Crises and Capital Requirements in Banking*

Forthcoming, *American Economic Review*

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March, 2005

*An earlier version of this paper was circulated as "The Role of Capital Adequacy Requirements in Sound Banking Systems." We thank Mathias Dewatripont, Douglas Diamond, Mariassunta Gianetti, Thomas Marriotti, Charles Goodhart, Denis Gromb, Michael Manove, Colin Mayer, Meg Meyer, Bruno Parigi, Patrick Rey, Jean-Charles Rochet, Jean Tirole, Jukka Vesala, and Andrew Winton for their comments and also seminar participants at Nuffield College, the Saïd Business School, the June 2001 CEPR Tenerife conference on Regulation of Financial Institutions, ESSFM Gerzensee 2001, the Bank of England, EFA Barcelona 2001, EEA Lausanne 2001, the London School of Economics, Mannheim University, Birkbeck College, Carnegie Mellon University, the University of Maryland, the University of Lausanne, Imperial College, London Business School, Washington University, the Anderson School (UCLA) and the Wharton School (University of Pennsylvania).

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Crises and Capital Requirements in Banking

Abstract

We analyze a general equilibrium model in which there is both adverse selection of and moral hazard by banks. The regulator can screen banks prior to giving them a licence, audit them ex post to learn the success probability of their projects, and impose capital adequacy requirements. Capital requirements combat moral hazard when the regulator has a strong screening reputation, and they otherwise substitute for screening ability. Crises of confidence can occur only in the latter case, and contrary to conventional wisdom, the appropriate policy response may be to tighten capital requirements to improve the quality of surviving banks.
Keywords: Capital requirements, banking crises.
JEL Classification: D51, D82, E58, G21

1. Introduction

Despite more than a decade of enforcement of the Basle Capital Adequacy Accord, the precise mechanism through which capital regulation promotes the stability of the banking system is still poorly understood. Moreover, the regulatory response to various different banking crises seems to be quite diverse. In turbulent times, should capital requirements be loosened to help struggling banks (as arguably happened in the savings and loans crisis), or should they be tightened to discourage desperate banks from undertaking further risky activities? In this paper we set up a general equilibrium model in which we attempt to explore these questions.

Two main theories predominate as to the role which capital requirements play. The first of these, which we may informally call the "moral hazard" theory, is most closely associated with economic theorists as well as public choice economists.[1] The idea is that if banks do not have sufficient equity "at stake" when they make their investment decisions then they may make decisions which, though optimal for equity-holders, are suboptimal from the point of view of society as a whole.[2] For example, banks may be tempted to make excessively risky and even negative net present value investments which maximize the returns to equity at the expense of debt-holders or the deposit insurance fund.

The second theory, which we might call the "safety net" theory, is more associated with practitioners, and, as far as we are aware, this intuitive idea has yet to be formally modelled.[3] It is the

[1] See for example, Bhattacharya (1982), Rochet (1992).

[2] In this literature, banks are generally assumed to act in the interest of shareholders; either because the models explicitly assume pure entrepreneurial banks, or (implicitly) because managers hold shares or options. See Dewatripont and Tirole (1994) for a rationale.

[3] Closely related to this intuitive idea is the literature arguing that capital requirements can be used to prevent destructive bank runs (Diamond and Dybvig, 1983; Dowd, 1993; Diamond and Rajan, 2000), though these theories, as stated, do not have any role for the *regulation* of capital. Probably the closest formal model to the 'safety net'

idea that a bank's capital forms a kind of cushion against losses for depositors. One might loosely capture this idea by saying that if the bank starts to lose money, equity value must fall to zero before debt-holders start to lose, so depositors cannot lose out if regulation ensures that the bank must be closed or recapitalized before this occurs.

Our theory incorporates both of these rationales for capital regulation, and also a third. Intuitively, capital regulation should have the desirable effect of discouraging unsound and unreliable institutions from setting up operations. We show that indeed this idea provides a further rationale for capital regulation: capital requirements can be used to solve adverse selection problems. In doing so we address some interesting issues.

Firstly, we examine the role of the banking regulator. We show that the presence of moral hazard in the banking system means that competent bankers must receive a rent to reward them for investing and monitoring other agents' deposits. Depositors, however, do not fully take account of this rent when deciding whether to deposit in banks or not. Thus from a social point of view, depositors are generally insufficiently willing to deposit, so any sound banking system will be smaller than is socially optimal. The regulator's role is therefore to take actions which, for given bank quality, maximize the size of the banking sector. This represents a rather broader view of the regulator's remit than that found in some of the existing literature (e.g. Dewatripont and Tirole, 1993*a*, 1993*b*), where the regulator simply represents the interests of depositors who are too dispersed and ill-informed to represent themselves.

Secondly, if a regulator wishes to use capital requirements to select out bad banks from the system she will have to set capital requirements more tightly than if she desired simply to solve the moral hazard problem of "gambling" by undercapitalized banks.[4] Thus solving adverse selection problems has a cost in terms of a banking system which is smaller (though on average more productive) than it otherwise would be. Regulators with a good ability to audit banks *ex ante* should therefore prefer the alternative of following a looser capital policy which merely solves the moral hazard problem, while relying on their own auditing skill to avoid chartering unsound banks. Regulators with a poor reputation, on the other hand, should adopt a tight regulatory policy, because by doing so they will gain more in average bank quality than they will lose in bank size. Thus, in contrast to the Basle Accord's emphasis on a "level playing field" across nations,[5] we suggest that capital regulation should be tighter in countries where regulator reputation is worse, since it is in effect a substitute for regulator auditing ability.

Thirdly, the regulator's ability to audit at the *interim* stage and determine in advance of their realization the likely outcome of banks' investments has an interesting interaction with the above policy prescription. In general, the more *transparent* are banks' investments (i.e. the easier it is for a regulator to determine early that investments are unprofitable), the looser capital requirements

theory is Dewatripont and Tirole (1993*b*). Their story is however much more focused on providing incentives for those managing banks. For an overview of different theories of banking regulation see Freixas and Rochet (1997) and Gorton and Winton (2002).

[4]For a description of how such gambling occurred in the S&L crisis, see Kane (1989*b*). Rather than allow our banks to gamble *per se*, we will allow them to fail to make effort to monitor their projects, reducing expected returns. In our simplified risk-neutral environment, the effect of this form of moral hazard is similar but more tractable.

[5]The importance of internationally level playing fields is stressed in the original 1988 Basle Accord (paragraph 3) and in the context of the proposed modifications to the Accord (Basle Committee 2002, paragraph 12) .

can be set. In our model, if the regulator recognizes bad investments early, then she can step in and redistribute all of their returns to depositors before bank shareholders benefit from them. A high probability of such regulatory intervention will reduce the likelihood that bad banks will benefit from bad investments and will thus alleviate both moral hazard and adverse selection problems. It will also render depositing more attractive. This feature of the model therefore incorporates the "safety net" theory of capital regulation, because a diminished equity base reduces the amount of capital which can be redistributed from shareholders to depositors in the event of bad behavior.

Fourthly, we show that when capital requirements are used to solve adverse selection problems, the economy exhibits multiple equilibria. This is because agents with capital can choose whether to use it to set up and manage a bank, to use it to run their own project, or to deposit it with another agent who may be able to invest it more productively than they can. The equilibrium therefore depends on agents' expectations about the quality of applicants for banking licences. If agents are *pessimistic* about the quality of applicants then the average quality of the financial system will be low and agents will be unwilling to deposit their capital with banks, preferring instead to use it to set up their own banks. Thus in equilibrium all agents with capital apply for licences, the average quality of successful applicants is low, and the pessimistic expectations are confirmed. On the other hand, if agents are *optimistic* about the quality of licence applicants they will anticipate a high quality banking system. Agents who lack ability in managing funds will therefore choose to deposit their capital in a bank rather than to set up a bank, thus confirming the high quality of the banking sector.

Notice that the solution of the adverse selection problem in a pessimistic economy requires setting capital requirements more tightly than the solution of the adverse selection problem in an optimistic economy, since pessimistic beliefs about the banking sector make unsound agents more inclined to apply for a banking licence. We interpret a switch between optimistic and pessimistic beliefs as a *crisis of confidence*. Such crises of confidence will arise only in economies where regulation solves adverse selection problems: that is, *crises occur only in economies where the regulator's reputation is poor*. However, the crises themselves may occur independently of changes to the poor regulator's reputation.[6] A regulator with a very good reputation will use capital requirements only to solve moral hazard problems and hence will not be vulnerable to such crises.

Finally, we show that the optimal response to crises of confidence depends on how bad the regulator's reputation is, but may be to *tighten* capital requirements. If agents switch from optimistic to pessimistic beliefs, then existing capital regulation is no longer tight enough to prevent unsound agents from applying for banking licences. The regulator has two possible reactions to this. If she has some auditing ability, she could simply accept the deterioration in banking sector quality, fall back upon her auditing ability to keep out some of the worst applicants, and use capital regulation only to solve moral hazard problems. Thus regulators of medium ability may respond to a crisis of confidence with a loosening of capital requirements, allowing a reduction in the average quality of the banking system because this is preferable to the alternative of a reduction in the size of

[6]This is true in our model, where the two equilibria are sunspots. But one could imagine endogenizing the occurrence of crises by applying the analysis of Morris and Shin (1998). This would yield a theory where, conditional on poor regulator reputation, the occurrence of banking crises depends upon fundamentals. See Goldstein and Pauzner (2002).

the banking system. Regulators with very little auditing skill may however prefer to respond to the crisis by tightening capital requirements. Although the banking sector will shrink in size they will continue to solve the adverse selection problem and thus maintain a highly productive banking sector despite their poor reputation.

The remainder of this paper is organized as follows. Section 2 describes the agents in the economy and sets out the circumstances under which regulation of the banking sector is necessary. Section 3 describes the regulator and derives her optimal policy as a function of both her reputation and the beliefs which obtain in the economy. Section 4 contains concluding remarks.

2. An Unregulated Banking Sector

In this section we consider a one-period economy without a banking regulator which contains N risk-neutral agents. Each agent has an initial endowment of \$1 which may be invested, with any returns being consumed at the end of the period. Each individual agent also has his own 'project' in which he may choose to invest. All projects return either 0 (failure) or R (success). If a project is not monitored then it is less likely to succeed and returns R with probability $p_L > 0$. But it is possible by spending $C > 0$ per unit invested upon monitoring the activities of the (exogenous) project management to increase the probability of the high return R to p_H, where $p_H > p_L$. Only $\mu < N$ agents are able to monitor: we call these agents *sound*; the other $(N - \mu)$ agents are said to be *unsound*. An agent's type is his private information. We assume the costs of monitoring are sufficiently low that it is efficient for agents to monitor if they are able to do so:

$$\Delta p R > C, \tag{1}$$

where $\Delta p \equiv p_H - p_L$. The basic set-up follows Holmström and Tirole (1997), extended to allow for adverse selection of agents.

There are constant returns to investment in projects, so that instead of managing his own project, an agent can deposit his endowment with another agent, who will use it to augment the size of his own project.[7] We call an intermediary which is established to accept such deposits a *bank*: the managing agent accepting the deposits is a *banker*. We will denote by $k - 1$ the dollar amount of other agents' capital which a bank receives to invest on their behalf. The total amount of investment by a banker will therefore be k, equal to the sum of his own dollar of equity capital and the other agents' investments. Investment by banks and the return on investments are verifiable so that bankers cannot steal project returns and cannot invest deposited funds with other banks.

When investors deposit an amount S with a bank, we can think of them as signing a *deposit contract* which stipulates the amount $(1 + r)S$ which they will receive at the end of the period if the bank is solvent. Thus r is the deposit rate. Any amount remaining after deposit obligations are met will be paid out to the bank's equity-holders (i.e., the banker himself, who puts up the bank's

[7] It is immaterial whether we think of each agent as having one infinitely scaleable project or many smaller sized, but perfectly correlated projects. In reality of course it is likely that larger banks have many imperfectly correlated projects leading to a diversification benefit which increases with size (Diamond, 1984). On the other hand, it is likely that the marginal cost of monitoring rises (or the incremental benefit of doing so falls) as more projects are taken on. In the interests of tractability we abstract from these two offsetting considerations, which are somewhat orthogonal to the issues we wish to consider here.

capital). Depositors are therefore senior to the bank's equity: they have first claim on the fruits of the bank's investments.[8] However, rather than working in terms of the promised deposit rate, it turns out to be more convenient to use the following (equivalent) accounting convention. We will denote by Q the "fee" which the banker will receive per unit of deposits if his project succeeds. Thus if the bank's investment succeeds each depositor receives a payment of $(1+r) = R - Q$ per dollar invested, leaving a total payment of $R + (k-1)\,Q$ for the banker. Neither the banker nor the investor receives anything if the project fails, since returns are zero and there is no deposit insurance.[9] Only a banker can observe the size of the bank which he manages; this information is not available to outside investors and hence it is impossible for any agent to make a credible commitment to limit the size of the bank which he manages.

Every agent can therefore take one of three actions: he can manage his own project; he can augment his own investment with those of other agents and run a bank; or he can invest his funds in a bank. An equilibrium comprises an action for each agent which maximizes his expected income, given the actions of other agents.

Notice that since sound agents' investments (when monitored) are more productive than those of unsound agents, the welfare optimum for this economy will be attained when all funds are managed by sound agents.[10] However, matters are complicated in that an agent's type is his private information and cannot be credibly communicated. When entry into the banking system is unrestricted, we say that the economy is *unregulated.* An equilibrium in which every sound agent runs a bank and performs monitoring is *(constrained) efficient.*[11]

There are two conditions for an equilibrium with bank size k to be efficient. Firstly, monitoring must be incentive compatible for sound agents: $(Q\,(k-1)+R)\,p_H - Ck \geq (Q\,(k-1)+R)\,p_L$, or

$$Q \geq MIC\,(k) \equiv \frac{Ck - R\Delta p}{\Delta p\,(k-1)}. \tag{MIC}$$

Note that because monitoring is efficient, sound agents will always monitor if they have no outside investors ($k=1$). But because monitoring is costly and not contractible, sound agents will not monitor if they have too much outside capital to manage (k large) and the reward for success is insufficiently high (Q low).[12]

[8] To make the contracts between the banker and his investors look like a true deposit contract, we ought to have a "first-come, first served" provision such that if there are insufficient funds to pay out all depositors, then depositors are paid in the order in which they arrive at the bank. Such a provision would not play any role in our analysis however, if the depositors are not informed until after the bank's returns are realized, and so we prefer to omit such a provision (however, see footnote 23). Also, the presence of such provisions can be used to generate bank runs (see, e.g. Diamond and Dybvig, 1983). As will become clear below, our model will generate the same sort of multiple equilibria phenomenon even without a sequential service constraint.

[9] The fact that returns are zero when the project fails is a merely a convenient normalization which does not affect our qualitative results. What we require is that there is some risk associated with placing funds in a bank. If there were 100% deposit insurance, depositors would not care about the quality of the banking system.

[10] For the purposes of the model it does not matter whether we think of the unsound agents' own projects as unwise (negative NPV) investments, as a storage technology ("putting the money under the mattress") or as moderately productive investments: what is important is that they are less productive than the monitored projects of the sound agents.

[11] Constrained efficiency might theoretically be achieved by having all sound agents manage banks, and some unsound agents manage banks too. However, we will see below that having a fraction of unsound agents manage banks is not feasible.

[12] We have implicitly assumed that the banker either monitors each dollar of investment or does no monitoring

Secondly, banking (as opposed to sole trading) must be incentive compatible for sound agents: $(Q(k-1)+R)\,p_H - kC \geq Rp_H - C$, or

$$Q \geq BIC \equiv \frac{C}{p_H.} \quad \text{(BIC)}$$

That is, sound agents will be just indifferent to running a bank if in expectation they receive exactly the cost of monitoring on their outside deposits, independently of the volume of deposits which they manage. The monitoring and banking incentive constraints for sound types - MIC and BIC, respectively - are illustrated in figure 1. The feasible parameter constellations for efficient economies are those above both MIC and BIC.

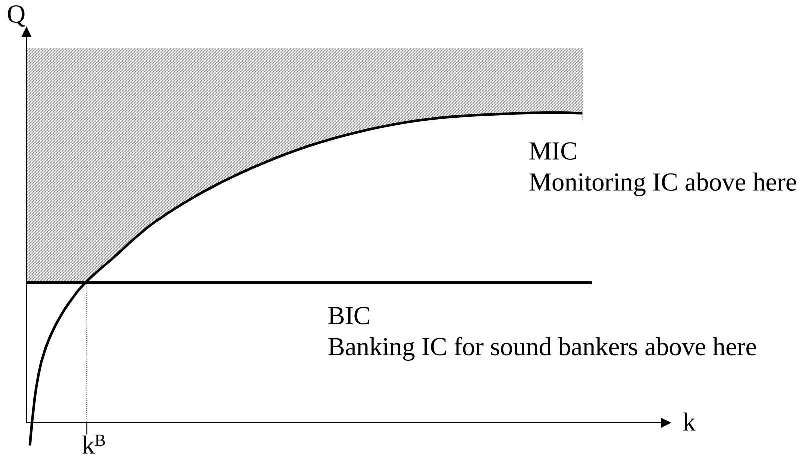

Figure 1: Sound banker participation region.

Throughout the paper we will be looking for the pure strategy Bayesian Nash equilibria of this economy, where each agent is maximizing given the actions of the other agents and given his beliefs – which must be correct in equilibrium – about which types of agents take which actions. It transpires there are no asymmetric pure strategy equilibria of the unregulated economy since it can be shown that in all pure strategy equilibria, either all or none of the unsound agents will wish to run banks. The intuition for this result is that it is not possible for some unsound agents to be content to run a bank while other unsound agents are content to invest in banks. For then an unsound agent who currently manages a bank could leave the banking system. This would increase the average quality of the banking system, so that the defecting agent would be strictly better off depositing than managing a bank. The converse is true if an unsound agent decides to switch to managing a bank rather than depositing, so the banking system must either grow until it contains all agents, or shrink until it contains only sound agents. This is stated formally in proposition 1 below; the proof is in the appendix.

at all. One can show that, if the choice to monitor, say $m < k$ dollars of investments results in success probability $mp_H + (k-m)p_L$, this is without further loss of generality, given our assumption that the outcomes on each dollar of investment are perfectly correlated.

Proposition 1 *There are no asymmetric pure strategy efficient equilibria in the unregulated economy.*

Proposition 1 tells us that the unregulated economy will contain either μ or N "banks". The case with N banks corresponds to autarky and we disregard it. In an efficient unregulated economy, banks therefore return R with probability p_H. In a symmetric equilibrium where everyone deposits or runs a bank and the size of a bank is k, there are $\frac{N}{k}$ banks: if a new bank enters the market, the size of every bank will therefore shrink from k to $\frac{N}{(N/k)+1}$. The incentive compatibility constraint for unsound agents to prefer investment to running a bank is therefore $\left(Q\left(\frac{N}{(N/k)+1}-1\right)+R\right)p_L \leq (R-Q)\,p_H$. This can be re-expressed as:

$$Q \leq B^U(k) \equiv \frac{R\Delta p}{\left(\frac{N}{N+k}\right)kp_L+\Delta p}. \tag{UIC}$$

Finally, in efficient unregulated economies, to avoid autarky bank investment must be individually rational for unsound agents, which implies:

$$Q \leq UIR \equiv R\frac{\Delta p}{p_H}. \tag{UIR}$$

In other words, unsound agents would prefer to manage their own projects unless the amount Qp_H which they must pay to bankers in expectation is less than the incremental value $R\Delta p$ which the latter add. Figure 2 plots the UIR and B^U constraints: depositing in banks is both individually rational and incentive compatible in the shaded region, where banks are sufficiently small and fees are sufficiently low.

Proposition 2 establishes the conditions which must obtain for an efficient equilibrium in the unregulated economy.

Proposition 2 *Define*

$$C^U \equiv \frac{R\Delta p\left(\mu p_H+\Delta p\right)}{Np_L+\Delta p\left(1+\mu\right)}.$$

Then efficient unregulated equilibria exist if and only if $C \leq C^U$.

The proof of this result appears in the appendix. Its intuition is as follows. When no one controls entry to the banking sector, an equilibrium with non-trivial financial intermediaries can exist only if unsound agents do not wish to run a bank. If the cost of monitoring is very low then the sound agents can squeeze out the unsound agents by charging a sufficiently low intermediation cost Q. Another way of putting this is that the sound agents' monitoring technology is so much more efficient than the unsound agents' investments that the former can offer a return on deposits which is so attractive to depositors that the latter are never tempted to run a bank themselves, no matter how large the bank: margins are too low.

When the monitoring cost is higher, however, unsound agents will wish to run banks which are sufficiently large. Recall from inspection of UIC that the reason why unsound agents want to run only large banks is that bankers receive fees per unit of deposits managed, while the opportunity cost of not depositing is fixed. Therefore, it might be possible by limiting bank size to prevent unsound agents from setting up and running banks. We explore this possibility in the next section. However, since in the unregulated economy it is impossible for agents to commit to limit the size of their banks, entry by unsound agents can be prevented only if the fraction of informed capital $\frac{\mu}{N}$ is sufficiently large that in equilibrium banks will be sufficiently small to deter unsound agents from banking.

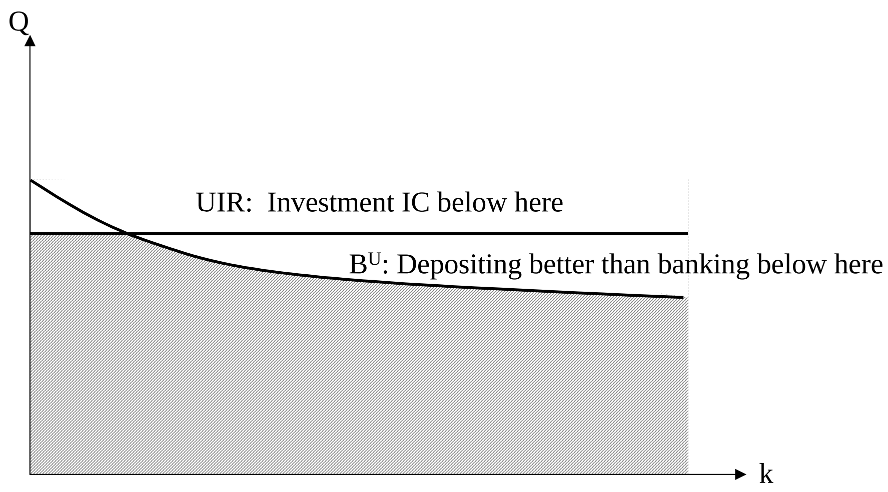

Figure 2: Unsound agent non-banking region.

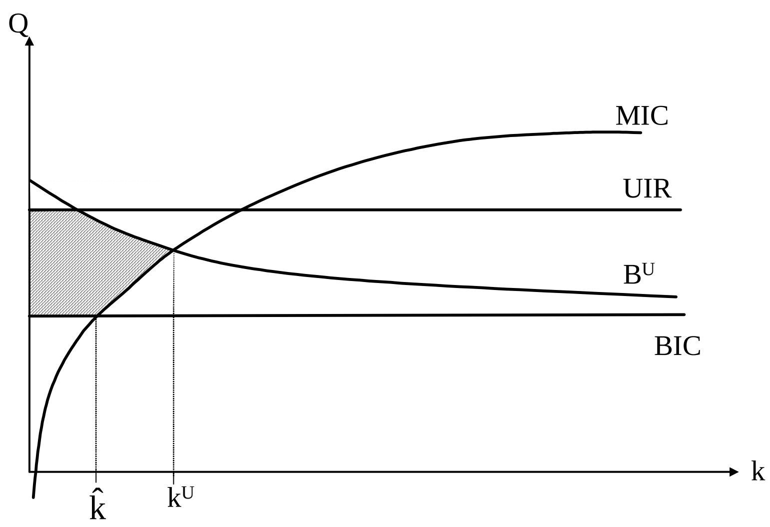

Figure 3: Unregulated equilibria with banks.

Figure 3 illustrates this result. It combines the regions illustrated in figures 1 and 2. Denote by k^U the bank size at which the MIC and B^U curves cross.[13] Larger banks than this are not feasible because the payment necessary to induce sound agents to monitor would induce all of the unsound agents to set themselves up as bankers, and thus cause degeneration into autarky. The difficulty

[13]The proof of proposition 2 demonstrates that these curves will cross as long as $C > \frac{R\Delta p^2}{Np_L+\Delta p}$.

for the unregulated economy arises because no one observes or controls the volume of deposits which banks accept, so the only realizable bank size is $\frac{N}{\mu}$. Thus, as is evident from the diagram, an efficient unregulated equilibrium is feasible only when $\frac{N}{\mu} \leq k^U$, which can be rearranged to yield $C \leq C^U$. If the cost of monitoring is too high ($C > C^U$), efficient equilibria are not possible and the only possibility in the absence of regulation is autarky, with each agent investing his own endowment.[14]

In summary, the results of this section imply that economies can yield a productive banking sector without regulation if the cost of monitoring C is very low, the value added (Δp) of monitoring is very high, and the fraction of sound agents ($\frac{\mu}{N}$) is large. In other words, to the extent that financial intermediation can add a large amount of value to the economy, it may be possible to sustain it without regulation.[15] Is the occurrence of such a scenario plausible? One possible example is England during the Industrial Revolution (1770-1850). It was in this period of historically unprecedented economic growth that deposit banking, as we would recognize it, was being invented. The number of deposit banks in England rose from around 50 in 1770 to around 650 by 1815. These banks were entirely unregulated,[16] and tended to be unit banks founded by small groups of wealthy local businessmen who made local investments using their contacts in their local community. The localized nature of banking and the fact that the bankers were well-informed meant that monitoring projects was not very costly. Our model suggests one reason why the banking sector flourished in this period despite the lack of regulation: the informed agents were able to add a lot of value because there were many profitable opportunities (in sectors such as agriculture, transportation and the production of goods such as iron, coal and cotton) to be exploited.[17] Nevertheless, as will become evident below, even in an economy such as this, a regulator may be able to improve financial intermediation by screening and auditing banks to alleviate the moral hazard (MIC) and adverse selection (UIR) problems inherent in the unregulated economy.

For the remainder of the paper we will assume that $C > C^U$ so that unregulated efficient equilibria are not feasible. This seems to correspond to most situations in the modern world. With slower growth in the developed world, the surplus available to banks from monitoring most projects ($R\Delta p - C$) may just be too small relative to the volume of deposits available ($N - \mu$) for an unregulated economy to be feasible.[18] Whereas in some developing economies there may

[14] We have illustrated the case where $C < C^U \frac{p_H}{\Delta p}$ so that B^U and BIC do not cross: note that whether or not this occurs is not germane to our discussion as it will always occur for a value of k which exceeds k^U. The crossing point $\hat{k} \equiv \frac{Rp_H - C}{Cp_L}\Delta p$ of BIC and MIC is illustrated. It is easy to show that $k^U > \hat{k}$ as we have drawn it if and only if $R\Delta p > C$, which is equation (1).

[15] We thank a referee for drawing our attention to the comparative statics mentioned here.

[16] Banks had to conform only to the economy-wide restriction that businesses be founded on partnerships of up to six people. (The 1720 Bubble Act allowed joint stock companies to be formed only via an Act of Parliament. The Bank of England was the only joint stock bank until the law changed in 1825.) In practice this restriction severely limited bank size.

[17] Moreover, at this time, banks were still an investment vehicle for the relatively wealthy - so the amount of "uninformed" deposits available to be managed by the "sound" bankers ($\frac{\mu}{N}$) was relatively small. For more detail on English banks during this period, see Presnell (1956) and Brunt (2005).

[18] An important exception to this may be the venture capital industry, which has until recently performed very well despite an absence of regulation. Venture capitalists operated in an environment which was strikingly similar to that of the English Industrial Revolution: the expected benefit of monitoring was high, and the volume of funds available for venture capital investment was relatively limited (i.e., $R\Delta p - C$ and $\frac{\mu}{N}$ are large for venture capitalists). It is interesting to see the deterioration in venture capital performance since the large influx of funds into the industry

be insufficient legal enforcement for bankers to be able credibly to promise to return depositors funds in case of success. In the next section, we examine how a regulator can improve upon the unregulated situation.

3. A Regulated Banking Sector

3.1. Regulator Technology and the Regulatory Game

Sound agents have valuable monitoring skills which unsound agents lack. When only sound agents run banks it follows that social welfare is maximized by maximizing the size of the banking sector. When $C > C^U$ social welfare is not maximized in an unregulated market because the moral hazard problem in banking implies that depositors must share some of the surplus that arises when their dollar of investment is monitored with the bank which promises to do the monitoring. The additional presence of the adverse selection problem in banking makes depositors reluctant to do so since they could end up paying fees to an unsound banker who will produce returns no higher than they could get on their own. However, from a social point of view, the transfer of fees between unsound depositors and bankers is welfare-neutral. It follows that in the unregulated economy depositors do not fully internalize the monitoring benefits of depositing, failing to allocate their capital optimally. In this section we introduce a welfare-maximizing agent called the *regulator* whose role is to correct for this market failure by controlling entry to the banking sector.

The regulator has three skills. Firstly, she can observe bank size and can therefore impose capital adequacy ratios by limiting the size of the bank to k times the capital of the banker. Secondly, she has access to an imperfect screening technology for evaluating the soundness of licence applicants. Thirdly, after licences have been awarded and investments made the regulator can examine each bank's investment and decide whether to close the bank or leave it open. The regulator maximizes social welfare by ensuring the existence of a sound banking sector and hence maximizing the productive capacity of the economy. She is not *per se* concerned with questions of distribution.[19]

Accordingly, the regulator has three policy instruments: she can set a capital adequacy requirement, she can allocate licences, and she can audit banks at the interim stage. For simplicity we assume that enforcement of capital requirements is unproblematic and focus on the other two instruments.[20] We assume that the regulator awards precisely μ licences. The licence allocation procedure is as follows. The regulator firstly announces the size k of each bank. Agents decide whether or not they wish to apply for a banking licence and licence applicants form a pool from which the regulator samples repeatedly. Sampled applicants are audited: if the audit indicates that

in the late 1990s in the light of our model. The influx of funds may have led to the violation of adverse selection and moral hazard constraints, since it attracted many new venture capital firms into the industry, as well as allowing existing firms to grow substantially.

[19] Our discussion of regulatory tools and the purposes of bank supervision closely follows the description of Mishkin (2001, chapter 11, especially pp. 284 - 286).

[20] Precise enforcement mechanisms vary between jurisdictions, but typically they rely upon the imposition of sanctions in response to breaches of the law: see Basle Committee on Banking Supervision (1997). For a theory in which regulators may have difficulty committing ex ante to imposing capital requirements ex post, see Gorton and Winton (2000). This type of time-inconsistency problem does not arise in our model.

they are sound then they are awarded a licence; if it indicates that they are unsound then they are returned to the pool. We are therefore explicitly ruling out policies under which the number of licences awarded is contingent upon the number of licence applicants (e.g., "If I receive μ applications then I will award μ licences: otherwise I will award no licences"). We do so this mainly because the joint analysis of the optimal number of licences and size of banks is intractable, but our choice can also be justified on two grounds. Firstly, policies such as this one which rely on threats about off-the-equilibrium path behavior are generally *ex post* suboptimal and are therefore difficult to impose with credibility. Secondly, such policies also rely upon a precise knowledge of μ and hence may not be robust to imprecise parameter knowledge by the regulator.

The ability of the regulator in screening banks for licences is uncertain. There are two types of regulators. The screening technology employed by *good* regulators yields the wrong answer with probability 0; thus if the regulator is good, ex post all banks will turn out to be sound. We assume that the technology employed by *bad* regulators yields a fraction of good banks exactly equal to their fraction in the population of licence applicants, i.e. μ/b.[21] No one (including the regulator) knows the regulator's type. An *ex ante* probability a is assigned that she is good: we call a the regulator's *ability.*

We assume further that after licences are awarded, any regulator can learn through monitoring and auditing about the quality of banks. Specifically, we assume that after deposits have been made and banks have invested, the expected outcome (i.e. Rp_L or Rp_H) of each bank is revealed to the regulator with probability λ. Project type revelation events are independent across banks and λ is independent of the regulator's ability. Since λ is independent of the regulator's ability we interpret it as a parameter reflecting the transparency of banks' accounting procedures. If bank accounting is transparent, regulators are more likely to realize early that a bank is in trouble and can react to save some of the assets for depositors.[22] We assume that after the regulator learns the project's type, she can force the bank to liquidate its investments and distribute *all* of its funds to the bank's depositors if she wishes. Liquidation yields a certain return of Rp_L per dollar invested by the bank. It follows that the regulator will never liquidate a sound bank.[23]

[21] For simplicity, we ignore integer constraints. We could allow the bad regulator's technology to give the wrong answer with probability $\frac{1}{2}$ independently across applicants which would yield the same expected number of good banks and avoid the integer constraint problem, but this would result in a random number of good banks, and thence considerably more algebraic complexity without any additional economic insight. The key idea which we wish to emphasize is that the bad regulator has a technology where the quality of the banking sector depends on the quality of the applicant pool. At the cost of reduced algebraic tractability we could endow good regulators with an imperfect technology and bad regulators with a technology which outperforms coin-tossing, but this would not affect our qualitative results.

[22] The importance of bank transparency has been highlighted by the regulators (Basle Committee, 1998). For a description of how lack of transparent accounting can seriously hamper attempts to recover banks' assets speedily, see Kane (1989*a*).

[23] This set-up can also be reinterpreted as a reduced form for the idea that with transparent accounting systems, the general public will learn the likely project outcome for each bank with probability λ and that they will then be able to run on the bank. Suppose that their expected payoff from running is π. If the expected outcome is Rp_L, the depositors will run on the bank in order to stake their claim to $\pi > (R - Q)p_L$ now, rather than waiting until next period. Note that they will not run on sound banks as long as $(R - Q)p_H > \pi$, which must be the case or no bank could expect to survive until its investments matured. If we keep this underlying model in mind, then the independence of λ from regulator ability seems more compelling (see Diamond and Rajan (2000) for more detail on how such a mechanism might be exploited). A system can be *ex post* transparent without the regulator having any particular skill in awarding licences *ex ante.* This interpretation also provides a role for "market discipline" in our

Liquidation of unsound banks is *ex post* welfare-neutral and hence a commitment to liquidate them will be credible. Such a commitment will be *ex ante* optimal for two reasons. Firstly, unsound agents lose their endowments after liquidation and hence have a reduced incentive to apply for licences. Secondly, after liquidation depositors in unsound banks receive a share of the banker's endowment, which makes depositing more attractive.

Figure 4 illustrates the time line for the game.

Figure 4: Time line for the regulator game.

3.2. Constraints with Regulation

In this section we set out the various incentive constraints in the regulated economy insofar as they differ from the unregulated case already studied. We will focus on providing an intuitive graphical analysis, relegating most of the formal expressions to the appendix. In the following section we will examine the regulator's choice as to which of these constraints to satisfy when optimally choosing capital adequacy requirements.

The regulator's screening activities do not affect the incentives of the sound agents, but her ability to perform *ex post* auditing does. This is because with probability λ the regulator now discovers that a sound agent has not monitored and forces liquidation (i.e. confiscates his capital and earnings and redistributes it to depositors).[24] The incentive to monitor is thus improved, and the monitoring IC constraint becomes $(R + Q(k-1))\, p_H - C \geq (1-\lambda)(R + Q(k-1))\, p_L$, or

$$Q \geq MIC(k, \lambda) \equiv \frac{Ck - R(\Delta p + \lambda p_L)}{(k-1)(\Delta p + \lambda p_L)}.$$

The incentives of the unsound agents in the regulated economy are also altered, for three reasons. Firstly, the regulator's ex ante audit of banks may improve their confidence in the banking system and make them more willing to deposit; secondly, the regulator sets limits on bank size which may cause rationing of banking services if they choose to deposit; and thirdly, the redistribution of liquidated banker funds at the interim stage renders bank depositing more attractive to

model. We could, however, also allow λ to vary with regulator reputation. Our substantive results would be largely unaffected, but prospects would be much grimmer for regulators with poor reputations. In this respect, our model shows that forcing banks to report their earnings promptly and transparently offers a glimmer of hope for regulators in otherwise difficult circumstances.

[24] Note that none of our substantive results would change if the regulator never learned when sound agents failed to monitor (i.e. that instead of revealing expected outcomes, λ revealed only the type of the agent running the bank). We make this assumption for modelling consistency, and also in the belief that empirically it is easier for regulators to observe *whether* a bank's projects are profitable or not than to observe *why* they are not profitable.

them. Notwithstanding the changed incentives, we are still able to establish a result analogous to proposition 1:

PROPOSITION 3 *Provided $N > 2\mu$, there are no asymmetric pure strategy equilibria in the regulated economy.*

Proof. In the appendix. □

Proposition 3 indicates that in equilibrium, where beliefs are correct, all unsound agents must hold one of two possible beliefs about the fraction of licence applicants which are sound. Either they believe that only sound agents will apply to the regulator for a banking licence, or they believe that every agent will apply for a banking licence, so that the fraction of sound applicants is 1 or $\frac{\mu}{N}$ respectively. In the former case all banks will be sound, irrespective of the regulator's quality: we therefore call these beliefs *optimistic*. In the latter case the expected quality of a randomly chosen bank will be lower, because the regulator may license some unsound banks: we call these beliefs *pessimistic*.

Proposition 4 establishes conditions under which optimistic and pessimistic expectations are rationally held, and hence the conditions under which banking will be preferred to depositing. It also sets out when depositing is preferred to managing one's own project.

PROPOSITION 4 *There exist functions $B^O(k)$, $B^P(a,k)$ and $R^{IR}(a,k)$ decreasing in k and with a common intersection point in (k,Q) space such that:*

1. *Optimistic expectations are sustainable if and only if $Q \leq B^O(k)$;*
2. *Pessimistic expectations are sustainable if and only if $Q \geq B^P(a,k)$;*
3. *Banking is individually rational for unsound agents in pessimistic economies if and only if $Q \leq R^{IR}(a,k)$.*

To the right of their intersection point, R^{IR} and B^P are increasing in a and $B^P \leq B^O \leq R^{IR}$.

Proof. In the appendix □

The three lines B^O, B^P and R^{IR} are illustrated in figure 5.[25]

Optimistic expectations are sustainable only if an unsound agent prefers depositing to banking when all banks are sound. This is the case for sufficiently low Q, as in the first part of the proposition. On the other hand, pessimistic expectations are sustainable provided unsound agents prefer to apply for a banking licence when the regulator chooses banks from a pool containing every agent. This is the case when Q is high enough, as in the second part of the proposition. Part 3 follows because unsound agents will deposit rather than self-manage only for low enough Q.

As in the unregulated case, increasing the size k of the bank makes banking relatively more attractive for unsound agents and hence causes B^O and B^P to decrease. R^{IR} also decreases now since increases in k reduce the expected value to the depositor of any *ex post* redistribution of an

[25] Proposition 4 does not mention the relative preferences of unsound agents for banking and sole-trading. For the remainder of the paper, we are concerned with equilibria in which one of the three constraints in the proposition binds. We demonstrate in the appendix that in this case, this fourth constraint is slack.

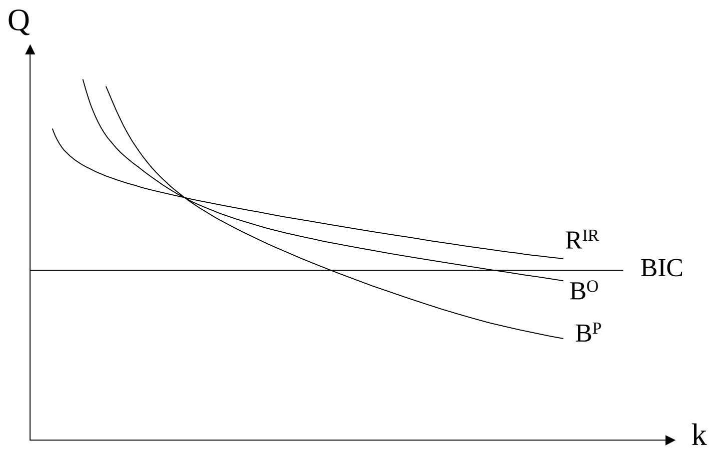

Figure 5: Regulated economy constraints.

unsound banker's capital. This reduces the expected income from depositing and hence reduces the maximum fee Q at which it is attractive.

We demonstrate below that the equilibria of our model fall in the region to the right of the intersection point in figure 5, where depositors prefer to invest with sound than with unsound banks.[26] (This preference is intuitive, but to the left of this intersection point, banks are sufficiently small that the capital redistribution which occurs with probability λ from unsound bankers is actually large enough per depositor to reverse this preference.) Thus in the region of interest, increased regulator ability a improves the average quality of the banking sector in pessimistic economies and hence makes depositing relatively more attractive. This increases both R^{IR} and B^P.[27]

Since to the right of the intersection point depositors prefer sound to unsound banks, they will be prepared to pay higher fees Q when all banks are sound (optimistic case) than if is anticipated that some unsound banks may be licensed (pessimistic case), which implies that $B^O > B^P$. To understand why $B^O < R^{IR}$, consider the income which an unsound agent makes relative to managing his own project. If the bank he invests in turns out to be sound, he makes an extra profit $\mathcal{G}$; whereas if it turns out to be unsound, then his loss $\mathcal{L}$ per dollar deposited equals the gain per dollar deposited he would have made if he had chosen instead to manage a bank. These relative profits and losses must cancel one another out along R^{IR} in order that he is indifferent between depositing and managing his own project. By contrast, in an optimistic economy, a depositor can make the gain $\mathcal{G}$ with certainty on each dollar deposited, since all banks are sound. Unfortunately, however,

[26] To understand why the lines have a common intersection, note that with pessimistic expectations, unsound agents are indifferent along B^P between depositing and running a bank. Along R^{IR}, they are indifferent between depositing and running their own project. It follows that at the intersection between B^P and R^{IR} they must be indifferent banking and running their own projects. Hence at this intersection, unsound bankers expect to earn Rp_L. Similarly, with optimistic expectations, unsound bankers earn Rp_L at the intersection of B^O and R^{IR}. Since unsound banker income depends only on k and Q and is independent of licence applicant quality, the two intersection points must coincide.

[27] To the left of the intersection, a higher a reduces the chance of an *ex post* disbursement of banker capital and hence reduces the attractiveness of depositing. Hence, as a increases R^{IR} and B^P both rotate clockwise about the intersection point.

we show in the appendix that since capital requirements are binding banks cannot accept all the deposits they would like to, so depositors are rationed and can deposit only a fraction $\frac{(k-1)\mu}{N-\mu}$ (equal to the size of the banking sector divided by the number of depositors) of their endowment (see the appendix). If the agent chooses instead to run a bank, he can earns the amount $\mathcal{L}$ on $(k-1)$ dollars. The two incomes from rationed depositing and banking must be equal along B^O. Note that, when the regulator has no *ex ante* screening ability ($a = 0$), the probability that a depositor's bank is sound when all agents apply for a licence is $\frac{\mu}{N}$: in this case the ratio of profits and losses is the same along R^{IR} and B^O, and hence the two lines coincide. Since R^{IR} is increasing in a to the right of the intersection point, it follows that $R^{IR} > B^O$ as long as $a > 0$.

3.3. *Optimal Policy Selection*

The regulator's role is to maximize social welfare. Conditional on the quality of the banking sector, the regulator would like to maximize the quantity of intermediated funds to maximize the productivity of the economy. Therefore optimal policy will be set along the upper envelope of BIC and MIC. The regulator must also satisfy the depositing incentive constraint R^{IR} of the unsound agents (in order that they will be willing to deposit their funds with sound agents). If the regulator chooses to satisfy only these three constraints, then we will say that she is following a *loose capital adequacy policy.* Alternatively, she can limit bank size k further and adopt a *tight capital adequacy policy*, satisfying an additional incentive constraint to ensure that unsound agents will not wish to apply for a banking licence as they prefer to deposit. This will result in a smaller but higher quality banking system. To understand how these two policies work, let k^M, k^O and k^P denote the bank sizes at the intersection points between the upper envelope of BIC and MIC and the R^{IR}, B^0 and B^P lines, respectively. These points are illustrated in figures 6 and 7.

(i) Tight Regulatory Policy

The region within which the regulator can achieve the tight capital adequacy policy is illustrated in figure 6. As in the unregulated case, she requires both banking and monitoring to be incentive compatible for sound agents, so that Q and k will be selected to lie above BIC and MIC. She also requires unsound agents to prefer depositing to banking: this requires that the (k, Q) pair lies below the B^P line when expectations are pessimistic and below the B^O line when expectations are optimistic. These cases correspond respectively to the regions shaded with horizontal and vertical lines. Note that when the regulator employs this policy, she is using capital requirements to exclude unsound agents from the banking market: in other words, to resolve an *adverse selection* problem. It is clear from the diagram that the regulator will set k equal to k^O when optimistic expectations obtain and to k^P when pessimistic expectations obtain. Furthermore, by proposition 4, k^P decreases as a worsens, so that the maximum size for the banking sector with pessimistic expectations will fall as a falls. When expectations are optimistic, however, the size of the banking sector under tight regulation is independent of regulatory ability, as it is anticipated that only sound agents will apply for licences so the regulator's ability is entirely irrelevant for capital requirements

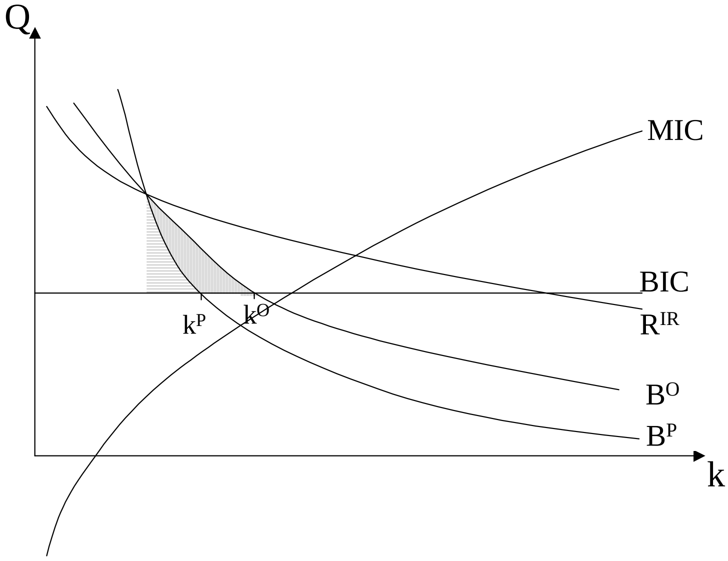

Figure 6: Tight capital adequacy policy.

and for the quality of the banking sector.[28]

(ii) Loose Regulatory Policy

Figure 7 indicates the region within which the regulator can achieve the loose capital requirements policy. With loose capital requirements, the regulator accepts that every agent will choose to apply for a banking licence. Unsound agents must still prefer depositing to running their own project, however. Hence, as in the picture, the B^P and B^O constraints will be violated, and the R^{IR} constraint will bind. (Q, k) will therefore be at k^M. In this case, the MIC constraint binds and the regulator is therefore setting capital requirements in order to resolve a *moral hazard* problem. Proposition 4 demonstrates that R^{IR} will fall as a falls and hence that the maximum size k^M of the banking sector with loose capital requirements will fall as regulator ability falls.

[28] Expressions for k^O and k^P, the respective bank sizes with optimistic and pessimistic expectations, appear in the appendix. They reveal the subtle yet important role played by the transparency of the system, λ. If the probability of ex post revelation of poor investment decisions is zero, then $k^O = k^P = 1$ and the economy is in autarky. In other words, capital requirements can be used to solve adverse selection problems only if the system has some transparency. This is not obvious, and would not be true in a partial equilibrium model. The simple intuition for the benefit of capital requirements is the following. Sound banks must receive payments roughly in proportion to the size of the bank to be induced to monitor, and this tends to attract unsound agents into the banking system. In a partial equilibrium setting one would expect limiting bank size through capital requirements to make entry unattractive for unsound agents, even when there is no possibility of *ex post* confiscation of assets by the regulator. In a general equilibrium model this is not enough, however, because unsound agents' best outside option is to deposit in the banking system. An increase in capital requirements then not only leads to a decrease in the attractiveness of running a bank, but also, as a consequence of rationing effects, to a decrease in the probability of being able to deposit in a bank. Both of these effects are in direct proportion to the size of the banking sector. Thus the net effect on unsound agents' incentive constraint is zero, *unless* managing a bank also entails the additional risk (not proportional to the size of the banking sector) of having one's capital confiscated (i.e., unless $\lambda \neq 0$).

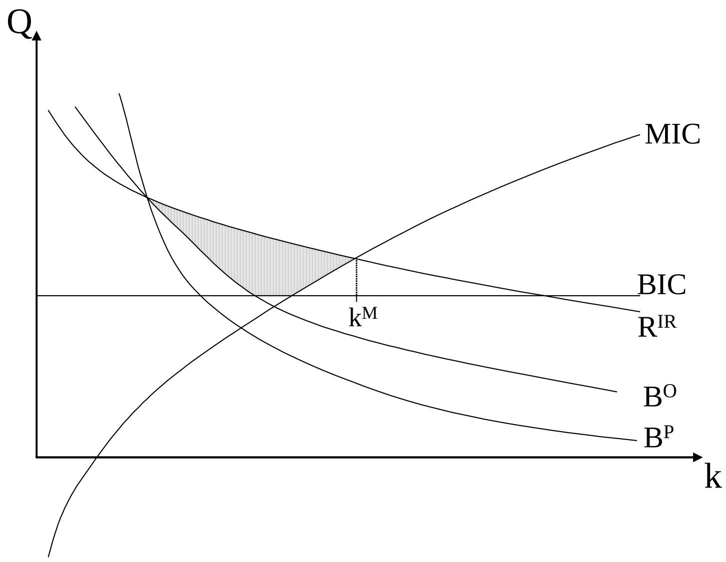

Figure 7: Loose capital adequacy policy.

(iii) Optimal Policy Choice

In choosing between the tight and the loose capital policies identified above, the regulator is attempting to maximize the productive capacity of the economy. She must therefore weigh up the benefits which come from a large banking sector in which sound bankers maximize the size of their investments, and the concomitant costs of a lower average quality of banker. The better the regulator's reputation, the larger the banking sector with loose capital requirements can be and the higher will be the average quality of the banks within it.

To understand how the trade-off is made, consider firstly the case with optimistic expectations. For non-trivial solutions, we require $k^O < N/\mu$, since otherwise the regulator could screen out every unsound agent by setting k equal to its maximum value N/μ. We demonstrate in the appendix (lemma 1) that $k^O < N/\mu$ for sufficiently large C, and we assume from now on that this is the case. As noted in section 3.3.ii, the size k^M of a loosely regulated bank falls as the regulator's ability falls. Hence the social welfare derived from loose capital regulations falls as well. Since the size k^O of a tightly regulated bank is independent of a, so is the social welfare derived from tight capital regulations when expectations are optimistic. The regulator will choose loose capital requirements in order to benefit from larger banks if she has a perfect *ex ante* screening technology ($a = 1$); since R^{IR} and B^O coincide when $a = 0$ she will certainly choose tight capital requirements in this case. At some a^*_O in between she will therefore switch between tight and loose capital requirements.

The case with pessimistic expectations is more complex. In this case, the welfare derived from loose capital requirements is the same as in the optimistic case. However, because $k^P < k^O$, the welfare derived from tight capital regulation is lower with pessimistic expectations than with optimistic. Hence, in a pessimistic economy the regulator will certainly not switch from loose to tight policy at a^*_O, preferring to remain with loose policy. Moreover, note from proposition 4 that *both* k^P and k^M fall as a falls. It is not therefore obvious in this case that the difference between welfare levels with tight and loose capital requirements is monotonic in a and hence that there is a cross over point $a_P^* < a_O^*$ between tight and loose capital requirements. However, we are able to show in the appendix that this is indeed the case for sufficiently high C. We summarize our discussion as follows:

PROPOSITION 5

1. *There exists* $a_o^* > 0$ *such that when optimistic expectations obtain, the regulator prefers a tight capital adequacy policy precisely when* $a < a_O^*$*;*
2. *For sufficiently high* C*, there exists* $a_P^* > 0$ *with* $a_P^* < a_O^*$ *such that when pessimistic expectations obtain, the regulator prefers a tight capital adequacy policy precisely when* $a < a_P^*$*.*

We assume for the remainder of the paper that C is high enough for part (2) of the proposition to hold.

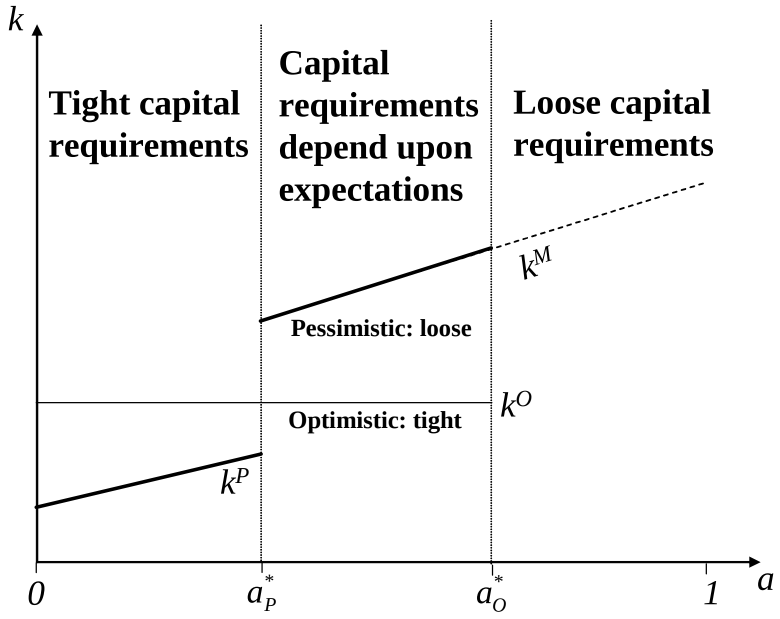

Figure 8: Bank size vs. regulator reputation

Our analysis is illustrated in figure 8, which depicts the optimal choice of capital requirements as a function of regulator reputation. Recall that the regulator has to choose between setting loose capital requirements, in which case banks are large but of lower average quality, and setting tight requirements, in which case banks are smaller but are guaranteed to be sound. When the regulator's ability to screen banks is sufficiently high ($a > a_O^*$), the deleterious effect of loose capital requirements upon bank quality is small compared to the benefits of large bank size and the regulator always sets loose capital requirements. When the regulator has sufficiently low screening ability ($a < a_P^*$), bank quality with loose capital requirements is extremely low and the regulator therefore always sets tight capital requirements. Finally, recall that the size of a tightly regulated banking sector is higher with optimistic than with pessimistic expectations. Tight capital regulation is therefore relatively more attractive when optimistic expectations obtain. Hence for intermediate ability levels ($a_P^* \leq a \leq a_O^*$) the regulator should set tight capital requirements with optimistic expectations, and loose requirements with pessimistic expectations.

Thus, broadly speaking, we argue that capital requirements should be negatively correlated with regulator reputation. Our analysis is largely normative - that is, we assume that policy is set in a way which maximizes social welfare. But one can also ask how well real-world capital requirements measure up to this normative benchmark. A systematic analysis of this issue is outside the scope of this paper, but a cursory glance at minimum capital adequacy requirements around the world lends casual support to our theory: there is substantial clustering at the Basle minimum of 8%, but higher income countries with better-enforced property rights tend to have lower capital requirements; developing and emerging economies are more likely to have higher minimum capital requirements.[29] Of course, we lack an empirical measure of regulator reputation: income and the rule of law are commonly used but very imperfect proxies (see e.g., Demirgüç-Kunt and Detragiache, 1998). In principle it would be possible to survey individuals and businesses in different countries to discover how much confidence they place in their financial regulator, but as far as we are aware this has not yet been done. However, based on our theory, one would also expect minimum capital requirements to be negatively correlated with financial outcome variables such as bank deposits to GDP; or positively correlated with banking crises, since better regulators can allow looser capital requirements and yet still suffer from fewer crises.[30]

The above analysis has focused on how the regulator should set capital requirements as a function of her reputation. However, one can also analyze how the other parameters of the model affect the optimal level of capital requirements. Inspection of the expressions for the various intersection points, k^O, k^P and k^M in the appendix shows that for a given policy choice (i.e., loose or tight policy) optimal capital requirements will get looser as the cost of monitoring falls (C), and the effect of monitoring on the probability of success (Δp) increases. This is intuitive as both of these changes raise the amount of surplus to be divided between sound and unsound agents when the latter deposit in banks run by the former, easing both the moral hazard and adverse selection constraints. An increase in the fraction of sound agents ($\frac{\mu}{N}$) also allows for looser capital regulation rises as it encourages unsound agents to deposit by raising expected bank quality and reducing the severity of deposit rationing. Higher transparency (λ) also allows the regulator to set looser capital requirements by encouraging monitoring and by deterring unsound agents from banking.

3.4. Banking Crises

Our model admits two possible rationally-held (self-fulfilling) beliefs about the quality of licence applicants. Proposition 3 demonstrates that unsound agents can have optimistic expectations about the quality of the banking sector, in which case they will refrain from licence application, or they can have pessimistic expectations, in which case they will all apply for a licence whenever this is

[29] See the data contained in Barth, Caprio and Levine (2001, figure 9). For a theory as to why countries may cluster at 8% see Morrison and White (2004).

[30] A simple analysis of the correlation between the minimum capital adequacy requirements and the ratio of bank deposits to GDP using the data in Barth et al. (2001) yields a Spearman's rank correlation coefficient of -0.423, which is significant at the 1% level. For a more detailed analysis of this data, see Barth, Caprio and Levine (2002).

desirable. Suppose that a shift occurs from optimistic to pessimistic expectations when a tight capital adequacy policy is in place. Such a change could be interpreted as a 'crisis of confidence' in the banking system. Notice that this can rationally occur independently of any change in fundamentals or in the regulator's reputation.[31] When a crisis occurs, the regulator can select one of two courses of action.

Firstly, she can retain a tight capital adequacy policy, continuing to use capital requirements to solve the adverse selection problem. She will do so precisely when $a < a_P^*$. In this case she will react to the lowering of expectations by *tightening* capital requirements from k^O to $k^P < k^O$. In other words, she will deliberately *institute* a credit crunch as the optimal *response* to a crisis of confidence. This prediction is in contradiction to other stories in which confidence crises are a *consequence* of credit crunches. Our model could thus explain the credit crunch of the late 1980s when capital requirements were significantly tightened in response to concern over banks' exposure to derivatives markets and over their losses in loans to less developed countries.

The second possible response to a crisis of confidence is to relax capital requirements and to adopt a loose capital adequacy policy. This will occur when $a_P^* < a < a_O^*$. In this case the regulator allows expectations to become 'self-fulfilling'. The quality of the banking system declines but its size expands. Our model thus demonstrates that relatively strong regulators will elect to fall back upon their reputation when there is public concern over the quality of banks, following an expansive policy. As noted above, weaker regulators will instead follow a "contractionary" policy which shrinks the banking sector. These varying responses can be seen in figure 8. Very strong regulators $a > a_O^*$ do not suffer from such crises at all since they never use capital regulation to solve the adverse selection problem.

One could also consider a simple extension of our model where the regulator is unsure *ex ante* whether the public's expectations will be optimistic or pessimistic and has to choose her regulatory policy before they are revealed to her. Suppose that expectations will be optimistic with some probability p. Clearly this uncertainty is important only when the regulator's reputation is such that she sometimes wishes to set capital levels to solve the adverse selection problem. Rather than present a formal analysis we argue informally as to how the regulator should behave. Consider the simplest case where the regulator's reputation was sufficiently poor ($a < a_P^*$) that she would choose to solve the adverse selection problem when expectations were both optimistic and pessimistic.[32] For this regulator, two forms of regulation are possible. The regulator can hope for optimistic expectations and follow a relatively lax regulatory policy ($k = k^O$) which will maximize the size of banks and so allow the largest possible amount of funds to be channelled into profitable investments, presumably promoting faster economic growth. But if she does so the economy will be vulnerable

[31] By this, we mean only to imply that the model exhibits multiple equilibria and our analysis does not provide us with any way of predicting which equilibria will arise or what might trigger a change in beliefs from optimistic to pessimistic or vice versa. But as noted in footnote 6, one could easily imagine how our analysis might be extended using the framework developed by Morris and Shin (1998). In that case one could have (large) crises caused by (small) changes in beliefs about fundamentals such as regulator reputation a, transparency λ or the fraction of informed capital $\frac{\mu}{N}$.

[32] Regulators with very high ability ($a > a_O^*$) are unaffected by this uncertainty. Regulators with middle reputation ($a_P^* > a > a_O^*$) may, in the face of this uncertainty, choose to give up altogether on solving the adverse selection problem, since now they are able to solve it only at the cost of a very conservative policy, or only with some probability.

to panics if expectations turn out instead to be pessimistic. Alternatively she can be conservative and follow a tighter regulation policy ($k = k^P$) which ensures that panics will not occur despite her poor reputation for auditing, but this means that when expectations are optimistic the banking sector is inefficiently small, and so output is inefficiently low. So the regulator faces a trade-off between inefficiently limiting production and avoiding crises of confidence. It is should be clear that since everyone in the economy is risk-neutral, the solution to this problem is bang-bang: the conservative policy should be chosen for p below some threshold, and the lax policy above this threshold. Thus it may in fact be optimal to allow the economy to be vulnerable to panics if these occur with sufficiently low probability (or alternatively, if the regulator expects to be able to react quickly enough by tightening policy). Thus our model confirms the view that the occurrence of a banking crisis does not necessarily constitute evidence of badly chosen regulatory policy.

4. Conclusion

In recent years, banking crises have become increasingly common and increasingly expensive to deal with.[33] Prudential regulation of banks is supposed to prevent or at least to reduce the frequency of such crises. In this paper we have examined the role of the regulator in the auditing of banks and in the setting of capital requirements in preventing crises. In doing this we departed from the existing debate in the literature, which has largely ignored the impact of regulator reputation on policy. We have shown that *if public confidence in the regulator's ability to detect bad banks through audit is sufficiently high then crises will not occur.* Capital adequacy requirements are then useful mainly in restricting bank size to be small enough to avoid moral hazard problems. Such regulation can be looser the better is the regulator's reputation for auditing banks. We also show that capital regulation can be looser in economies where accounting procedures are more transparent.

On the other hand, if the regulator's reputation is poor, then crises may occur. The regulator then has several policy options. She can follow a loose regulation policy which will maximize the size of banks and so allow the largest possible amount of funds to be channelled into profitable investments. But if she does so, the quality of the banking sector will be low. Alternatively, she can follow a tight regulation policy which raises the average quality of the banking system, at the cost of reducing its size. Other things being equal, poor regulators must always follow tighter capital regulation policy than good regulators.

Existing international regulation of bank capital focuses on the need to ensure a "level playing field" to ensure fair competition among financial institutions from different countries. Our analysis implies that this emphasis may be misplaced, since within a given country it is optimal to have stricter regulations when accounting is less transparent, and the regulator's reputation for identifying incompetent banks gets worse; policy should also vary according to agents' beliefs about the quality of the banking system. Other things being equal, a less competent regulator should impose tighter capital adequacy requirements. This suggests that other things being equal we should not try to impose a uniform standard across all countries, as the Basle Accord on capital requirements sets out to do. Such a one-size-fits-all approach is likely to precipitate crises in countries with poor

[33] See Hellman, Murdock and Stiglitz (2000) for a discussion of the increasing costs of banking crises and for an explanation based on financial liberalization.

regulators and to limit bank size inefficiently in economies with very competent regulators. Instead, a better policy would be to tie the laxity of capital requirements in an economy to a measure of the 'reputation' of that economy's banking regulator for rooting out problems before they occur. For example, if a country has experienced few bank collapses in the past, this country could be allowed to have looser capital requirements than one which has experienced frequent banking crises. Although outside the scope of this paper, one can also imagine that such a structure might have other beneficial effects, such as enhancing the incentives for efficient oversight by banking regulators and for 'peer-monitoring' among banks. Indeed, *de facto* some regulators with less strong reputations for oversight have already moved in this direction by imposing tighter regulation than the Basle Accord requires. This fact may seem difficult to rationalize if one thinks of regulators as trying to improve the position of their own financial institutions in the world; yet makes perfect sense within the context of our theory, because regulators can substitute for the public's lack of confidence in their lack of screening ability by imposing tighter regulation.

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Appendix

Proof of Proposition 1

Consider an efficient unregulated economy in which b banks exist and assume that an equilibrium exists for $N > b > \mu$. Let $\beta_U(b) \equiv \left(Q\left(\frac{N}{b} - 1\right) + R\right) p_L$ be the expected income which an unsound banker earns in a b bank economy and let $\eta_b \equiv \frac{\mu}{b} p_H + \left(1 - \frac{\mu}{b}\right) p_L$ be the unconditional probability that a bank in such an economy earns R on its investments.

Unsound bankers must prefer bank management to investment in a bank, so that $\beta_U(b) \geq (R - Q)\,\eta_{b-1}$. Equivalently,

$$Q \geq \frac{R\mu b \Delta p}{N(b-1)\,p_L + \mu b \Delta p}. \tag{2}$$

Depositors must prefer bank investment to establishing another bank: $(R - Q)\,\eta_b \geq \beta_U(b+1)$, or

$$Q \leq \frac{R\mu(b+1)\,\Delta p}{Nbp_L + \mu(b+1)\,\Delta p}. \tag{3}$$

Equations 2 and 3 can be satisfied simultaneously provided

$$\frac{R\mu b \Delta p}{N(b-1)\,p_L + \mu b \Delta p} \leq \frac{R\mu(b+1)\,\Delta p}{Nbp_L + \mu(b+1)\,\Delta p}.$$

This reduces to $b^2 - 1 \geq b^2$ which is a contradiction. It follows that any efficient equilibrium must have $b = \mu$ or $b = N$, as required.

Proof of Proposition 2

An efficient equilibrium can exist provided there exists Q which satisfies conditions MIC, BIC, UIC and UIR. Note firstly that $MIC(1) = -\infty$, $MIC'(k) > 0$ and $MIC(k) \to \frac{C}{\Delta p} > BIC$ as $k \to \infty$ and secondly that $B^U(1) = \frac{R\Delta p}{\left(\frac{N}{N+1}\right)p_L + \Delta p} > UIR$, $\frac{d}{dk}B^U(k) < 0$ and $B^U(k) \to \frac{R\Delta p}{Np_L + \Delta p}$ as $k \to \infty$. An efficient unregulated equilibrium is guaranteed to exist provided MIC is always below UIR and below B^U. Since B^U crosses UIR from above this is equivalent to the requirement that $\frac{C}{\Delta p} \leq \frac{R\Delta p}{Np_L + \Delta p}$, or $C \leq \frac{R\Delta p^2}{Np_L + \Delta p}$. If $C > \frac{R\Delta p^2}{Np_L + \Delta p}$ then MIC and B^U cross at $k^U \equiv \frac{N\Delta p(Rp_H - C)}{C(Np_L + \Delta p) - R\Delta p^2}$. An efficient equilibrium can exist provided $k < k^U$. In such an equilibrium, $k = \frac{N}{\mu}$ so the existence requirement is $\frac{N}{\mu} \leq k^U$, which reduces to $C \leq C^U$, as required.

Proof of Proposition 3

Suppose that b agents apply for a licence in an efficient economy and that the regulator has ability a. Let

$$\alpha_b = a + (1 - a)\frac{\mu}{b}$$

be the probability that an arbitrary bank is sound and let r_b be the expected payout from investment in a bank:

$$r_b = \alpha_b (R - Q)\,p_H + (1 - \alpha_b)\left\{(1 - \lambda)(R - Q)\,p_L + \lambda R p_L \frac{k}{k-1}\right\}.$$

The first of these terms is the expected return from investing in a sound bank. The expression in curly brackets is the return from investing in an unsound bank: the first of the terms gives the expected return if the bank's quality is not detected by the regulator and the second includes the redistribution of banker funds in the event that the bank's low quality is detected. Finally, note that the income which unsound bankers earn from running an unsound bank is $(1-\lambda)(R+(k-1)Q)p_L$.

Let R_b be the proportion of wealth which a depositor will invest in a bank given that the regulator is bad. As we demonstrate in the proof of proposition 4, $R_b = \frac{(\mu-1)\mu}{N-2\mu+\frac{\mu^2}{b}}$. In any asymmetric pure strategy efficient equilibrium, unsound depositors must prefer not to become bankers and unsound bankers must prefer not to become depositors. In other words,

$$R_b r_b + (1-R_b)Rp_L \geq (1-\lambda)[R+(k-1)Q]p_L \geq R_{b-1}r_{b-1} + (1-R_{b-1})Rp_L. \quad (4)$$

When an unsound agent applies for a licence, he knows that he will be unsuccessful and hence will be a depositor if $a=1$. It follows that it suffices to show that 4 cannot be satisfied when $a=0$. Straightforward manipulation yields:

$$\begin{aligned}&\frac{\partial}{\partial b}\left[R_b(r_b - Rp_L) + Rp_L\right]_{a=0}\\&\quad = \frac{\mu^2(k-1)}{b^2\left(N-2\mu+\frac{\mu^2}{b}\right)}\left\{\left[(R-Q)(\Delta p + p_L) - p_L R\lambda\frac{k}{k-1}\right]\left(\frac{\mu^2}{(N-2\mu)b+\mu^2}-1\right)\right.\\&\qquad\left. + \frac{\mu}{N-2\mu+\frac{\mu^2}{b}}\left[(1-\lambda)(R-Q)p_L - \frac{Rp_L}{k-1}(k(\lambda+1)-1)\right]\right\}.\end{aligned}$$

Since $N > 2\mu$, the first of these terms is clearly negative. The second term has the same sign as $(1-\lambda)(R-Q)p_L - \frac{Rp_L}{k-1}(k(\lambda+1)-1) < (R-Q)p_L - Rp_L\frac{k}{k-1} < 0$: this concludes the proof.

Proof of Proposition 4

Deposit rationing – If the regulator chooses to restrict k, this may result in equilibrium in deposit rationing. We start by considering its effect. We assume that when the demand for deposit contracts exceeds their availability, all depositors invest an equal proportion of their funds in a bank and self-manage the remainder. Note that in equilibrium no sound agent without a licence will wish to deposit, since at best he will deposit with another sound agent who will charge Q for managing his deposit. Suppose that in addition, all unsound agents without a licence will wish to deposit: this is the case in the equilibria which concern us. If there are μ banks of which $s \leq \mu$ are sound then unsound agents will manage to deposit only the following fraction of their endowment:

$$\frac{(k-1)\mu}{N-\mu-(\mu-s)} = \frac{(k-1)\mu}{N-2\mu+s}; \quad (5)$$

the numerator of this expression is the volume of permitted deposits, equal to the total size of the banking sector less the endowment of the bankers, and the denominator is the number of agents wishing to deposit, equal to the number of agents without licences minus the number of sound agents without licences.

Alternative notation – It is convenient when reasoning about the regulated economy to define the quantities $\mathcal{L}$ and $\mathcal{G}$ to be respectively the expected loss and gain which an unsound agent experiences when making a deposit in an unsound or a sound bank, compared to managing his own project. Then

$$\begin{aligned}\mathcal{L} &= Rp_L - \left\{(R-Q)(1-\lambda)p_L + \lambda R p_L \frac{k}{k-1}\right\}, \\ \mathcal{G} &= (R-Q)p_H - Rp_L = R\Delta p - Qp_H.\end{aligned}$$

With this notation, the expected return to an unsound agent from managing a bank is

$$Rp_L + \mathcal{L}(k-1),$$

the expected income from depositing when there are optimistic expectations is

$$Rp_L + \frac{(k-1)\mu}{N-\mu}\mathcal{G},$$

and the expected income from depositing when pessimistic expectations obtain is

$$Rp_L + \frac{(k-1)\mu}{N-\mu}\left[a\mathcal{G} + \frac{(1-a)}{N-\mu}(\mu\mathcal{G} - (N-\mu)\mathcal{L})\right].$$

The first of the terms in the square brackets corresponds to the case where the regulator is good and the second to the case where the regulator is bad. In this case, note that the rationing fraction is modified in line with equation 5 and that the depositor will make a profit or a loss, according to the type of banker which he encounters.

Constraints – We now derive the constraints in the proposition. Optimistic expectations are sustainable only if unsound agents prefer bank investment to licence application when it is anticipated that all banks are sound:

$$\frac{\mu}{N-\mu}\mathcal{G} \geq \mathcal{L}. \tag{OPIC}$$

Rearranging gives us the following equivalent expression in (k, Q) space:

$$Q \leq B^O(k) \equiv \frac{R\left(\mu\Delta p + \lambda p_L\left(\frac{N-\mu}{k-1}\right)\right)}{N(1-\lambda)p_L + \mu(p_H - (1-\lambda)p_L)}.$$

Similarly, pessimistic beliefs are sustainable only if unsound agents prefer to apply for a banking licence rather than to invest in a bank when they anticipate that all agents will apply for a banking licence:

$$\mathcal{L}(N-a\mu) \geq \mathcal{G}\mu\left(\frac{aN-2a\mu+\mu}{N-\mu}\right). \tag{PESSIC}$$

This equation can similarly be rearranged to give the following necessary condition in (k, Q) space for pessimistic beliefs to obtain:

$$Q \geq B^P(a,k) \equiv \frac{R\ ((k-1)\ \mu\ (a\ (N-2\,\mu)+\mu)\ \Delta p + \lambda\ (N-\mu)\ (N-a\,\mu)\ p_L)}{(k-1)\ (\mu\ (a\ (N-2\,\mu)+\mu)\ p_H + (1-\lambda)\ (N-\mu)\ (N-a\,\mu)\ p_L)}.$$

The IR condition for unsound agents to invest in a bank rather than to run their own project when there are pessimistic beliefs is the following:

$$\frac{aN-2a\mu+\mu}{N-\mu}\mathcal{G} \geq (1-a)\mathcal{L}, \tag{RIR}$$

or

$$Q \leq R^{IR}(a,k) \equiv R\frac{(aN - 2a\mu + \mu)\Delta p + \frac{\lambda p_L}{k-1}(1-a)(N-\mu)}{p_H(aN - 2a\mu + \mu) + p_L(1-a)(N-\mu)(1-\lambda)}.$$

Finally, we define $B^{OP}(a,k)$ to be the locus of points in (k,Q) space along which unsound agents are indifferent between banking and running their own projects. Along B^{OP}, $Rp_L + \mathcal{L}(k-1) = Rp_L$ or

$$\mathcal{L} = 0. \tag{BOP}$$

Hence $B^{OP}(a,k) = \frac{R\lambda}{(k-1)(1-\lambda)}$.

We can re-write the BIC constraint as follows:

$$\mathcal{G} = R\Delta p - C. \tag{BIC1}$$

Common intersection point – It is clear from equations OPIC, PESSIC, BOP and RIR that the four lines all pass through $(\mathcal{L} = 0, \mathcal{G} = 0)$, or $\left(Q = R\frac{\Delta p}{p_H}, k = 1 + \lambda\frac{p_H}{\Delta p(1-\lambda)}\right)$. Equation BIC1 implies that $\mathcal{G} > 0$ on BIC and hence that intersection point must occur for $Q > BIC$, as in figure 5.

Constraints decreasing in k – To differentiate with respect to k, note that $\frac{d\mathcal{L}}{dk} = \frac{dQ}{dk}(1-\lambda)p_L + \lambda R\frac{p_L}{(k-1)^2}$ and $\frac{d\mathcal{G}}{dk} = -\frac{dQ}{dk}p_H$, whence, using OPIC, $\frac{dB^{OP}}{dk}\left[(1-\lambda)p_L + \mu\frac{p_H}{N-\mu}\right] + \lambda R\frac{p_L}{(k-1)^2} = 0$ and $\frac{dB^{OP}}{dk} < 0$. The result for the other lines follows similarly.

R^{IR} and B^P increasing in a – Differentiate R^{IR} and B^P with respect to a and manipulate to obtain:

$$\begin{aligned}
\frac{\partial}{\partial a}R^{IR}(a,k) &= \frac{R(N-\mu)^2 p_L\left((1-\lambda)\Delta p - \frac{\lambda p_H}{k-1}\right)}{\left((a(N-2\mu)+\mu)p_H + (1-a)(1-\lambda)(N-\mu)p_L\right)^2};\\
\frac{\partial}{\partial a}B^P(a,k) &= \frac{R(N-\mu)^3\mu p_L\left((1-\lambda)\Delta p - \frac{\lambda p_H}{k-1}\right)}{\left(\mu(a(N-2\mu)+\mu)p_H + (1-\lambda)(N-\mu)(N-a\mu)p_L\right)^2}.
\end{aligned}$$

Both expressions are positive precisely when $k > 1 + \lambda\frac{p_H}{\Delta p(1-\lambda)}$: in other words, to the right of the intersection point.

$B^{OP} < B^P \leq B^O \leq R^{IR}$ – Straightforward though tedious manipulations yield the following:

$$\begin{aligned}
B^P - B^{OP} &= \frac{R\mu(a(N-2\mu)+\mu)\left((1-\lambda)\Delta p - \frac{\lambda p_H}{k-1}\right)}{(1-\lambda)\left(\mu(a(N-2\mu)+\mu)p_H + (1-\lambda)(N-\mu)(N-a\mu)p_L\right)};\\
B^O - B^P &= \frac{(1-a)R(N-\mu)^2\mu p_L\left((1-\lambda)\Delta p - \frac{\lambda p_H}{k-1}\right)}{\left(\mu p_H + (1-\lambda)(N-\mu)p_L\right)\left(\mu(a(N-2\mu)+\mu)p_H + (1-\lambda)(N-\mu)(N-a\mu)p_L\right)};\\
R^{IR} - B^O &= \frac{aR(N-\mu)^2 p_L\left((1-\lambda)\Delta p - \frac{\lambda p_H}{k-1}\right)}{\left(\mu p_H + (1-\lambda)(N-\mu)p_L\right)\left((a(N-2\mu)+\mu)p_H + (1-a)(1-\lambda)(N-\mu)p_L\right)}.
\end{aligned}$$

Once again, each of these expressions is positive precisely to the right of the intersection point: when $k > 1 + \lambda\frac{p_H}{\Delta p(1-\lambda)}$. Note moreover that $\left(R^{IR} - B^O\right)\big|_{a=0} \equiv 0$.

Note that, as stated in the text, whenever one of (OPPIC), (PESSIC) and (RIR) is binding to the right of the intersection point $(\mathcal{L} = 0, \mathcal{G} = 0)$, unsound agents strictly prefer banking to running their own project and hence that we can ignore the constraint (BOP) for the remainder of the paper.

Definition 1 *Let k^{BP}, k^{MP}, k^{BO}, k^{MO}, k^{BM} and k^{MM} be the intersections of B^P, B^O and R^{IR} with BIC and MIC respectively. Then the values k^P, k^O and k^M defined in the text satisfy $k^P = \min\left(k^{BP}, k^{MP}\right)$, $k^O = \min\left(k^{BO}, k^{MO}\right)$ and $k^M = \min\left(k^{BM}, k^{MM}\right)$.*

Lemma 1 *If condition (6) is satisfied then $k^{BO} < k^{MO} < N/\mu$; if it is not then the inequalities are all reversed:*

$$C \geq \frac{R\mu p_H\left(\Delta p + \lambda p_L\right)}{\mu p_H + (1-\lambda)(N-\mu)p_L}. \tag{6}$$

Hence when condition (6) implies that $k^O = k^{BO}$ and $k^P = k^{BP}$.

Proof. Let $\hat{k}$ be the intersection between MIC and BIC, i.e. the bank size at which sound agents' monitoring constraint becomes stronger than their participation constraint. It is clear from inspection of figure 5 either $k^{BO} < k^{MO} < \hat{k}$ or $k^{BO} > k^{MO} > \hat{k}$.

Setting $Q = C/p_H$ in B^O and $MIC(k,\lambda)$ gives us

$$\begin{aligned}\hat{k} &= 1 + \frac{\left((R\Delta p + \lambda p_L) - C\right)p_H}{(1-\lambda)Cp_L};\\ k^{BO} &= 1 + \frac{\lambda R(N-\mu)p_L p_H}{C(1-\lambda)(N-\mu)p_L - (R\Delta p - C)\mu p_H}.\end{aligned}$$

Simple manipulations give us $k^{BO} < \hat{k}$ iff $k^M < \frac{N}{\mu}$, which is true iff condition (6) is satisfied. □

Proof of Proposition 5

Part (1) of the proposition follows by the argument in the text.

For part (2), note firstly that if a_P^* exists, it must be less than a_O^* since $B^P < B^O$. Now denote by $G(a)$ the difference between welfare in tightly and loosely regulated economies when pessimistic expectations obtain:

$$G(a) = \left(k^P - 1\right) - \left(k^M - 1\right)\frac{\mu + a(N-\mu)}{N}.$$

The regulator will elect to set tight capital requirements with pessimistic expectations precisely when $G(a) > 0$. So to prove part (2), it is sufficient to demonstrate that for sufficiently high C, $G'(a)$ is negative, and that $G(0) > 0$.

We firstly compute k^P, k^{BM} and k^{MM}, by finding the intersection points of B^P with BIC and of R^{IR} with BIC and MIC respectively:

$$\begin{aligned}k^P &= 1 + \frac{R\lambda(N-\mu)(N-a\mu)p_H p_L}{C(1-\lambda)(N-\mu)(N-a\mu)p_L - \left(\mu\left(a(N-2\mu)+\mu\right)p_H(R\Delta p - C)\right)};\\ k^{BM} &= 1 + \frac{(1-a)R\lambda(N-\mu)p_H p_L}{C(1-\lambda)(N-\mu)(1-a)p_L - p_H\left((a(N-2\mu)+\mu)(R\Delta p - C)\right)};\\ k^{MM} &= \frac{R(N-a\mu)p_L(\Delta p + \lambda p_L)}{(1-a)C(1-\lambda)(N-\mu)p_L - (a(N-2\mu)+\mu)\left(R\Delta p(\Delta p + \lambda p_L) - Cp_H\right)}.\end{aligned}$$

We use these to determine the welfare gap. Firstly, when $k^{BM} < k^{MM}$, substitution and extensive manipulation yields

$$
\begin{aligned}
G(a)|_{k^{BM}<k^{MM}} = & \frac{R\lambda\,(N-\mu)\,(N-a\,\mu)\,p_H\,p_L}{C\,(1-\lambda)\,(N-\mu)\,(N-a\,\mu)\,p_L-(\mu\,(a\,(N-2\,\mu)+\mu)\,p_H\,(R\Delta p-C))} \\
& -\left(\frac{(1-a)\,R\lambda\left(1-\frac{\mu}{N}\right)(a\,(N-\mu)+\mu)\,p_Hp_L}{C\,(1-a)\,(1-\lambda)\,(N-\mu)\,p_L-((a\,(N-2\mu)+\mu)\,p_H\,(R\Delta p-C))}\right).
\end{aligned}
$$

Whence further manipulation yields, when $k^{BM}<k^{MM}$,

$$
\begin{aligned}
G'(a)|_{k^{BM}<k^{MM}} = {} & R\lambda(N-\mu)^2p_Hp_L\times \\
& \left\{-\left(\frac{a\,(a\,(N-2\mu)+2\mu)\,p_H\,(R\Delta p-C)+(1-a)^2C\,(1-\lambda)\,(N-\mu)\,p_L}{N(C\,(1-a)\,(1-\lambda)\,(N-\mu)\,p_L-((a\,(N-2\mu)+\mu)\,p_H\,(R\Delta p-C)))^2}\right)\right. \\
& \left.+\frac{(N-\mu)\,\mu p_H\,(R\Delta p-C)}{(C\,(1-\lambda)\,(N-\mu)\,(N-a\mu)\,p_L-(\mu\,(a\,(N-2\mu)+\mu)\,p_H\,(R\Delta p-C)))^2}\right\}. \qquad (7)
\end{aligned}
$$

When $k^{BM}>k^{MM}$, manipulation again yields the following:

$$
\begin{aligned}
G(a)|_{k^{BM}>k^{MM}} = {} & \frac{R\lambda\,(N-\mu)\,(N-a\mu)\,p_Hp_L}{C\,(1-\lambda)\,(N-\mu)\,(N-a\,\mu)\,p_L-(\mu\,(a\,(N-2\mu)+\mu)\,p_H\,(R\Delta p-C))} \\
& -\frac{a\,(N-\mu)+\mu}{N}\times\left\{-1\right. \\
& \left.+\frac{R\,(N-a\mu)\,p_L\,(\Delta p+\lambda p_L)}{C\,(1-a)\,(1-\lambda)\,(N-\mu)\,p_L-(a\,(N-2\mu)+\mu)\,(R\Delta p\,(\Delta p+\lambda p_L)-Cp_H)}\right\},
\end{aligned}
$$

and

$$
\begin{aligned}
G'(a)|_{k^{BM}>k^{MM}} = {} & \frac{N-\mu}{N} \\
& +\frac{R\lambda(N-\mu)^3\mu {p_H}^2\,(R\Delta p-C)\,p_L}{(C\,(1-\lambda)\,(N-\mu)\,(N-a\mu)\,p_L-(\mu\,(a\,(N-2\mu)+\mu)\,p_H\,(R\Delta p-C)))^2} \\
& -\frac{(a\,(N-\mu)+\mu)}{N}\frac{R(N-\mu)^2\,(R\Delta p-C)\,p_L\,(\Delta p+\lambda p_L)^2}{(C\,(1-\lambda)\,(1-a)\,(N-\mu)\,p_L-(a\,(N-2\mu)+\mu)\,(R\Delta p\,(\Delta p+\lambda p_L)-Cp_H))^2} \\
& -\frac{(N-\mu)}{N}\frac{R\,(N-a\mu)\,p_L\,(\Delta p+\lambda p_L)}{C\,(1-\lambda)\,(1-a)\,(N-\mu)\,p_L-(a\,(N-2\mu)+\mu)\,(R\Delta p\,(\Delta p+\lambda p_L)-Cp_H)}. \qquad (8)
\end{aligned}
$$

Note that when $a=0$, R^{IR} coincides with B^O, and hence that $k^{BM}<k^{MM}$. Hence:

$$
G(0)=\frac{R\lambda\mu\left(1-\frac{\mu}{N}\right)p_Hp_L}{C\,(1-\lambda)\,(N-\mu)\,p_L-\mu p_H\,(R\Delta p-C)}+\frac{R\lambda\,(N-\mu)\,p_Hp_L}{C\,(1-\lambda)\,(N-\mu)\,p_L-\mu\frac{\mu}{N}p_H\,(R\Delta p-C)}.
$$

For C sufficiently close to its maximum value $R\Delta p$ this is clearly positive, as required.

Finally, we require $G'(a)$ to be negative for sufficiently high C. Substituting into equations (7) and (8) yields the following in both cases:

$$
G'(a)|_{C=R\Delta p}=-\frac{\lambda\,(N-\mu)\,p_H}{N\,(1-\lambda)\,\Delta p}<0,
$$

as required.