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Diego Moreno – Tuomas Takalo

Optimal bank transparency



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Optimal Bank Transparency*

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Abstract

Consider a competitive bank whose illiquid asset portfolio is funded by short-term debt that needs to be refinanced before the asset matures. In this setting, we show that maximal transparency is *not* socially optimal, and that the existence of social externalities of bank failures reduces further the optimal level of transparency. Moreover, asset risk taking decreases as the level of transparency decreases towards the socially optimal level. As for the sign of the impact of transparency on refinancing risk, it is negative given the asset's risk, but it is ambiguous if we account for its indirect effect via risk taking.

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1 Introduction

Since Louis D. Brandeis' article on Harper's Weekly (December 20, 1913), enhanced transparency is recurrently offered as a remedy for the problems of banking. Indeed, a reaction to the recent global financial crisis has been the creation of a new international banking regulatory framework (Basel III) that has as a key aim to strengthen banks' transparency and assure disclosure. However, the discussions on whether the results of banks' stress tests should be publicized, and on how stringent these tests should be, suggests that the case for increasing transparency is not clear-cut – see Landier and Thesmar 2011 for a survey of arguments in favor and against increasing disclosure of financial information. In this paper we provide an analysis of the impact of changes of the level of transparency on welfare, risk taking, and refinancing risk for a competitive banking sector.

Consider a competitive bank whose illiquid asset portfolio is funded by short-term debt supplied by risk-neutral creditors. The bank selects the level of asset risk and the credit contract it offers. Creditors decide whether or not to roll over their credit upon receiving a noisy signal of the probability that the asset will pay its return. The bank's asset portfolio is divisible and can be liquidated before maturity incurring a cost. We show that under some natural parameter restrictions, given the bank's asset risk choice the creditor's game has a unique equilibrium. We identify the level transparency with the precision of creditors signals of the probability that the bank's asset will yield its return. Our comparative static analysis shows that when the banking system is sufficiently transparent (i.e., when creditors' signals are sufficiently precise), further increasing the level of transparency reduces total welfare. Thus, maximal transparency is *not* socially optimal.

In our setting there is no conflict of interests between a bank and its creditors. Thus, one may argue against a need for regulating the level of transparency since competitive pressure should lead banks to select the socially optimal level. If there are social externalities (i.e., if a bank failure involves social costs beyond those imposed on the bank's creditors) which may recommend regulating the level of transparency, then we show that optimal regulation involves making banks more opaque rather than more transparent.

In addition, we show that banks' asset risk taking increases with the level of

transparency above and around its socially optimal level. The impact of changes in transparency on risk taking for levels of transparency sufficiently lower than the socially optimal, however, is ambiguous. As for the sign of the effect of changes in transparency on refinancing risk (i.e., on the probability that the bank will be able to refinance its short-term debt), it is negative for a given level of asset risk, but is ambiguous when we account for its indirect effect via risk taking.

A key element explaining our results is the existence of a negative externality that arises when some creditors withdraw their credit: the liquidation costs that must be assumed to pay back these creditors reduce the expected payoff of the creditors who roll over. Increasing transparency decreases the fraction of creditors' who mistakenly roll over as well as the fraction of those who mistakenly withdraw. Each of these two types of errors has opposite effects on the payoff of creditors who roll over, but the net impact is negative due to the externality. Therefore, given the level of risk, increasing transparency leads creditors to optimally raise their threshold to roll over, and consequently impedes banks' refinancing. Banks compensate this effect by increasing risk taking, thus promising higher returns to those creditors who roll over. These negative impacts of increasing transparency on welfare are counterbalanced by fostering (discouraging) efficient (inefficient) liquidation.

Our model shares some features with the classical bank-run model of Diamond and Dybvig (1983) and is hence related to the work in this tradition. Chari and Jaggannathan (1988), Calomiris and Kahn (1991), Chen (1999) and Chen and Hasan (2006), for example, study the role of creditors' information at an interim stage in generating information and panic-based bank runs, and observe it disciplining bank behavior. In this literature, as in our model, creditors observe an interim signal on the asset's return before they decide whether or not to roll over their credit, and withdrawals cause negative payoff externalities. We, too, find that enhanced transparency may decrease creditors' willingness to roll over, but in our setting banks may counter this effect by increasing risk taking. Another paper closely related to ours is Chen and Hasan (2008) who, akin to our results, show that increasing (decreasing) the precision of creditors' signal of the asset's return fosters efficient (inefficient) liquidation, and increases the likelihood of a bank run when prospects are poor. This paper, however, focuses on the Pareto dominant equilibrium, and neither studies the

socially optimal level of transparency, nor does it deal with banks' risk choice.

There is also a related literature on ex ante bank transparency initiated by Matutes and Vives (1996) and Cordella and Yeyati (1998). This literature studies the impact of information on creditors' lending decisions and, ultimately, on banks' risk choice. Blum (2002) shows that enhanced transparency may increase banks' risk taking if banks can adjust their asset portfolio after obtaining funding. While we model asset risk taking in a similar fashion as in these papers, we study the impact of interim transparency. We find that enhanced transparency may increase risk taking even if banks can commit to their asset portfolio choice.

Our paper also has a connection to the literature studying transparency regulation and financial market liquidity - see, e.g., Dang, Gorton, and Holmström (2009) and Pagano and Volpin (2010). While we do not model liquidity provision explicitly, we show that enhanced transparency has an adverse direct effect on banks' possibilities to roll over its short-term funding.

Since transparency hinges on incomplete information, and since banks are inherently vulnerable to self-fulfilling runs, theoretical models of bank transparency easily generate multiple equilibria, which often render comparative statics and welfare analyses inconclusive. While the literature on bank runs has been influential in pointing out the importance of creditors confidence and its dependence on creditors' expectations, it does not allow an assessment of how confidence relates to the level of creditors' information. Our result on uniqueness of equilibrium builds on the theory of global games, and is closely related to Morris and Shin (1998). Uniqueness of equilibrium allows us to explicitly compute the volume of credit roll over, facilitating comparative statics and welfare analyses exercises. In this respect, our paper relates to other papers that use global game methodology to study the problems of banking and lending such as Rochet and Vives (2004), Goldstein and Pauzner (2005), Huang (2011), and more closely to Morris and Shin (2006) who study the roll over decisions of government debt. While most of the papers in this literature deal with a binary action game, in our setting, similarly to Morris and Shin (2006), we have to deal with an agent (the bank) whose decisions (risk choice) affect the support of creditors' signals.

In the global game literature, the impact of the level of information on equilibrium

has been extensively studied. In a pioneering work, Morris and Shin (2002) study the value of public information in a setting reminiscent of a beauty contest, in which the payoff of an agent depends on how well the agent is able to guess the state and on the level of conformity. They provide conditions under which the social value of public information is negative. They conclude that the social value of public information is negative whenever its precision is low relative to the precision of agents' private information. In their model, the detrimental effect of public information arises from the coordination motive that drives agents' actions, which leads agents to overreact to public information. The significance and interpretation of Morris and Shin (2002)'s results has been debated by, among others, Angeletos and Pavan (2004), Hellwig (2005), and Svensson (2006). In particular, Angeletos and Pavan (2004) study a model where conformity plays no role and coordination is socially beneficial, and conclude that welfare unambiguously increases with the precision of public information.

We depart from these papers in that we study the impact of transparency by examining directly the effect on equilibrium of changes in the precision of agents' private signals, avoiding the complication of dealing with an additional noisy public signal, which given our distributional assumptions provides no interesting insights. In other words, we identify the level of transparency with the precision of creditors' private information. Alternative levels of transparency may result from specific regulation on how much information about their asset portfolios banks must disclose to their creditors. We may also interpret that bank transparency is affected by public disclosures, e.g. by the disclosure policy on banks' stress tests. Our results contrast with those of Angeletos and Pavan (2004) in that we find that welfare does not monotonically increase with transparency, even though in our setting, like in theirs, conformity does not play a role.

The paper is organized as follows. In Section 2 we layout the basic setting. In section 3 we describe the creditors' game. In section 4 we prove that creditors' game has a unique equilibrium, which we show is the solution to a simple equation. In Section 5 we study the impact of transparency given the asset risk. Section 6 studies the banks' risk choice. In Section 7 we extend our welfare analysis. The Appendix presents some calculations used to derive our results.

2 The Model

We consider a competitive bank whose illiquid asset portfolio is funded by short-term credit that needs to be refinanced. The bank's asset pays at maturity a return of $1 + R > 1$ with probability p and zero with probability $1 - p$, where p , the *probability of success*, is drawn from a uniform distribution on $[1 - \mu, 1]$. The parameter $\mu \in (0, 1)$ captures the level of risk of the asset: the larger μ the more likely it is that the asset pays no return. (Naturally, the asset's return R will generally depend on the level of risk μ . In this section we take μ , and therefore R , as given, but we endogenize the bank's choice of risk μ in Section 6.) Thus, the return of the asset is $(1 + R)p$, which is distributed uniformly on $[(1 - \mu)(1 + R), 1 + R]$. The mean return is

$$Q := E((1 + R)p) = (1 + R)E(p),$$

where

$$E(p) = 1 - \frac{\mu}{2}$$

is the mean probability of success. The bank's asset portfolio is divisible and can be liquidated before maturity: one unit of the asset liquidated before maturity yields λ monetary units. We assume that

$$Q > 1 > \lambda > 0, \tag{1}$$

which implies that liquidating the asset before maturity is both costly and ex-ante inefficient.

The bank has a continuum of creditors, whose measure is normalized to one, each of whom has one unit of uninsured credit. Creditors are risk neutral (i.e., they maximize expected returns). Hence, in contrast to many bank run models, in our setting risk-sharing is not an issue. A fraction $h > 0$ of creditors are *active* and may withdraw their credit before the asset matures. The remaining fraction of creditors, $1 - h$, maintain their unit of credit until the asset matures, and therefore play a passive role. Henceforth we refer to the active creditors simply as creditors when no confusion may arise. The assumption that only a fraction of creditors are active captures the fact that some of the bank's loans (e.g., long-term retail deposits) are stickier than others (e.g., wholesale funding from the overnight interbank market).

We assume that

$$h < \lambda, \tag{2}$$

which implies that the bank is always liquid, i.e., the bank does not fail even if all active creditors withdraw their credit. (The bank only fails when the realized return of the asset is zero.) Although the bank is always liquid, condition (1) implies that ex ante it is in a creditor's (and society's) interest to roll over. These simplifying assumptions allow for an analysis focused on the impact of transparency on risk taking, refinancing risk, and welfare.

Each creditor observes a noisy signal of the realized probability of success p ,

$$s_i = p + \epsilon_i,$$

where the noise terms ϵ_i are conditionally independently and uniformly distributed on $[-\epsilon, \epsilon]$, for some $\epsilon > 0$. Then all creditors simultaneously decide whether to *withdraw* or to *roll over* their credit. Note that although creditors information about the state differs, no creditor has superior information.

The timing of the game that active creditors face is as follows: (1) The bank offers a credit contract; (2) nature draws the success probability p from $[1 - \mu, 1]$; (3) each creditor observes a noisy signal s of the realized value of p , and then decides whether to withdraw or to roll over her credit; (4) the returns are realized and the creditors are compensated according to the credit contract.

3 The Creditors Game

In the creditors game, a strategy for a creditor is a mapping from the set of signals $[1 - \mu - \epsilon, 1 + \epsilon]$ into the set of actions {roll over, withdraw}. The payoff to a creditor depends on the state p , and the fraction of *all* creditors who withdraw, which we denote by $x \in [0, h]$. Following the tradition of Diamond and Dybvig (1983) we focus on contracts where each creditor gets at least her money back if she withdraws her credit, whereas a creditor who rolls over becomes a residual claimant; in equilibrium, competition forces the bank to promise to pay their money back exactly to the creditors who withdraw, as well as the entire asset's returns to the creditors

who roll over.¹ Thus, our assumption that $h < \lambda$ implies that the payoff to a creditor who withdraws is 1, whatever may be the state and the fraction of creditors who withdraw. (Note that a creditor who withdraws gets more than the liquidation value of her asset.) The payoff to a creditor who rolls over depends on p and x , and is given by

$$\begin{aligned} u(p, x) &= \frac{1 - x/\lambda}{1 - x} (1 + R) p \\ &= \frac{\lambda - x}{\lambda(1 - x)} (1 + R) p. \end{aligned} \tag{3}$$

Since $\lambda < 1$, then $\partial u(p, x)/\partial x < 0$ and $\partial^2 u(p, x)/\partial x^2 < 0$; that is, withdrawals cause a negative externality on those who roll over, and the size of this externality is increasing in the fraction of creditors who withdraw. Obviously, the payoff to rolling over increases with the probability of success, i.e., $\partial u(p, x)/\partial p > 0$. These properties play an important role in establishing our key results.

A profile of creditors' strategies may be described by a *strategy distribution* τ that for each signal $s \in [1 - \mu - \varepsilon, 1 + \varepsilon]$ provides the fraction of active creditors that withdraw their credit upon receiving the signal s , $\tau(s) \in [0, 1]$. Given a strategy distribution τ the fraction of all creditors who withdraw if the state is p is

$$x(p, \tau) = hE(\tau(s)|p), \tag{4}$$

and the *expected payoff* to a creditor who rolls over when her signal is s is

$$U(s, \tau) = E(u(\cdot, x(\cdot, \tau))|s),$$

where $p|s$ is the probability of success conditional on signal s , which is distributed uniformly on $[1 - \mu, 1] \cap [s - \varepsilon, s + \varepsilon] = [\max\{1 - \mu, s - \varepsilon\}, \min\{1, s + \varepsilon\}]$. Note that the upper and lower bounds of this interval are both increasing in s . Since $u(p, x)$ is continuous, then $U(s, \tau)$ is continuous. Also note that if $\tau, \hat{\tau}$ satisfy $\hat{\tau}(s) \geq \tau(s)$ for all s , then

$$x(p, \hat{\tau}) = hE(\hat{\tau}(s)|p) \geq hE(\tau(s)|p) = x(p, \tau)$$

¹Alternatively, we may reinterpret our model, in line with Rochet and Vives (2004), as if all the credit is initially at the banks, with a nominal value pre-determined and normalized to unity in case of a withdrawal. The banks then compete for renewals of these credits by offering rates of returns to the creditors who rollover.

for all $p \in [1 - \mu, 1]$, and therefore, since u is decreasing in x , we have

$$U(s, \hat{\tau}) \leq U(s, \tau).$$

A strategy distribution τ is an *equilibrium* of the creditors' game if for all $s \in [1 - \mu - \varepsilon, 1 + \varepsilon]$, $U(s, \tau) < 1$ implies $\tau(s) = 1$, and $U(s, \tau) > 1$ implies $\tau(s) = 0$; i.e., the strategy profile defining the strategy distribution τ is such that (almost) all active creditors follow an optimal strategy.

Under complete information, i.e., when creditors observe the probability of success with no error ($\varepsilon = 0$), since u is continuous and decreasing in x , if $u(1, h) > 1$ then for p near one we have

$$u(p, x) \geq u(p, h) > 1.$$

Hence in the subgames where p is near one, rolling over is a strictly dominant strategy and equilibrium is unique. Likewise, if $u(1 - \mu, 0) < 1$, then for p near $1 - \mu$ we have

$$u(p, x) \leq u(p, 0) < 1.$$

Hence in the subgames where p is near $1 - \mu$, withdrawing is dominant strategy and equilibrium is unique.² However, the subgames corresponding to intermediate values of p , i.e., values such that $u(p, h) < 1 < u(p, 0)$, a creditor's optimal action depends on the fraction of creditors who roll over, and therefore depending on which action creditors *coordinate on* different equilibria arise – e.g., there is an equilibrium in which all creditors coordinate on withdrawing, and another equilibrium in which all creditors coordinate on rolling over. This multiplicity of equilibrium arising from coordination is common in models of banking.

Under incomplete information (i.e., when $\varepsilon > 0$), the existence of *dominance* or *contagious regions* as those described above, in which a creditor's optimal behavior does not depend on the actions of the other creditors, implies uniqueness of equilibrium. We derive some natural parameter restrictions that guarantee the existence of these dominance regions.

The existence of an *upper dominance* region requires the existence of an interval of sufficiently high signals of the probability of success that a creditor's optimal action

²The inequalities $u(1 - \mu, 0) < 1 < u(1, h)$ are implied by conditions (5) and (7) below.

is to roll over her credit, even if all the other active creditors withdraw (i.e., $x = h$). Specifically, if the inequality

$$\frac{(\lambda - h)}{\lambda(1 - h)} (1 + R) (1 - \varepsilon) > 1 \quad (5)$$

holds, then the expected payoff to a creditor who rolls over when her signal is $s > 1 - \varepsilon$ is

$$\begin{aligned} E(u(\cdot, x) | s) &\geq E(u(\cdot, h) | s) \\ &= \frac{\lambda - h}{\lambda(1 - h)} (1 + R) E(p | s) \\ &\geq \frac{\lambda - h}{\lambda(1 - h)} (1 + R) (1 - \varepsilon) \\ &> 1; \end{aligned} \quad (6)$$

i.e., the expected payoff to rolling over is greater than the expected payoff to withdrawing regardless of what the other active creditors do. Hence a creditor getting a signal $s > 1 - \varepsilon$ rolls over. Since $Q > 1$ implies that $1 + R > 1$, the inequality (5) holds when ε is small and λh is sufficiently close h . The difference $\lambda h - h$ is the maximum (negative) externality of withdrawals on the payoff of the creditors who roll over, which is smaller the closer is λ (resp. h) to one (resp. zero).³

The existence of a *lower dominance* region requires that there be an interval of sufficiently low signals of the probability of success that a creditor's optimal action is to withdraw even if everyone else rolls over (i.e., $x = 0$). Specifically, if the inequality

$$(1 + R) (1 - \mu + \varepsilon) < 1 \quad (7)$$

holds, then the expected payoff to a creditor who rolls over when her signal is $s < 1 - \mu + \varepsilon$ is

$$\begin{aligned} E(u(\cdot, x) | s) &\leq E(u(\cdot, 0) | s) \\ &= (1 + R) E(p | s) \\ &\leq (1 + R) (1 - \mu + \varepsilon) \\ &< 1; \end{aligned} \quad (8)$$

³As is clear from condition (5), assumption (2) is needed for the existence of the upper dominance region. For the same reason, Goldstein and Pauzner (2005) assume that premature liquidations do not reduce asset returns and Huang (2011) assumes suspension of convertibility.

i.e., the expected payoff to withdrawing is greater than the expected payoff to rolling over regardless of what the other active creditors do. Hence a creditor getting a signal $s < 1 - \mu + \varepsilon$ withdraws. In essence, (7) implies that the return distribution must have a sufficiently wide support to allow for net-present values below 1 even though the ex-ante expected return of the asset is above 1.

Henceforth we assume that

$$\varepsilon < \bar{\varepsilon} := \min \left\{ \frac{1}{1+R} - (1-\mu), 1 - \frac{\lambda(1-h)}{(1+R)(\lambda-h)} \right\}. \quad (9)$$

This inequality warrants that conditions (5) and (7) hold. We show that under this assumption the creditors' game has a unique equilibrium.

4 Equilibrium of the Creditors Game

A simple class of strategies is that of *switching* strategies, whereby a creditor withdraws if her signal is below a *threshold* $t \in [1 - \mu - \varepsilon, 1 + \varepsilon]$, and rolls over otherwise. When all creditors follow the same switching strategy identified by a threshold t , then we denote by τ_t the resulting strategy distribution, which is given by $\tau_t(s) = 1$ if $s < t$, and $\tau_t(s) = 0$ otherwise. Also we write $V(s, t) := U(s, \tau_t)$. Since $\tau_{\hat{t}}(s) \geq \tau_t(s)$ whenever $\hat{t} \geq t$, then $V(s, t)$ is decreasing in t . Moreover, since τ_t is decreasing in s , then $x(s, \tau_t)$ is decreasing in s , and therefore the payoff to rolling over, $u(s, x(s, \tau_t))$, is increasing in s ; hence $V(s, t)$ is increasing in s . We establish below that $V(t, t)$ (i.e., the restriction of V to the diagonal) is strictly increasing on the interval $[1 - \mu + \varepsilon, 1 - \varepsilon]$. Note that the inequalities (1) and (7) jointly imply that

$$(1+R)(1-\mu+\varepsilon) < 1 < Q = (1+R)(1-\mu/2),$$

i.e.,

$$2\varepsilon < \mu.$$

Hence $1 - \mu + \varepsilon < 1 - \varepsilon$, so that the interval $[1 - \mu + \varepsilon, 1 - \varepsilon]$ is non-empty.

For $t \geq 1 - \varepsilon$ the inequality (6) implies

$$V(t, t) = E(u(\cdot, x(\cdot, \tau_t)) | t) > 1.$$

Likewise, for $t \leq 1 - \mu + \varepsilon$ the inequality (8) implies

$$V(t, t) = E(u(\cdot, x(\cdot, \tau_t)) | t) < 1.$$

Hence there is a unique $t^* \in (1 - \mu + \varepsilon, 1 - \varepsilon)$ such that $V(t^*, t^*) = 1$. Moreover, the strategy distribution τ_{t^*} is an equilibrium: Since V is increasing in s , if

$$V(s, t^*) = U(s, \tau_{t^*}) < 1 = V(t^*, t^*),$$

then $s < t^*$, and therefore $\tau_{t^*}(s) = 1$; and if

$$V(s, t^*) = U(s, \tau_{t^*}) > 1 = V(t^*, t^*),$$

then $s > t^*$ and $\tau_{t^*}(s) = 0$. We establish that in fact τ_{t^*} is the unique equilibrium of the creditors' game.

Proposition 1. *The creditors' game has a unique equilibrium. Moreover, in equilibrium all creditors follow the threshold strategy τ_{t^*} , where $t^* \in (1 - \mu + \varepsilon, 1 - \varepsilon)$ is the unique solution to the equation $V(t, t) = 1$.*

Proof. The proof follows the lines of Morris and Shin (1998)'s Lemma 3. Assume that τ is an equilibrium strategy distribution, and define

$$\underline{s} := \inf\{s \mid \tau(s) < 1\},$$

and

$$\bar{s} := \sup\{s \mid \tau(s) > 0\}.$$

Then

$$\bar{s} \geq \sup\{s \mid 0 < \tau(s) < 1\} \geq \inf\{s \mid 0 < \tau(s) < 1\} \geq \underline{s}.$$

Since τ is an equilibrium and U is continuous, then

$$U(\underline{s}, \tau) \geq 1 \geq U(\bar{s}, \tau).$$

Consider the strategy distribution $\tau_{\underline{s}}$. We have $\tau(s) \geq \tau_{\underline{s}}(s)$ for all s , and therefore

$$V(\underline{s}, \underline{s}) = U(\underline{s}, \tau_{\underline{s}}) \geq U(\underline{s}, \tau) \geq 1 = V(t^*, t^*).$$

Since $V(t, t)$ is increasing, then $t^* \leq \underline{s}$.

Likewise, consider the strategy distribution $\tau_{\bar{s}}$. We have $\tau_{\bar{s}}(s) \geq \tau(s)$ for all s , and therefore

$$V(\bar{s}, \bar{s}) = U(\bar{s}, \tau_{\bar{s}}) \leq U(\bar{s}, \tau) \leq 1 = V(t^*, t^*).$$

Since $V(t, t)$ is increasing, then $\bar{s} \leq t^*$.

Thus, $\bar{s} = \underline{s} = t^*$, and therefore $\tau(s) = \tau_{t^*}(s)$ for all s . \square

By Proposition 1, in equilibrium all creditors follow the same threshold strategy. Moreover, the equilibrium threshold belongs to the interval $[1 - \mu + \varepsilon, 1 - \varepsilon]$ and solves the equation $V(t, t) = 1$. We calculate the function $V(s, t)$. When all active creditors follow the threshold strategy $t \in [1 - \mu + \varepsilon, 1 - \varepsilon]$, then the expected fraction of active creditors who withdraw $E(\tau_t(s)|p)$ is zero if $p \in [t + \varepsilon, 1]$, it is one if $p \in [1 - \mu, t - \varepsilon]$, and it is

$$\frac{1}{2\varepsilon} \int_{p-\varepsilon}^t ds = \frac{1}{2\varepsilon} (t - p + \varepsilon),$$

for intermediate values $p \in (t - \varepsilon, t + \varepsilon)$. Hence, using equation (4) we can calculate the expected fraction of all creditors who withdraw as

$$x(p, \tau_t) = \begin{cases} 0 & \text{if } p \in [t + \varepsilon, 1], \\ \frac{h}{2\varepsilon} (t - p + \varepsilon) & \text{if } p \in (t - \varepsilon, t + \varepsilon), \\ h & \text{if } p \in [1 - \mu, t - \varepsilon]. \end{cases} \quad (10)$$

If a creditor signal is $s \in [1 - \mu + \varepsilon, 1 - \varepsilon]$, then $p|s$ is distributed uniformly on $[s - \varepsilon, s + \varepsilon]$, and her expected payoff if she rolls over is

$$V(s, t) = \frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} u(p, x(p, \tau_t)) dp,$$

which can be rewritten using (3) as

$$V(s, t) = \frac{1 + R}{\lambda} \left(\frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} pdp - (1 - \lambda) \int_{s-\varepsilon}^{s+\varepsilon} \frac{pdp}{2\varepsilon(1 - x(p, \tau_t))} \right). \quad (11)$$

Evaluating the integrals in this expression, and setting a creditor's signal equal to the threshold t , we obtain the function $V(t, t)$. This is a tedious task that we relegate to the Appendix. There we show that for $t \in (1 - \mu + \varepsilon, 1 - \varepsilon)$ we have

$$V(t, t) = \frac{1 + R}{\lambda h} (\beta t + \alpha \varepsilon), \quad (12)$$

where

$$\alpha := -\frac{(1-\lambda)}{h} [2h + (2-h) \ln(1-h)],$$

and

$$\beta := h + (1-\lambda) \ln(1-h).$$

In the Appendix we also show that $\alpha > 0$ and $h > \beta > 0$. Hence,

$$\frac{dV(t,t)}{dt} = \frac{1+R}{\lambda h} \beta > 0,$$

i.e., $V(t,t)$ is strictly increasing in t .

The *equilibrium threshold* t^* solves $V(t,t) = 1$; i.e.,

$$t^* = \frac{1}{\beta} \left(\frac{\lambda h}{1+R} - \alpha \varepsilon \right). \quad (13)$$

The ex-ante expected fraction of creditors who withdraw is

$$\begin{aligned} E(x(\cdot, \tau_t)) &= \frac{1}{\mu} \int_{1-\mu}^1 x(p, \tau_t) dp \\ &= \frac{1}{\mu} \left(\int_{1-\mu}^{t-\varepsilon} x(p, \tau_t) dp + \int_{t-\varepsilon}^{t+\varepsilon} x(p, \tau_t) dp + \int_{t+\varepsilon}^1 x(p, \tau_t) dp \right). \end{aligned}$$

Since $t^* \in (1-\mu+\varepsilon, 1-\varepsilon)$, using equations (10) we calculate the equilibrium ex-ante expected fraction of creditors who withdraw,

$$x^* = E(x(\cdot, \tau_{t^*})) = \frac{h}{\mu} (t^* - (1-\mu)). \quad (14)$$

Note that $x^* \in (h\varepsilon/\mu, h(\mu-\varepsilon)/\mu)$.⁴ Proposition 2 below states these results.

Proposition 2. *The equilibrium threshold is $t^* = (\lambda h/(1+R) - \alpha \varepsilon)/\beta$ and the ex-ante expected fraction of creditors who withdraw is $x^* = h(t^* - (1-\mu))/\mu$, where $\alpha = -(1-\lambda)[2h + (2-h) \ln(1-h)]/h > 0$ and $\beta = h + (1-\lambda) \ln(1-h) > 0$.*

⁴Following Goldstein and Pauzner (2005), $(t^* - (1-\mu))/\mu = 1 - (1-t^*)/\mu$ may be interpreted as the ex ante limiting probability of a bank run (as $\varepsilon \rightarrow 0$). With this interpretation, x^* is the fraction of active creditors times the probability that an agent runs on the bank.

5 The Effects of Transparency Given Asset Risk

In this section we study the effect of transparency on *refinancing risk* (i.e., on the ex ante expected fraction of creditors who withdraw x^*), and on *welfare*. In this first pass, we continue treating the level of asset risk μ as exogenous, focusing on the effect of transparency on banks' liabilities.

Changes in the level of transparency may be associated with the release of public information regarding banks' asset portfolios. The literature has studied the impact on equilibrium outcomes of the introduction of a noisy public signal. Notably, in a beauty contest setup in which the payoff of an agent depends on how well the agent is able to guess the state and on the level of conformity of her guess and the guesses of the other agents, Morris and Shin (2002) show that if the precision of the public signal relative to that of the agents' private signals is below (above) a threshold, then public information has a negative (positive) effect on welfare. Angeletos and Pavan (2004) show, however, that if conformity plays no role and coordination is socially beneficial, then it is the overall precision of agents information that influences the agents' actions and determines the equilibrium outcome, and conclude that public information always has a beneficial effect.

We identify the level of transparency with the precision of creditors' private signals of the probability of success, i.e., with the value of ε . Smaller values of ε correspond to greater levels of transparency, and vice versa. What we have in mind is that alternative levels of transparency may result from regulating how much information about asset portfolios banks must disclose to their creditors. Such disclosures need not be public, but privately communicated to the creditors. Our approach allows studying the impact of changes in transparency via comparative static analysis, avoiding the complication of adding an additional noisy public signal. Nevertheless, given our distributional assumptions, the introduction of a public signal whose distribution is also uniform and independent of the creditors private signal, e.g., the disclosure of the results of banks' stress tests, would have an impact on equilibrium akin to that of a discrete increase on the precision of creditors' signals, and therefore provide no additional insights. For simplicity, we assume that changes in ε have no impact on bank's costs – see Landier and Thesmar 2011 for a description of the costs of transparency, and Hyytinen and Takalo 2002 for an analysis of their implications for

bank stability.

In order to evaluate the impact of ε on refinancing risk (i.e., on x^*), it is first instructive to study the impact of ε on the fraction of creditors who withdraw for a given p . Taking derivatives in equation (10) makes it clear that the sign of $\partial x(p, \tau_t)/\partial \varepsilon$ is the same as that of $(p - t)$; that is, the fraction of creditors who withdraw increases with the level of transparency (i.e., as ε becomes smaller) when the probability of success is high relative to the threshold for withdrawal (i.e., $p > t$), and vice versa. This is intuitive: as ε decreases, choosing the optimal action becomes more likely; that is, a creditor is more likely to roll over (withdraw) when the true value of p is above (below) the threshold t . In this sense, increasing transparency has *procyclical* effects, facilitating refinancing when the prospects of getting the asset returns are good, but impeding refinancing when they are bad.

The effect of transparency on refinancing risk *through the cycle* is given by the derivative $\partial x^*/\partial \varepsilon$. Equation (14) makes it clear that x^* depends on ε only indirectly through t^* . Taking derivatives in (13) we get

$$\frac{\partial t^*}{\partial \varepsilon} = -\frac{\alpha}{\beta} < 0.$$

Hence the equilibrium threshold t^* increases with the level of transparency; i.e., the more precise are the creditors' signals (i.e., the smaller is ε), the larger is the creditors' equilibrium threshold. Taking derivatives in (14) we get

$$\frac{\partial x^*}{\partial \varepsilon} = \frac{h}{\mu} \frac{\partial t^*}{\partial \varepsilon} < 0.$$

Hence the ex ante expected fraction of creditors who withdraw increases with the level of transparency; i.e., the more precise are the creditors' signals (i.e., the smaller is ε), the larger is refinancing risk x^* . We state this result in Proposition 3 below.

Proposition 3. *Given the level of asset risk μ , increasing the level of transparency (i.e., decreasing ε) increases refinancing risk (i.e., increases x^*).*

Proposition 3 is a direct implication of the fact that $V(t, t)$ is increasing in ε – see (12). The intuition of this property is as follows: As discussed above, for a given p the effects of increasing transparency (i.e., decreasing ε) on the fraction of creditors who withdraw $x(p, \tau_t)$ are procyclical, i.e., x decreases when $p > t$ and increases

when $p < t$. Hence its effects on $u(p, x)$ are countercyclical, i.e., if ε decreases, then u increases when $p > t$ and decreases when $p < t$. That is, increasing transparency has a negative (positive) impact on the expected payoff of a creditor who rolls over since it decreases the fraction of creditors' who *mistakenly* roll over (withdraw). Nevertheless, the externality of withdrawals on the payoff of creditors who roll over (which arises because liquidations are costly, i.e., $\lambda < 1$) makes the negative effect more pronounced than the positive effect, so that the net effect is negative. (Mathematically, this result hinges on the fact that $\lambda < 1$ implies $\partial u(p, x)/\partial x < 0$ and $\partial u(p, x)/\partial x^2 < 0$.) Hence a decrease of ε prompts the creditors to optimally raise their threshold to roll over their credit.

The equilibrium fraction of creditors who roll over, $1 - x^*$, may also be interpreted as a measure of creditors' *confidence* on banks. By Proposition 3, increasing transparency has a negative effect on creditors' confidence. The comparative statics of creditors' confidence with respect to other exogenous parameters, such as λ and h , are complex. However, it is straightforward to show that $\partial^2 x^*/\partial \varepsilon \partial \lambda > 0$; i.e., the larger the liquidation value of the asset, the smaller is the negative impact of transparency on creditors' confidence. This again hinges on the (absolute) value of the derivative $\partial^2 u(p, x)/\partial x^2$, which is proportional to $(1 - \lambda)$.

Let us now study the impact of transparency on welfare given the asset's risk. Since competitive banks promise the full asset returns to creditors, social welfare W is simply the creditors' ex-ante expected payoffs, and is therefore given by

$$\begin{aligned} W(\varepsilon, \mu) &= E \left[x(p, \tau_{t^*}) + \left(1 - \frac{x(p, \tau_{t^*})}{\lambda} \right) (1 + R)p \right] \\ &= x^* + (1 + R) \left(E(p) - \frac{E(x(p, \tau_{t^*})p)}{\lambda} \right). \end{aligned} \quad (15)$$

Here $x(p, \tau_{t^*})$ is the total payoff to the creditors who withdraw and get their monetary unit, and $(1 - x(p, \tau_{t^*})/\lambda)(1 + R)p$ is the returns of the non-liquidated assets, which is also the total payoff to the creditors who roll over.

For $t \in [1 - \mu + \varepsilon, 1 - \varepsilon]$, using (10) we have

$$\begin{aligned}
E[x(p, \tau_t)p] &= \frac{1}{\mu} \int_{1-\mu}^1 x(p, \tau_t) p dp \\
&= \frac{h}{\mu} \int_{1-\mu}^{t-\varepsilon} p dp + \frac{h}{2\mu\varepsilon} \int_{t-\varepsilon}^{t+\varepsilon} (t - p + \varepsilon) p dp \\
&= \frac{h}{6\mu} (3t^2 + \varepsilon^2 - 3(1 - \mu)^2).
\end{aligned}$$

Thus, using (14) and $E(p) = 1 - \mu/2$ we may write (15) as

$$W(\varepsilon, \mu) = \frac{h}{\mu} (t^* - (1 - \mu)) + (1 + R) \left(1 - \frac{\mu}{2} - \frac{h}{6\lambda\mu} (3t^{*2} + \varepsilon^2 - 3(1 - \mu)^2) \right).$$

Since t^* is linear in ε , then W is a quadratic function of the level of transparency ε .

We have

$$\begin{aligned}
\frac{\partial W}{\partial \varepsilon} &= \frac{h}{\mu} \left(1 - \frac{(1 + R)}{\lambda} t^* \right) \frac{\partial t^*}{\partial \varepsilon} - \frac{(1 + R)h\varepsilon}{3\lambda\mu} \\
&= -\frac{h}{\mu} \left(1 - \frac{h}{\beta} + \frac{(1 + R)}{\lambda\beta} \alpha \varepsilon \right) \frac{\alpha}{\beta} - \frac{(1 + R)h\varepsilon}{3\lambda\mu} \\
&= \frac{h}{\mu} (a - b\varepsilon),
\end{aligned} \tag{16}$$

where

$$a = \frac{(h - \beta)\alpha}{\beta^2},$$

and

$$b = \frac{(1 + R)}{\lambda} \left(\frac{\alpha^2}{\beta^2} + \frac{1}{3} \right) > 0.$$

Also we have

$$\frac{\partial^2 W}{\partial \varepsilon^2} = -\frac{hb}{\mu} < 0.$$

Since $0 < \beta < h$ and $\alpha > 0$, then $a > 0$. Hence $\partial W/\partial \varepsilon > 0$ (i.e., W is increasing) when ε is smaller than a/b . In particular, $\partial W/\partial \varepsilon > 0$ if $\varepsilon = 0$. And $\partial W/\partial \varepsilon < 0$ (i.e., W is decreasing) for ε larger than a/b . That is, when creditors' signals are very noisy, social welfare increases with the level of transparency. When creditors' signals are very precise, however, social welfare decreases with the level of transparency. Hence maximal transparency is not socially optimal.

We summarize these findings in Proposition 4 below.

Proposition 4. *Given the level of asset risk μ , social welfare decreases with the level of transparency when the level of transparency is high, but increases when it is low, i.e., $\partial W/\partial \varepsilon \gtrless 0$ when $\varepsilon \lesseqgtr a/b$. Thus, maximal transparency is not socially optimal.*

Even though increasing transparency impedes refinancing of banks' liabilities by Proposition 3, its impact on welfare is counterbalanced by reducing creditors' mistakes, which are costly for individual creditors and, when they lead to inefficient liquidation, involve negative externalities. In addition, increasing transparency fosters efficient liquidations when the realized value of p is very low, i.e., when $p \leq \lambda/(1+R)$. These counterbalancing effects favor an intermediate level of transparency $\varepsilon^* = a/b$, provided that it is feasible (i.e., $a/b < \bar{\varepsilon}$ as given by condition (9)).

Proposition 4 implies that if $a/b > \bar{\varepsilon}$, social welfare decreases with transparency on $(0, \bar{\varepsilon})$. (Recall that $\varepsilon \in (0, \bar{\varepsilon})$ by assumption.) Thus, the optimal level of transparency may be the minimal feasible level. Note the role of the restriction on the value ε in guaranteeing uniqueness of equilibrium. If ε were above $\bar{\varepsilon}$, multiple equilibria arise, and the banking system becomes vulnerable to self-fulfilling crises. In the literature, this rational has suggested regulation to warrant a sufficiently high level of transparency to prevent these self-fulfilling crises from arising – see, e.g., Rochet and Vives (2004). In our setup, this argument may favor a more transparent banking system than that implied by $\varepsilon = a/b$, since the latter may be efficient but vulnerable to self-fulfilling crises; that is, this argument suggests that the socially optimal level of transparency is $\varepsilon^* = \min\{a/b, \bar{\varepsilon}\} > 0$.

Summarizing, the socially optimal level of transparency is below the maximal, and may be the minimal level that guarantees that self-fulfilling crises do not arise.

6 Asset Risk Taking

In order to endogenize asset risk, we assume that banks choose the level of risk μ , which together with all the other aspects of the credit contract offered becomes common knowledge. Competition then forces banks to choose the level of asset risk μ that maximizes the creditors' welfare, in addition to paying the full asset returns to the creditors who roll over.

Let us write the asset's return conditional on success, as well as the mean asset

return, explicitly as a function of μ ; i.e.,

$$Q(\mu) = (1 + R(\mu)) E(p(\mu)).$$

Note that the expected probability of success, $E(p(\mu)) = 1 - \mu/2$, decreases with μ .

We assume that the mean asset return is non-decreasing with the level of risk, i.e.,

$$Q'(\mu) \geq 0.$$

Hence

$$R'(\mu) \geq \frac{1 + R(\mu)}{2 - \mu} > 0,$$

i.e., the return conditional on success is strictly increasing with the level of risk.⁵

Recall that our proof of existence and uniqueness of equilibrium given the level of risk involves the condition $\varepsilon < \bar{\varepsilon}$, where $\bar{\varepsilon}$ is given by condition (9), which shows how $\bar{\varepsilon}$ depends on the level of risk μ both directly and via the return function R . In order to guarantee existence and uniqueness of equilibrium for all $\mu \in [\underline{\mu}, \bar{\mu}]$, where $\underline{\mu} > 0$ and $\bar{\mu} < 1$ are the minimum and maximum levels of asset risk available, respectively, we assume that

$$\varepsilon < \min_{\mu \in [\underline{\mu}, \bar{\mu}]} \bar{\varepsilon}(\mu). \quad (17)$$

In equilibrium μ^* solves the problem

$$\max_{\mu \in [\underline{\mu}, \bar{\mu}]} W(\varepsilon, \mu).$$

We proceed under the assumption that the solution to this problem is interior, i.e., we assume that the banks' asset risk choice $\mu^* \in (\underline{\mu}, \bar{\mu})$ solves the equation

$$\frac{\partial W}{\partial \mu} = 0,$$

and that W satisfies the the second order sufficient condition for welfare maximization

$$\frac{\partial^2 W}{\partial \mu^2} \leq 0. \quad (18)$$

Note that if μ^* is a corner solution, then transparency has no impact on the banks' asset risk choice.

⁵If Q is a mean-preserving spread, i.e., $Q'(\mu) = 0$, a case often studied in the literature, e.g., Matutes and Vives (1996), Cordella and Yeyati (1998), then $R'(\mu) = (1 + R(\mu)) / (2 - \mu) > 0$.

Let us consider the impact of transparency on the level of risk chosen by banks. Since in an interior equilibrium the level of asset risk μ^* solves $\partial W/\partial \mu = 0$, we have

$$\frac{\partial W^2}{\partial \mu^2} d\mu + \frac{\partial W^2}{\partial \mu \partial \varepsilon} d\varepsilon = 0,$$

and therefore

$$\frac{d\mu^*}{d\varepsilon} = \frac{\partial W^2}{\partial \mu \partial \varepsilon} \left(-\frac{\partial W^2}{\partial \mu^2} \right)^{-1}.$$

Moreover, since $\partial^2 W/\partial \mu^2 < 0$, then

$$\text{sign} \left(\frac{d\mu^*}{d\varepsilon} \right) = \text{sign} \left(\frac{\partial W^2}{\partial \mu \partial \varepsilon} \right).$$

By Young's theorem, we have

$$\frac{\partial W^2}{\partial \mu \partial \varepsilon} = \frac{\partial W^2}{\partial \varepsilon \partial \mu}.$$

Differentiating (16) with respect to μ we get

$$\begin{aligned} \frac{\partial W^2}{\partial \varepsilon \partial \mu} &= -\frac{h}{\mu^2} (a - b\varepsilon) - \frac{h\varepsilon}{\mu} \frac{\partial b}{\partial \mu} \\ &= -\frac{h}{\mu^2} (a - b\varepsilon) - \frac{h\varepsilon}{\mu} \frac{R'}{\lambda} \left(\frac{\alpha^2}{\beta^2} + \frac{1}{3} \right). \end{aligned} \quad (19)$$

Since $R' > 0$, then the second term on the RHS of (19) is negative. As for the first term, it is negative for $\varepsilon < a/b$, and it is positive for $\varepsilon > a/b$. Thus, if $\varepsilon \leq a/b$, then $\partial W^2/\partial \varepsilon \partial \mu < 0$, whereas if $\varepsilon > a/b$, then the sign $\partial W^2/\partial \varepsilon \partial \mu$ is ambiguous.

Therefore if the level of transparency decreases towards the socially optimal level, i.e., if ε approaches a/b from below, then risk taking increases; i.e., $d\mu^*/d\varepsilon < 0$ on $(0, a/b]$. In particular, if ε is around its optimal value of a/b , then risk taking increases with the level of transparency. However, if ε is well above its optimal value (assuming such levels are feasible, i.e. condition (17) is not violated), then the impact of increasing transparency towards the socially optimal level on risk taking is ambiguous. We state these results in Proposition 5 below.

Proposition 5. *Banks' asset risk taking increases with the level of transparency above and around the socially optimal level, i.e., $d\mu^*/d\varepsilon < 0$ for $\varepsilon \leq a/b$. For levels of transparency sufficiently low, however, the impact of transparency on risk taking is ambiguous.*

Recall that more risk taking (i.e., a greater value of μ) is associated with a larger probability of a bank failure in our model. Thus, Proposition 5 implies that for high levels of transparency and for the levels of transparency around its optimal value increasing the level of transparency increases the probability of a bank failure, i.e., $d\mu^*/d\varepsilon < 0$. This holds for all $\varepsilon \in (0, \bar{\varepsilon})$ when, e.g., $a/b \geq \bar{\varepsilon}$. More generally, even if ε is well above a/b , then $d\mu^*/d\varepsilon < 0$ may hold since the second term on the RHS of (19) is negative. In fact, we can show that if the elasticity of asset returns with respect to the level of risk is above one, then $d\mu^*/d\varepsilon < 0$ for all $\varepsilon \in (0, \bar{\varepsilon})$. An increase in transparency makes creditors less willing to roll over for a given asset risk (Proposition 3); this leads banks to compensate this effect by taking *more* risk: From (13) we observe that

$$\frac{\partial t^*}{\partial \mu} = -\frac{\lambda h R'}{\beta (1 + R)^2} < 0, \quad (20)$$

i.e., the creditors' threshold for rolling over decreases with the bank's asset risk. The effect is due to the expected asset returns at maturity being increasing in the risk level (i.e., $Q' \geq 0$), implying that the expected payoff of creditors who roll over is increasing in the risk level (see (3)).

As for the impact of changes in the level of transparency on the level of refinancing risk x is now twofold: there is a *direct effect* on banks refinancing risk given the banks' asset risk choice μ , and an *indirect effect* through its influence on banks' asset risk choice; i.e.,

$$\frac{dx^*}{d\varepsilon} = \frac{\partial x^*}{\partial \varepsilon} + \frac{\partial x^*}{\partial \mu} \frac{d\mu^*}{d\varepsilon}.$$

By Proposition 3, the direct effect $\partial x^*/\partial \varepsilon$ is negative. For the sign of the indirect effect, $d\mu^*/d\varepsilon < 0$ for a wide range of parameter values by Proposition 5, and in fact may hold for all $\varepsilon \in (0, \bar{\varepsilon})$. For simplicity, in the following discussion we concentrate on the case where $d\mu^*/d\varepsilon \leq 0$. Differentiating (14) with respect to μ yields

$$\frac{\partial x^*}{\partial \mu} = \frac{h}{\mu^2} (1 - t^* (1 + \eta)),$$

where

$$\eta := -\frac{\partial t^*}{\partial \mu} \frac{\mu^*}{t^*}$$

is the elasticity of the equilibrium threshold with respect to the asset risk. Note from (20) that η is positive.

Since $t^* \in (1 - \mu + \varepsilon, 1 - \varepsilon)$ by Proposition 1, then $1 - t^* > 0$. However, the sign $1 - t^*(1 + \eta)$ is ambiguous and, by implication, the sign of the indirect effect $\partial x^*/\partial \mu$ is ambiguous too. If η is small, then $\partial x^*/\partial \mu > 0$, and the sign of both the indirect effect and total effect are negative.

Proposition 6. *If the elasticity of the equilibrium threshold with respect to asset risk is sufficiently small, then increasing the level of transparency increases refinancing risk around and above its socially optimal level. Otherwise, the effect of changes in the level of transparency on refinancing risk is ambiguous.*

Transparency has potentially ambiguous effects on refinancing risk because the impact of asset risk taking on withdrawals ($\partial x^*/\partial \mu$) is ambiguous due to two opposing forces. On the one hand, the probability that creditors get low signals of p and withdraw increases with risk taking. This effect of asset risk taking *increases* refinancing risk. On the other hand, (20) suggests that the bank can lower the creditors' threshold by taking more risk. This effect of asset risk taking *decreases* refinancing risk.

7 Welfare Analysis

Let us reconsider the impact of transparency on welfare incorporating that banks react to the level of transparency by choosing accordingly the level of asset risk. Given the level of transparency ε social welfare is therefore given by

$$W^*(\varepsilon) = W(\varepsilon, \mu^*(\varepsilon)),$$

where $\mu^*(\varepsilon)$ is banks' risk choice given ε . Thus,

$$\frac{dW^*}{d\varepsilon} = \frac{\partial W}{\partial \varepsilon} + \frac{\partial W}{\partial \mu} \frac{\partial \mu^*}{\partial \varepsilon}.$$

Since $\mu = \mu^*$ maximizes $W(\varepsilon, \mu)$ given ε , the Envelope Theorem implies that

$$\frac{dW^*}{d\varepsilon} = \frac{\partial W}{\partial \varepsilon}.$$

Thus, the marginal impact of changes of the level of transparency on welfare are the same as in the version of the model where μ is exogenous. Therefore the results

established in Proposition 4 above apply with no change. In particular, maximal transparency is not socially optimal.

Our assumption that the bank's objectives are perfectly aligned with those of society provides a basis for arguing against any need for regulation: competitive pressure leads banks to choose the socially optimal level of transparency as well as the socially optimal level of asset risk. However, the equilibrium of the banking sector may have welfare implications beyond its direct effects on the welfare of banks' creditors. In particular, the failure of a bank may have social costs beyond the costs it imposes on its creditors. For example, depriving some agents of bank's services may lead to a misallocation of savings and investments, or may constrain the credit available to borrowers in the real sector. Moreover, banks' investments may generate social returns in addition to private returns. Also, bank failures may be contagious and lead to a credit crunch. The existence of these externalities may misalignment of the objectives of banks and those of society.

Consider a social welfare function \hat{W}^* that accounts for these externalities,

$$\hat{W}^*(\varepsilon) = W^*(\varepsilon) - F(1 - E(p(\mu^*))).$$

In this expression, the term $F(1 - E(p(\mu^*)))$, with $F > 0$, captures the external social cost of a banks' failures, as e.g. in Freixas, Lóránth and Morrison (2007).

Since $dW^*/d\varepsilon = \partial W/\partial\varepsilon$, as shown above, we have

$$\frac{d\hat{W}^*(\varepsilon)}{d\varepsilon} = \frac{\partial W}{\partial\varepsilon} - \frac{F}{2} \frac{d\mu^*}{d\varepsilon}. \quad (21)$$

Since W^* increases and μ^* decreases with ε on $(0, a/b)$ by Propositions 4 and 5, then the RHS of (21) is strictly increasing on $(0, a/b)$. Furthermore, around $\varepsilon = a/b$ the first term on the RHS is zero but the second term is positive. Hence, when the social cost of bank failures are taken into account, social welfare \hat{W}^* increases with ε beyond a/b . That is, when we account for the social cost of bank failures, the socially optimal level of transparency is smaller than when only the private interests of creditors are taken into account; in particular, it becomes more likely that the socially optimal level of transparency is the minimal one. This result is summarized in Proposition 7.

Proposition 7. *If bank failures have negative social externalities, in addition to their direct effect on creditors payoffs, then the socially optimal level of transparency is below the optimal level when only the interest of creditors are taken into account.*

The policy implications of Proposition 7 are strong: to the extent that bank failures call for transparency regulation, this regulation should result in a more opaque rather than a more transparent banking system.

8 A Numerical Example

Despite its apparent complexity, our model is parsimonious in that the primitives are just the liquidation cost, λ , the fraction of active creditors, h , and the return function, $R(\mu)$. It is not obvious which range of values for λ we should postulate since in practice the liquidation value may depend upon the realized state (it may be low if it is the result of a firesale in a recession, but large if the asset is traded in a booming market) and on the nature of the specific asset (e.g., loans to high-tech start ups may have a low liquidation value, whereas prime mortgage loans may have a high one). As for the fraction of active creditors, we may identify it with the share of short-term debt to banks' total external debt or total liabilities, which also varies wildly. We therefore postulate values for these parameters that we deem as reasonable, but certainly there are other interesting values to try.

In our numerical example we set up $\lambda = 2h = 3/4$, and postulate a linear return function, $R(\mu) = \mu$. Note that $h < \lambda$, and

$$\begin{aligned} Q(\mu) &= (1 + R(\mu)) \left(1 - \frac{\mu}{2}\right) \\ &= 1 + \frac{1}{2}\mu(1 - \mu) > 1, \end{aligned}$$

so that

$$Q(\mu) > 1 > \lambda > h > 0,$$

holds as required.

Using the values of λ and h , we calculate α and β . Then we use these values and the function R we calculate the equilibrium threshold t^* , the values a and b , and the optimal level of transparency $\varepsilon^* = a/b$. Substituting these values in we obtain the welfare function $W(\varepsilon^*, \mu)$. Assuming that the optimal level of transparency, $\varepsilon^* = a/b$, satisfies $\varepsilon^* < \bar{\varepsilon}(\mu)$, we calculate the maximizer of $W(\varepsilon^*, \mu)$, to obtain $\mu^* \approx 0.64738$. We then use the value of μ^* to calculate $\varepsilon^* \approx 0.022112$. The bound $\bar{\varepsilon}$ when the level of asset risk is μ^* can be readily calculated as $\bar{\varepsilon} \approx 0.24122 > \varepsilon^*$. If the feasible levels

of asset risk satisfy $\underline{\mu} < \mu^* < \bar{\mu}$, and are not too far from μ^* , then equilibrium would be unique for a broad range of values of ε around ε^* .

9 Conclusion

Our main conclusion is that maximal bank transparency is not socially optimal. Moreover, in a competitive banking sector transparency may need to be regulated only when there are social costs or social externalities associated to bank failures; when this is the case regulation is required to reduce the level of transparency over the level that is socially optimal in the absence of these externalities. In addition, asset risk taking increases with the level of transparency above and around the socially optimal level. (The relation between risk taking and transparency is ambiguous for levels of transparency sufficiently below the social optimal.) As for the sign of the impact of transparency on refinancing risk, it is negative given the asset's risk, but it is ambiguous if we account for its indirect effect via risk taking.

That the socially optimal level of transparency is interior results from optimally trading off the opposing effects induced by changes of the level of transparency: for high levels of transparency, further increasing transparency increases efficient liquidation but also increases risk taking and may increase refinancing risk. These effects have been used to argue in favor and against increasing bank transparency, and have rendered an inconclusive debate – see Landier and Thesmar 2011. Our model allow us to put these effects in perspective, allow us to conclude that calls for maximal transparency are not justified, and that rather assessing the socially optimal level of transparency requires a quantitative exercise.

In our model, the negative externality imposed by the creditors who withdraw their short-term debt on the creditors who roll over plays a key role. Studying the effect of transparency on the agency problem facing bank “insiders” (e.g. its management and controlling shareholders) and outside creditors (e.g. short-term creditors and small investors) seems an interesting topic of future research – this line of research is pursue by Vauhkonen (2010). Also important is analysis of the effects of transparency on contagion, an issue that is outside the scope of the present paper – see Chen and Hasan (2006) and Giannetti (2007).

10 Appendix

In this appendix we calculate the function $V(s, t)$ for $s, t \in (1 - \mu + \varepsilon, 1 - \varepsilon)$. As established in (11) in the main text

$$V(s, t) = \frac{1 + R}{\lambda} \left(\frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} pdp - (1 - \lambda) \int_{s-\varepsilon}^{s+\varepsilon} \frac{pdp}{2\varepsilon(1 - x(p, \tau_t))} \right).$$

We have

$$\frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} pdp = s.$$

For p and t satisfying $p - \varepsilon < t < p + \varepsilon$ we have

$$\begin{aligned} 2\varepsilon(1 - x(p, \tau_t)) &= 2\varepsilon \left(1 - \frac{h(t - p + \varepsilon)}{2\varepsilon} \right) \\ &= c + hp, \end{aligned}$$

where

$$c := 2\varepsilon - h(t + \varepsilon).$$

Also we have

$$\int \frac{pdp}{2\varepsilon(1 - x(p, \tau_t))} = \frac{p}{h} - \frac{c}{h^2} \ln(c + hp) + \text{constant}.$$

Assume that $s > t$. For $p \in (t + \varepsilon, s + \varepsilon)$ equation (4) yields $x(p, \tau_t) = 0$. Also, since $p - \varepsilon < t < p + \varepsilon$ for $p \in (s - \varepsilon, t + \varepsilon)$, we may write

$$\begin{aligned} \frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} \frac{pdp}{1 - x(p, \tau_t)} &= \int_{s-\varepsilon}^{t+\varepsilon} \frac{pdp}{2\varepsilon(1 - x(p, \tau_t))} + \frac{1}{2\varepsilon} \int_{t+\varepsilon}^{s+\varepsilon} pdp \\ &= -\frac{1}{h^2} [c \ln(c + hp) - hp]_{s-\varepsilon}^{t+\varepsilon} + \frac{1}{2\varepsilon} \int_{t+\varepsilon}^{s+\varepsilon} pdp \\ &= -\frac{1}{h^2} \left(c \ln \frac{c + h(t + \varepsilon)}{c + h(s - \varepsilon)} - h(t + \varepsilon) + h(s - \varepsilon) \right) \\ &\quad + \frac{1}{4\varepsilon} (s - t)(s + t + 2\varepsilon). \end{aligned}$$

Hence

$$\begin{aligned} V(s, t) &= \frac{1 + R}{\lambda} \left(s - \frac{(1 - \lambda)(s - t)(s + t + 2\varepsilon)}{4\varepsilon} \right) \\ &\quad + \frac{(1 + R)(1 - \lambda)}{\lambda h^2} \left(c \ln \frac{c + h(t + \varepsilon)}{c + h(s - \varepsilon)} - h(t + \varepsilon) + h(s - \varepsilon) \right). \end{aligned}$$

Assume that $s < t$. For $p \in (s - \varepsilon, t - \varepsilon)$ equation (4) yields $x(p, \tau_t) = h$. Also since $p - \varepsilon < t < p + \varepsilon$ for $p \in (t - \varepsilon, s + \varepsilon)$, then we may write

$$\begin{aligned} \frac{1}{2\varepsilon} \int_{s-\varepsilon}^{s+\varepsilon} \frac{pdp}{1-x(p, \tau_t)} &= \frac{1}{2\varepsilon} \int_{s-\varepsilon}^{t-\varepsilon} \frac{pdp}{1-h} + \int_{t-\varepsilon}^{s+\varepsilon} \frac{pdp}{2\varepsilon(1-x(p, \tau_t))} \\ &= -\frac{(s-t)(s+t-2\varepsilon)}{4\varepsilon(1-h)} - \frac{1}{h^2} [c \ln(c+hp) - hp]_{t-\varepsilon}^{s+\varepsilon} \\ &= -\frac{(s-t)(s+t-2\varepsilon)}{4\varepsilon(1-h)} \\ &\quad - \frac{1}{h^2} \left(c \ln \frac{c+h(s+\varepsilon)}{c+h(t-\varepsilon)} - h(s+\varepsilon) + h(t-\varepsilon) \right). \end{aligned}$$

Hence

$$\begin{aligned} V(s, t) &= \frac{1+R}{\lambda} \left(s + \frac{(1-\lambda)(s-t)(s+t-2\varepsilon)}{4\varepsilon(1-h)} \right) \\ &\quad + \frac{(1+R)(1-\lambda)}{\lambda h^2} \left(c \ln \frac{c+h(s+\varepsilon)}{c+h(t-\varepsilon)} - h(s+\varepsilon) + h(t-\varepsilon) \right). \end{aligned}$$

When the signal of the creditor coincides with the threshold, i.e., $s = t$, then $c + h(s + \varepsilon) = 2\varepsilon$ and $c + h(s - \varepsilon) = 2\varepsilon(1 - h)$, and the expected payoff becomes

$$V(t, t) = \frac{1+R}{\lambda h} \left\{ [h + (1-\lambda) \ln(1-h)] t - \varepsilon(1-\lambda) \left[2 + \frac{2-h}{h} \ln(1-h) \right] \right\}.$$

Define

$$\alpha := -[2h + (2-h) \ln(1-h)](1-\lambda)/h$$

and

$$\beta := h + (1-\lambda) \ln(1-h).$$

We can then rewrite $V(t, t)$ as

$$V(t, t) = \frac{1+R}{\lambda h} (\beta t + \alpha \varepsilon),$$

which is equation (12) in Section 4.

We show that $0 < \beta < h$. Since $1 > \lambda > h > 0$, then $(1-\lambda) \ln(1-h) < 0$ and therefore $\beta < h$. And since

$$\frac{\partial \beta}{\partial h} = \frac{\lambda - h}{1-h} > 0,$$

and $\beta = 0$ for $h = 0$, then $\beta > 0$.

We show that $\alpha > 0$. Since $1 > \lambda > h > 0$, then $(1 - \lambda)/h > 0$. Moreover, for $h > 0$ we have

$$\frac{\partial}{\partial h} (2h + (2 - h) \ln(1 - h)) = -\frac{h + (1 - h) \ln(1 - h)}{1 - h} < 0.$$

(Showing that the numerator is positive is analogous to proving that $\beta > 0$.) Hence

$$2h + (2 - h) \ln(1 - h) < 0,$$

and therefore

$$\alpha = -(2h + (2 - h) \ln(1 - h)) \frac{1 - \lambda}{h} > 0.$$

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