Social Value of Information in a Levered Economy

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Abstract

We investigate the role of public information in a general equilibrium economy with aggregate liquidity shocks and endogenous incomplete contracts. The investment decisions of entrepreneurs impose a negative externality on others because of capital rationing: they reduce the resources available for reinvestment and thus increase the equilibrium probability of liquidity shortage for all entrepreneurs. The source of inefficiency rests on entrepreneurs' inability to privately insure against aggregate liquidity shocks as competitive financiers are better off with incomplete contracts because they earn ex-post rents in the event of capital rationing. Public information may lead to a reduction in social welfare because it exacerbates the negative externality in entrepreneurs' investment decisions. Capital adequacy requirements, targeted disclosure of information, and mandatory lines of credit are possible policies to achieve constrained efficiency as competitive market equilibrium.

JEL classification: D61, D62, G01, G21, G28.

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1 Introduction

Well-functioning financial markets should facilitate the allocation of capital to their best economic use: information is instrumental to serve this purpose. In the highly receptive world of today's financial markets populated with central banks' watchers, economic analysts, and various economic commentators, disclosure policies assume great importance. On any given day, many institutions with high public visibility such as government agencies, central banks, international organizations and credit rating agencies release news potentially affecting the allocative efficiency in the economy. It is commonly believed that disclosure of more precise information by these institutions as well as by market participants is socially valuable. For instance, a common theme of Basel III has been to enhance the quality, consistency and transparency of financial institutions to allow market discipline to operate more effectively (Basel Committee on Banking Supervision, 2010). More generally, among the various policy responses to the turbulence in international financial markets there has been a call for increased transparency through better disclosure from governments and other official bodies (International Monetary Fund, 1998, 2008). For instance, the International Monetary Fund has actively encouraged its members to be more transparent and made more of its own documents publicly available (Glennerster and Shin, 2003).[1]

In this paper, we question the view that the disclosure of more precise public information is socially beneficial. We show that public information can indeed trigger systemic liquidity shortages, and hence be the source of allocative inefficiency, in an economy with aggregate shock to firms' production and endogenous incomplete contracts.

We develop a general equilibrium model with three periods. At date 0 a continuum of wealthless risk-neutral entrepreneurs have access to a risky investment technology. Wealthy, risk-neutral financiers decide how much capital to provide entrepreneurs and how much to invest in an alternative technology. At date 1, entrepreneurs' technology is hit by an aggregate liquidity shock: with positive probability, entrepreneurs need to raise new capital

[1] Among those there are IMF country documents and, in particular, Article IV reports, which evaluate the macroeconomic performance of all member countries; the production and publication of Reports on the Observance of Standards and Codes (ROSCs), which assess members' institutions; and the creation of the Special Data Dissemination Standard (SDDS), which sets common definitions for macroeconomic data as well as minimum frequency and timeliness standards.

to meet their reinvestment needs. If they secure new funds, their projects continue and produce a return at date 2. If entrepreneurs fail to secure new funds, their projects yield nothing. Their ability to raise new funds depends on the aggregate resources available at date 1, which in turn depend on the funds originally invested at date 0: more entrepreneurs' investment at date 0 leaves fewer resources for reinvestment at date 1.

The paper delivers three main contributions. First, we show that financial market failure and inefficient investment decisions naturally emerge in a competitive equilibrium with an informative public signal about the profitability of entrepreneurs' technology. Compared with the constrained efficient equilibrium (i.e. social planner economy with the same constraints as the private economy), the competitive equilibrium exhibits excessive risk taking, as atomistic entrepreneurs do not internalize the impact of their collective investment decisions on the equilibrium risk of liquidity shortage. The investment decisions of some entrepreneurs impose a negative externality on others because of capital rationing: they reduce the resources available in case of a liquidity shock and thus increase the equilibrium probability of liquidity shortage for all entrepreneurs. The source of inefficiency rests on entrepreneurs' inability to fully insure against aggregate liquidity shocks as contracts are endogenously incomplete. Financiers are better off if they do not issue claims on their technology (which could provide ex-ante insurance to entrepreneurs) because they earn ex-post rents in the event of capital rationing.

Second, we investigate the social value of public information in the competitive equilibrium. A public signal conveys valuable information on the underlying state of the world, but it also generates correlated investment decisions by equalizing entrepreneurs' beliefs. Whenever capital rationing is likely, a more informative public signal can be welfare reducing because it exacerbates the negative externality in entrepreneurs' investment decisions.

Third, we consider the constrained efficient equilibrium chosen by a social planner who can coordinate entrepreneurs' actions given their available information. The social welfare is now increasing in the quality of public information as entrepreneurs' coordination fully internalizes the negative externality in the individual choice of investment. Constrained efficiency can be achieved as a competitive market equilibrium outcome via capital adequacy requirements, targeted disclosure of information, and mandatory lines of credit.

Capital adequacy restrictions on financiers prevent excessive risk taking and systemic liquidity shortages by optimally restricting aggregate investment in entrepreneurs' technology. With targeted disclosure of information, only informed entrepreneurs would invest, thus limiting welfare-reducing liquidity shortages. For those who access the information, a high informativeness about underlying fundamentals enhances efficiency of private decisions. Capital adequacy restrictions and the degree of disclosure should optimally vary with the informativeness of the public signal. No capital adequacy restrictions and full disclosure of public information are optimal only when the quality of the public signal is sufficiently high.

Mandatory lines of credit can also achieve the constrained efficient outcome as they provide entrepreneurs with means to insure privately against systemic liquidity shocks. Unlike the previous policies, the social optimality of mandatory lines of credit is independent of the quality of public information: financiers' supply of credit lines is always socially optimal. Lines of credit need to be mandatory as financiers would never offer them voluntarily because they would otherwise lose the ex-post rents.

The paper's main contribution can be placed within the large literature on credit cycles and fire-sale externalities.[2] A closely related paper is Lorenzoni (2008), where inefficient credit booms result from fire-sale externalities. In his model with limited commitment in financial contracts, competitive entrepreneurs do not internalize the equilibrium effects of asset sales on prices when making investment decisions. Hence, a pecuniary externality leads to over-borrowing in equilibrium. In our model the externality operates also through quantities because of capital rationing. The investment decision of some entrepreneurs reduces the resources available for future reinvestment and thus imposes two forms of negative externality on other entrepreneurs: a price externality by increasing the cost of new financing; and a quantity externality by decreasing the probability of receiving new funds because of capital rationing. This form of externality may even lead to financial market breakdowns. Furthermore, we emphasize the role of public information as a trigger of systemic liquidity crisis.

[2] See Bernanke and Gertler (1989), Shleifer and Vishny (1992), Allen and Gale (1994), Kiyotaki and Moore (1997), Holmström and Tirole (1998), Krishnamurthy (2003), Rampini (2004), Lorenzoni (2008), and Acharya and Vishwanathan (2009), Brunnermeier and Sannikov (2010) and Korinek (2010), among others.

As in Holmström and Tirole (1998), we model liquidity shocks as shocks to firms' production technologies. While they study the role of private and public provision of liquidity within a moral hazard framework, we investigate the positive and normative properties of an economy, where public information triggers liquidity shortages because of incomplete contracts. Krishnamurthy (2003) shows that only if firms cannot fully insure privately against aggregate liquidity shocks, there is a feedback from collateral values to real investment decisions. In our context, incomplete hedging is an endogenous outcome, as financiers realize ex-post rents from liquidity shortages by restricting entrepreneurs' access to their technology. In this respect our contribution is similar to Acharya and Viswanathan (2009), who endogeneize the liquidity shocks as the equilibrium mismatch between firms' assets and liabilities. The liabilities become liquidity shocks because they take the form of hard debt contracts and the asset quality is uncertain. The optimality of hard debt contract is a solution to a risk-shifting moral hazard problem. Hence, in their model credit rationing arises endogenously because of moral hazard. In our model, capital rationing arises endogenously because financiers are better off by restricting entrepreneurs' access to their technology to realize ex-post rents from liquidity shortages.

The paper also contributes to the literature on the social value of information dating back to Hirshleifer (1971), who shows how disclosure of public information may preempt socially valuable risk-sharing opportunities. More recently, Morris and Shin (2002) and Angeletos and Pavan (2004) examine the impact of public information when agents' payoffs exhibit exogenous externalities like in Keynesian beauty contests. Angeletos and Pavan (2007) develop a more general framework of the basic game with applications to production externalities, beauty contests, business cycles, and large Cournot and Bertrand games. Adding to this literature, we investigate the social value of information in a competitive economy with externalities that arise endogenously because of aggregate liquidity shocks and incomplete contracts.

The structure of the paper is as follows. In Section 2, we present the model and derive the main results. Section 3 provides the constrained efficient equilibrium and characterizes its normative implications. Section 4 concludes. All omitted proofs are in the Appendix.

2 The Model

We consider an economy with three periods, $t \in \{0, 1, 2\}$, a continuum of entrepreneurs indexed by $i \in [0, 1]$, and a continuum of financiers indexed by $j \in [0, 1]$. There is one (perishable) good used for both consumption and investment. All agents are risk-neutral and derive utility from final consumption: $U = c_2$. Financiers are perfectly competitive and have an initial endowment $W > 0$. They can use it either to finance entrepreneurs or to invest in their own technology, which for simplicity is assumed to be riskless with a gross return of 1. Entrepreneurs have no initial endowment, but they have access to a constant-returns-to-scale technology, which for any unit of initial investment returns R at date 2 and incurs an effort cost per unit of invested capital $b > 0$ (in units of consumption) at date 0. The scale of the investment D_i can be chosen freely, subject only to resource constraints, $D_i \in [0, W]$. The investment is made at date 0. At date 1, all firms experience the same liquidity shock: an additional, uncertain amount $\lambda D_i \geq 0$ of financing is needed to cover operating expenditures and other cash needs. For simplicity, the liquidity shock can only take the value of 0 (no liquidity shock) or 1 (liquidity shock equals initial investment) with equal probabilities. If λD_i is raised, the project continues and a final payoff is realized at date 2. If λD_i is not raised, the project terminates and yields nothing. λ can be interpreted as a shock to production technology as it affects the profitability of entrepreneurs' investment.

There is a public signal $\theta \in \{L, H\}$ about the size of the liquidity shock, which is distributed as

$$\Pr(\theta = H|\lambda = 0) = \Pr(\theta = L|\lambda = 1) = \sigma,$$

where $\sigma \in [1/2, 1]$ measures its informativeness, with $\sigma = 1/2$ being perfectly uninformative and $\sigma = 1$ being perfectly informative.

At date 0, all agents observe the public signal $\theta \in \{L, H\}$ and make investment and financing decisions. Using Bayes' rule, entrepreneurs and financiers compute the conditional probabilities of the liquidity shock as

$$\mu_\theta \equiv \Pr(\lambda = 0|\theta) = \begin{cases} \sigma & \text{if } \theta = H \\ 1 - \sigma & \text{if } \theta = L \end{cases}$$

where $\Pr(\theta = H) = \Pr(\theta = L) = 1/2$. In order to finance their investment, entrepreneurs can borrow against (or issue claims on) the future risky investment proceeds at date

2. Entrepreneurs have limited liability: they cannot pay out more funds than they have. Each entrepreneur i applies for funding $D_i \in [0, W]$ against a repayment $r_{D,0} D_i$ at date 2. Financiers choose whether to provide funding $D_i^S \in [0, W]$ at $r_{D,0}$ or invest in their own technology.

At date 1, the liquidity shock $\lambda \in \{0, 1\}$ hits the economy. When $\lambda = 0$, there is no need of additional funds. Entrepreneurs continue the projects and their final payoffs are realized at date 2. When $\lambda = 1$, entrepreneurs need an additional amount D_i of new funds, as they are not allowed to re-scale their investment at this stage. If there is no liquidity shortage, i.e. there are enough aggregate resources to finance all entrepreneurs, old and new financiers are paid their promised competitive rates, respectively $r_{D,0}$ and $r_{D,1}$, out of entrepreneurs' future investment proceeds. If there is a liquidity shortage, entrepreneurs are capital rationed and financiers can extract all entrepreneurs' rents. If entrepreneurs secure new funds, their projects continue and their final payoffs are realized at date 2. In this case, old and new financiers share equally entrepreneurs' investment proceeds at date 2.[3] If entrepreneurs are unable to secure new funds, their projects terminate and yield nothing.

At date 2, financiers consume their profits and entrepreneurs consume their investment proceeds net of financiers' repayments. Figure 1 summarizes the timeline, actions and payoffs.

Three additional assumptions are useful in the analysis. First, we assume that the project's net present value $(R - b - 1 - \lambda)$ is strictly positive when there is no liquidity shock, which is $1 < R - b$. This assumption is necessary for financiers to finance entrepreneurs investment at date 0. Second, we assume that the project's net present value at date 1 after a liquidity shock $(R - 1 - 1)$ is strictly positive, which is $R > 2$. This assumption ensures that when there is a liquidity shock, reinvestment is always ex-post efficient. Third, we assume that $R - b < 3/2$, that is, the project's net present value in the absence of public information is negative, $\sum_{\lambda=0,1} \Pr(\lambda)(R - b - 1 - \lambda) = R - b - 3/2 < 0$. This assumption

[3] This can be interpreted as the solution of a cooperative Nash bargaining equilibrium between the new and old financiers where each set of financiers has the same bargaining power and can force the firm into liquidation if there is no agreement. An alternative interpretation is that new and old financiers have the same seniority. Allowing for a different split of the surplus between old and new financiers would not affect the main results.

also implies that the project's net present value is negative when $\theta = L$.[4]

2.1 Market for Liquidity

We find the subgame perfect equilibria by backward induction, starting from the equilibrium in the market for liquidity at date 1. When $\lambda = 0$, there is no market for liquidity because there is no demand for new financing. When $\lambda = 1$, all entrepreneurs need new funds. Therefore, the aggregate demand of liquidity is:

$$L^D = \begin{cases} 0 & \text{if } \lambda = 0 \\ D^* & \text{if } \lambda = 1 \end{cases},$$

where D^* is the equilibrium entrepreneurs' investment made at date 0. When there is a liquidity shock, given that without new funds the project would terminate and yield nothing, the payments to the old financiers can be renegotiated to $\widetilde{r}_{D,0}$. Financiers choose whether to provide new funds $L^S \in [0, W - D^*]$ at a cost $r_{D,1}$ so as to maximize their final consumption:

$$\max_{L^S \in [0, W - D^*]} r_{D,1} L^S + (W - D^* - L^S)$$

subject to entrepreneurs' solvency constraint $r_{D,1} + \widetilde{r}_{D,0} \leq R$. Hence, the supply of liquidity is

$$L^S = \begin{cases} W - D^* & \text{if } r_{D,1} > 1 \\ [0, W - D^*] & \text{if } r_{D,1} = 1 \\ 0 & \text{if } r_{D,1} < 1 \end{cases}$$

with $r_{D,1} + \widetilde{r}_{D,0} \leq R$. In equilibrium, $r_{D,1}$ - i.e. the cost of new financing conditional on $\lambda = 1$ - is set to equate demand and supply of liquidity via an internal market where competitive financiers can transfer liquidity among themselves. If $L^D \leq W - D^*$, then $L^S = L^D$ and $r^*_{D,1} = 1$ since there is excess supply of liquidity and competition among financiers drives the return on new financing $r_{D,1}$ down to their opportunity cost of 1. In this case, there is no opportunity for renegotiation of the payments to pre-existing financiers and $\widetilde{r}^*_{D,0} = r_{D,0}$. If instead $L^D > W - D^*$, then $L^S = L^D$ cannot be an equilibrium as financiers' resource constraint is now binding. Therefore, there is capital rationing and

[4] The assumption that $R - b <, 3/2$ gives rise to a non monotonic relationship between the informativeness of the public signal and social welfare. If $R - b > 3/2$, there is always investment with no public signal. An increase in the informativeness of the public signal is always welfare improving because its only effect is to reduce the probability of making bad investment decisions.

$L^S = W - D^* < L^D$. Entrepreneurs compete for new funds thus transferring all the surplus to financiers, who can now provide new financing at the maximum possible rate satisfying entrepreneurs' solvency constraint, $r^*_{D,1} + \widetilde{r}^*_{D,0} = R$. Since the capital provided by the old financiers is still needed for production, old and new financiers (who now also provide an equal amount of new capital), have the same bargaining power. Hence, according to a cooperative Nash bargaining equilibrium, old and new financiers split equally the surplus R, and $r^*_{D,1} = \widetilde{r}^*_{D,0} = R/2$.

Therefore, when $\lambda = 1$, the equilibrium in the market for liquidity is

$$\left\{L^*, r^*_{D,1}, \widetilde{r}^*_{D,0}\right\} = \begin{cases} \{D^*, 1, r_{D,0}\} & \text{if } D^* \leq W/2 \\ \{W - D^*, R/2, R/2\} & \text{if } D^* > W/2 \end{cases}. \tag{1}$$

When financiers net worth falls short of the liquidity needs, entrepreneurs will be capital rationed. Since it is socially inefficient to provide new funds to all entrepreneurs pro-rata because they will all lose the proceeds from investment, only a portion $\frac{W-D^*}{D^*}$ of entrepreneurs demanding liquidity will secure new funds.[5] Therefore, the probability of new financing, conditional on the liquidity shock, for each entrepreneur is:

$$\rho = \begin{cases} 1 & \text{if } D^* \leq W/2 \\ \frac{W-D^*}{D^*} & \text{if } D^* > W/2 \end{cases}. \tag{2}$$

2.2 Market for Funding

We can now proceed backwards to date 0 when the market for funding opens.

2.2.1 Demand of Funding

Entrepreneurs take the cost of financing $r_{D,0}$ and the aggregate entrepreneurs' investment D^* as given. They are rational and can perfectly foresee the continuation of the game: they know the equilibrium $r^*_{D,1}$, $\widetilde{r}^*_{D,0}$ and L^* as in (1), and the probability of new financing ρ as in (2).

[5] Allowing for partial reinvestment would not affect the main results. Intuitively, new funds would be provided pro rata to all entrepreneurs, who will receive funds to cover only a fraction ρ of their reinvestment needs, with resulting aggregate investment payoff ρR. This is the same aggregate investment payoff that is achieved in our current setup, where only a fraction ρ of entrepreneurs fully covers their reinvestment needs, while the others get nothing.

Entrepreneurs' optimal investment policy is the solution to the following maximization problem:

$$\max_{D_i^D \in [0,W]} \left[\mu_\theta \left(R - r_{D,0}\right) + \left(1-\mu_\theta\right) \rho \left(R - \widetilde{r}^*_{D,0} - r^*_{D,1}\right) - b\right] D_i^D. \tag{3}$$

With probability μ_θ there is no liquidity shock, and entrepreneurs consume the return on their investment net of the financing costs, $D_i^D \left(R - r_{D,0}\right)$. With probability $(1-\mu_\theta)$ there is a liquidity shock, and only if entrepreneurs secure new funds, which happens with probability ρ, they consume the return on the risky investment net of the old and new financing costs, $D_i^D \left(R - \widetilde{r}^*_{D,0} - r^*_{D,1}\right)$. Regardless of the liquidity shock, entrepreneurs incur effort costs bD_i^D.

Each entrepreneur's demand of funding can then be characterized as:

$$D_i^D = \begin{cases} W & \text{if } r_{D,0} < R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \\ [0,W] & \text{if } r_{D,0} = R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \\ 0 & \text{if } r_{D,0} > R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \end{cases} \tag{4}$$

When financing is relatively cheap, the expected benefit of investing exceeds its expected cost, thus it is optimal to invest as much as possible, $D_i^D = W$. If $r_{D,0} = R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta}$, entrepreneurs are indifferent between any values of $D_i^D \in [0,W]$. When financing is relatively expensive, it is optimal not to invest, $D_i^D = 0$.

We can thus derive the aggregate demand of funds as:

$$D^D = \begin{cases} W & \text{if } r_{D,0} < R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \\ \phi_\theta W & \text{if } r_{D,0} = R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \\ 0 & \text{if } r_{D,0} > R + \frac{(1-\mu_\theta)\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b}{\mu_\theta} \end{cases} \tag{5}$$

with $\phi_\theta \in [0,1]$ as the investment chosen by entrepreneurs when indifferent, which is to be determined in equilibrium.

2.2.2 Supply of Funding

Taking the cost of financing $r_{D,0}$, the equilibrium values of $r^*_{D,1}$ and $\widetilde{r}^*_{D,0}$ in (1), and the probability of new financing ρ in (2) as given, each financier j chooses competitively the supply of loans $D_j^S \in [0,W]$ to maximize expected final consumption:

$$\max_{D_j^S \in [0,W]} D_j^S \left[\mu_\theta r_{D,0} + \left(1-\mu_\theta\right) \rho \widetilde{r}^*_{D,0}\right] + \left(W - D_j^S\right) \left[\mu_\theta + \left(1-\mu_\theta\right) r^*_{D,1}\right]. \tag{6}$$

With probability μ_θ there is no liquidity shock, and financiers consume the payoff from the funds supplied to entrepreneurs $r_{D,0}D_j^S$ plus any payoff from their own technology $\left(W - D_j^S\right)$. With probability $(1-\mu_\theta)$ there is a liquidity shock, and financiers consume the renegotiated payoff from the initial funds supplied to entrepreneurs $\widetilde{r}_{D,0}^* D_j^S$, which happens with probability ρ, and the payoff from any capital used for new financing, $\left(W - D_j^S\right) r_{D,1}^*$. Hence, the supply of funds can be summarized as:

$$D_j^S = \begin{cases} W & \text{if } r_{D,0} > 1 + \frac{(1-\mu_\theta)\left(r_{D,1}^* - \rho\widetilde{r}_{D,0}^*\right)}{\mu_\theta} \\ [0,W] & \text{if } r_{D,0} = 1 + \frac{(1-\mu_\theta)\left(r_{D,1}^* - \rho\widetilde{r}_{D,0}^*\right)}{\mu_\theta} \\ 0 & \text{if } r_{D,0} < 1 + \frac{(1-\mu_\theta)\left(r_{D,1}^* - \rho\widetilde{r}_{D,0}^*\right)}{\mu_\theta} \end{cases}.$$

When the expected marginal benefit of financing exceeds its expected marginal cost, it is optimal to finance as much as possible, $D_j^S = W$. Otherwise, it is optimal to invest the capital in their own technology and potentially use the proceeds for future financing. When $r_{D,0} = 1 + \frac{(1-\mu_\theta)\left(r_{D,1}^* - \rho\widetilde{r}_{D,0}^*\right)}{\mu_\theta}$, financiers are indifferent among any values of $D_j^S \in [0, W]$. Given that financiers are identical, the aggregate supply of funding is $D^S = D_j^S$.

2.2.3 Equilibrium Funding

In equilibrium, given perfect competition, financiers must be indifferent ex-ante between financing entrepreneurs and investing in their technology (including the provision of liquidity in the future). Hence, the equilibrium cost of financing is given by

$$r_{D,0}^* = 1 + \frac{(1-\mu_\theta)\left(r_{D,1}^* - \rho\widetilde{r}_{D,0}^*\right)}{\mu_\theta}, \tag{7}$$

which implies that financiers' expected utility from final consumption is:

$$E\left(U_j|\theta\right) = \left[\mu_\theta + (1-\mu_\theta)\, r_{D,1}^*\right] W. \tag{8}$$

The equilibrium liquidity provision L^*, cost of new financing $r_{D,1}^*$, renegotiated cost of old financing $\widetilde{r}_{D,0}^*$, and probability of new financing ρ are given in (1) and (2), respectively. Finally, market clearing requires aggregate supply to equal aggregate demand of funds, $D^* = D^D$ as given in (5).

The next proposition characterizes the competitive market equilibrium. We focus on symmetric equilibria, where entrepreneurs make the same investment decision.

Proposition 1 (Competitive Market Equilibrium). *Let* $\overline{\sigma} \equiv \frac{b}{R-1}$ *and* $\overline{\overline{\sigma}} \equiv \frac{R+2b}{3R-2}$. *The competitive equilibrium is as follows:*

1) *If* $\theta = L$ *or if* $(\theta = H \ \& \ \sigma \in [1/2, b+2-R])$, *there is no entrepreneurs' investment:*

$$\left\{r^*_{D,0}, \widetilde{r}^*_{D,0}, r^*_{D,1}, \rho^*, D^*, L^*\right\} = \{1,1,1,1,0,0\};$$

2) *If* $\theta = H$ *and* $\sigma \in (b+2-R, \overline{\sigma})$, *there is no equilibrium;*

3) *If* $\theta = H$ *and* $\sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right)$, *there is partial capital rationing:*

$$\left\{r^*_{D,0}, \widetilde{r}^*_{D,0}, r^*_{D,1}, \rho^*\right\} = \left\{R - \frac{b}{\sigma}, \frac{R}{2}, \frac{R}{2}, \frac{(1-\sigma)R - 2\sigma(R-1) + 2b}{(1-\sigma)R}\right\}$$

and

$$\{D^*, L^*\} = \left\{\frac{(1-\sigma)R}{2\left[(1-\sigma)R - \sigma(R-1) + b\right]}W, \frac{(1-\sigma)R - 2\sigma(R-1) + 2b}{2\left[(1-\sigma)R - \sigma(R-1) + b\right]}W\right\};$$

4) *If* $\theta = H$ *and* $\sigma \in \left(\overline{\overline{\sigma}}, 1\right]$, *there is complete capital rationing:*

$$\left\{r^*_{D,0}, \widetilde{r}^*_{D,0}, r^*_{D,1}, \rho^*, D^*, L^*\right\} = \left\{1 + \frac{(1-\sigma)}{\sigma}\frac{R}{2}, \frac{R}{2}, \frac{R}{2}, 0, W, 0\right\}.$$

Figure 2 and 3 provide graphical representations of the competitive equilibria, conditional on $\theta = H$ in the market for funding, and conditional on $\theta = H$ and $\lambda = 1$ in the market for liquidity, respectively. Each figure is further separated into four regions corresponding to no capital rationing, market failure, partial capital rationing (only a fraction of entrepreneurs are rationed) and capital rationing (all entrepreneurs are rationed) if there is a liquidity shock.

When $\theta = L$, there is no investment by entrepreneurs as its expected payoff never exceeds the financing cost, which in equilibrium equals the return on financiers' technology normalized to 1. This is true even when the public signal is positive, i.e. $\theta = H$, and its informativeness is low, i.e. $\sigma \in [1/2, b+2-R]$.[6]

[6] When $\sigma = b + 2 - R$, entrepreneurs are indifferent for any $D_i^D \in [0, W]$. Therefore, any values of $D^* \in [0, W/2]$ are possible equilibria consistent with the financing cost $r^*_{D,0} = 1$. For simplicity, we make the tie-breaking assumption that entrepreneurs do not invest when $\sigma = b + 2 - R$.

When the public signal is positive and its informativeness is in the low-medium range, i.e. $\sigma \in (b+2-R, \overline{\sigma})$, there is a market breakdown as it does not exist a competitive rational equilibrium. The strategy of investing W in entrepreneurs' technology cannot be an equilibrium as, in such case, the cost of financing would increase to $1 + \frac{(1-\sigma)}{\sigma}\frac{R}{2}$, at which level entrepreneurs would prefer not to invest. Similarly, the strategy of zero investment cannot be an equilibrium as, in such case, the cost of financing would decrease to 1, at which level entrepreneurs would prefer to invest. Concerning the intermediate values of investment, the amount $\phi_H W$ consistent with the cost of financing, $r^*_{D,0} = R - \frac{b}{\sigma}$, which makes entrepreneurs and financiers indifferent between any values of $D \in (0, W)$, would have to be smaller than $W/2$. This cannot be an equilibrium because, if the demand of funding was smaller than $W/2$, there would never be a liquidity shortage, and therefore, $r^*_{D,0} = 1$. However, if this was the case, entrepreneurs would strictly prefer to invest and would not be anymore indifferent between any values of $D \in (0, W)$.

When the public signal is positive and its informativeness is in the medium-high range, i.e. $\sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right)$, there exist only equilibria for $D \in (0, W)$. At $r^*_{D,0} = R - \frac{b}{\sigma}$, entrepreneurs are indifferent between any values of $D_i \in (0, W)$, and there exists an aggregate demand of funding, D^*, for which competitive financiers are indifferent between any values of $D_j \in (0, W)$. The higher the informativeness of the public signal, the larger the equilibrium financing for entrepreneurs' investment because of its higher expected payoff. However, the larger the equilibrium financing, the fewer the resources available for future financing and the lower the equilibrium conditional probability of new financing ρ. Therefore, if there is a liquidity shock, only some entrepreneurs will be able to secure new funds - i.e. there would be partial capital rationing - and financiers can now extract the maximum possible rents both from charging a high financing cost, $r^*_{D,0}$, to all entrepreneurs and from providing liquidity to some of the competing entrepreneurs at the maximum possible rate, $r^*_{D,1} = R/2$. Specifically, an increase in σ has (i) a negative direct effect on the equilibrium cost of financing $r^*_{D,0}$ because it decreases the probability of a liquidity shock, and (ii) a positive indirect effect through the decreased conditional probability of new financing ρ^*. That is, an increase in σ, while making the liquidity shock less likely, conditional on the liquidity shock it increases the likelihood of being capital rationed. Hence, an increase in the informativeness of the public signal makes financing overall more expensive as capital rationing becomes more likely (both conditionally on $\lambda = 1$ and unconditionally), thus leading financiers to anticipate the expected profits from capital rationing through a higher cost of financing.[7]

Finally, when the public signal is positive and its informativeness is high, i.e. $\sigma \in \left(\overline{\overline{\sigma}}, 1\right]$, the entire financiers' endowment W is invested in entrepreneurs' technology, thus leaving no resources for future financing, $\rho^* = L^* = 0$, even at the maximum rate, $r^*_{D,1} = R/2$. In this case, if there is a liquidity shock, there will be complete capital rationing, and financiers can now only extract the maximum possible rents from competing entrepreneurs through a high financing cost, $r^*_{D,0}$. With the aggregate demand of funding already at its maximum W, and the conditional probability of new financing at zero, the more informative the positive public signal, the lower the financing cost that in equilibrium competitive financiers can charge to competing entrepreneurs as now capital rationing becomes unconditionally less likely. At the extreme, when the signal is perfectly informative, i.e. $\sigma = 1$, financiers cannot extract any rents, $r^*_{D,0} = 1$, as the unconditional probability of capital rationing becomes zero since there is no liquidity shock for sure, i.e. $\Pr(\lambda = 0|\theta = H) = 1$.

2.3 Social Welfare

The equilibrium social welfare is defined as the sum of entrepreneurs' and financiers' expected utilities:

$$E\left[U^W\right] = E\left(U_i^*\right) + E\left(U_j^*\right) = \sum_{\theta} \left[E\left(U_i|\theta\right) + E\left(U_j|\theta\right)\right] \Pr\left(\theta\right). \tag{9}$$

The following proposition characterizes the social welfare under the competitive equilibrium in Proposition 1.

Proposition 2 (Social Welfare). *The social welfare under the competitive equilibrium is:*

$$E\left[U^W\right] = \begin{cases} W & \text{if } \sigma \in [1/2, b+2-R] \\ \text{Not defined} & \text{if } \sigma \in (b+2-R, \overline{\sigma}) \\ \frac{W}{2}\left[1+\sigma+\frac{R}{2}(1-\sigma)\right] & \text{if } \sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right) \\ \frac{W}{2}\left(\sigma R + 1 - b\right) & \text{if } \sigma \in \left[\overline{\overline{\sigma}}, 1\right] \end{cases}$$

Figure 4 provides a graphical representation of the social welfare and its components as functions of the public signal's informativeness σ. When the signal informativeness is

[7] In equilibrium, the unconditional probability of capital rationing given $\theta = H$ is $(1-\sigma)(1-\rho^*)$, whose derivative with respect to the public signal's informativeness σ is $2(R-1)/R > 0$.

low, i.e. $\sigma \in [1/2, 2+b-R]$, the social welfare equals financiers' endowment as there is no investment by entrepreneurs. Hence, a marginal increase in σ has no effect on social welfare. However, except for $\sigma \in (2+b-R, \overline{\sigma})$ where financial markets break down, large increases in σ are strictly beneficial because of the increase in entrepreneurs' expected utility and/or financiers' expected profits from capital rationing.

When the informativeness of the public signal is in the medium-high range, i.e. $\sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right)$, entrepreneurs have zero expected utility as they are indifferent between investing and not investing. A marginal increase in σ leaves unaffected entrepreneurs' welfare as the increase in the expected risky investment payoff is exactly offset by the increase in the expected cost of financing. However, financiers' expected welfare decreases monotonically with the public signal's informativeness for any $\sigma \in (\overline{\sigma}, 1]$: financiers make profits only from liquidity provision in the event of capital rationing, whose likelihood decreases with σ. Therefore, an increase in σ, while leaving entrepreneurs' utility unaffected, reduces financiers' expected profits and affects negatively the social welfare, i.e. $\partial E\left[U^W\right]/\partial\sigma = -W(R-2)/4 < 0$.

When the public signal is highly informative, i.e. $\left(\overline{\overline{\sigma}}, 1\right]$, an increase in σ improves entrepreneurs' welfare as now there is not only an increase in the expected risky investment payoff, but also a reduction in the expected cost of financing. Therefore, the reduction in financiers' expected profits is now balanced against the increase in entrepreneurs' welfare, with a net positive effect on social welfare, i.e. $\partial E\left[U^W\right]/\partial\sigma = WR/2 > 0$.

3 Constrained Efficient Equilibrium

So far we have focused on the positive properties of the equilibrium. We now analyze its normative aspects by examining whether there exist a welfare-improving allocation, given the underlying information structure and resource constraints of the economy.

When making investment decisions, competitive entrepreneurs do not internalize the impact of their collective actions on the equilibrium probability of capital rationing and cost of financing. Specifically, the financing decisions of some entrepreneurs impose a negative externality on other entrepreneurs by reducing the resources available for future financing and thus increasing the conditional probability of capital rationing for all entrepreneurs. This matters only when the public signal is positive, i.e. $\theta = H$, as there is no entrepreneurs' investment otherwise. In such circumstances, if entrepreneurs were to coordinate their investment decisions to internalize the impact of their collective actions on the market equilibrium outcomes, they would be collectively better off. We let a social planner coordinate entrepreneurs' decisions by choosing aggregate investment to maximize the social welfare:

$$\max_{\widehat{D}\in[0,W]} \left[\sigma\left(R-r^*_{D,0}\right)+(1-\sigma)\,\rho\left(R-\widetilde{r}^*_{D,0}-r^*_{D,1}\right)-b\right]\widehat{D}+W\left[\sigma+(1-\sigma)\,r^*_{D,1}\right] \tag{10}$$

subject to $r^*_{D,0}$ as given in (7), $r^*_{D,1}$ and $\widetilde{r}^*_{D,0}$ as given in equation (1) and ρ as in equation (2). The next proposition characterizes the constrained efficient equilibrium and its corresponding social welfare.

Proposition 3 (Constrained Efficient Equilibrium). *Let* $\widehat{\sigma} \equiv \frac{R+b}{2R-1}$. *The optimal aggregate financing in the constrained efficient equilibrium is*

$$\widehat{D}^*=\begin{cases} 0 & \text{if } \sigma\in[1/2,b+2-R] \\ \frac{W}{2} & \text{if } \sigma\in(b+2-R,\widehat{\sigma}] \\ W & \text{if } \sigma\in(\widehat{\sigma},1] \end{cases}$$

with corresponding social welfare

$$E\left[U_S^W\right]=\begin{cases} W & \text{if } \sigma\in[1/2,b+2-R] \\ \frac{W}{4}\left(R+\sigma-b+2\right) & \text{if } \sigma\in(b+2-R,\widehat{\sigma}] \\ \frac{W}{2}\left(\sigma R+1-b\right) & \text{if } \sigma\in(\widehat{\sigma},1] \end{cases}.$$

Figure 5 and 6 provide graphical representations of the constrained efficient equilibrium outcomes, conditional on $\theta = H$ in the market for funding, and conditional on $\theta = H$ and $\lambda = 1$ in the market for liquidity, respectively. Each figure is further separated into two regions corresponding to no capital rationing and capital rationing (all entrepreneurs are rationed) if there is a liquidity shock.

When $\theta = L$ or the public signal is positive, $\theta = H$, but its informativeness is low, i.e. $\sigma \in [1/2, b+2-R]$, it is still optimal to have no entrepreneurs' investment as its expected payoff never exceeds the equilibrium financing cost of 1.

In the constrained efficient equilibrium, entrepreneurs invest less than the competitive market equilibrium for $\sigma \in (\overline{\sigma}, \widehat{\sigma}]$. The difference arises because atomistic and dispersed entrepreneurs do not internalize the negative externality their individual financing decisions have on the probability of capital rationing and the cost of financing. When the negative externality is factored in, entrepreneurs find financing more costly, and thus optimally choose less investment. Specifically, they invest $W/2$, which is the highest possible amount that still prevents capital rationing from ever happening, i.e. $\rho = 1$. When the public signal's informativeness is high, i.e. $\sigma \in (\widehat{\sigma}, 1]$, the expected risky investment payoff is so high and the unconditional probability of capital rationing is so low that it is still optimal to allocate the entire financiers' endowment W to finance entrepreneurs' investment. Furthermore, the coordination of entrepreneurs' investment decisions ensures financial markets never break down, unlike the competitive market equilibrium.

Welfare under the constrained efficient equilibrium never decreases with the informativeness of the public signal. For $\sigma \in [1/2, b + 2 - R]$ the social welfare is insensitive to changes in σ as there is no entrepreneurs' investment. However, whenever there is entrepreneurs' investment, i.e. $\sigma \in (b + 2 - R, 1]$, welfare is strictly increasing in σ as the equilibrium investment ensures that the increase in the expected risky investment payoff is not offset by an increase in the probability of capital rationing and thus current cost of financing.

Figure 7 compares the social welfare under the constrained efficient and competitive equilibria as functions of the public signal's informativeness σ. The constrained efficient allocation increases welfare by

$$\begin{aligned} \Delta U^W &= E\left[U_S^W\right] - E\left[U^W\right] \\ &= \begin{cases} 0 & \text{if } \sigma \in [1/2, b+2-R] \\ \text{Not defined} & \text{if } \sigma \in (b+2-R, \overline{\sigma}) \\ \frac{W}{4}\left[\sigma\left(R-1\right) - b\right] > 0 & \text{if } \sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right) \\ \frac{W}{4}\left[R - \sigma\left(2R-1\right) + b\right] > 0 & \text{if } \sigma \in \left[\overline{\overline{\sigma}}, \widehat{\sigma}\right) \\ 0 & \text{if } \sigma \in [\widehat{\sigma}, 1] \end{cases}. \end{aligned}$$

The welfare under the constrained efficient equilibrium strictly dominates the competitive equilibrium welfare for $\sigma \in (b + 2 - R, \widehat{\sigma}]$: unlike the social planner, atomistic entrepreneurs cannot coordinate their individual actions to avoid capital rationing in the competitive equilibrium. The absence of entrepreneurs' coordination leads to underinvestment when $\sigma \in (b + 2 - R, \overline{\sigma})$ and overinvestment when $\sigma \in (\overline{\sigma}, \widehat{\sigma}]$. Therefore, the constrained efficient optimal policy not only dominates the market equilibrium outcomes, but also ensures no failure in financial markets.

The increase in social welfare under the constrained efficient equilibrium benefits entirely entrepreneurs while making financiers worse off. The difference in entrepreneurs' welfare under the constrained efficient and the competitive equilibrium allocation is

$$\begin{aligned}\Delta U_i &= E\left(U_i^S\right) - E\left(U_i^*\right) \\ &= \begin{cases} 0 & \text{if } \sigma \in [1/2, b+2-R] \\ \text{Not defined} & \text{if } \sigma \in (b+2-R, \overline{\sigma}) \\ [\sigma + R - 2 - b]\,\frac{W}{4} > 0 & \text{if } \sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right) \\ [2(R-1) - 3\sigma(R-1) + b]\,\frac{W}{4} > 0 & \text{if } \sigma \in \left[\overline{\overline{\sigma}}, \widehat{\sigma}\right) \\ 0 & \text{if } \sigma \in [\widehat{\sigma}, 1] \end{cases}\end{aligned}$$

while the difference in financiers' welfare is

$$\begin{aligned}\Delta U_j &= E\left(U_j^S\right) - E\left(U_j^*\right) \\ &= \begin{cases} 0 & \text{if } \sigma \in [1/2, b+2-R] \\ \text{Not defined} & \text{if } \sigma \in (b+2-R, \overline{\sigma}) \\ -\frac{W}{4}(1-\sigma)[R-2] < 0 & \text{if } \sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right) \\ -\frac{W}{4}(1-\sigma)[R-2] < 0 & \text{if } \sigma \in \left[\overline{\overline{\sigma}}, \widehat{\sigma}\right) \\ 0 & \text{if } \sigma \in [\widehat{\sigma}, 1] \end{cases}.\end{aligned}$$

Hence, while the constrained efficient equilibrium maximizes the social welfare as defined by the sum of entrepreneurs' and financiers' utilities, moving from the competitive equilibrium to the constrained efficient equilibrium is not a Pareto improvement.

In what follows, we investigate how society can implement the constrained efficient equilibrium as market equilibrium outcome. We focus on optimal capital adequacy requirements, optimal information disclosure, and mandatory lines of credit.[8]

3.1 Capital Requirements

In this section, we consider whether society can replicate the constrained efficient solution by imposing capital requirements on financiers' risky investment. For this purpose, we solve

[8] While not the focus of the current paper, optimal taxation contingent on the informativeness of public information is also a mechanism to achieve the constrained efficient equilibrium. For instance, imposing on financiers a lump-sum tax, $T_0 = \frac{W}{2} 1_{\{\sigma \in (b+2-R, \widehat{\sigma}]\}}$ optimally restrict the equilibrium financing at date 0. Then, at date 1 the tax proceeds can be returned to financiers and potentially used for liquidity provision, as in Holmström and Tirole (1998).

for the competitive market equilibrium in an otherwise identical economy, which differs for the fact that financiers can now allocate only up to $\overline{D}$ of their capital W to finance entrepreneurs. We then solve for the optimal $\overline{D}$.

We find the subgame perfect equilibria by backwards induction. The equilibrium in the market for liquidity at date 1 is the same as before. At date 0, each entrepreneur i solves the following problem:

$$\max_{D_i \in \left[0, \overline{D}\right]} \left[\mu_\theta \left(R - r_{D,0}\right) + \left(1-\mu_\theta\right) \rho \left(R - \widetilde{r}_{D,0} - r^*_{D,1}\right) - b\right] D_i.$$

Hence, the aggregate demand of funding is

$$D^D = \begin{cases} \overline{D} & \text{if } \theta = H \ \& \ r_{D,0} < R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ \phi_H \overline{D} & \text{if } \theta = H \ \& \ r_{D,0} = R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ 0 & \text{otherwise} \end{cases}, \tag{11}$$

where $\phi_H \in [0, 1]$ is to be determined in equilibrium.

As in the basic case, in equilibrium competitive financiers must be indifferent ex-ante between financing entrepreneurs and investing in their own technology, implying that $r_{D,0}$ is as given in (7) and $D^* = D^D$ in (11).

The next proposition characterizes the main result.

Proposition 4 (Optimal Capital Requirement). *The optimal choice of capital requirement is*

$$\overline{D}^* = \begin{cases} [0, W] & \text{if } \sigma \in [1/2, b + 2 - R] \\ \frac{W}{2} & \text{if } \sigma \in (b + 2 - R, \widehat{\sigma}] \\ W & \text{if } \sigma \in (\widehat{\sigma}, 1] \end{cases}$$

where $\widehat{\sigma} = \frac{R+b}{2R-1}$ *and the corresponding social welfare is* $E\left[U^W_{\overline{D}^*}\right] = E\left[U^W_S\right]$.

In the proof of Proposition 4, first we characterize the competitive market equilibrium with capital restriction. Then, we maximize the corresponding social welfare to find the optimal capital requirement $\overline{D}^*$. The critical difference from Proposition 1 arises when $\overline{D} \leq W/2$ as now there is no capital rationing.

Evaluated at the optimal capital requirement $\overline{D}^*$, the welfare function is identical to the one in Proposition 3. Hence, a financial regulator can perfectly replicate the constrained efficient solution by limiting the size of financiers' risky investment to $\overline{D}^*/W$ times the capital of the financiers, W: the worst the quality of the public information, the tighter the optimal capital ratio.

3.2 Targeted Disclosure of Information

In this section, we consider whether society can do better, relative to the equilibrium with public information, by restricting entrepreneurs' access to information. Therefore, we solve for the competitive market equilibrium in an otherwise identical economy, which differs only for the information structure: the signal θ is given as private information to each entrepreneur with some probability γ. Since we have a continuum of identical entrepreneurs, the fraction of entrepreneurs who receive information equals γ almost certainly. Without loss of generality, we may assume that entrepreneurs $i \in [0, \gamma]$ receive the signal θ and entrepreneurs $i \in (\gamma, 1]$ are uninformed. To allow for a direct comparison with the case of public information, we assume that the same signal θ is distributed to all informed entrepreneurs $i \in [0, \gamma]$. Uninformed entrepreneurs can neither observe informed entrepreneurs' individual actions nor aggregate outcomes to infer the signal θ; nor they can buy information about θ from informed entrepreneurs.

We find the subgame perfect equilibria by backwards induction, starting from the market for liquidity at date 1. Since the aggregate demand and supply of liquidity are identical to the public information case, the equilibrium outcomes conditional on $\lambda = 1$ can be conveniently summarized as

$$\left\{L^*, \widetilde{r}^*_{D,0}, r^*_{D,1}, \rho^*\right\} = \begin{cases} \left\{D^*, r^*_{D,0}, 1, 1\right\} & \text{if } D^* \leq \frac{W}{2} \\ \left\{W - D^*, \frac{R}{2}, \frac{R}{2}, \frac{W-D^*}{D^*}\right\} & \text{if } D^* > \frac{W}{2} \end{cases} . \tag{12}$$

When $\lambda = 0$, there is no market for liquidity since there is no aggregate demand. At date 0 the market for funding opens. For a fraction γ of entrepreneurs with access to the signal, the individual demand for funding is exactly as in (4). The fraction $1 - \gamma$ of uninformed entrepreneurs instead do not invest in the risky technology because its expected net present value is negative as $R - b < 3/2$.

Hence, the aggregate demand of risky assets is

$$D^D = \begin{cases} \gamma W & \text{if } \theta = H \ \& \ r_{D,0} < R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ \gamma \phi_I W & \text{if } \theta = H \ \& \ r_{D,0} = R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ 0 & \text{otherwise} \end{cases}, \tag{13}$$

where $\phi_I W \in [0, W]$ is the investment by informed entrepreneurs when the signal is $\theta = H$.

Since only informed entrepreneurs with $\theta = H$ demand capital, financiers can infer the information content of the signal, hence the supply of funding does not change from the case with public information. In equilibrium competitive financiers must be indifferent ex-ante between financing entrepreneurs and investing in their own technology, implying that $r_{D,0}$ is as given in (7) and $D^* = D^D$ as in (13).

The next proposition summarizes the main result.

Proposition 5 (Optimal Information Disclosure). *The optimal information disclosure policy is*

$$\gamma^* = \begin{cases} [0,1] & \text{if } \sigma \in [1/2, b+2-R] \\ \frac{1}{2} & \text{if } \sigma \in (b+2-R, \widehat{\sigma}] \\ 1 & \text{if } \sigma \in (\widehat{\sigma}, 1] \end{cases}$$

where $\widehat{\sigma} = \frac{R+b}{2R-1}$ *and the corresponding social welfare is* $E\left[U^W_{\gamma^*}\right] = E\left[U^W_S\right]$.

In the proof of Proposition 5, first we characterize the competitive market equilibrium with targeted disclosure of information. Then, we maximize the corresponding social welfare to find the optimal information disclosure γ^*.

While reported in the Appendix, we omit for brevity the competitive market equilibrium with targeted disclosure of information from the main body of the paper. Intuitively, given that uninformed entrepreneurs do not invest, when $\gamma \leq 1/2$ there is no risk of capital rationing as all entrepreneurs can secure new funds if a liquidity shock occurs. If instead, γ is chosen above $1/2$, the results are only qualitatively different from those obtained in Proposition 1. As in that case, there are four cases to consider depending on the informativeness of the signal σ. The only difference is that the cutoff at which all informed entrepreneurs choose to invest is now smaller than in Proposition 1 and increasing in γ. Since only $\gamma \leq 1$ of entrepreneurs invest, the extent of capital rationing is smaller than in Proposition 1 and a lower quality of the signal is now enough to induce entrepreneurs' investment.

The equilibrium social welfare is defined as the sum of informed (I) and uninformed (U) entrepreneurs' and financiers' expected utilities. Evaluated at the optimal disclosure, the welfare function is identical to the one in Proposition 3. Hence, a financial regulator can perfectly replicate the constrained efficient solution by optimally choosing the information disclosure γ. The optimal disclosure policy increases with the quality of information. For low σ, a limited information disclosure prevents excess risk taking by effectively confining aggregate investment to informed entrepreneurs. For high σ, full information disclosure is optimal as the probability that risk taking reduces welfare becomes sufficiently low.

It is important to note that the effectiveness of the targeted information disclosure rests on the assumption that uninformed agents are unable to infer private information from observing aggregate outcomes or informed agents' individual actions. Allowing agents to condition their actions on aggregate outcomes would indeed undo the effectiveness of such a policy. However, even though outside of the model, the ability of uninformed agents to condition their actions on contemporaneous aggregate outcomes or informed agents' individual actions, can indeed be limited in reality by the existence of observational lags.

3.3 Mandatory Lines of Credit

In this section, we show that the constrained efficient outcome emerges as a competitive equilibrium when entrepreneurs have access to lines of credit at date 0. Lines of credit allow individual entrepreneurs to insure privately against the liquidity shock, thus making them independent from the market for liquidity. However, since financiers' expected profits in the competitive equilibrium without lines of credit exceed those in the constrained efficient equilibrium, lines of credit have to be mandatory.

We consider an economy identical to the one described in Section 2, where now each entrepreneur i sets up a line of credit for a total amount of capital $D_i \in [0, W]$ at date 0 and uses a fraction $\alpha_i \in [0, 1]$ at a rate $r_{D,0}$ for investment, with an option to use the remaining fraction $(1 - \alpha_i)$ at date 1 at the then prevailing market rate $r^*_{D,1}$.

3.3.1 Market for Liquidity

As in the analysis above, the equilibrium in the market for liquidity, conditional on the liquidity shock $\lambda = 1$, depends on the relation between the demand and supply of liquidity. If $L_D \leq L_S$, all entrepreneurs are able to reinvest ($\rho = 1$), the cost of liquidity is $r^*_{D,1} = 1$ and there is no renegotiation on the cost of the initial capital ($\widetilde{r}_{D,0} = r_{D,0}$); if $L_D > L_S$, instead all surplus from renegotiation is captured by the new and old financiers ($r^*_{D,1} = \widetilde{r}_{D,0} = \frac{R}{2}$) and only a fraction $\rho = \frac{L_S}{L_D}$ of the entrepreneurs is able to reinvest. In summary,

$$\left\{\rho, r^*_{D,1}, \widetilde{r}^*_{D,0}\right\} = \begin{cases} \{1, 1, r_{D,0}\} & \text{if } L_D \leq L_S \\ \left\{\frac{L_S}{L_D}, \frac{R}{2}, \frac{R}{2}\right\} & \text{if } L_D > L_S \end{cases}.$$

The critical difference in this case is that L_D and L_S depend on the individual choice of α_i. Entrepreneurs with enough unused lines of credit to cover their reinvestment needs choose to use the line of credit up to their reinvestment needs, as the return from investment is $R - \widetilde{r}^*_{D,0} - r^*_{D,1} \geq 0$. Hence, all entrepreneurs with $\alpha_i \leq \frac{1}{2}$ do not demand liquidity in the market and leave unused lines of credit for an amount $(1 - 2\alpha_i) D_i$. Entrepreneurs with not enough unused lines of credit to meet their reinvestment needs (those with $\alpha_i > \frac{1}{2}$) instead participate in the market for liquidity on the demand side, so as to cover their shortfall $(2\alpha_i - 1) D_i$.

In a symmetric equilibrium where $\alpha_i = \alpha^*$ for all i, the aggregate demand for liquidity is:

$$L_D = \max\left[(2\alpha^* - 1) D^*, 0\right],$$

while the aggregate supply of liquidity is the total amount of liquidity available to financiers including the unused lines of credit $(1 - 2\alpha^*) D^*$ and the amount invested in their own technology $W - D^*$:

$$L_S = \max\left[(1 - 2\alpha^*) D^* + (W - D^*), 0\right].$$

Hence, the equilibrium in the market for liquidity is given by

$$L^* = \begin{cases} 0 & \text{if } \alpha^* \leq \frac{1}{2} \\ (2\alpha^* - 1) D^* & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* \leq \frac{W}{4\alpha^* - 1} \\ (1 - 2\alpha^*) D^* + (W - D^*) & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* \in \left(\frac{W}{4\alpha^* - 1}, \frac{W}{2\alpha^*}\right] \\ 0 & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* > \frac{W}{2\alpha^*} \end{cases},$$

and

$$\left\{\rho, r^*_{D,1}, \widetilde{r}^*_{D,0}\right\} = \begin{cases} \{0, 1, r_{D,0}\} & \text{if } \alpha^* \leq \frac{1}{2} \\ \{1, 1, r_{D,0}\} & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* \leq \frac{W}{4\alpha^*-1} \\ \left\{\frac{W-D^*}{(2\alpha^*-1)D^*} - 1, \frac{R}{2}, \frac{R}{2}\right\} & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* \in \left(\frac{W}{4\alpha^*-1}, \frac{W}{2\alpha^*}\right] \\ \left\{0, \frac{R}{2}, \frac{R}{2}\right\} & \text{if } \alpha^* > \frac{1}{2} \ \& \ D^* > \frac{W}{2\alpha^*} \end{cases}. \tag{14}$$

3.3.2 Market for Funding

We consider next the equilibrium in the market for funding at date 0. The problem of financiers varies with α_i: if $\alpha_i \leq 1/2$, then each financier j solves

$$\max_{D^S_j \in [0,W]} \quad \begin{array}{c} D^S_j \left\{\mu_\theta \left(\alpha_i r_{D,0} + 1 - \alpha_i\right) + \left(1-\mu_\theta\right)\left[\alpha_i r_{D,0} + \left(1-\alpha_i\right) r^*_{D,1}\right]\right\} \\ + \left(W - D^S_j\right)\left[\mu_\theta + \left(1-\mu_\theta\right) r^*_{D,1}\right] \end{array}$$

while if $\alpha_i > 1/2$, then

$$\max_{D^S_j \in [0,W]} \quad \begin{array}{c} D^S_j \left\{\mu_\theta \left(\alpha_i r_{D,0} + 1 - \alpha_i\right) + \left(1-\mu_\theta\right)\left[\alpha_i \rho \widetilde{r}_{D,0} + \left(1-\alpha_i\right) r^*_{D,1}\right]\right\} \\ + \left(W - D^S_j\right)\left[\mu_\theta + \left(1-\mu_\theta\right) r^*_{D,1}\right] \end{array}$$

Financiers are indifferent between providing the line of credit and investing in their own technology only if

$$r_{D,0} = \begin{cases} \mu_\theta + \left(1-\mu_\theta\right) r^*_{D,1} & \text{if } \alpha_i \leq \frac{1}{2} \\ 1 + \frac{\left(1-\mu_\theta\right)\left(r^*_{D,1} - \rho \widetilde{r}_{D,0}\right)}{\mu_\theta} & \text{if } \alpha_i > \frac{1}{2} \end{cases}. \tag{15}$$

In this setup, entrepreneurs' problem is as follows. If entrepreneur i invests less than half of his line of credit at date 0 ($\alpha_i \leq \frac{1}{2}$), he insures himself against the liquidity shock and does not depend on the market for liquidity. Hence, the return on investment is either $\alpha_i \left(R - r_{D,0}\right)$ if there is no liquidity shock, or $\alpha_i \left(R - r^*_{D,1} - r_{D,0}\right)$ if there is a liquidity shock. If the entrepreneur invests a share $\alpha_i > 1/2$ at date 0, his return depends on the market for liquidity: the return on investment is $\alpha_i \left(R - r_{D,0}\right)$ if there is no liquidity shock, and $\alpha_i \left(R - r^*_{D,1} - \widetilde{r}_{D,0}\right)$ if there is a liquidity shock and he can secure new financing (which happens with probability ρ), otherwise he receives nothing. Hence, each entrepreneur's decision is:

$$\max_{\substack{D_i \in [0,W] \\ \alpha_i \in [0,1]}} D_i \left\{ \begin{array}{c} \alpha_i \left\{\mu_\theta \left(R - r_{D,0}\right) + \left(1-\mu_\theta\right)\left(R - r^*_{D,1} - r_{D,0}\right) - b\right\} \mathbf{1}_{\{\alpha_i \leq 1/2\}} + \\ \alpha_i \left\{\mu_\theta \left(R - r_{D,0}\right) + \rho\left(1-\mu_\theta\right)\left(R - r^*_{D,1} - \widetilde{r}_{D,0}\right) - b\right\} \mathbf{1}_{\{\alpha_i > 1/2\}} \end{array} \right\} \tag{16}$$

where $r_{D,0}$ is contingent on the choice of α_i as given in (15) and $\left\{\rho, r^*_{D,1}, \widetilde{r}^*_{D,0}\right\}$ are given in (14).

In the Appendix, we prove the following result.

Proposition 6 (Competitive Market Equilibrium with Lines of Credit). *The optimal entrepreneurs' investment is*

$$\alpha^* D^* = \begin{cases} 0 & \text{if } \sigma \in [1/2, b+2-R] \\ \frac{W}{2} & \text{if } \sigma \in (b+2-R, \widehat{\sigma}] \\ W & \text{if } \sigma \in (\widehat{\sigma}, 1] \end{cases} \tag{17}$$

where $\widehat{\sigma} = \frac{R+b}{2R-1}$ *and the corresponding social welfare is* $E\left[U^W\right] = E\left[U_S^W\right]$.

With lines of credit, the market equilibrium outcomes and corresponding social welfare are identical to those in the constrained efficient equilibrium given in Proposition 3.

4 Concluding Remarks and Discussion

This paper investigates the social value of information in an economy with aggregate liquidity shocks and incomplete contracts. In equilibrium, a negative externality in entrepreneurs' investment decisions may cause excessive risk taking in the presence of an informative public signal about the quality of the investment. Public information, while acting as "information equalizer" which reduces any information gaps among entrepreneurs, directs all entrepreneurs towards the same action and, thereby, may trigger systemic liquidity shortages. Such external effect may be damaging to the welfare of society as a whole. The negative externality arises endogenously from the competitive nature of entrepreneurs, who do not internalize the impact of their investment decisions on the equilibrium probability of liquidity shortages. The inefficiency arises from entrepreneurs' inability to fully insure against aggregate liquidity shocks. Contracts are endogenously incomplete because financiers prefer not to issue claims on their technology (which could provide ex-ante insurance to entrepreneurs) as they earn ex-post rents in the event of capital rationing.

Our results suggest a set of normative implications to tackle excessive risk taking. First, macro-prudential capital adequacy requirements can achieve constrained efficiency, provided that they are based on the resources available at the aggregate rather than at the individual level, and that they are contingent on the quality of public information. In contrast to the emphasis in the Basel Accords on a "level playing field" across nations, our analysis suggests that capital regulation should be tighter in countries where the quality of public information is worse, since it acts as a coordination device to internalize the impact of collective actions on an otherwise excessive risk of liquidity crises.

Second, lines of credit can also achieve the constrained efficient outcome as they provide entrepreneurs with means to insure privately against systemic liquidity shocks. Lines of credit must be mandatory as financiers have no incentives to supply them voluntarily to entrepreneurs, because they would otherwise lose any rent from liquidity shortages. Unlike the previous policy, the social optimality of mandatory lines of credit is independent of the quality of public information and therefore its implementation does not require an assessment of public information quality.

With optimal capital adequacy requirements or mandatory lines of credit in place, improving the quality of public information is always welfare increasing. Hence, institutions affecting the allocative efficiency in the economy including central banks and government agencies can freely focus on the achievement of their social priorities without having to decide which information to disclose or withhold from the public. However, without optimal capital adequacy requirements or mandatory lines of credit, disclosure policies become critical for the prevention of information-induced liquidity crises: targeting the disclosure of low-quality information (e.g. preliminary or incomplete data and noisy forecasts) is beneficial.

An important caveat of the above policy implications is that their social optimality rests on the Benthamite definition of social welfare as equally-weighted sum of agents' utilities. Since moving from the competitive market equilibrium to the Benthamite constrained efficient one is not a Pareto improvement (as financiers are worse off), the "true" social optimality may depend on political economy considerations, which we leave for future research.

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Appendix

Proof of Proposition 1

First, consider $D^* = W$. Then, $\rho = 0$, $r^*_{D,1} = \widetilde{r}_{D,0} = R/2$ and

$$r^*_{D,0} = 1 + \frac{(1-\mu_\theta)}{\mu_\theta}\frac{R}{2}$$

This is an equilibrium only if

$$r^*_{D,0} = 1 + \frac{(1-\mu_\theta)}{\mu_\theta}\frac{R}{2} < R - \frac{b}{\mu_\theta}$$

or $\mu_\theta > \overline{\overline{\sigma}} \equiv \frac{R+2b}{3R-2}$. Consider next $D^* = 0$. In this case, $\rho = 1$ and $r^*_{D,1} = 1$, $\widetilde{r}_{D,0} = r_{D,0}$ and $r^*_{D,0} = 1$. This is an equilibrium only if

$$1 \geq R + \frac{(1-\mu_\theta)(R-2) - b}{\mu_\theta}$$

or $\mu_\theta \leq b + 2 - R$. If instead, $\mu_\theta \in \left(b+2-R, \overline{\overline{\sigma}}\right]$, the only equilibrium (if it exists) features mixed strategies: $D^* = \phi_\theta W$. The mixed strategy equilibrium is constructed so that $r^*_{D,0}$ satisfies the following conditions:

$$r^*_{D,0} = 1 + \frac{(1-\mu_\theta)\left(r^*_{D,1} - \rho\widetilde{r}_{D,0}\right)}{\mu_\theta} \text{ and } r^*_{D,0} = R + \frac{(1-\mu_\theta)\rho\left(R - \widetilde{r}_{D,0} - r^*_{D,1}\right) - b}{\mu_\theta}$$

The only case in which a mixed strategy equilibrium exists is for $\phi_\theta > 1/2$. In fact, if $\phi_\theta \leq 1/2$, then $\rho = 1$, $r^*_{D,1} = 1$, $\widetilde{r}_{D,0} = r_{D,0}$ and the two conditions above cannot be jointly satisfied. Hence, we focus on $\phi_\theta > 1/2$. In such a case, $r^*_{D,1} = \widetilde{r}_{D,0} = R/2$ and $\rho = \frac{1-\phi_\theta}{\phi_\theta}$, thus the equilibrium condition becomes

$$1 + \frac{(1-\mu_\theta)(1-\rho)}{\mu_\theta}\frac{R}{2} = R - \frac{b}{\mu_\theta}$$

which implies

$$\phi^*_\theta = \frac{(1-\mu_\theta)R}{2\left[(1-\mu_\theta)R - \mu_\theta(R-1) + b\right]}.$$

This mixed strategy equilibrium exist only if $1/2 < \phi^*_\theta \leq 1$, which corresponds to

$$1 < \frac{(1-\mu_\theta)R}{(1-\mu_\theta)R - \mu_\theta(R-1) + b} \leq 2$$

or $\overline{\sigma} < \mu_\theta \leq \overline{\overline{\sigma}}$, where $\overline{\sigma} \equiv \frac{b}{R-1}$. Therefore, there is no equilibrium when $\mu_\theta \in (b+2-R, \overline{\sigma}]$, while the mixed strategy equilibrium only exists for $\mu_\theta \in \left(\overline{\sigma}, \overline{\overline{\sigma}}\right]$. Finally, to find the competitive equilibrium notice that when $\theta = L$, there is no investment in the risky asset as

$\mu_L = 1 - \sigma \leq \frac{1}{2} < b + 2 - R$ as by assumption $R - b < 3/2$. Conversely, when $\theta = H$, any of the four cases above is possible depending on the informativeness of the public signal σ. Proposition 1 follows by substituting $\mu_H = \sigma$ in the expressions above.

Q.E.D.

Proof of Proposition 2

The social welfare is defined as the sum of entrepreneurs' expected utility and financiers' expected profits:

$$E\left[U^W\right] = E\left(U_i\right) + E\left(U_j\right) = \sum_{\theta} \left[E\left(U_i|\theta\right) + E\left(U_j|\theta\right)\right] \Pr\left(\theta\right)$$

where

$$\begin{aligned} E\left(U_i|\theta\right) &= \begin{cases} \left[\mu_\theta\left(R - r_{D,0}\right) + \left(1-\mu_\theta\right)\rho\left(R - \widetilde{r}_{D,0} - r^*_{D,1}\right) - b\right] W & \text{if } r_{D,0} < \widehat{r}_{D,0} \\ 0 & \text{otherwise} \end{cases} \\ E\left(U_j|\theta\right) &= W\left[\mu_\theta + \left(1-\mu_\theta\right) r^*_{D,1}\right]. \end{aligned}$$

where $\widehat{r}_{D,0} \equiv R + \frac{(1-\mu_\theta)\rho\left(R - \widetilde{r}^*_{D,0} - r^*_{D,1}\right) - b}{\mu_\theta}$. Given Proposition 1, there are four cases to consider: First, if $\sigma \leq b + 2 - R$, there is no investment regardless of θ: $E\left(U_i\right) = 0$, $E\left(U_j\right) = W$ and $E\left[U^W\right] = W$. Second, if $\sigma \in \left(b + 2 - R, \overline{\sigma}\right)$, welfare is not defined because there is no equilibrium when $\theta = H$. Third, $\sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\right)$, there is partial capital rationing (when $\theta = H$). Hence,

$$E\left(U_i\right) = 0,\ E\left(U_j\right) = \frac{W}{2}\left[1 + \sigma + \frac{R}{2}\left(1-\sigma\right)\right]$$

and

$$E\left[U^W\right] = \frac{W}{2}\left[1 + \sigma + \frac{R}{2}\left(1-\sigma\right)\right].$$

Fourth, if $\sigma \in \left[\overline{\overline{\sigma}}, 1\right]$, there is complete capital rationing (when $\theta = H$). Hence,

$$\begin{aligned} E\left(U_i\right) &= \frac{W}{2}\left[\sigma\left(R-1\right) - \left(1-\sigma\right)\frac{R}{2} - b\right] \\ E\left(U_j\right) &= \frac{W}{2}\left[1 + \sigma + \frac{R}{2}\left(1-\sigma\right)\right] \end{aligned}$$

and

$$E\left[U^W\right] = \frac{W}{2}\left(\sigma R + 1 - b\right).$$

Q.E.D.

Proof of Proposition 3

We now proceed to maximize the social welfare conditional on $\theta = H$:

$$\max_{\widehat{D}\in[0,W]} \left[\sigma\left(R - r_{D,0}\right) + (1-\sigma)\,\rho\left(R - \widetilde{r}^{*}_{D,0} - r^{*}_{D,1}\right) - b\right]\widehat{D} + W\left[\sigma + (1-\sigma)\,r^{*}_{D,1}\right]$$

subject to

$$\left\{r_{D,0}, \widetilde{r}^{*}_{D,0}, r^{*}_{D,1}, \rho\right\} = \begin{cases} \{1,1,1,1\} & \text{for } \widehat{D} \leq \frac{W}{2} \\ \left\{1 + \frac{(1-\sigma)}{\sigma}\left(1 - \frac{W-\widehat{D}}{\widehat{D}}\right)\frac{R}{2}, \frac{R}{2}, \frac{R}{2}, \frac{W-\widehat{D}}{\widehat{D}}\right\} & \text{for } \widehat{D} > \frac{W}{2} \end{cases}$$

First, consider $\widehat{D} \leq \frac{W}{2}$. In this case, $\rho = r^{*}_{D,1} = \widetilde{r}^{*}_{D,0} = r_{D,0} = 1$. The maximization problem becomes

$$\max_{\widehat{D}\in[0,\frac{W}{2}]} \left[\sigma\left(R-1\right) + (1-\sigma)\left(R-2\right) - b\right]\widehat{D} + W$$

whose solution is $\widehat{D}^{*} = \frac{W}{2}$, if $\sigma > b + 2 - R$ with corresponding welfare

$$E\left[U_W|\theta = H\right] = \frac{W}{2}\left(R + \sigma - b\right).$$

and $\widehat{D}^{*} = 0$ otherwise. Consider next $\widehat{D} > \frac{W}{2}$. In this case, $\rho = \frac{W-\widehat{D}}{\widehat{D}}$, $r^{*}_{D,1} = \widetilde{r}^{*}_{D,0} = R/2$ and $r_{D,0} = 1 + \frac{1-\sigma}{\sigma}\left(1 - \frac{W-\widehat{D}}{\widehat{D}}\right)\frac{R}{2}$. The maximization problem becomes

$$\max_{\widehat{D}\in\left(\frac{W}{2},W\right]} \left[\sigma\left(R-1\right)\widehat{D} - (1-\sigma)\left(2\widehat{D} - W\right)\frac{R}{2} - b\widehat{D}\right] + W\left[\sigma + (1-\sigma)\frac{R}{2}\right].$$

which is linear in $\widehat{D}$. Hence, there is no internal maximum. If $\widehat{D} = W$, then

$$E\left[U_W|\theta = H\right] = W\left(\sigma R - b\right)$$

If $\widehat{D} \to \frac{W}{2}$, then $E\left[U_W|\theta = H\right] \to \frac{W}{2}\left(R + \sigma - b\right)$, as in the case $\widehat{D} = \frac{W}{2}$. Comparing the welfare functions above, we find that the optimal choice is $\widehat{D} = W$ when

$$\sigma > \widehat{\sigma} \equiv \frac{R+b}{2R-1}.$$

Hence, the aggregate borrowing is

$$\widehat{D}^{*} = \begin{cases} 0 & \text{if } \sigma \in [1/2, b+2-R] \\ \frac{W}{2} & \text{if } \sigma \in (b+2-R, \widehat{\sigma}] \\ W & \text{if } \sigma \in (\widehat{\sigma}, 1] \end{cases}.$$

Q.E.D.

Proof of Proposition 4

The structure of the proof is as follows. First, we derive the competitive market equilibrium under capital restrictions. Then, we derive the social welfare; and finally we solve for the optimal capital requirements.

(i) The market equilibrium must satisfy the following conditions:

$$\left\{L^*,\widetilde{r}^*_{D,0},r^*_{D,1},\rho^*,r^*_{D,0}\right\}=\begin{cases}\left\{D^*,r^*_{D,0},1,1,1\right\} & \text{if } D^*\le\frac{W}{2}\\ \left\{W-D^*,\frac{R}{2},\frac{R}{2},\frac{W-D^*}{D^*},1+\frac{(1-\mu_\theta)}{\mu_\theta}\left(1-\frac{W-D^*}{D^*}\right)\frac{R}{2}\right\} & \text{if } D^*>\frac{W}{2}\end{cases}$$

along with the market clearing condition

$$D^*=D^D=\begin{cases}\overline{D} & \text{if } \theta=H \;\&\; r_{D,0}<R+\frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma}\\ \phi_H\overline{D} & \text{if } \theta=H \;\&\; r_{D,0}=R+\frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma}\\ 0 & \text{otherwise}\end{cases}.$$

First, consider $D^*\le\frac{W}{2}$. This is an equilibrium if $\theta=L$, if $(\theta=H \;\&\; \sigma\le b+2-R)$ or if $\left(\theta=H \;\&\; \overline{D}\le W/2\right)$. Consider next $D^*>W/2$. In this case, $\widetilde{r}^*_{D,0}=r^*_{D,1}=R/2$ and $\rho^*=\frac{W-D^*}{D^*}$. This is an equilibrium only if $\theta=H \;\&\; \overline{D}>W/2$. For the equilibrium in pure strategies $(D^*=\overline{D})$ to exist

$$1+\frac{1-\sigma}{\sigma}\left(1-\frac{W-\overline{D}}{\overline{D}}\right)\frac{R}{2}<R-\frac{b}{\sigma}$$

or

$$\sigma>\frac{\left(2\overline{D}-W\right)R+2b\overline{D}}{2\overline{D}\left(R-1\right)+\left(2\overline{D}-W\right)R}\equiv\overline{\overline{\sigma}}\left(\overline{D}\right)$$

where $\overline{\overline{\sigma}}\left(\overline{D}\right)$ is strictly increasing in $\overline{D}$ and converges to $\overline{\overline{\sigma}}$ as $\overline{D}\to W$. If instead, $\overline{\sigma}<\sigma<\overline{\overline{\sigma}}\left(\overline{D}\right)$ the only equilibrium is in mixed strategies with ϕ_H such that

$$1+\frac{1-\sigma}{\sigma}\left(1-\frac{W-\phi_H\overline{D}}{\phi_H\overline{D}}\right)\frac{R}{2}=R-\frac{b}{\sigma}$$

that is

$$\phi_H=\frac{(1-\sigma)\,R}{(1-\sigma)\,R+b-\sigma\,(R-1)}\frac{W}{2\overline{D}}$$

and $r^*_{D,0}=R-\frac{b}{\sigma}$. Notice that there is no equilibrium if $\sigma\in(b+2-R,\overline{\sigma})$ as $\phi_H\overline{D}>W/2$ must hold.

(ii) The social welfare is defined as the sum of entrepreneurs' expected utility and financiers' expected profits. Given the results above, there are the following cases to consider. When

$\sigma \in \left[\frac{1}{2}, b+2-R\right]$, there is no investment regardless of θ and

$$E\left(U_i\right)=0,\ E\left(U_j\right)=W \text{ and } E\left[U^W\right]=W.$$

If $\overline{D} \leq W/2$ and $\sigma \in (b+2-R, 1]$, there is investment with no rationing. Hence,

$$E\left(U_i\right)=\frac{\overline{D}}{2}\left[R-2+\sigma-b\right] \text{ and } E\left(U_j\right)=W,$$

which imply

$$E\left[U^W\right]=\frac{\overline{D}}{2}\left[R-2+\sigma-b\right]+W.$$

When $\overline{D} > W/2$ and $\sigma \in (b+2-R, \overline{\sigma})$, there is no equilibrium. Hence, welfare is not defined. If instead $\sigma \in \left[\overline{\sigma}, \overline{\overline{\sigma}}\left(\overline{D}\right)\right]$, there is a mixed-strategy equilibrium with partial capital rationing. Hence,

$$E\left(U_i\right)=0,\ E\left(U_j\right)=\frac{W}{2}\left[(1+\sigma)+(1-\sigma)\frac{R}{2}\right],$$

which imply

$$E\left[U^W\right]=\frac{W}{2}\left[(1+\sigma)+(1-\sigma)\frac{R}{2}\right].$$

If $\sigma > \overline{\overline{\sigma}}\left(\overline{D}\right)$, there is a pure-strategy equilibrium with complete capital rationing. Hence,

$$\begin{aligned} E\left(U_i\right) &= \frac{1}{2}\left[\sigma(R-1)\overline{D}-(1-\sigma)\left(2\overline{D}-W\right)\frac{R}{2}-b\overline{D}\right] \\ E\left(U_j\right) &= \frac{W}{2}\left[(1+\sigma)+(1-\sigma)\frac{R}{2}\right] \end{aligned}$$

which imply

$$E\left[U^W\right]=\left[\sigma(R-1)-(1-\sigma)R-b\right]\frac{\overline{D}}{2}+\frac{W}{2}\left[(1+\sigma)+(1-\sigma)R\right].$$

(iii) Notice that the social welfare is unaffected by $\overline{D}$ when $\sigma \in \left[\frac{1}{2}, b+2-R\right]$, thus the optimal capital requirement is $\overline{D}^* \in [0, W]$. When $\sigma \in (b+2-R, \overline{\sigma})$, the optimal choice is $\overline{D}^* = W/2$ as the social welfare is strictly increasing in $\overline{D}$ for $\overline{D} \leq W/2$ and it is not defined if $\overline{D} > W/2$. The corresponding social welfare is

$$E\left[U^W_{\overline{D}^*}\right]=\frac{W}{4}\left[R+2+\sigma-b\right]$$

When $\sigma \in \left(\overline{\sigma}, \overline{\overline{\sigma}}\left(\overline{D}\right)\right]$, the optimal choice is $\overline{D}^* = W/2$ as

$$\frac{W}{4}\left[R+2+\sigma-b\right] > \frac{W}{2}\left[(1+\sigma)+(1-\sigma)\frac{R}{2}\right] \text{ for } \sigma > \overline{\sigma}.$$

Furthermore, for $\sigma \in \left(\overline{\overline{\sigma}}\left(\overline{D}\right), 1\right]$ and $\overline{D} > W/2$, we have that

$$\frac{\partial E\left[U^W_{\overline{D}}\right]}{\partial \overline{D}} = \frac{1}{2}\left[\sigma\left(R-1\right) - \left(1-\sigma\right)R - b\right] > 0 \text{ iff } \sigma > \widehat{\sigma}$$

where $\widehat{\sigma} = \frac{R+b}{2R-1} > \overline{\overline{\sigma}}\left(\overline{D}\right)$, $\forall \overline{D}$. Therefore, for $\sigma \in \left(\overline{\overline{\sigma}}\left(\overline{D}\right), \widehat{\sigma}\right]$, $\overline{D}^* = W/2$. When $\sigma \in (\widehat{\sigma}, 1]$, $\overline{D}^* = W$ as

$$\frac{W}{4}\left[R+2+\sigma-b\right] < \max_{\frac{W}{2}<\overline{D}\leq W}\left[\sigma\left(R-1\right)-\left(1-\sigma\right)R-b\right]\frac{\overline{D}}{2} + \frac{W}{2}\left[\left(1+\sigma\right)+\left(1-\sigma\right)R\right].$$

Hence, the optimal capital requirement $\overline{D}^*$ is given in Proposition 4. Finally, evaluating the equilibrium social welfare at $\overline{D}^*$leads to $E\left[U^W_{\overline{D}^*}\right] = E\left[U^W_S\right]$.

Q.E.D.

Proof of Proposition 5

The structure of the proof is as in Proposition 4. First, we find the competitive market equilibrium under partial dissemination of information. Then, we derive the social welfare; and finally we solve for the optimal dissemination policy.

(i) The market equilibrium must satisfy the following conditions:

$$\left\{L^*, \widetilde{r}^*_{D,0}, r^*_{D,1}, \rho^*, r^*_{D,0}\right\} = \begin{cases} \left\{D^*, r^*_{D,0}, 1, 1, 1\right\} & \text{if } D^* \leq \frac{W}{2} \\ \left\{W - D^*, \frac{R}{2}, \frac{R}{2}, \frac{W-D^*}{D^*}, 1 + \frac{(1-\mu_\theta)}{\mu_\theta}\left(1 - \frac{W-D^*}{D^*}\right)\frac{R}{2}\right\} & \text{if } D^* > \frac{W}{2} \end{cases}$$

along with the market clearing condition

$$D^* = D^D = \begin{cases} \gamma W & \text{if } \theta = H \ \&\ r_{D,0} < R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ \gamma\phi_I W & \text{if } \theta = H \ \&\ r_{D,0} = R + \frac{(1-\sigma)\rho\left(R-\widetilde{r}_{D,0}-r^*_{D,1}\right)-b}{\sigma} \\ 0 & \text{otherwise} \end{cases}.$$

First, consider $D^* \leq \frac{W}{2}$. This is an equilibrium if $\theta = L$, if $(\theta = H \ \&\ \sigma \in [1/2, b+2-R])$ or if $(\theta = H \ \&\ \gamma \leq 1/2)$. Consider next $D^* > \frac{W}{2}$. In this case, $\widetilde{r}^*_{D,0} = r^*_{D,1} = R/2$ and $\rho = \frac{W-D^*}{D^*}$. This is an equilibrium only if $\theta = H \ \&\ \gamma > 1/2$ &

$$1 + \frac{(1-\sigma)}{\sigma}\left(1 - \frac{W-D^*}{D^*}\right)\frac{R}{2} \leq R - \frac{b}{\sigma}.$$

For the equilibrium with $D^* = \gamma W$ to exist

$$\left(1-\sigma\right)\frac{(2\gamma-1)}{\gamma}R \leq 2\sigma\left(R-1\right) - 2b$$

or

$$\sigma \geq \frac{2b + \left(2 - \frac{1}{\gamma}\right) R}{\left(4 - \frac{1}{\gamma}\right) R - 2} \equiv \overline{\overline{\sigma}}\left(\gamma\right)$$

where $\sigma\left(\gamma\right)$ is strictly increasing in γ and converges to $\overline{\overline{\sigma}}$ as $\gamma \to 1$. If instead,

$$\overline{\overline{\sigma}}\left(\gamma\right) > \sigma > \overline{\sigma}$$

the only equilibrium is with $D^* = \gamma\phi_I W$ such that

$$1 + \frac{1-\sigma}{\sigma}\left(1 - \frac{1-\gamma\phi_I}{\gamma\phi_I}\right)\frac{R}{2} = R - \frac{b}{\sigma}$$

or

$$\gamma\phi_I = \frac{1}{2}\frac{\left(1-\sigma\right)R}{\left(1-\sigma\right)R + b - \left(R-1\right)\sigma}$$

and $r^*_{D,0} = R - \frac{b}{\sigma}$. Notice that there is no equilibrium if $\sigma < \overline{\sigma}$ as $\gamma\phi_I$ must be greater than 1/2.

(ii) The social welfare is defined as before as the sum of entrepreneurs' expected utility and financiers' expected profits. Given the results above, there are the following cases to consider. When $\gamma \leq \frac{1}{2}$ and $\sigma \in [1/2, b + 2 - R]$, there is no investment regardless of θ. Thus

$$E\left(U_I\right) = E\left(U_U\right) = 0,\ E\left(U_j\right) = W \text{ and } E\left[U^W\right] = W.$$

If $\gamma \leq \frac{1}{2}$ and $\sigma \in (b + 2 - R, 1]$, the informed entrepreneurs invest when $\theta = H$ and there is no rationing. Hence,

$$E\left(U_I\right) = \frac{W}{2}\left[\sigma - \left(b + 2 - R\right)\right],\ E\left(U_U\right) = 0 \text{ and } E\left(U_j\right) = W,$$

which imply

$$E\left[U^W\right] = \frac{W}{2}\left[\gamma\left(R - 2 + \sigma - b\right) + 2\right]. \tag{A1}$$

When $\frac{1}{2} < \gamma \leq 1$ and $\sigma \in [1/2, b + 2 - R]$, there is no investment regardless of θ, and thus

$$E\left(U_I\right) = E\left(U_U\right) = 0,\ E\left(U_j\right) = W \text{ and } E\left[U^W\right] = W.$$

If $\frac{1}{2} < \gamma \leq 1$ and $\sigma \in (b + 2 - R, \overline{\sigma}]$, there is no equilibrium. Hence, welfare is not defined. If instead $\sigma \in \left(\overline{\sigma}, \overline{\overline{\sigma}}\left(\gamma\right)\right]$, there is a mixed-strategy equilibrium with partial capital rationing. Hence,

$$E\left(U_I\right) = E\left(U_U\right) = 0,\ E\left(U_j\right) = \frac{W}{2}\left[1 + \sigma + \left(1-\sigma\right)\frac{R}{2}\right],$$

which imply

$$E\left[U^W\right] = \frac{W}{2}\left[1+\sigma+(1-\sigma)\frac{R}{2}\right]. \tag{A2}$$

If $\frac{1}{2} < \gamma \leq 1$ and $\sigma \in \left(\overline{\overline{\sigma}}\left(\gamma\right),1\right]$, there is a pure-strategy equilibrium with partial capital rationing. Hence,

$$\begin{aligned}
E\left(U_I\right) &= \frac{W}{2}\left[\sigma\left(R-1\right)-\left(1-\sigma\right)\left(1-\frac{1-\gamma}{\gamma}\right)\frac{R}{2}-b\right] \\
E\left(U_U\right) &= 0 \\
E\left(U_j\right) &= \frac{W}{2}\left[1+\sigma+\left(1-\sigma\right)\frac{R}{2}\right]
\end{aligned}$$

which imply

$$E\left[U^W\right] = \frac{W}{2}\left[\gamma\sigma\left(R-1\right)+\left(1-\sigma\right)\left(1-\gamma\right)R+1+\sigma-\gamma b\right]. \tag{A3}$$

(iii) We now proceed to maximize the social welfare with respect to the degree of public information dissemination γ:

$$\max_{0\leq\gamma\leq1} E\left[U^W_\gamma\right]$$

where the expected social welfare is given in (A1), (A2) and (A3). First, for $\sigma \in \left[\frac{1}{2}, b+2-R\right]$, the expected welfare is insensitive to changes in γ, thus the optimal degree of dissemination is $\gamma^* \in [0,1]$. Then, we focus on $\sigma \in (b+2-R,1]$. When $\gamma \leq \frac{1}{2}$, the maximization problem becomes:

$$\max_{0\leq\gamma\leq\frac{1}{2}} \frac{W}{2}\left[\gamma\left(R-2+\sigma-b\right)+2\right]$$

whose solution is $\gamma^* = \frac{1}{2}$, with corresponding welfare

$$E\left[U^W_{\gamma^*}\right] = \frac{W}{4}\left(R+2+\sigma-b\right). \tag{A4}$$

When $\frac{1}{2} < \gamma \leq 1$, the maximization problem becomes

$$\max_{\frac{1}{2}<\gamma\leq1} \begin{cases} \text{Not defined} & \text{if } \sigma \in \left(b+2-R,\overline{\sigma}\right] \\ \frac{W}{2}\left[1+\sigma+\left(1-\sigma\right)\frac{R}{2}\right] & \text{if } \sigma \in \left(\overline{\sigma},\overline{\overline{\sigma}}\left(\gamma\right)\right] \\ \frac{W}{2}\left[\gamma\sigma\left(R-1\right)+\left(1-\sigma\right)\left(1-\gamma\right)R+1+\sigma-\gamma b\right] & \text{if } \sigma \in \left(\overline{\overline{\sigma}}\left(\gamma\right),1\right] \end{cases}.$$

When $\sigma \in \left(\overline{\sigma},\overline{\overline{\sigma}}\left(\gamma\right)\right]$, $\gamma^* = \frac{1}{2}$ as

$$\frac{W}{4}\left(R+2+\sigma-b\right) > \frac{W}{2}\left[1+\sigma+\left(1-\sigma\right)\frac{R}{2}\right] \text{ for } \sigma > \overline{\sigma}.$$

Furthermore, for $\sigma \in \left(\overline{\overline{\sigma}}(\gamma), 1\right]$, we have that

$$\frac{\partial E\left[U_{\gamma}^{W}\right]}{\partial\gamma} = \frac{W}{2}\left[\sigma(R-1)-(1-\sigma)R-b\right] > 0 \text{ iff } \sigma > \widehat{\sigma}$$

where $\widehat{\sigma} = \frac{R+b}{2R-1} > \overline{\overline{\sigma}}(\gamma)$, $\forall\gamma$. Therefore, for $\sigma \in \left(\overline{\overline{\sigma}}(\gamma), \widehat{\sigma}\right]$, $\gamma^* = \frac{1}{2}$. When $\sigma \in (\widehat{\sigma}, 1]$, $\gamma^* = 1$ as

$$\frac{W}{4}(R+2+\sigma-b) < \max_{\frac{1}{2}<\gamma\leq 1} \frac{W}{2}\left[\gamma\sigma(R-1)+(1-\sigma)(1-\gamma)R+1+\sigma-\gamma b\right].$$

Hence, the optimal degree of publicity γ^* is given in Proposition 4. Finally, evaluating the equilibrium social welfare at γ^* leads to $E\left[U_{\gamma^*}^{W}\right] = E\left[U_{S}^{W}\right]$.

Q.E.D.

Proof of Proposition 6

Given the rates (15), entrepreneur i's decision problem in equation (16) becomes:

$$\max_{\substack{D_i\in[0,W]\\ \alpha_i\in[0,1]}} \alpha_i D_i \left\{ \begin{array}{c} \left[R-\mu_\theta-2(1-\mu_\theta)r_{D,1}^{*}-b\right]\mathbf{1}_{\{\alpha_i\leq 1/2\}}+ \\ \left[\mu_\theta(R-1)-(1-\mu_\theta)r_{D,1}^{*}(1+\rho)+\rho(1-\mu_\theta)R-b\right]\mathbf{1}_{\{\alpha_i>1/2\}} \end{array} \right\}$$

First, notice that $D_i^* = W$ whenever $\alpha_i^* > 0$ and D_i^* is indeterminate whenever $\alpha_i^* = 0$. This follows from the observation that the derivative of the entrepreneur's objective function with respect to D_i is strictly positive if the optimal choice of α_i is strictly positive (i.e. $\alpha_i^* > 0$) and it is 0 if $\alpha_i^* = 0$. Hence, we can assume without loss of generality that $D_i^* = W$, so that we can concentrate on the choice of α_i (since the case where D_i^* is indeterminate because $\alpha_i^* = 0$ is not particularly insightful). Comparing these payoffs, the optimal choice of investment in the risky technology is:

$$\alpha_i^* = \begin{cases} 1 & \text{if } \mu_\theta > \frac{R+b-2\rho\left(R-r_{D,1}^{*}\right)}{2R-1-2\rho\left(R-r_{D,1}^{*}\right)} \\ \left\{\frac{1}{2},1\right\} & \text{if } \mu_\theta = \frac{R+b-2\rho\left(R-r_{D,1}^{*}\right)}{2R-1-2\rho\left(R-r_{D,1}^{*}\right)} \\ \frac{1}{2} & \text{if } \mu_\theta \in \left(\frac{2r_{D,1}^{*}-R+b}{2r_{D,1}^{*}-1}, \frac{R+b-2\rho\left(R-r_{D,1}^{*}\right)}{2R-1-2\rho\left(R-r_{D,1}^{*}\right)}\right) \\ \left\{0,\frac{1}{2}\right\} & \text{if } \mu_\theta = \frac{2r_{D,1}^{*}-R+b}{2r_{D,1}^{*}-1} \\ 0 & \text{if } \mu_\theta < \frac{2r_{D,1}^{*}-R+b}{2r_{D,1}^{*}-1} \end{cases}.$$

Hence, in a symmetric equilibrium $\alpha_i^* = \alpha^*$,

$$\left\{\rho, r_{D,1}^{*}, \widetilde{r}_{D,0}\right\} = \begin{cases} \left\{0, 1, r_{D,0}\right\} & \text{if } \alpha^* \leq \frac{1}{2} \\ \left\{0, \frac{R}{2}, \frac{R}{2}\right\} & \text{if } \alpha^* > \frac{1}{2} \end{cases}$$

and therefore:

$$\alpha^* = \begin{cases} 1 & \text{if } \mu_\theta \geq \frac{R+b}{2R-1} \\ \frac{1}{2} & \text{if } \mu_\theta \in \left[2-R+b, \frac{R+b}{2R-1}\right) \\ 0 & \text{if } \mu_\theta < 2-R+b \end{cases}$$

where we have broken the indifference cases by assuming that entrepreneurs prefer to invest in the risky investment when indifferent.

To complete the analysis, recall that $\mu_\theta = \sigma$ if $\theta = H$ and $\mu_\theta = 1-\sigma$ if $\theta = L$. When $\theta = L$, there is no investment in the risky asset as $\mu_L = 1-\sigma \leq \frac{1}{2} \leq b+2-R$ as by assumption $R-b \leq 3/2$. Conversely, when $\theta = H$, any of the three cases above is possible depending on the informativeness of the public signal σ.

Q.E.D.

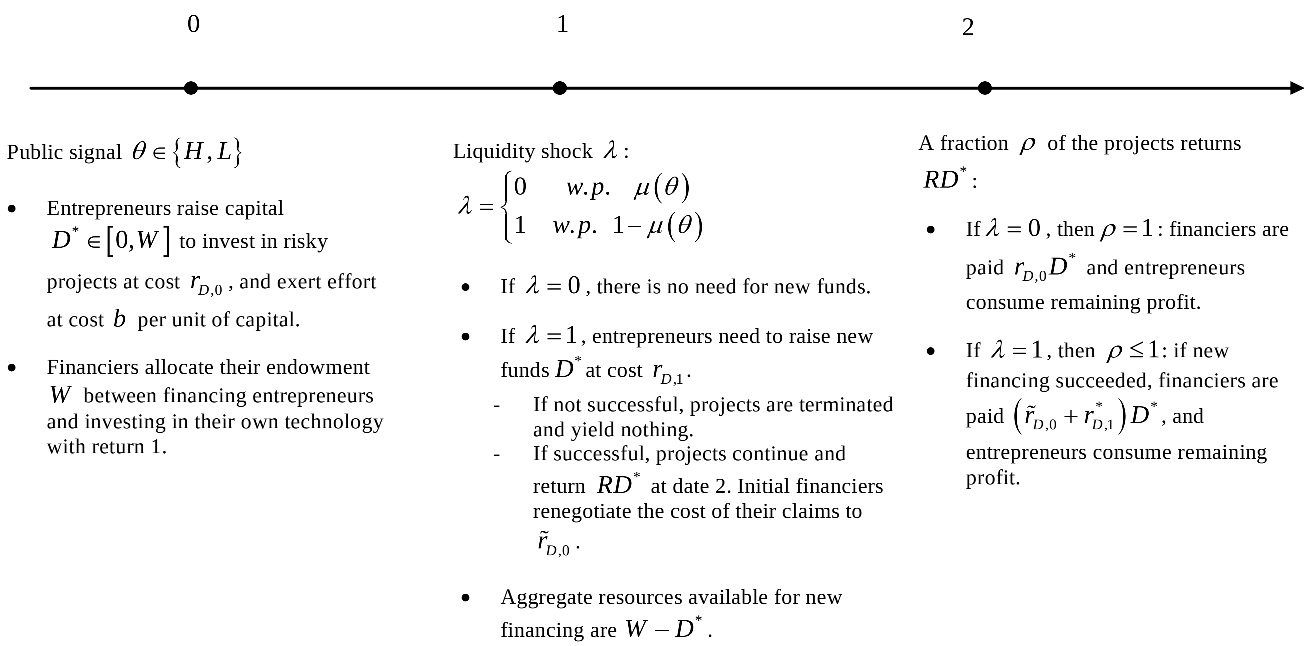

Figure 1: Timeline, Actions and Payoffs

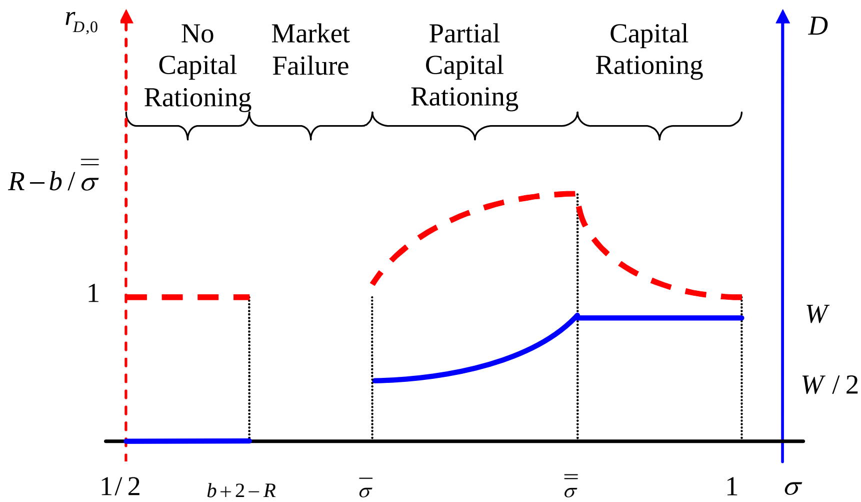

Figure 2: Market for funding conditional on $\theta = H$. Equilibrium $r^*_{D,0}$ (dashed line) and D^* (solid line) as functions of public signal's informativeness σ.

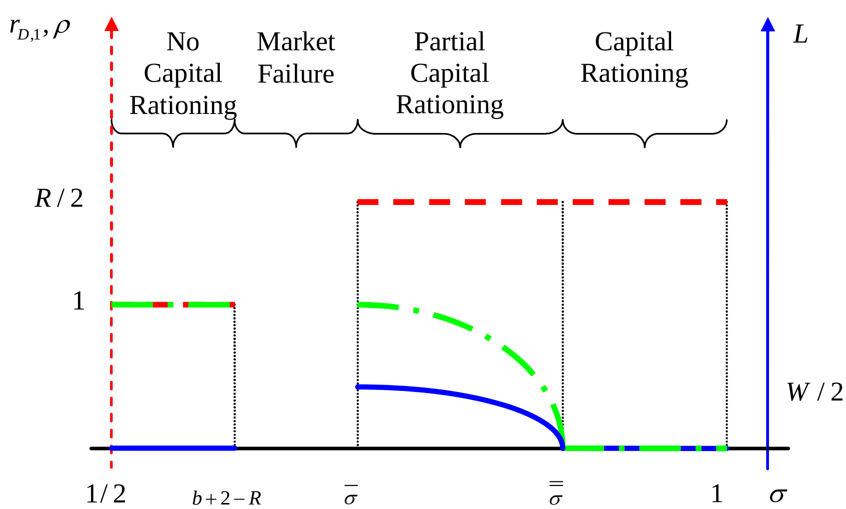

Figure 3: Market for liquidity conditional $\theta = H$ and $\lambda = 1$. Equilibrium $r^*_{D,1}$ (dashed line), L^* (solid line) and ρ^* (dashed-dotted line) as functions of public signal's informativeness σ.

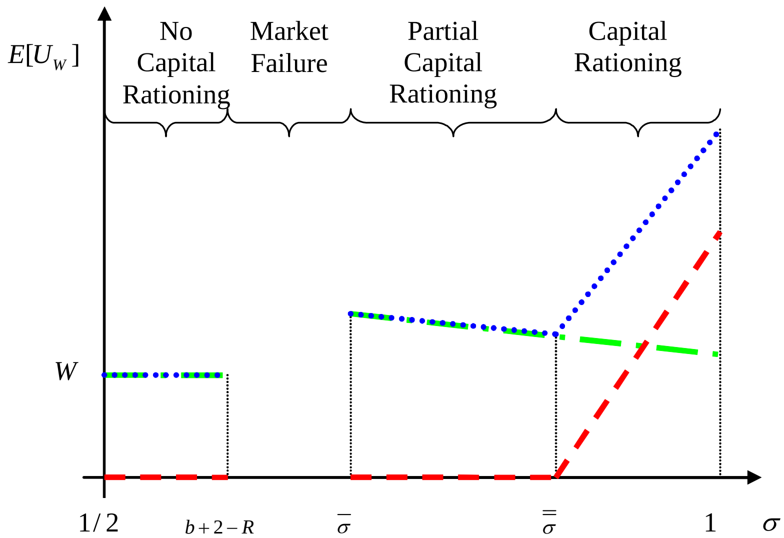

Figure 4: Ex-ante social welfare (dotted line), entrepreneurs' expected utility (dashed line) and financiers' expected utility (dashed-dotted line) in the competitive equilibrium as functions of public signal's informativeness σ.

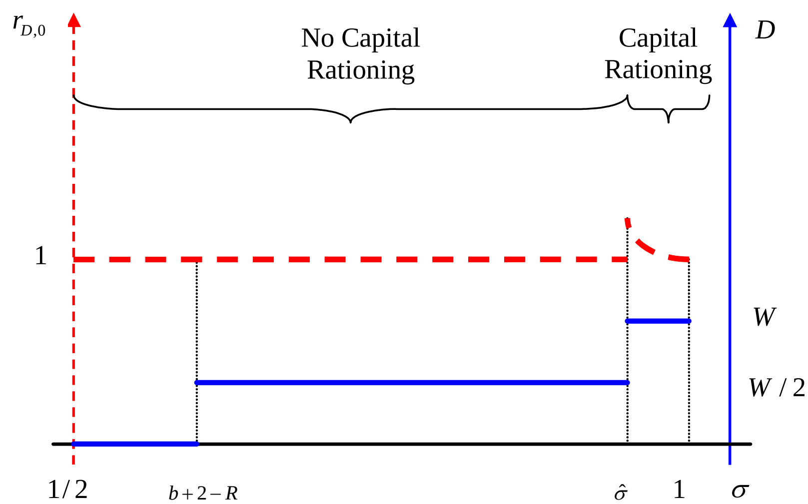

Figure 5: Market for funding under constrained efficient equilibrium conditional on $\theta = H$. Equilibrium $r^*_{D,0}$ (dashed line) and D^* (solid line) as functions of public signal's informativeness σ.

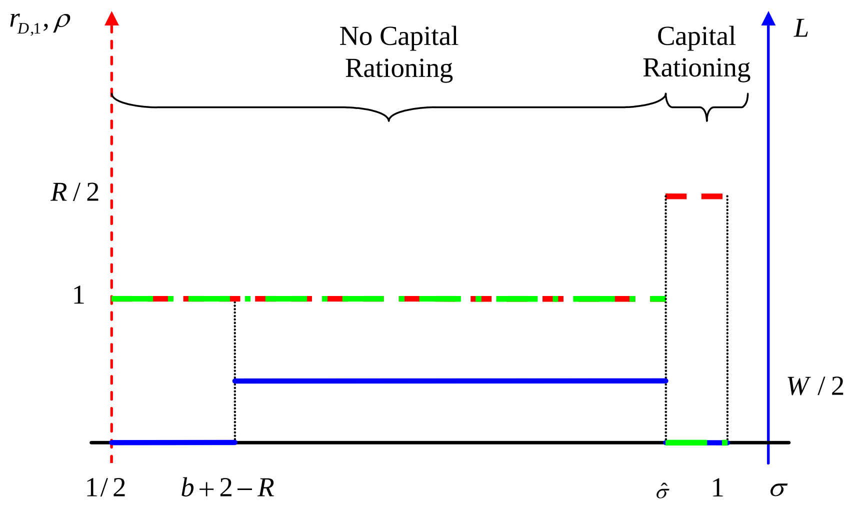

Figure 6: Market for liquidity under constrained efficient equilibrium conditional on $\theta = H$ and $\lambda = 1$. Equilibrium $r^*_{D,1}$ (dashed line), L^* (solid line) and ρ^* (dashed-dotted line) as functions of public signal's informativeness σ.

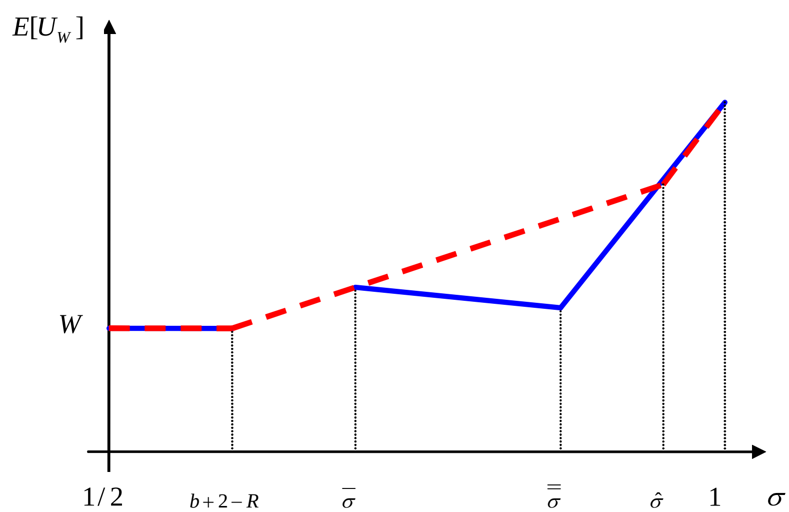

Figure 7: Social welfare in the competitive market equilibrium (solid line) and in the constrained efficient equilibrium (dashed line) as functions of public signal's informativeness σ.