] For instance, the mission of the Board of Governors of the Federal Reserve is to "foster the stability, integrity, and efficiency of the nation's monetary, financial, and payment systems so as to promote optimal macroeconomic performance" (Federal Reserve, Government Performance and Results Act Annual Performance Report, 2011) whereas standard setters such as the Financial Accounting Standards Board aim at "providing financial information about the reporting entity that is useful to existing and potential investors" (Financial Accounting Standards Board, FASB Concepts Statement No. 8, 2010).

Such systems, in turn, depend on the prevailing accounting standards (Barth and Landsman 2010; Bushman 2014), and we highlight the role that accounting standards play in influencing prudential regulation.

We augment a standard banking model of a representative bank subject to shareholders-depositors conflicts with a measurement friction. The bank's shareholders have incentives to engage in excessive risk-taking, and a regulator can mitigate the inefficiency in two ways: (1) by imposing a capital requirement that constrains the bank's ability to originate risky loans and (2) by designing a reporting system informative about loan default, thereby affecting regulatory intervention. To provide efficient *ex ant*e incentives to originate safe and high-quality loans, the regulator prefers an intervention policy that is excessive from an *ex post* perspective—implying regulatory intervention in some otherwise healthy banks. However, this policy is not credible in a pure prudential regulation benchmark with full information on default risk. Thus, in response to full transparency, the prudential regulator must impose overly strict capital requirements, thereby constraining lending.

The accounting reporting system can be designed *ex ante* to increase *ex post* regulatory interventions, akin to a conservative bias in which bad news becomes more likely and triggers more frequent interventions. Excessive *ex post* interventions, in turn, reduce the bank's risk-taking incentives, which allows the regulator to set looser capital requirements and spur lending. Our main result is that the optimal reporting system and capital requirement are complementary regulatory tools that generate more surplus when used together. Our model further allows us to examine how bank leverage and transparency adjust to shocks to the economic environment, and we discuss their dependence on the proportion of safe loans in the economy, the payoff structure of safe and risky loans, and the proceeds from regulatory intervention.

Specifically, our model generates comparative statics that link the optimal capital requirement to characteristics of the optimal reporting system. An increase in the proportion of safe loans, the payoff of safe loans, and the proceeds from intervention reduces the severity of the bank's risk-taking problem. When the capital requirement and the reporting system are considered in isolation, factors that reduce the severity of the bank's risk-taking lead to a looser capital requirement and a more precise reporting system, as expected. However, when considering the two tools jointly, regulators may prefer to loosen the capital requirement while decreasing the precision of the reporting system. Conversely, environments with greater risk-taking problems may feature a stricter capital requirement but a more precise reporting system.

As an application, our model may inform the recent debate surrounding the change in the way banks should recognize losses on their loan portfolios. Under the new standards (current expected credit loss under US GAAP and expected credit loss under IFRS), banks no longer use an incurred loss model, which has been criticized for delaying recognition of loan losses as it only considers current and historical information to determine if a credit loss exists. Rather, the new standards require banks to use an expected loss model to measure credit losses based on estimates of cash flows that the lender does not expect to collect. We view our mechanism design problem as an efficient expected loss model, in the sense that banks report information about a probability of default before the realization of loan payoffs. The efficient expected loan loss provisioning model does not provide perfect information about the probability of default because it would imply excessively strict capital requirements. However, an expected loss model relying on less precise information causes excessive interventions. Such excessive interventions induced by an expected loss model could be socially desirable because it not only reduces the bank's risk-taking behavior but it also increases the bank's capacity to originate loans. In summary, we demonstrate that the optimal expected loan loss provisioning model should be designed to elicit more *ex ante* lending and *ex post* interventions.

Related Literature

From a theoretical standpoint, there is an extensive literature showing how agency frictions place bounds on the size of firms; see, e.g., Holmström and Tirole (1997) or Liang, Rajan, and Ray (2008). We borrow heavily from these approaches because, in our model, a capital requirement on the bank bounds the size of its loan portfolio. To our knowledge, this literature does not jointly focus on the size of firms and the design of the information system, which we view as the novel elements of our model.

The broader question of the optimal information design in response to agency problems has a long history in accounting, with contributions along two paths: first, the design of the information system can address commitment problems in contracting settings (Crémer 1995; Arya, Glover, and Sivaramakrishnan 1997; Göx and Wagenhofer 2009); second, prior literature finds many environments in which reporting motives affect investment decisions (Kanodia and Sapra 2016). Within this literature, Arya and Glover (2006) show that designing the information system can commit the principal not to bail out colluding agents in a team. Other studies in corporate governance show that excess information acquisition by boards may induce CEOs to take value-decreasing actions (Baldenius, Melumad, and Meng 2014; Li, Nan, and Zhao 2018) or misreport project performance (Meng and Tian 2020). Our study is related to these prior studies in that we examine the interactions between commitment, information design, and the optimal size of a loan portfolio. We further contribute to this literature by developing the trade-offs in the institutional context of risk-taking in banks.

A strand of the banking and accounting literature has emerged since the 2007–2008 financial crisis and highlights the differences between fair value and historical cost accounting. Bleck and Liu (2007), Allen and Carletti (2008), Plantin, Sapra, and Shin (2008), Burkhardt and Strausz (2009), and Mahieux (2021) examine the impact of mark-to-market accounting on bank risk and financial stability. Heaton, Lucas, and McDonald (2010) analyze the interaction between mark-to-market accounting and capital requirements in affecting the social cost of regulation. Corona, Nan, and Zhang (2019a) examine the discretionary use of fair value accounting and its impact on bank lending. Lu, Sapra, and Subramanian (2019) study the optimal use of mark-to-market accounting in implementing capital requirements in the presence of asymmetric information and agency conflicts. Furthermore, Dewatripont and Tirole (1994) show that historical cost accounting may reduce the ability of prudential regulators to discipline banks, whereas Bleck and Gao (2022) study the effects of mark-to-market on banks' loan origination and retention decisions. While these earlier studies take the bank's information system as given by comparing two specific accounting regimes, we endogenize the bank's accounting system as well as the prudential regulation.

Our paper is also related to the literature that examines more broadly the role of accounting measurements and disclosure in affecting financial stability and prudential regulation; see Goldstein and Sapra (2014) for a recent survey. Corona, Nan, and Zhang (2019b) examine the coordination role of stress-test disclosure in affecting bank risk-taking. Gao and Jiang (2018), Liang and Zhang (2019), Zhang (2021), and G. Zhang and R. Zheng (2021) analyze the role of accounting information in stabilizing bank runs. Corona, Nan, and Zhang (2015) examine the impact of accounting information quality on the efficiency of capital requirements and banks' risk-taking incentives taking into account the competition among banks. In this paper, we solve for the optimal information system, and we shed light on how regulatory capital should be tailored to the accounting standards. Our results therefore call for a better coordination between prudential regulators and accounting standard-setters.

Several empirical studies provide evidence that financial reporting affects banks' risk-taking incentives. Chircop and Novotny-Farkas (2016) suggest that extending the use of fair values for regulatory purposes reduces *ex ante* risk-taking, and Ellul, Jotikasthira, Lundblad, and Wang (2015) find that the use of fair values in statutory accounting reduces *ex ante* risk-taking incentives in insurance firms. Beatty and Liao (2011) and Bushman and Williams (2012) find that forward-looking provisions reflecting timely recognition of expected future loan losses is associated with enhanced risk-taking discipline. Consistent with these studies, we show how a well-designed accounting system may interact with a bank's capital requirement to control the bank's risk-taking incentives.

Lastly, the papers by Li (2017) and Mahieux, Sapra, and Zhang (2022) are the closest to ours. Li (2017) analyzes risk-taking incentives in banks in the presence of capital regulation under different accounting regimes. She shows that the accounting regime that maximizes social welfare is determined by a trade-off between the social cost of capital regulation and the efficiency of the bank's project discovery efforts. In our paper, there is no exogenous cost of capital regulation, and the bank is not focused on short-term earnings. Mahieux et al. (2022) study two loan loss provisioning regimes and analyze the trade-offs of early and imprecise loss recognition versus delayed and precise loss recognition on banks' risk-taking incentives. They demonstrate that, while early and imprecise information can help regulators curb banks' *ex post* asset substitution incentives, they may either discipline or hamper *ex ante* risk incentives. In contrast, we solve for the optimal accounting system that trades off banks' *ex ante* risk-taking incentives versus *ex post* excessive intervention. Thus, while they focus on the timing of accounting information, we analyze the characteristics of the optimal accounting system.

Section II describes the baseline model. Section III analyzes the equilibrium with regulatory commitment both in the single policy benchmarks and in the main model with joint policies. Section IV discusses the robustness of our main results to two alternative mechanisms: (1) the presence of additional negative externalities and (2) the optimal persuasion mechanism. Section V concludes. Appendix A contains all the proofs of Section III. An Online Appendix (see Appendix B for link to download files) provides the proofs of Section IV, along with some additional comparative statics derived with the optimal persuasion mechanism.[2]

II. THE MODEL

Timing of Events

The model has four dates, indexed by $t = 0, 1, 2, 3$, and features a regulator, a bank, and passive insured depositors. For simplicity, we assume that the bank's manager acts in the best interests of the bank's shareholders: hence, we use the terms "bank shareholders" and "bank" interchangeably in the rest of the paper. The regulator's task is to provide

[2] The Online Appendix also shows that our results are qualitatively similar when the bank can also make the restructuring decision and when there is an adverse selection friction instead of a moral hazard friction.

deposit insurance while maximizing social welfare, i.e., the expected surplus of the bank's loan portfolio.[3] Figure 1 summarizes the sequence of events.

At $t = 0$, the bank has an exogenous amount of equity $E > 0$. The regulator chooses a leverage ratio $\gamma \geq 1$ for the bank, which we model as a maximum size of the bank's loan portfolio $A \geq E$.[4] The regulator also designs a reporting system δ that maps a random variable $p \in [0, 1]$, capturing the probability of success of the bank's loan portfolio, to an interim signal $s \in [0, 1]$ that will determine whether the regulator intervenes at $t = 2$. The probability p has a distribution $F(.)$ and a density $f(.)$, mean p_m and full support on $[0, 1]$.

Given the capital requirement γ set by the regulator, the bank chooses its size $A \in [E, \gamma E]$ and obtains $D = A - E$ from depositors. Deposits are fully insured, and depositors receive a risk-free interest rate normalized to zero. At $t = 0$, after raising deposits, the bank's balance sheet is therefore given by

$$A = E + D \text{ such that } \frac{A}{E} \leq \gamma.$$

At $t = 1$, the bank makes an unobservable risk choice $r \in \{0, 1\}$ upon originating a loan portfolio. Conditional on originating a low-risk loan portfolio, $r = 0$, the bank receives a safe loan with probability $q \in (0, 1)$ and a risky loan with probability $1 - q$. Conditional on originating a high-risk loan portfolio, $r = 1$, the bank receives a risky loan with probability 1. The parameter q captures the proportion of safe loans in the economy. To avoid a trivial solution to the model, we assume that a high-risk portfolio is always socially undesirable while a low-risk portfolio may have positive social value (see the formal assumptions under *Assumptions* at the end of this section). After making the risk choice r, the bank originates and invests its cash A in the loan portfolio.[5]

We use a standard payoff structure for the safe loan and the risky loan to capture risk-taking in the banking industry (Hellmann et al. 2000; Repullo 2004). A safe loan returns a payoff α regardless of the probability of success p, whereas a risky loan returns $\beta > \alpha$ with probability p and zero with probability $1 - p$. As a result, an increase in risk implies a larger payoff in case of no default but a higher likelihood of default. As in Hellmann et al. (2000) and Repullo (2004), this payoff structure combined with deposit insurance implies a negative risk externality: the bank and depositors do not bear the full loss from a failing loan because the bank shareholders cannot lose more than the initial equity E and depositors are fully insured. Hence, in the absence of capital requirements, the bank may increase its expected payoff by originating a value-destroying high-risk loan portfolio and does not internalize the cost on regulators from failing loans. In our model, therefore, capital requirements are useful because the regulator bears the externality of failing loans.[6]

At $t = 2$, the regulator and the bank observe a signal s sent by the reporting system. The signal s is equal to the true probability of success p with probability $\delta \in [0, 1]$ and is pure noise with probability $1 - \delta$, in which case s is randomly drawn from a distribution with density $f(.)$.[7] The parameter δ captures the precision of the reporting system designed by the regulator at $t = 0$.[8] At $\delta = 0$, observing s reveals no information regarding p, whereas at $\delta = 1$, observing s perfectly reveals p.

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[3] The assumption that the regulator maximizes social welfare is consistent with the prior literature on banking regulation (Campbell, Chan, and Marino 1992; Giammarino, Lewis, and Sappington 1993; Hellmann, Murdock, and Stiglitz 2000; Repullo 2004; Gorton and Winton 2017). Moreover, in line with a vast strand of the banking literature, we assume that deposits are insured for reasons outside the model (Hellmann et al. 2000; Repullo 2004; Boyd and De Nicoló 2005; Martinez-Miera and Repullo 2010). We leave aside questions pertaining to runs, noting that there exists a literature modeling the issue of excessive coordination on accounting outputs, see, e.g., Plantin et al. (2008) or, recently, Gao and Jiang (2018). Runs create an additional channel through which bank failures may contaminate other banks.

[4] The leverage ratio is inversely related to the bank's capital, so we also refer to γ as the bank's capital requirement. Note that, in our model, the regulator only uses a simple leverage ratio to regulate capital. This is consistent with the newly proposed Basel III framework. Under Basel II and III, bank regulators may also use some risk-weighted measure of assets to regulate capital. Adding an additional risk-weighted capital constraint in our model would not affect any of our results for two reasons. First, at $t = 0$, the bank always satisfies the risk-weighted capital requirement because, prior to originating its loans, the bank's assets consist of only cash, which receives a risk weight of zero. Second, as shown in our later analysis, with only the leverage requirement, the regulator already implements the *ex post* optimal restructuring policy at $t = 2$.

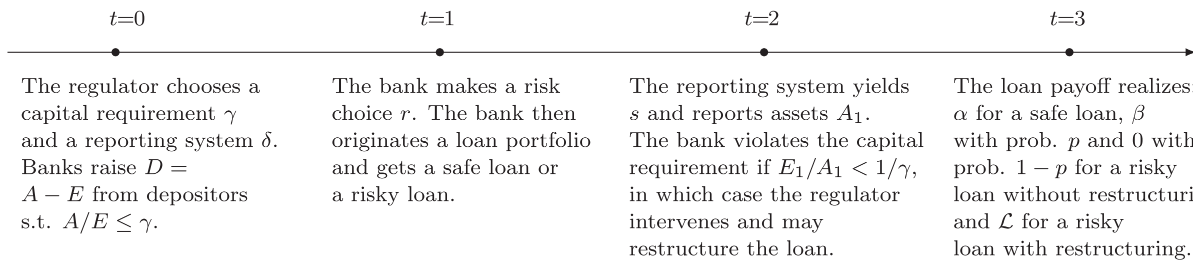
[5] Note that, after originating the loan portfolio, whether the bank learns that the loan is safe or risky is irrelevant because the bank does not take any action after $t = 1$.

[6] The cost of failing loans in terms of making up the losses of depositors is only one of the potential costs, but there could be other costs of risk-taking that would further increase the need (in our model) for regulation. In our model, prudential regulation is caused by the regulator acting as a lender of last resort. In the "Negative Externalities of Bank Failure" section, we study an extension of our model in which there is an additional negative externality in case of bank failure. A potential solution to the risk-taking problem would be to prohibit loans whose interest rate is too high, which we do not allow in our model since we assume that loan characteristics are not contractible. However, in practice, not all loan characteristics are easily observable by regulators, and issuing a set of acceptable interest rates conditional on each type of loan would require a degree of regulatory control that is far beyond current institutions. As shown by Chan, Greenbaum, and Thakor (1992) and Li (2017), even a fairly priced deposit insurance would therefore not solve the risk-taking problem.

[7] Without loss of generality, specifying in these models the distribution of the noise to be equal to the distribution of the probability of success makes the analysis more tractable in that posterior expectations remain linear in the signal (Guttman and Marinovic 2018; Ganuza and Penalva 2019).

[8] The regulator only controls the probability that the interim signal s is noisy but takes the distribution of the noise as a given. In the "Optimal Persuasion" section, we assume that the regulator controls the entire distribution of the accounting signal; i.e., we solve for the optimal persuasion mechanism, and we obtain similar results.

FIGURE 1
Model Timeline



After observing the signal s, the bank updates the book value of its loan portfolio. The expected probability of success given the signal s is

$$\mathbb{E}(p|s) = \delta s + (1-\delta)p_m,$$

and the updated book value of the bank's assets is equal to the expected repayment of the loan

$$A_1 \equiv A(q\alpha + (1-q)\mathbb{E}(p|s)\beta).$$

Given that the liability D to depositors is fixed, the bank's equity becomes

$$E_1 \equiv A_1 - D = A(q\alpha + (1-q)\mathbb{E}(p|s)\beta) - D.$$

As a result, at $t=2$, the bank violates the capital requirement if and only if

$$\frac{E_1}{A_1} < \frac{1}{\gamma},$$

in which case the regulator intervenes. In practice, a regulator has broad discretion in terms of what actions to take upon intervention ranging from being passive, thereby allowing the bank to continue its operations to a reorganization, a partial asset sale, a reduction in the scope of the bank, or even a liquidation. For simplicity, we focus on two possible regulatory actions: continuation or restructuring.[9] The regulator learns the type of the loan upon violation of the capital requirement.[10] Otherwise, if the capital requirement is not violated, the regulator does not intervene, and the bank continues.

In our model, restructuring is not contractible; that is, the regulator cannot implement a policy to restructure the bank's loan if doing so does not increase surplus at $t=2$. For example, while a policy can prescribe how to measure assets, each regulatory intervention is tailored to many practical contingencies (types of loans and suitable liquidation, soft information, etc.) and specifics of a bank that cannot be written down in advance. Further, regulators may be subject to public pressure not to take corrective actions that reduce surplus *ex post*.[11] In summary, if the bank violates the capital requirement, the regulator restructures the bank's loan if and only if the expected payoff from restructuring is greater than the expected payoff from continuation. In Section III, we contrast the main results with a benchmark when the regulator has full commitment power.

A safe loan yields a payoff less than α with restructuring, so that the regulator always continues after observing a safe loan; then, the bank gets the same payoff as without regulatory intervention. By contrast, if the bank has a risky loan and the regulator restructures the loan, the bank shareholders do not recover terminal dividends. This assumption is consistent with most bank liquidations observed in practice (Granja, Matvos, and Seru 2017). It can be microfounded if banks cannot efficiently

[9] It may be useful to interpret the restructuring action further. In the United States, the banking regulators can stop from engaging in a practice they consider harmful to safety and soundness using "cease and desist powers." A bank can also be forced to increase its provisions for loan losses, thus reducing its solvency ratio and, indirectly, its investments in risky assets (Dewatripont and Tirole 1994).

[10] In practice, the regulator may incur inspection costs in order to learn the type of the loan. We analyzed a variant of our model in which the regulator incurs an inspection cost $c > 0$ in order to learn the type of the loan, and the results are qualitatively similar. The analysis is available upon request.

[11] For instance, the U.S. prompt corrective action regime provides detailed rules governing prompt corrective action proceedings by providing trigger points that determine when a particular regulatory action can be taken, thereby enhancing legal certainty, while allowing the regulator the flexibility not to apply an enhanced regulatory measure if it might exacerbate market conditions or worsen depositors' interests (Alexander 2019).

restructure loans and, instead, restructuring requires action by a second-best party such as a regulator or a better-capitalized intermediary. Only the regulator can restructure a risky loan and recover, possibly over time, a payoff $\mathcal{L} \in (p_m\beta, 1)$, so that the residual payoff of the bank conditional on restructuring is zero.[12] The payoff of the risky loan with restructuring, $\mathcal{L}$, is sufficiently large in order to rule out a setting in which restructuring would never be credible. This is consistent with Dewatripont and Tirole (1994) in which regulatory intervention is *ex post* desirable if and only if the bank's asset is a low-quality asset.

At $t = 3$, the payoff of the loan is realized. The payoff of the loan is $\pi = \alpha$ if the loan is safe. Otherwise, if the loan is risky, the payoff is $\pi = \mathcal{L}$ with restructuring, and $\pi = \beta$ with probability p or $\pi = 0$ with probability $1 - p$ with no restructuring. The regulator compensates depositors if the bank fails, i.e., if $A\pi < A - E$, with a lump-sum payment that we assume is financed via a frictionless *ex ante* tax.

Assumptions

For our baseline model, we make the following three assumptions on the parameter values to rule out uninteresting corner solutions.

Assumption 1: If the bank originates a high-risk loan portfolio, i.e., $r = 1$, its value is negative:

$$\mathbb{E}(\max(\mathcal{L}, p\beta)) < 1. \tag{2.1}$$

This assumption ensures that regulator must provide incentives to the bank to originate a low-risk loan portfolio to create value.

Assumption 2: Given that, in our model, the bank chooses the size of its loan portfolio, we assume that the informational friction rules out the case in which the bank originates a low-risk loan portfolio with an arbitrarily large size (which would imply unbounded bank size and surplus). A sufficient condition for this to hold is that, at the precision δ_0 such that the value of the low-risk loan portfolio is zero,[13] the bank's incentive constraint does not hold for an arbitrarily large bank size:

$$\int_{\frac{1}{\delta_0}\left(\frac{\mathcal{L}}{\beta} - (1-\delta_0)p_m\right)}^{1} (\delta_0 p + (1 - \delta_0)p_m) f(p) dp > \frac{\alpha - 1}{\beta - 1}. \tag{2.2}$$

Put differently, Assumption 2 implies that, for any precision such that the value of the low-risk loan portfolio is positive, a sufficiently large bank always originates a high-risk loan portfolio (which we could, alternatively, directly assume). If this condition does not hold, there could exist parameter values such that the bank grows to infinite size.

Assumption 3: A low-risk loan portfolio has a positive value if the reporting system is perfectly informative:

$$q\alpha + (1 - q)\mathbb{E}(\max(\mathcal{L}, p\beta)) > 1. \tag{2.3}$$

Assumption 3 rules out situations in which the bank has no access to a positive value loan portfolio. Note that Assumption 3 and Assumption 1 both imply that $\beta > \alpha > 1 > \mathcal{L}$.

In summary, Assumption 1 requires the high-risk loan portfolio to be value-destroying, Assumption 2 rules out unbounded bank size and surplus, and Assumption 3 sets the low-risk loan portfolio to be value-creating if the reporting system is sufficiently precise.

III. MAIN ANALYSIS

We solve the model by backward induction. We start by solving the regulator's optimal restructuring decision at $t = 2$ given the signal s sent by the reporting system. Next, we solve for the risk decision r of the bank and the bank's

[12] In the Online Appendix, we analyze a variant of the model in which the bank can also make the restructuring decision. We show that similar results hold when the bank with a risky loan has no residual equity left after restructuring.

[13] The condition that ensures that the low-risk loan portfolio has a zero value at $\delta = \delta_0$ can be written as

$$q\alpha + (1 - q)\mathbb{E}(\max(\mathcal{L}, (\delta_0 p + (1 - \delta_0)p_m)\beta)) = 1.$$

In Lemmas 1–4, we will prove that condition (2.2) is the bank's incentive constraint for an arbitrarily large A given the precision δ_0. Similar to Holmström and Tirole (1997), a larger size causes a more severe agency problem.

choice of A. Lastly, we obtain the optimal reporting system δ and the optimal capital requirement γ set by the regulator at $t=0$.

We will show that the bank optimally chooses the size A^* such that the capital requirement γ is binding at $t=0$, i.e., $A^* = \gamma E$. Thus, we only need to consider the case in which the bank size is γE when deriving the regulator's optimal restructuring decision at $t=2$. At $t=2$, given the signal s sent by the reporting system, the equity of the bank is

$$E_1 = A(q\alpha + (1-q)\mathbb{E}(p|s)\beta) - D.$$

Therefore, at $t=2$, if $q\alpha + (1-q)\mathbb{E}(p|s)\beta \geq 1$, the bank does not violate the capital requirement γ,

$$\frac{E_1}{A_1} = \frac{A(q\alpha + (1-q)\mathbb{E}(p|s)\beta) - D}{A(q\alpha + (1-q)\mathbb{E}(p|s)\beta)} \geq \frac{E}{A} = \frac{1}{\gamma},$$

and the regulator does not intervene to restructure the loan. Otherwise, if $q\alpha + (1-q)\mathbb{E}(p|s)\beta < 1$, the bank violates the capital requirement γ:

$$\frac{E_1}{A_1} < \frac{1}{\gamma}.$$

The regulator then restructures a risky loan if and only if the associated payoff is greater than the expected continuation value, i.e., $q\alpha + (1-q)\mathbb{E}(p|s)\beta < q\alpha + (1-q)\mathcal{L}$, which implies that the bank equity,

$$E_1 < \hat{E} \equiv A(q\alpha + (1-q)\mathcal{L}) - D. \tag{3.1}$$

The following lemma summarizes the restructuring policy implemented by the regulator in this model.

Lemma 1: At $t=2$, conditional on realized equity, (a) if $E_1/A_1 > 1/\gamma$, the bank does not violate the capital requirement and the regulator does not restructure the loan; (b) if $E_1/A_1 \in [\hat{E}/A_1, 1/\gamma)$, the bank violates the capital requirement but the regulator does not restructure the loan; and (c) if $E_1/A_1 < \hat{E}/A_1$, the bank violates the capital requirement and the regulator restructures a risky loan.

The regulator first observes the level of equity of the bank E_1 after the accounting signal s is received, and two scenarios may then occur. If the bank does not violate the capital requirement, i.e., (*a*) holds, or restructuring would not increase value, i.e., (*b*) holds, the regulator anticipates that restructuring would decrease total surplus and lets the bank continue. On the other hand, if the bank's equity is sufficiently low, $E_1 < \hat{E}$, the regulator restructures the bank's loan when it identifies a risky loan.

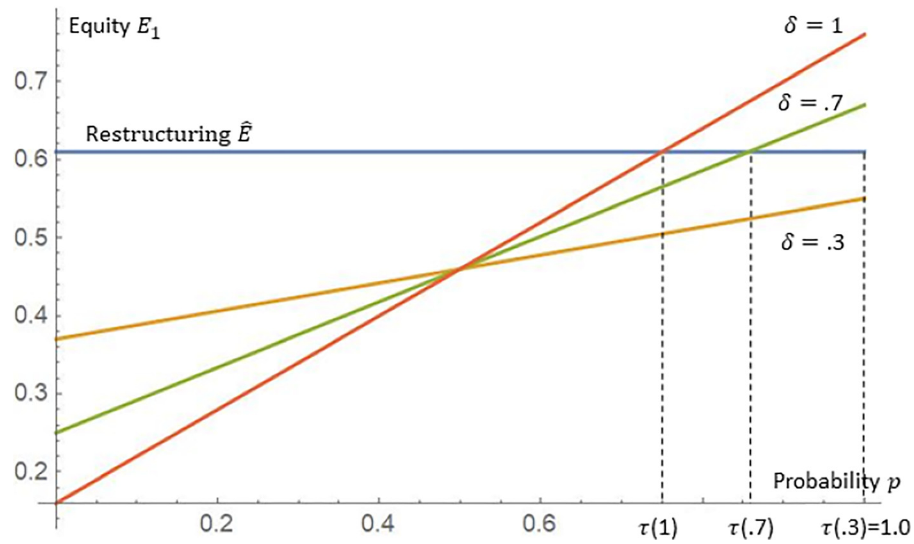
Given the realized signal s sent by the reporting system at $t=2$, it is convenient to rewrite the regulator's restructuring decision in (3.1) in terms of a threshold $\tau(\delta)$ such that the regulator restructures a risky loan if and only if $p < \tau(\delta)$, where $\tau(\delta)$ is defined as follows:

$$\tau(\delta) \equiv \begin{cases} 1 & \text{if } 0 \leq \delta < \dfrac{\frac{\mathcal{L}}{\beta} - p_m}{1-p_m}. \\ \dfrac{1}{\delta}\left(\dfrac{\mathcal{L}}{\beta} - (1-\delta)p_m\right) & \text{otherwise} \end{cases} \tag{3.2}$$

Figure 2 plots the bank's equity, E_1, as a function of the probability of success against the restructuring threshold: the regulator restructures a risky loan when $E_1 < \hat{E}$, i.e., to the left of the intersection between the horizontal line and the upward sloping continuation payoff line.[14] The continuation payoff line is steepest in the probability of success when the reporting system is perfectly informative ($\delta = 1$) in which case the restructuring threshold is $\tau(1) = \mathcal{L}/\beta$. As the reporting system becomes more imprecise (lower δ), the continuation payoff line rotates, increasing the set of reports such that the regulator restructures a risky loan: by creating uncertainty about the probability of success, an imprecise

[14] We use the following parameter values that satisfy all the assumptions of our model: $q=0.4$, $\alpha = 1.15$, $\mathcal{L} = .75$, $p_m = .5$, $D=0.3$, $A=1$, and $\beta = 1.45$.

FIGURE 2
Restructuring Policy as a Function of the Probability of Success



(The full-color version is available online.)

measure increases the likelihood of *ex post* restructuring. Note that an imprecise reporting system ($\delta < 1$) induces excessive restructuring because the regulator restructures a risky loan for the probabilities of success $p \in [\mathcal{L}/\beta, \tau(\delta)]$. The next lemma summarizes this result and provides additional comparative statics.

Lemma 2: The restructuring threshold $\tau(\delta) \in [\mathcal{L}/\beta, 1]$ increases in the restructuring payoff $\mathcal{L}$ and decreases in the payoff of a risky loan β and in the precision δ of the reporting system.

Next, we derive the bank's expected payoff and examine the bank's choice of the size A as well as the bank's risk decision r. Recall that the bank with a risky loan receives a zero payoff with restructuring but, otherwise, receives a payoff $A\alpha - (A - E)$ when continuing with a safe loan and $\mathbb{E}(p|s)(A\beta - (A - E))$ when continuing with a risky loan. Thus, the bank's payoff from originating a low-risk loan portfolio is

$$q(A\alpha - (A - E)) + (1 - q)k(\delta)(A\beta - (A - E)),$$

where the function $k(.)$ is defined such that

$$k(\delta) \equiv \int_{\tau(\delta)}^{1} (\delta p + (1 - \delta)p_m)f(p)dp. \tag{3.3}$$

This function captures the expected probability of success times the probability that the regulator does not restructure a risky loan. In the following lemma, we show that the expected payoff of the bank increases in the bank size, which implies that the capital requirement γ is binding at $t = 0$.

Lemma 3: In equilibrium, given a capital requirement γ set by the regulator, the bank chooses $A^* = \gamma E$.

With a perfectly informative reporting system ($\delta = 1$) and no capital requirement (γ very large), the bank would choose the maximal bank size and would originate a high-risk loan portfolio (Assumption 2), which is suboptimal for the regulator (Assumption 1). This result highlights the role of capital requirements in our setting: insured depositors do not monitor the management of their banks, and, as a result, banks are engaged in excessive risk-taking (Hellmann et al. 2000; Repullo 2004; Freixas and Rochet 2008). Hence, the regulator needs to address the risk-taking problem with a capital requirement and an accounting reporting system.

Next, we state the bank's risk-taking incentive constraint that must be satisfied to ensure the bank originates a low-risk loan portfolio. At $t = 1$, the bank prefers to originate a low-risk loan portfolio, i.e., $r = 0$, over a high-risk loan portfolio, i.e., $r = 1$, if and only if

$$\underbrace{q(A\alpha-(A-E))+(1-q)k(\delta)(A\beta-(A-E))}_{\text{bank's expected pay off with } r=0} \geq \underbrace{k(\delta)(A\beta-(A-E))}_{\text{bank's expected pay off with } r=1}.$$

This incentive constraint can be rewritten as

$$\underbrace{A\alpha-(A-E)}_{\text{bank's expected pay off with a safe loan}} \geq \underbrace{k(\delta)(A\beta-(A-E))}_{\text{bank's expected pay off with a risky loan}}. \quad (3.4)$$

Given that the bank chooses the maximal bank size such that $A^* = \gamma E$, the bank's incentive constraint (3.4) can be conveniently expressed in terms of a constraint on the capital requirement:

$$\gamma \leq \frac{1-k(\delta)}{k(\delta)(\beta-1)-(\alpha-1)}. \quad (3.5)$$

At $t=0$, the regulator's problem is to maximize the expected surplus from the bank's loan by inducing the bank to originate a low-risk loan portfolio. The maximization problem of the regulator can be written as

$$(P) \qquad \max_{\gamma\geq 1,\, \delta\in[0,1]} \Sigma(\gamma,\delta) \equiv (q\alpha+(1-q)(F(\tau(\delta))\mathcal{L}+k(\delta)\beta)-1)\gamma E$$

such that

$$\gamma \leq \frac{1-k(\delta)}{k(\delta)(\beta-1)-(\alpha-1)}. \quad (3.6)$$

Naturally, if the value of the loan portfolio is negative, i.e., $\Sigma(\gamma,\delta)<0$, the regulator would want to set $\gamma=0$ and achieve zero total surplus. However, in what follows, we will show that the regulator can always implement a positive-value loan portfolio. In this case, the expected surplus from the bank's loan is increasing in the bank size A or, equivalently, in the capital requirement γ. As a result, the regulator finds it optimal to set the capital requirement γ such that the incentive constraint of the bank always binds in equilibrium.

Lemma 4: In equilibrium, the bank's risk-taking incentive constraint (3.6) binds.

Lemma 4 implies that, the bank's incentive constraint (3.6) can be rewritten as

$$\gamma = \frac{1-k(\delta)}{k(\delta)(\beta-1)-(\alpha-1)}. \quad (3.7)$$

The expression of the capital requirement γ is intuitive. The greater the payoff from a risky loan β (safe loan α), the more attractive to the bank such loans are, the stricter (looser) the capital requirement. Further, from (3.3), the function $k(\delta)$ decreases in the restructuring threshold $\tau(\delta)$: a higher likelihood of restructuring facilitates a looser capital requirement, thus revealing the economic channel through which the reporting system and the capital requirement interact in our model.

Regulatory Commitment

Lack of commitment power to efficiently restructure a loan is a critical part of the role of information in our model, similar to Crémer (1995) or Arya, Glover, and Sivaramakrishnan (1997). This assumption is consistent with the practice of prudential regulation and has been examined extensively in the literature (Dewatripont and Tirole 1994).[15] In our setting, the regulator choosing to act at $t=2$ does not internalize the impact of restructuring on the *ex ante* bank's risk decision because this decision is sunk by the time restructuring occurs. Next we develop this point further by solving program (P) under the assumption of regulatory commitment, that is, replacing the restructuring threshold, $\tau(\delta)$, by a restructuring threshold, τ_c, independent of the reporting system and optimizing in (γ,δ,τ_c). The following proposition gives the optimal policies when the regulator has full commitment power.

[15] It is also consistent with a wide literature on dynamic inconsistency in policymaking starting with Kydland and Prescott (1977). Many prior studies build on this assumption, noting that this type of inconsistency arises because (banking) regulators cannot ignore political pressures (Dewatripont and Tirole 1994; Rochet 2004). Dewatripont and Tirole (1994) also argue that regulatory capture may be a reason for the lack of commitment power of banking regulators. Relatedly, Boot and Thakor (1993) show that, if regulators are self-interested, they may be captured by the banking industry. Finally, when the time comes to enforce their commitment, prudential regulators often ignore long-term concerns and violate earlier commitments because of the "too-big-to-fail" or "too-many-to-fail" issues (Stern and Feldman 2004; Acharya and Yorulmazer 2007).

Proposition 1: With commitment, there exists a unique restructuring threshold $\tau_c^* > \tau(1) = \frac{\mathcal{L}}{\beta}$. The regulator always sets $\delta_c^* = 1$, restructures a risky loan if and only if $p < \tau_c^*$, and imposes a capital requirement,

$$\gamma_c^* = \frac{1 - \int_{\tau_c^*}^{1} pf(p)dp}{\int_{\tau_c^*}^{1} pf(p)dp(\beta - 1) - (\alpha - 1)}.$$

With full commitment power, the regulator is better off using as much information as possible to condition restructuring on low probabilities of success, implying a perfectly informative reporting system, i.e., $\delta_c^* = 1$. But Proposition 1 also shows that the restructuring threshold, τ_c^*, is stricter than the threshold that would prevail absent commitment: for moderate realizations of the probability of success $p \in \left(\tau(1) = \mathcal{L}/\beta, \tau_c^*\right)$, a regulator would be better off not restructuring a risky loan *ex post*. Excessive *ex post* restructuring is part of the optimal regulation because the intervention curbs the bank's *ex ante* risk-taking incentives, which allows the regulator to set a looser capital requirement. In what follows, we show that, without commitment power, such *ex post* excessive restructuring can be achieved via an imprecise reporting system.

Single Policy Benchmarks

To analyze the interaction between the two regulatory tools, we examine the comparative statics of two benchmarks in which the regulator optimizes only one regulatory tool, taking the other tool as given.

First, in the prudential benchmark, the precision of the reporting system $\delta = \delta_f$ is exogenously given and the regulator sets the optimal capital requirement γ^*. Recall that the precision δ_0 is defined such that the value from a low-risk loan portfolio is zero, i.e.,

$$q\alpha + (1 - q)(F(\tau(\delta_0))\mathcal{L} + k(\delta_0)\beta) = 1.$$

Therefore, if $\delta_f < \delta_0$, the regulator sets $\gamma^* = 1$, and the bank does not originate a loan portfolio because the expected surplus from any loan portfolio is negative. Otherwise, if $\delta_f \geq \delta_0$, the regulator sets γ^* such that the bank's incentive constraint (3.6) is binding. The optimal capital requirement, γ^*, is readily verified to be decreasing in the precision of the report, δ_f, providing preliminary insight about the interaction between (exogenous) characteristics of the reporting system and the capital requirement. A more precise measurement constrains the maximum size of the bank.

Second, in the measurement benchmark, the capital requirement $\gamma = \gamma_f$ is fixed and the regulator designs the optimal reporting system δ^*. If $\gamma_f \leq \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$, the capital requirement is sufficiently tight so that the bank always chooses to originate a low-risk loan portfolio whatever the precision of the reporting system. The regulator therefore sets $\delta^* = 1$ (or maximum precision) to maximize the expected surplus. Otherwise, if $\gamma_f > \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$, the regulator must control the bank's risk-taking incentives with the reporting system. The regulator designs the reporting system $\delta^* < 1$ such that the bank's incentive constraint (3.6) is binding. Note that, if $\gamma_f > \frac{1-k(\delta_0)}{k(\delta_0)(\beta-1)-(\alpha-1)}$, the surplus is negative as the capital requirement is excessively loose, which implies that the bank's risk-taking problem is too severe. Proposition 2 summarizes the equilibrium in the single policy benchmarks.

Proposition 2: First, in the prudential benchmark, if $\delta_f < \delta_0$, the regulator sets $\gamma^* = 1$. Otherwise, if $\delta_f \geq \delta_0$, the optimal capital requirement is given by

$$\gamma^* = \frac{1 - k(\delta_f)}{k(\delta_f)(\beta - 1) - (\alpha - 1)}$$

and is decreasing in the precision δ_f of the reporting system.

Second, in the measurement benchmark, if $\gamma_f \leq \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$, then the optimal precision of the reporting system is $\delta^* = 1$; otherwise, if $\gamma_f > \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$, the optimal precision δ^* is defined by $k(\delta^*) = \frac{1+(\alpha-1)\gamma_f}{1+(\beta-1)\gamma_f}$ and is decreasing in the capital requirement γ_f.

With a single policy benchmark, the capital requirement and the reporting system are substitutes, as both serve to curb the bank's risk-taking incentives. This result is intuitive and serves to set ideas for the intuitions in the model with two optimal policies. Specifically, Proposition 2 implies that an imprecise reporting system inducing excessive restructuring mitigates the risk-taking problem and allows the regulator to set a looser capital requirement. Conversely, if the capital requirement is strict, a perfectly informative reporting system would provide sufficient restructuring incentives to control the risk-taking problem but, otherwise, the reporting system must induce excessive restructuring with a looser capital requirement. We derive next the comparative statics of each of these policies for changes in the environment.

Corollary 1: In the single policy benchmarks, the optimal capital requirement γ^* and the optimal precision δ^* increase in the payoff α of a safe loan, and in the restructuring payoff $\mathcal{L}$ of a risky loan, and decrease in the payoff β of a risky loan.

In the two benchmarks, reducing bank size via a stricter capital requirement or inducing more *ex post* restructuring via a less precise reporting system reduces the expected loan surplus. This, in turn, implies that the degree of reliance on these two tools is a function of the relative attractiveness of the high-risk loan portfolio. As expected, the capital requirement is stricter and the reporting system more imprecise when the severity of the risk-taking problem is larger, i.e., the payoff α of a safe loan and the restructuring payoff $\mathcal{L}$ are lower, and the payoff β of a risky loan is higher.

Joint Maximization Problem

We next solve the full-fledged model in which the regulator jointly chooses the optimal capital requirement γ and the optimal precision δ of the reporting system at $t=0$. To decompose this problem, it is convenient to rewrite the objective function of the regulator as

$$\Sigma(\gamma,\delta) = NPV(\delta)\phi(\delta)E,$$

where $NPV(\delta) \equiv q\alpha + (1-q)(F(\tau(\delta))\mathcal{L} + k(\delta)\beta) - 1$ is the value of the low-risk loan portfolio and $\phi(\delta)$ is the required capital requirement. Note that $\phi(\delta) \equiv \gamma$ given the precision δ to bind the bank's incentive constraint (3.6). Hence, the first-order condition of the optimization program (*P*) with respect to δ can be written as

$$\begin{aligned}\left.\frac{d\Sigma(\phi(\delta),\delta)}{d\delta}\right|_{\delta=\delta^*} &= NPV'(\delta^*)\phi(\delta^*)E + NPV(\delta^*)\phi'(\delta^*)E \\ &= \underbrace{(1-q)\int_{\tau(\delta)}^{1}(p-p_m)f(p)dp\beta\phi(\delta^*)E}_{\text{benefit of increasing precision}} - \underbrace{\frac{NPV(\delta^*)k'(\delta^*)(\beta-\alpha)E}{(k(\delta^*)(\beta-1)-(\alpha-1))^2}}_{\text{cost of increasing precision}}.\end{aligned}$$

The first-order condition is composed of two terms that highlight the trade-off faced by the regulator when designing the reporting system. The first term is the benefit of increasing precision and implies more valuable loans because restructuring more accurately targets probabilities of success in which the regulator should restructure risky loans. The second term reflects how an increase in precision requires a smaller bank size and, hence, a stricter capital requirement.

Contrasting with the single policy benchmark in which one policy is held fixed by the incentive constraint, there is now a trade-off between increasing loan surplus via a looser capital requirement or a more informative reporting system. We examine this trade-off in the following proposition and the associated corollary.

Proposition 3: The regulator sets the capital requirement $\gamma^* = \frac{1-k(\delta^*)}{k(\delta^*)(\beta-1)-(\alpha-1)}$ and the reporting system is not fully precise, i.e., $\delta^* < 1$, if either (a) the payoff of a safe loan α is large enough so that $k(1)(\beta-1)-(\alpha-1)$ is small enough, (b) the proportion of safe loans q is large enough, or (c) the restructuring payoff $\mathcal{L}$ is large enough, $(\beta-1)+(\alpha-1)-2k(1)(\beta-1)\geq 0$, and $f'\left(\frac{\mathcal{L}}{\beta}\right)$ is positive or sufficiently close to 0.

Proposition 3 demonstrates that the regulator may use a combination of imprecise accounting information to induce the optimal level of restructuring jointly with a capital requirement looser than with a perfectly informative reporting system. On the one hand, imprecision triggers excessive restructuring for a given capital requirement and, therefore, allows for a looser capital requirement and a larger bank size. On the other hand, imprecision matches restructuring less precisely with the probability of success and, therefore, reduces the value of the low-risk loan portfolio. The regulator balances those two effects when designing the optimal policies.

Interestingly, the regulator optimally designs an imprecise information system when the risk-taking problem is not too severe under full information, i.e., when the payoff α of a safe loan is large enough. Then, the regulator controls the risk-taking problem using a less precise reporting system and allows the bank to choose a larger size. Similarly, the regulator finds it optimal to increase the size of the bank via a less precise reporting system when the proportion q of safe loans is large, since this implies that each low-risk loan portfolio is *ex ante* more valuable. An increase in the restructuring payoff $\mathcal{L}$ may also lead to more imprecision because, as intuitive, the potential restructuring cost is smaller.[16]

We investigate next how the optimal reporting system δ^* and the optimal capital requirement γ^* vary with the different parameters of our environment. In order to derive the comparative statics, we make the (generic) assumption that the regulator's objective function $\Sigma(\gamma, \delta)$ has a unique global maximum, so that optimal policies change continuously in each parameter.

Corollary 2: The optimal precision of the reporting system δ^* (the capital requirement γ^*) decreases (increases) in (a) the payoff α of a safe loan, (b) the proportion of safe loans q, and (c) the restructuring payoff $\mathcal{L}$ if $(\beta-1)+(\alpha-1)-2k(1)(\beta-1)\geq 0$ and $f'\left(\tau(\delta^*)\right)$ is positive or sufficiently close to 0.[17] Further, δ^* *and* γ^* cannot both increase in β.

Corollary 2 shows how the comparative statics in the model using both an optimal capital requirement and the optimal level of precision may not be fully aligned with those of a single optimal policy. Recall that, if the regulator relies on a single optimal policy, the policy must respond to environments with more demanding credit frictions with stricter policies, e.g., either a stricter capital requirement or a less precise reporting system that triggers more excessive restructuring. Using the two optimal policies in tandem, however, reveals a more nuanced analysis.

First, an increase in the payoff of a safe loan increases the payoff from larger banks, and, while it also makes it easier to solve the risk-taking problem because safe loans are more attractive to the bank, the adjustment takes the form of decreasing the precision of the reporting system, i.e., reallocates the provision of incentives toward the reporting system. Second, an increase in the proportion of safe loans increases the value of a low-risk loan portfolio, which makes bank size more attractive. The regulator induces a larger bank size by increasing imprecision and loosening the capital requirement. Third, the effect of the restructuring payoff is ambiguous because it can shift the efficient restructuring to regions of the probability of success where there is more uncertainty (thus, increasing the cost of imprecision). However, if the density of probabilities of success does not decrease too steeply, an increase in the restructuring payoff implies a decrease in precision: similar to the other comparative statics, the regulator reallocates the provision of risk-taking incentives toward the reporting system and tends to prefer a larger bank size.

The impact of the payoff, β, of the risky loan is the result of two opposing forces. First, an increase in β makes a high-risk loan portfolio—which reduces expected surplus—more attractive to the bank and aggravates the risk-taking problem. Second, an increase in β increases the expected surplus from a high-risk loan portfolio. Therefore, even though a high-risk loan portfolio reduces total surplus, the adverse impact of a risky loan on the bank's surplus becomes more muted as β increases. The latter effect increases the expected surplus generated by the bank. Corollary 2 reveals that, if the regulator sets a looser capital requirement in response to higher β, restructuring must increase, and the regulator chooses a less precise information system. Vice versa, if the regulator increases the precision of the reporting system, then the more severe risk-taking problem must be solved with a stricter capital requirement.

Table 1 summarizes the comparative statics of our baseline model.[18] Our main insight is that, in the single policy benchmarks, the capital requirement and the reporting system are substitutes and respond to an economic primitive of the model in the same direction, in the sense that a situation with economic primitives more favorable to a well-functioning banking system leads to a looser capital requirement and a more precise reporting system (Table 1, rows "exogenous precision" and "exogenous capital requirement"). By contrast, in the joint maximization problem, an improvement in fundamentals may lead to a looser capital requirement and a less precise reporting system (Table 1, row "joint maximization"), causing the response of optimal regulations to be qualitatively different from what they would be if considering the policies independently.

[16] If p is uniformly distributed, then the conditions in Proposition 3 are satisfied: $f'\left(\frac{\mathcal{L}}{\beta}\right)=0$ and $(\beta-1)+(\alpha-1)-2k(1)(\beta-1) = \alpha-1+\left(\frac{\mathcal{L}}{\beta}\right)^2(\beta-1)>0$.

[17] This occurs when $\tau(\delta^*)$ is not too large in single-peaked distributions, which is the case when α is sufficiently low as δ^* decreases in α and $\tau(\delta)$ decreases in δ.

[18] Under the conditions of Corollary 2 for the comparative statics with respect to $\mathcal{L}$.

TABLE 1

Summary of the Comparative Statics

		α	$\mathcal{L}$	q	β
Joint maximization with $\delta^* < 1$	γ^*	+	+	+	+/−
	δ^*	−	−	−	+/−
Exogenous precision with $\delta_f \geq \delta_0$	γ^*	+	+	0	−
Exogenous capital requirement with $\gamma_f > \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$	δ^*	+	+	0	−

IV. ROBUSTNESS TO OTHER MECHANISMS

In this section, we show that our main result is robust to two alternative mechanisms: the presence of additional negative externalities from bank failure and an approach based on persuasion theory in which the signal structure is optimally designed. Proofs for this section are available in the Online Appendix.

Negative Externalities of Bank Failure

We study next the impact of negative externalities in case of banking failure at $t = 3$ on the optimal policies set by the regulator at $t = 0$. As in Bleck and Opp (2019), risk-taking entails an additional social cost: if a bank with a risky loan fails at $t = 3$, the regulator incurs a cost $\mathcal{K} > 0$. This social cost can be interpreted as an increase in systemic risk or as the social cost from insufficient lending as a result of bank failures.[19] For brevity, we assume that $\mathcal{K}$ is not too large so that the assumptions of the baseline model still hold. At $t = 2$, the regulator restructures a risky loan if and only if

$$q\alpha + (1-q)\mathcal{L} > q\alpha + (1-q)(\mathbb{E}(p|s)\beta - (1-\mathbb{E}(p|s))\mathcal{K}),$$

which is equivalent to

$$\frac{\mathcal{L}+\mathcal{K}}{\beta+\mathcal{K}} > \mathbb{E}(p|s) = \delta s + (1-\delta)p_m.$$

Given the negative externalities, $\mathcal{K}$, the restructuring threshold is now defined as

$$\tau(\delta) \equiv \begin{cases} 1 & \text{if } 0 \leq \delta < \dfrac{\dfrac{\mathcal{L}+\mathcal{K}}{\beta+\mathcal{K}} - p_m}{1-p_m} \\ \dfrac{1}{\delta}\left(\dfrac{\mathcal{L}+\mathcal{K}}{\beta+\mathcal{K}} - (1-\delta)p_m\right) & \text{otherwise} \end{cases}.$$

The bank's risk choice is not affected by this additional externality and is therefore the same as in our baseline model. In this new environment, the regulator's maximization problem becomes

$$\max_{\gamma,\delta} \Sigma(\gamma,\delta) = (q\alpha + (1-q)(F(\tau(\delta))\mathcal{L} + k(\delta)\beta - (1-k(\delta))\mathcal{K}) - 1)\gamma E$$

subject to the same bank incentive constraint given by (3.6).

As in our main model, we now show that the regulator optimally chooses an imperfect reporting system if the payoff of safe loans is sufficiently large or if the proportion of safe loans is sufficiently large.

Lemma 5: The reporting system is not fully precise, i.e., $\delta^* < 1$, if either the payoff of a safe loan α is large enough or the proportion of safe loans q is large enough.

Lemma 5 shows that our main result is similar in the presence of additional negative externalities. We then analyze the impact of these externalities on the optimal capital requirement and the optimal precision of the reporting system.

Corollary 3: If the proportion q of safe loans is sufficiently large and $f'(\tau(\delta^*))$ is positive or sufficiently close to 0, then the precision of the reporting system δ^* decreases in $\mathcal{K}$ whereas the capital requirement γ^* increases in $\mathcal{K}$.

[19] See Greenwood, Landier, and Thesmar (2015) for a discussion of the negative externalities that exist in the banking industry.

As the externality of bank failures $\mathcal{K}$ increases, restructuring becomes more attractive for the regulator. Hence, the regulator optimally designs a less precise reporting system in order to increase the likelihood of restructuring. This increase in the likelihood of restructuring curbs the risk-taking incentives, which implies that the regulator sets a looser capital requirement. Overall, this extension provides additional insights into how externalities in the banking industry may affect optimal capital requirements and accounting rules.

Optimal Persuasion

In this extension, we study an alternative reporting system, and we show that our main result, i.e., that the regulator may rely on imprecise information systems, still holds. In our baseline model, the regulator only controls the probability that the interim signal is noisy and takes the distribution of the noise as a given. By contrast, we now assume that the regulator controls the entire distribution of the accounting signal and therefore solve for the optimal persuasion mechanism (Kamenica and Gentzkow 2011; Cheynel and Ziv 2021; Cianciaruso, Marinovic, and Smith 2021; Laux and Zheng 2022).

Specifically, the information system chosen at $t = 0$ is a *function* $\delta(p)$ which prescribes the probability that the accounting signal $s = p$ is the true probability of success. We generalize the baseline assumption about the noise distribution by assuming that the distribution of the noise is the cumulative distribution function of $p|\delta(p) = 0$; this nests as a special case the baseline model since, if $\delta(.)$ is a constant, the noise distribution is simply $F(.)$.[20] Lastly, adapting Assumptions 1–3 to this setting, we require the payoff $\int_{\mathcal{L}/\beta}^{1} pf(p)dp$ to be neither too large nor too small to preserve the primary trade-offs.[21]

The next lemma is critical to this analysis and reveals that the optimal accounting signal would feature asymmetric imprecision and characterizes the signal structure.

Lemma 6: The optimal information system is unique and such that there exists $\tau \geq \frac{\mathcal{L}}{\beta}$ with $\delta(p) = 0$ if $p < \tau$, in which case the accounting signal s is drawn from $p|p \leq \tau$, and $\delta(p) = 1$ if $p > \tau$, in which case the accounting signal is $s = p$.

The regulator's maximization problem is the choice of a restructuring threshold τ and a capital requirement γ to maximize the expected surplus:

$$\Sigma(\tau) \equiv \max_{\gamma,\, \tau\in[0,1]} \left(q\alpha + (1-q)\left(\int_0^{\tau} f(p)dp\mathcal{L} + \int_{\tau}^{1} pf(p)dp\beta \right) - 1 \right)\gamma E$$

such that

$$\int_0^{\tau} f(p)dp\frac{\mathcal{L}}{\beta} - \int_0^{\tau} pf(p)dp \geq 0 \tag{4.2}$$

$$\tau - \frac{\mathcal{L}}{\beta} \geq 0 \tag{4.3}$$

$$\gamma\alpha - (\gamma - 1) - \int_{\tau}^{1} pf(p)dp(\gamma\beta - (\gamma - 1)) \geq 0, \tag{4.4}$$

[20] In the Online Appendix, we prove that doing so is optimal among all persuasion mechanisms in our game. As is common in persuasion games, the mechanism is not unique if we let the regulator use other functional forms $G(.)$ (e.g., which could be other distributions with support on $[0, \tau^*]$). However, a noise distribution $G(.)$ that corresponds to the conditional distribution of p is natural for our setting since it assumes the noise is drawn from the distribution of the set of probabilities of success consistent with imprecision. This formulation also implies that there is a well-defined continuous distribution for the accounting signals and, hence, for the equity construct in our model.

[21] Formally, Assumptions 1–3 are now more cumbersome and must be written as

$$\max\left(\frac{\alpha-1}{\beta-1}, \frac{1-q\alpha}{(1-q)\beta} - F\left(\frac{\mathcal{L}}{\beta}\right)\frac{\mathcal{L}}{\beta}\right) < \int_{\mathcal{L}/\beta}^{1} pf(p)dp < \min\left(\frac{\alpha}{\beta}, \frac{1}{\beta} - F\left(\frac{\mathcal{L}}{\beta}\right)\frac{\mathcal{L}}{\beta}\right). \tag{4.1}$$

The first part of the left-hand side of the inequality states that the bank originates a high-risk loan portfolio if the bank size is arbitrarily large and the reporting system is fully informative. The second part requires the low-risk loan portfolio to have positive expected value because, otherwise, the regulator would always set $\gamma = 1$. The first part of the right-hand side of the inequality rules out parameter values for which the risk-taking problem is so severe that the bank would only lend its own equity, E. The second part of the right-hand side of the inequality guarantees that the high-risk loan portfolio is value-destroying.

where the constraints (4.2) and (4.3) ensure that restructuring a risky loan is optimal for the regulator if and only if $s < \tau$, and (4.4) is the bank's incentive constraint. We prove in the next proposition that the regulator always chooses to distort the restructuring threshold.

Proposition 4: The optimal restructuring threshold τ^* is strictly higher than the restructuring threshold when the reporting system is fully informative, i.e., $\tau^* > \mathcal{L}/\beta$.

Recall that the restructuring decision is also governed by an *ex post* constraint (4.2) which bars policies in which the regulator would restructure a risky loan with greater value if it were continued. The higher the restructuring threshold, the more this constraint becomes difficult to satisfy. Specifically, the *ex post* constraint (4.2) is satisfied if and only if $\tau \leq \overline{\tau}$, where $\overline{\tau}$ is such that

$$\int_{0\overline{\tau}} pf(p)dp = F(\overline{\tau})\frac{\mathcal{L}}{\beta}. \tag{4.5}$$

Note that $\overline{\tau} < 1$ if and only if $\mathbb{E}(p)\beta > \mathcal{L}$. To characterize the optimal threshold, note that $\Sigma'(\overline{\tau}) < 0$ is a sufficient condition for the existence of an interior solution $\tau^* < \overline{\tau}$ since, then, the regulator would increase expected surplus by reducing the restructuring threshold.

Proposition 5: There exists $\nu > 0$, which is not a function of q, such that the restructuring threshold is set at the maximum level $\tau^* = \overline{\tau}$ if and only if the proportion of safe loans is large enough, i.e.,

$$q > \overline{q} \equiv \frac{\nu}{(\alpha - 1)(\beta - \alpha)\overline{\tau} + \nu} \in (0, 1). \tag{4.6}$$

The intuition for Proposition 5 is given in two steps, starting with a comparative static in q and followed by the rationale for $\tau^* = \overline{\tau}$. When q is large, there is a greater net benefit from increasing leverage. The regulator (weakly) increases the restructuring threshold τ^* in response to an increase in the proportion of safe loans. This requires an increase in imprecision by pooling more positive realizations of p into the restructuring region. When q becomes greater than $\overline{q}$, the required restructuring threshold to implement the ideal leverage would be above $\overline{\tau}$. At this point, the regulator implements the maximal credible threshold $\overline{\tau}$. In the Online Appendix, we derive the comparative statics with this alternative specification of the measurement. The intuitions from our baseline model carry over to this model with optimal persuasion.

V. CONCLUDING REMARKS

We develop a simple integrated role of accounting standards and capital requirements under the assumption that accounting standards play an important role in influencing the information available to prudential regulators.

An implication of our analysis is that the current focus of standard-setters on providing decision-useful information to investors can be detrimental to banks. Put differently, in a strategic setting, more decision-useful information can lead to worse regulatory interventions and demand stricter prudential regulations. Standard-setters have noted that they are not equipped to exert judgment about prudential issues, since these involve policy judgments. Our analysis suggests that there are benefits in creating a stronger articulation between the missions of the two regulatory bodies and encouraging communication between them.

Our study also generates an important insight about expected loan loss provisioning models recently mandated by standard-setters. Expected loss models require the use of timely and potentially imprecise information about credit risk as an input to measuring loan losses. We show that, by relying on imprecise information about credit risk, a banking regulator can loosen capital requirements, thereby affecting the quantity of quality of loans that banks originate. More work is needed to further analyze the optimal loan loss provisioning model and to fully understand the trade-offs at stake (see, e.g., Mahieux et al. 2022). In particular, the procyclical impact of the provisions for loan losses on bank lending has been heavily debated since the 2007–2008 financial crisis. Our static model does not speak to this question, and we would need a dynamic setting to highlight the features of the optimal provisioning model. We leave this important question for future research.

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APPENDIX A

Proofs

Proof of Lemmas 1–4

At $t = 2$, the regulator optimally restructures a risky loan if and only if the bank violates the capital requirement γ and $q\alpha + (1-q)\mathbb{E}(p|s)\beta < q\alpha + (1-q)\mathcal{L}$. First, note that the condition $q\alpha + (1-q)\mathbb{E}(p|s)\beta < q\alpha + (1-q)\mathcal{L}$ is equivalent to $p < \tau(\delta)$, where $\tau(\delta)$ is such that

$$\tau(\delta) = \begin{cases} 1 & \text{if } 0 \leq \delta < \dfrac{\dfrac{\mathcal{L}}{\beta} - p_m}{1 - p_m}. \\ \dfrac{1}{\delta}\left(\dfrac{\mathcal{L}}{\beta} - (1-\delta)p_m\right) & \text{otherwise} \end{cases} \tag{5.1}$$

Further, Assumption 2 implies that $q\alpha + (1-q)\mathcal{L} < 1$. As a result, if the bank chooses the maximal bank size at $t = 0$, i.e., $A = \gamma E$, the bank violates the capital requirement γ if and only if $q\alpha + (1-q)\mathbb{E}(p|s)\beta < 1$. Otherwise, if the bank chooses $A < \gamma E$, then the bank violates the capital requirement if and only if

$$\frac{A(q\alpha + (1-q)\mathbb{E}(p|s)\beta) - D}{A(q\alpha + (1-q)\mathbb{E}(p|s)\beta)} < 1/\gamma, \quad \text{i.e.,} \quad q\alpha + (1-q)\mathbb{E}(p|s)\beta < \frac{\gamma(A-E)}{(\gamma-1)A}.$$

There are three cases to consider. First, if the bank chooses A such that

$$\frac{\gamma(A-E)}{(\gamma-1)A} \geq q\alpha + (1-q)\mathcal{L}, \quad \text{i.e.,} \quad A \geq \frac{\gamma E}{\gamma - (\gamma-1)(q\alpha + (1-q)\mathcal{L})}, \tag{5.2}$$

the regulator restructures a risky loan if and only if $p < \tau(\delta)$.

Second, if the bank chooses $A < \frac{E\gamma}{\gamma - q\alpha(\gamma-1) - (1-q)p_m\beta(\gamma-1)}$, then the bank violates the capital requirement and the regulator restructures a risky loan if and only if $p < \tau'(A,\gamma,\delta)$, where $\tau'(A,\gamma,\delta)$ is defined as follows:

$$\tau'(A,\gamma,\delta) \equiv \begin{cases} 0 & \text{if } 0 \leq \delta \leq 1 - \dfrac{\gamma(1-E/A) - q\alpha(\gamma-1)}{(1-q)\beta(\gamma-1)p_m} \\ \dfrac{1}{\delta}\left(\dfrac{\gamma(1-E/A) - q\alpha(\gamma-1)}{(1-q)\beta(\gamma-1)} - (1-\delta)p_m\right) & \text{otherwise} \end{cases}.$$

Third, if the bank chooses $\frac{E\gamma}{\gamma - q\alpha(\gamma-1) - (1-q)p_m\beta(\gamma-1)} \leq A < \frac{\gamma E}{\gamma - (\gamma-1)(q\alpha + (1-q)\mathcal{L})}$, then the bank violates the capital requirement and the regulator restructures a risky loan if and only if $p < \hat{\tau}(A,\gamma,\delta)$, where $\hat{\tau}(A,\gamma,\delta)$ is defined as follows

$$\hat{\tau}(A,\gamma,\delta) \equiv \begin{cases} 1 & \text{if } 0 \leq \delta < \dfrac{\dfrac{\gamma(1-E/A) - q\alpha(\gamma-1)}{(1-q)\beta(\gamma-1)} - p_m}{1 - p_m} \\ \dfrac{1}{\delta}\left(\dfrac{\gamma(1-E/A) - q\alpha(\gamma-1)}{(1-q)\beta(\gamma-1)} - (1-\delta)p_m\right) & \text{otherwise} \end{cases}.$$

We focus until the end of the proof on the first case given that the proofs of the two other cases follow similar steps. The regulator's maximization problem is

$$\max_{A,\gamma,\delta} A\big(q\alpha + (1-q)\big(F(\tau)\mathcal{L} + k(\delta)\beta\big) - 1\big)$$

such that

$$(A\alpha - (A-E)) \geq k(\delta)(A\beta - (A-E)),$$

and

$$A \in \arg\max_{A \leq \gamma E} q(A\alpha - (A - E)) + (1 - q)k(\delta)(A\beta - (A - E)).$$

In equilibrium, the regulator chooses δ such that $\delta > \delta_0$, where δ_0 is defined in (2.2) as the minimum precision consistent with a positive value low-risk loan portfolio. We now prove that the incentive constraint binds and, for a given γ, the bank chooses $A^* = \gamma E$. First, if the incentive constraint binds, the bank's payoff is

$$q(A\alpha - (A - E)) + (1 - q)k(\delta)(A\beta - (A - E)) = A\alpha - (A - E),$$

which strictly increases in A. Thus, the bank chooses $A^* = \gamma E$. Second, if the incentive constraint is not satisfied, i.e.,

$$A\alpha - (A - E) < k(\delta)(A\beta - (A - E)),$$

then the bank originates a high-risk loan portfolio with negative value. Third, assume that the incentive constraint is strictly satisfied and the bank chooses $A^* < \gamma E$. The bank's payoff becomes

$$q(A^*\alpha - (A^* - E)) + (1 - q)k(\delta)(A^*\beta - (A^* - E)),$$

with $A^*\alpha - (A^* - E) > k(\delta)(A^*\beta - (A^* - E))$. Suppose the bank deviates and chooses $A' > A^*$ such that

$$A'\alpha - (A' - E) = k(\delta)\big(A'\beta - (A' - E)\big).$$

The bank's expected payoff becomes

$$\begin{aligned} &q\big(A'\alpha - (A' - E)\big) + (1 - q)k(\delta)\big(A'\beta - (A' - E)\big) \\ &\quad = A'\alpha - (A' - E) > A^*\alpha - (A^* - E) > q(A^*\alpha - (A^* - E)) + (1 - q)k(\delta)(A^*\beta - (A^* - E)). \end{aligned}$$

Thus, the bank is strictly better-off with $A = A'$ than with $A = A^*$. □

Proof of Proposition 1

We solve program (P) with commitment, that is, replacing $\tau(\delta)$ by τ_c and optimizing in (γ, τ_c, δ). Substituting γ from the binding incentive constraint into the objective function, the regulator's maximization problem becomes

$$\begin{aligned} \max_{\tau_c,\,\delta} \Sigma_b(\delta) \equiv &\left(q\alpha + (1 - q)\left(F(\tau_c)\mathcal{L} + \int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp\beta\right) - 1\right) \\ &\times \frac{1 - \int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp}{\int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp(\beta - 1) - (\alpha - 1)} E. \end{aligned}$$

Taking the first-order condition with respect to τ_c,

$$\begin{aligned} 0 = &(1 - q)(\mathcal{L} - (\delta\tau_c + (1 - \delta)p_m)\beta) \underbrace{\left(1 - \int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp\right)}_{>0} \\ &\times \underbrace{\left(\int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp(\beta - 1) - (\alpha - 1)\right)}_{>0} \\ &+ \underbrace{\left(q\alpha + (1 - q)\left(F(\tau_c)\mathcal{L} + \int_{\tau_c}^{1} (\delta p + (1 - \delta)p_m)f(p)dp\beta\right) - 1\right)(\beta - \alpha)(\delta\tau_c + (1 - \delta)p_m)}_{>0}. \end{aligned}$$

Assumption 2 implies that $q\alpha + (1 - q)\mathcal{L} < 1$. Thus, always restructuring a risky loan, i.e., $\tau_c = 1$, is suboptimal for the regulator. Further, if the regulator never restructures, i.e., $\tau_c = 0$, then the per-unit surplus is

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$$q\alpha + (1-q)\int_0^1 (\delta p + (1-\delta)p_m)f(p)dp\beta - 1 < q\alpha + (1-q)\mathcal{L} - 1,$$

which is negative by Assumption 2. Hence, the solution $\tau_c^* \in (0,1)$ satisfies $\frac{\partial \Sigma_b}{\partial \tau_c} = 0$, which implies

$$(1-q)\big(\mathcal{L} - (\delta\tau_c^* + (1-\delta)p_m)\beta\big) < 0. \tag{5.3}$$

Taking the first-order condition with respect to δ yields

$$\begin{aligned} 0 =& (1-q)\beta\left(1 - \int_{\tau_c}^1 (\delta p + (1-\delta)p_m)f(p)dp\right)\left(\int_{\tau_c}^1 (\delta p + (1-\delta)p_m)f(p)dp(\beta-1) - (\alpha-1)\right) \\ & - \left(q\alpha + (1-q)\left(F(\tau_c)\mathcal{L} + \int_{\tau_c}^1 (\delta p + (1-\delta)p_m)f(p)dp\beta\right) - 1\right)(\beta-\alpha). \end{aligned} \tag{5.4}$$

Thus, evaluating (5.4) at $\tau = \tau_c^*$,

$$0 = \beta - \frac{\mathcal{L} - (\delta\tau_c^* + (1-\delta)p_m)\beta}{\delta\tau_c^* + (1-\delta)p_m}. \tag{5.5}$$

The right-hand side of (5.5) is strictly positive, which implies $\delta^* = 1$. As a result, given that $\delta^* = 1$, the condition in (5.3) implies that $\tau_c^* > \frac{\mathcal{L}}{\beta}$. □

Proof of Proposition 2 and Corollary 1

Suppose the precision of the reporting system $\delta = \delta_f$ is fixed and $\delta_f \geq \delta_0$ (from the definition of δ_0, if $\delta_f < \delta_0$, then a low-risk loan portfolio has *ex ante* negative value). It follows from Lemma 4 that the optimal capital requirement is $\gamma^* = \frac{1-k(\delta_f)}{k(\delta_f)(\beta-1)-(\alpha-1)}$. Recalling that $k(\delta_f) = \int_{\tau(\delta_f)}^1 (\delta_f p + (1-\delta_f)p_m)f(p)dp$, it follows readily from (5.1) that $k(\delta_f)$ is increasing in β and δ_f, and decreasing in $\mathcal{L}$. Then,

$$\frac{\partial\gamma^*}{\partial\alpha} = \frac{1-k(\delta_f)}{(k(\delta_f)(\beta-1)-(\alpha-1))^2} > 0,$$

$$\frac{\partial\gamma^*}{\partial\mathcal{L}} = \frac{-\frac{\partial k(\delta_f)}{\partial\mathcal{L}}(k(\delta_f)(\beta-1)-(\alpha-1)) - (1-k(\delta_f))\frac{\partial k(\delta_f)}{\partial\mathcal{L}}(\beta-1)}{(k(\delta_f)(\beta-1)-(\alpha-1))^2} > 0,$$

$$\frac{\partial\gamma^*}{\partial\beta} = \frac{-\frac{\partial k(\delta_f)}{\partial\beta}(k(\delta_f)(\beta-1)-(\alpha-1)) - (1-k(\delta_f))\left(\frac{\partial k(\delta_f)}{\partial\beta}(\beta-1) + k(\delta_f)\right)}{(k(\delta_f)(\beta-1)-(\alpha-1))^2} < 0,$$

$$\frac{\partial\gamma^*}{\partial\delta_f} = \frac{-\frac{\partial k(\delta_f)}{\partial\delta_f}(k(\delta_f)(\beta-1)-(\alpha-1)) - (1-k(\delta_f))\frac{\partial k(\delta_f)}{\partial\delta_f}(\beta-1)}{(k(\delta_f)(\beta-1)-(\alpha-1))^2} < 0.$$

Suppose next that $\gamma = \gamma_f$ is fixed. First, suppose that $\gamma_f < \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$; this implies that the bank's incentive constraint is satisfied for any δ. As a result, the regulator maximizes the low-risk loan portfolio surplus and sets $\delta^* = 1$. Next, suppose that $\gamma_f \geq \frac{1-k(1)}{k(1)(\beta-1)-(\alpha-1)}$. We know from Lemma 4 that the optimal precision δ^* satisfies $k(\delta^*) = \frac{1+(\alpha-1)\gamma_f}{1+(\beta-1)\gamma_f} \in \left(\frac{\alpha}{\beta}, \frac{\alpha-1}{\beta-1}\right)$. Note that, if $0 \leq \delta < \frac{\frac{\mathcal{L}}{\beta}-p_m}{1-p_m}$, the function $k(\delta)$ is strictly increasing in δ with $k\left(\frac{\frac{\mathcal{L}}{\beta}-p_m}{1-p_m}\right) = 0$ and $k(1) = \int_{\frac{\mathcal{L}}{\beta}}^1 pf(p)dp > \frac{\alpha-1}{\beta-1}$ by Assumption 2. As a result, the function $k(.)$ is invertible, i.e., the solution is unique.

We next derive the partial derivatives of the left-hand side and the right-hand side of equation $k(\delta^*) = \frac{1+(\alpha-1)\gamma_f}{1+(\beta-1)\gamma_f}$:

$$-(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\frac{\partial\tau(\delta^*)}{\partial\alpha}+\int_{\tau(\delta^*)}^1(p-p_m)\frac{\partial\delta^*}{\partial\alpha}f(p)dp=\frac{\gamma_f}{1+(\beta-1)\gamma_f}>0,$$
$$-(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\frac{\partial\tau(\delta^*)}{\partial\mathcal{L}}+\int_{\tau(\delta^*)}^1(p-p_m)\frac{\partial\delta^*}{\partial\mathcal{L}}f(p)dp=0,$$
$$-(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\frac{\partial\tau(\delta^*)}{\partial\beta}+\int_{\tau(\delta^*)}^1(p-p_m)\frac{\partial\delta^*}{\partial\beta}f(p)dp=\frac{-(1+(\alpha-1)\gamma_f)\gamma_f}{(1+(\beta-1)\gamma_f)^2}<0,$$
$$-(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\frac{\partial\tau(\delta^*)}{\partial\gamma_f}+\int_{\tau(\delta^*)}^1(p-p_m)\frac{\partial\delta^*}{\partial\gamma_f}f(p)dp=\frac{\alpha-\beta}{(1+(\beta-1)\gamma_f)^2}<0.$$

Further, we know that

$$\frac{\partial\tau(\delta^*)}{\partial\mathcal{L}}=\frac{1}{\delta^*\beta}-\frac{1}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\frac{\partial\delta^*}{\partial\mathcal{L}},$$
$$\frac{\partial\tau(\delta^*)}{\partial\beta}=-\frac{\mathcal{L}}{\delta^*\beta^2}-\frac{1}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\frac{\partial\delta^*}{\partial\beta},$$
$$\frac{\partial\tau(\delta^*)}{\partial\delta^*}=-\frac{1}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right)<0.$$

It follows that $\frac{\partial\delta^*}{\partial\alpha}>0$, $\frac{\partial\delta^*}{\partial\mathcal{L}}>0$, $\frac{\partial\delta^*}{\partial\beta}<0$, and $\frac{\partial\delta^*}{\partial\gamma_f}<0$. □

Proof of Proposition 3

Substituting $\gamma=\frac{1-k(\delta)}{k(\delta)(\beta-1)-(\alpha-1)}$ into the objective of the regulator, we can rewrite (P) as

$$\max_\delta \Sigma_b(\delta)\equiv(q\alpha+(1-q)(F(\tau(\delta))\mathcal{L}+k(\delta)\beta)-1)\frac{1-k(\delta)}{k(\delta)(\beta-1)-(\alpha-1)}E.$$

Taking the first-order condition with respect to δ,

$$\begin{aligned}&(k(\delta)(\beta-1)-(\alpha-1))\big(-k'(\delta)(q\alpha+(1-q)(F(\tau(\delta))\mathcal{L}+k(\delta)\beta)-1)+(1-k(\delta))\big((1-q)\big(f(\tau(\delta))\mathcal{L}\tau'(\delta)+k'(\delta)\beta\big)\big)\big)\\&-(\beta-1)k'(\delta)(q\alpha+(1-q)(F(\tau(\delta))\mathcal{L}+k(\delta)\beta)-1)(1-k(\delta))=0,\end{aligned}$$

which is equivalent to

$$\begin{aligned}&-(\beta-\alpha)(q\alpha+(1-q)(F(\tau(\delta))\mathcal{L}+k(\delta)\beta)-1)k'(\delta)\\&\quad+(k(\delta)(\beta-1)-(\alpha-1))(1-k(\delta))(1-q)\big(f(\tau(\delta))\tau'(\delta)\mathcal{L}+k'(\delta)\beta\big)=0.\end{aligned}\tag{5.6}$$

Defining the function $H(\delta)$ as the left-hand side of (5.6), we can rewrite the first-order condition as $H(\delta)=0$.

Let us derive the conditions under which $H(1)<0$, or equivalently, the conditions under which $\delta^*<1$. Evaluating the first-order condition at $\delta=1$,

$$\begin{aligned}H(1)=&-\left(q\alpha+(1-q)\left(F\left(\frac{\mathcal{L}}{\beta}\right)\mathcal{L}+k(1)\beta\right)-1\right)(\beta-\alpha)\left(\int_{\frac{\mathcal{L}}{\beta}}^1(p-p_m)f(p)dp-\frac{\mathcal{L}}{\beta}\tau'(1)f\left(\frac{\mathcal{L}}{\beta}\right)\right)\\&+(k(1)(\beta-1)-(\alpha-1))(1-k(1))(1-q)\int_{\frac{\mathcal{L}}{\beta}}^1(p-p_m)f(p)dp\beta.\end{aligned}$$

Full precision $\delta^*=1$ cannot be a solution to (P) if $H(1)<0$. Hence, if $k(1)(\beta-1)-(\alpha-1)$ is sufficiently small, we have $H(1)<0$. Further, it is readily seen that $H(1)$ is decreasing in q. Hence, we have $H(1)<0$ if q is sufficiently large. Finally,

$$
\begin{aligned}
\frac{\partial H(1)}{\partial \mathcal{L}} &= -(\beta-\alpha)\big(q\alpha+(1-q)(F(\tau(1))\mathcal{L}+k(1)\beta)-1\big) \\
&\quad \times\left[-\big(\tau(1)-p_m\big)f(\tau(1))\frac{1}{\beta}+\left(\frac{f'(\tau(1))}{\beta}\frac{\mathcal{L}}{\beta}\left(\frac{\mathcal{L}}{\beta}-p_m\right)+f(\tau(1))\left(2\frac{\mathcal{L}}{\beta^2}-\frac{p_m}{\beta}\right)\right)\right] \\
&\quad -(\beta-\alpha)\left(\int_{\tau(1)}^{1}(p-p_m)f(p)dp+f(\tau(1))\frac{\mathcal{L}}{\beta}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\right) \\
&\quad \times\left[(1-q)F(\tau(1))+(1-q)\frac{\mathcal{L}f(\tau(1))}{\beta}-(1-q)\beta\tau(1)\frac{f(\tau(1))}{\beta}\right] \\
&\quad -\tau(1)\frac{f(\tau(1))}{\beta}\big((\beta-1)+(\alpha-1)-2k(1)(\beta-1)\big)(1-q)\beta\int_{\tau(1)}^{1}(p-p_m)f(p)dp \\
&\quad -\big(k(1)(\beta-1)-(\alpha-1)\big)(1-k(1))(1-q)\beta\big(\tau(1)-p_m\big)\frac{f(\tau(1))}{\beta}.
\end{aligned}
$$

Hence, if $(\beta-1)+(\alpha-1)-2k(1)(\beta-1)=(\beta-1)+(\alpha-1)-2\int_{\frac{\mathcal{L}}{\beta}}^{1}pf(p)dp(\beta-1)\geq 0$ and $f'\left(\frac{\mathcal{L}}{\beta}\right)\geq 0$ or $f'\left(\frac{\mathcal{L}}{\beta}\right)$ sufficiently close to 0, $H(1)$ is decreasing in $\mathcal{L}$; as a result, $H(1)<0$ if $\mathcal{L}$ is sufficiently large. □

Proof of Corollary 2

Given that δ^* maximizes Σ_b, it must $H'(\delta^*)\leq 0$. For comparative statics, we also need to assume that the *global* maximum is unique and regular $H'(\delta^*)\neq 0$, which is a generic condition and guaranteed if (P) is a convex program ($H'<0$). It then follows that the comparative static of δ^* in a variable x has the sign of $\partial H/\partial x$. First, we have

$$
\begin{aligned}
\frac{\partial H(\delta^*)}{\partial \alpha} &= -q(\beta-\alpha)k'(\delta^*)+(q\alpha+(1-q)\big(F(\tau(\delta^*))\mathcal{L}+k(\delta^*)\beta\big)-1)k'(\delta^*) \\
&\quad -(1-k(\delta^*)(1-q)\beta\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp.
\end{aligned}
$$

From (5.6),

$$
\begin{aligned}
H(\delta^*) &= -(\beta-\alpha)\big(q\alpha+(1-q)(F(\tau(\delta^*))\mathcal{L}+k(\delta^*)\beta)-1\big)k'(\delta^*) \\
&\quad +\big(k(\delta^*)(\beta-1)-(\alpha-1)\big)(1-k(\delta^*))\beta(1-q)\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp=0. \qquad (5.7)
\end{aligned}
$$

As a result,

$$
\begin{aligned}
\frac{\partial H(\delta^*)}{\partial \alpha} &= -q(\beta-\alpha)k'(\delta^*)+\frac{k(\delta^*)(\beta-1)-(\alpha-1)}{\beta-\alpha}(1-k(\delta^*))\beta(1-q)\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp \\
&\quad -(1-k(\delta^*)(1-q)\beta\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp \\
&= -q(\beta-\alpha)k'(\delta^*)-\frac{(\beta-1)(1-k(\delta^*))}{\beta-\alpha}(1-k(\delta^*))\beta(1-q)\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp<0.
\end{aligned}
$$

Next, let us derive the partial derivative of H with respect to $\mathcal{L}$.

$$\frac{\partial H(\delta^*)}{\partial \mathcal{L}} = -\overbrace{(\beta-\alpha)(q\alpha+(1-q)\big(F(\tau(\delta^*))\mathcal{L}+k(\delta^*)\beta\big)-1)}^{>0} \times \overbrace{\frac{1}{(\delta^*)^2}\left[\frac{f(\tau(\delta^*))}{\beta}\left(\frac{\mathcal{L}}{\beta}\right)+\left(\frac{f'(\tau(\delta^*))}{\delta^*\beta}\frac{\mathcal{L}}{\beta}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\right)\right]}^{\equiv\chi}$$
$$-\overbrace{(\beta-\alpha)\left(\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp+f(\tau(\delta^*))\frac{\mathcal{L}}{(\delta^*)^2\beta}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\right)}^{>0}$$
$$\times\overbrace{\left[(1-q)F(\tau(\delta^*))+(1-q)\frac{\mathcal{L}f(\tau(\delta^*))}{\delta^*\beta}-(1-q)\beta(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)\frac{f(\tau(\delta^*))}{\delta^*\beta}\right]}^{>0}$$
$$-\overbrace{(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)\frac{f(\tau(\delta^*))}{\delta^*\beta}((\beta-1)+(\alpha-1)-2k(\delta^*)(\beta-1))(1-q)\beta\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp}^{\equiv\zeta}$$
$$-\overbrace{(k(\delta^*)(\beta-1)-(\alpha-1))(1-k(\delta^*))(1-q)\beta(\tau(\delta^*)-p_m)\frac{f(\tau(\delta^*))}{\delta^*\beta}}^{>0}.$$

We are left to show that the two terms, χ and ζ, in the above expression are positive. If $(\beta-1)+(\alpha-1)-2k(1)(\beta-1) = (\beta-1)+(\alpha-1)-2\int_{\frac{\mathcal{L}}{\beta}}^{1}pf(p)dp(\beta-1)\geq 0$, the term ζ is readily shown to be positive. Similarly, if $f'\big(\tau(\delta^*)\big)\geq 0$ or $f'\big(\tau(\delta^*)\big)$ sufficiently close to 0, then the term χ is also positive. As a result, if $(\beta-1)+(\alpha-1)-2k(1)(\beta-1)\geq 0$ and $f'\big(\tau(\delta^*)\big)\geq 0$ or $f'\big(\tau(\delta^*)\big)$ sufficiently close to 0, then $\frac{\partial H(\delta^*)}{\partial \mathcal{L}}<0$.

We now derive the partial derivative of H with respect to q. We have

$$\frac{\partial H(\delta^*)}{\partial q} = -(\beta-\alpha)(q\alpha+(1-q)\big(F(\tau(\delta^*))\mathcal{L}+k(\delta^*)\beta\big)-1)$$
$$-(\beta-\alpha)(\alpha-(F(\tau(\delta^*))\mathcal{L}+k(\delta^*)\beta))k'(\delta^*)$$
$$-(k(\delta^*)(\beta-1)-(\alpha-1))(1-k(\delta^*))\beta\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp<0.$$

Next, we derive the comparative statics on the optimal capital requirement γ^*. Note that

$$\frac{\partial\tau(\delta^*)}{\partial\alpha} = -\frac{\frac{\partial\delta^*}{\partial\alpha}}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right).$$

As a result,

$$\frac{\partial k(\delta^*)}{\partial\alpha} = \frac{\partial\delta^*}{\partial\alpha}\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp+(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\left(\frac{\frac{\partial\delta^*}{\partial\alpha}}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\right).$$

Taking the derivative of $\gamma^* = \frac{1-k(\delta^*)}{k(\delta^*)(\beta-1)-(\alpha-1)}$ with respect to α yields

$$\frac{\partial\gamma^*}{\partial\alpha} = \frac{-\frac{\partial k(\delta^*)}{\partial\alpha}(k(\delta^*)(\beta-1)-(\alpha-1))-(1-k(\delta^*))\frac{\partial k(\delta^*)}{\partial\alpha}(\beta-1)}{(k(\delta^*)(\beta-1)-(\alpha-1))^2}.$$

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Hence, $\frac{\partial \delta^*}{\partial \alpha} < 0$ implies $\frac{\partial \gamma^*}{\partial \alpha} > 0$.

Second, note that

$$\frac{\partial \tau(\delta^*)}{\partial \mathcal{L}} = \frac{1}{\delta^* \beta} - \frac{\frac{\partial \delta_2^*}{\partial \mathcal{L}}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right).$$

It follows that

$$\frac{\partial k(\delta^*)}{\partial \mathcal{L}} = \frac{\partial \delta^*}{\partial \mathcal{L}} \int_{\tau(\delta^*)}^{1} (p - p_m) f(p) dp + (\delta^* \tau(\delta^*) + (1 - \delta^*) p_m) f(\tau(\delta^*)) \left(-\frac{1}{\delta^* \beta} + \frac{\frac{\partial \delta^*}{\partial \mathcal{L}}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right) \right).$$

Taking the derivative of $\gamma^* = \frac{1 - k(\delta^*)}{k(\delta^*)(\beta - 1) - (\alpha - 1)}$ with respect to $\mathcal{L}$ yields

$$\frac{\partial \gamma^*}{\partial \mathcal{L}} = \frac{-\frac{\partial k(\delta^*)}{\partial \mathcal{L}} (k(\delta^*)(\beta - 1) - (\alpha - 1)) - (1 - k(\delta^*)) \frac{\partial k(\delta^*)}{\partial \mathcal{L}} (\beta - 1)}{(k(\delta^*)(\beta - 1) - (\alpha - 1))^2}.$$

Hence, $\frac{\partial \delta^*}{\partial \mathcal{L}} < 0$ implies $\frac{\partial \gamma^*}{\partial \mathcal{L}} > 0$.

Third, note that

$$\frac{\partial \tau(\delta^*)}{\partial q} = -\frac{\frac{\partial \delta_2^*}{\partial q}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right),$$

implying

$$\frac{\partial k(\delta^*)}{\partial q} = \frac{\partial \delta^*}{\partial q} \int_{\tau(\delta^*)}^{1} (p - p_m) f(p) dp + (\delta^* \tau(\delta^*) + (1 - \delta^*) p_m) f(\tau(\delta^*)) \frac{\frac{\partial \delta^*}{\partial q}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right).$$

Taking the derivative of $\gamma^* = \frac{1 - k(\delta^*)}{k(\delta^*)(\beta - 1) - (\alpha - 1)}$ with respect to q yields

$$\frac{\partial \gamma^*}{\partial q} = \frac{-\frac{\partial k(\delta^*)}{\partial q} (k(\delta^*)(\beta - 1) - (\alpha - 1)) - (1 - k(\delta^*)) \frac{\partial k(\delta^*)}{\partial q} (\beta - 1))}{(k(\delta^*)(\beta - 1) - (\alpha - 1))^2}.$$

Hence, $\frac{\partial \delta^*}{\partial q} < 0$ implies $\frac{\partial k(\delta^*)}{\partial q} < 0$, which implies $\frac{\partial \gamma^*}{\partial q} > 0$.

Finally, we derive the comparative statics with respect to β. Note that

$$\frac{\partial \tau(\delta^*)}{\partial \beta} = -\frac{\mathcal{L}}{\delta^* \beta^2} - \frac{\frac{\partial \delta^*}{\partial \beta}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right),$$

so that

$$\frac{\partial k(\delta^*)}{\partial \beta} = \frac{\partial \delta^*}{\partial \beta} \int_{\tau(\delta^*)}^{1} (p - p_m) f(p) dp + (\delta^* \tau(\delta^*) + (1 - \delta^*) p_m) f(\tau(\delta^*)) \left(\frac{\mathcal{L}}{\delta^* \beta^2} + \frac{\frac{\partial \delta^*}{\partial \beta}}{(\delta^*)^2} \left(\frac{\mathcal{L}}{\beta} - p_m \right) \right). \tag{5.8}$$

Taking the derivative of $\gamma^* = \frac{1 - k(\delta^*)}{k(\delta^*)(\beta - 1) - (\alpha - 1)}$ with respect to β yields

$$\frac{\partial \gamma^*}{\partial \beta} = \frac{-\frac{\partial k(\delta^*)}{\partial \beta}(k(\delta^*)(\beta-1)-(\alpha-1))-(1-k(\delta^*))(k(\delta^*)+\frac{\partial k(\delta^*)}{\partial \beta}(\beta-1))}{(k(\delta^*)(\beta-1)-(\alpha-1))^2},$$

which is equivalent to

$$\frac{\partial \gamma^*}{\partial \beta} = -\frac{(1-k(\delta^*))k(\delta^*)+(\beta-\alpha)\frac{\partial k(\delta^*)}{\partial \beta}}{(k(\delta^*)(\beta-1)-(\alpha-1))^2}. \tag{5.9}$$

Note that $\frac{\partial \delta^*}{\partial \beta} > 0$ and (5.8) imply that $\frac{\partial k(\delta^*)}{\partial \beta} > 0$. Further, $\frac{\partial k(\delta^*)}{\partial \beta} > 0$ and (5.9) imply that $\frac{\partial \gamma^*}{\partial \beta} < 0$. Hence, $\frac{\partial \delta^*}{\partial \beta} > 0$ implies that $\frac{\partial \gamma^*}{\partial \beta} < 0$. Further, we know that the optimal capital requirement is given by

$$\frac{\gamma^*\alpha-(\gamma^*-1)}{\gamma^*\beta-(\gamma^*-1)} = k(\delta^*). \tag{5.10}$$

Taking the derivative of the left-hand side with respect to β yields

$$(\gamma^*\beta-(\gamma^*-1))\frac{(\alpha-1)\frac{\partial \gamma^*}{\partial \beta}}{(\gamma^*\beta-(\gamma^*-1))^2}-(\gamma^*\alpha-(\gamma^*-1))\frac{\gamma^*+(\beta-1)\frac{\partial \gamma^*}{\partial \beta}}{(\gamma^*\beta-(\gamma^*-1))^2}.$$

Suppose that $\frac{\partial \gamma^*}{\partial \beta} > 0$. This implies that the left-hand side of (5.10) decreases in β, which in turn implies that $k(\delta^*)$ decreases in β, which is equivalent to

$$\frac{\partial k(\delta^*)}{\partial \beta} = \frac{\partial \delta^*}{\partial \beta}\int_{\tau(\delta^*)}^{1}(p-p_m)f(p)dp+(\delta^*\tau(\delta^*)+(1-\delta^*)p_m)f(\tau(\delta^*))\left(\frac{\mathcal{L}}{\delta^*\beta^2}+\frac{\frac{\partial \delta^*}{\partial \beta}}{(\delta^*)^2}\left(\frac{\mathcal{L}}{\beta}-p_m\right)\right) < 0.$$

It follows that $\frac{\partial \delta^*}{\partial \beta} < 0$. Hence, $\frac{\partial \gamma^*}{\partial \beta} > 0$ implies that $\frac{\partial \delta^*}{\partial \beta} < 0$. □

APPENDIX B

TAR-2018-0705_Online Appendix: http://dx.doi.org/10.2308/TAR-2018-0705.s01