The Three Pillars of Basel II: Optimizing the Mix in a Continuous-time Model.

by

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Abstract

The on-going reform of the Basel Accord relies on three "pillars": capital adequacy requirements, centralized supervision and market discipline. This article develops a simple continuous-time model of commercial banks' behavior where the articulation between these three instruments can be analyzed. We show that market discipline can reduce the minimum capital requirements needed to prevent moral hazard. We also discuss regulatory forbearance and procyclicality issues.

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1 Introduction

The on-going reform of the Basel Accord[4] relies on three "pillars": capital adequacy requirements, centralized supervision and market discipline. Yet, the articulation between these three instruments is far from being clear. On the one hand, the recourse to market discipline is rightly justified by common sense arguments about the increasing complexity of banking activities, and the impossibility for centralized supervision to monitor in detail these activities. It is therefore legitimate to encourage monitoring of banks by professional investors and financial analysts as a complement to limited centralized supervision. Similarly, a notion of gradualism in regulatory intervention is introduced (in the spirit of the reform of US banking regulation, following the FDIC Improvement Act of 1991).[5] It is suggested that commercial banks should, under "normal circumstances" maintain economic capital way above the regulatory minimum and that supervisors could intervene if this is not the case. Yet, and somewhat contradictorily, while the on-going reform states very precisely the complex refinements of the risk-weights to be used in the computation of this regulatory minimum, it remains silent on the other intervention thresholds.

It is true that the initial accord (Basel, 1988) has been severely criticized for being too crude,[6] and introducing a wedge between the market assessment of asset risks and its regulatory counterpart.[7] However, it seems contradictory to insist so much on the need to "enable early supervisory intervention if capital does not provide a sufficient buffer against risk" and to remain silent on the threshold and form of intervention, while putting so much effort on the design of risk weights.

A possible explanation is that most of the theoretical literature on banks capital regulation relies on static models, where capital requirements are used to curb banks' incentives for excessive risk-taking and where the choice of risk weights is fundamental. However, as suggested by Hellwig (1998), a static framework fails to capture important intertemporal effects. For example, in a static model, a capital requirement can only have an impact on banks' behaviour if it is binding. In practice however, capital requirements

[4] The Basel Accord, elaborated in July 1988 by the Basel Committee on Banking Supervision (BCBS) required internationally active banks from the G10 countries to hold a minimum total capital equal to 8% of risk-adjusted assets. It was later amended to cover market risks. It is currently being revised by the BCBS, who has released for comment a proposal of amendment, commonly referred to as Basel II (Basel Committee, 1999, 2001).

[5] The FDIC Improvement Act of 1991 requires that each US bank be placed in one of five categories based on its regulatory capital position and other criteria (CAMELS ratings). Undercapitalized banks are subject to increasing regulatory intervention as their capital ratios deteriorate. This prompt corrective action (PCA) doctrine is designed to limit supervisory forbearance. Jones and King (1995) provide a critical assessment of PCA. They suggest that the risk weights used in the computation of capital requirements are inadequate.

[6] Jones (2000) also criticizes the Basel Accord by showing how banks can use financial innovation to increase their reported capital ratios without enhancing their soundness.

[7] See our discussion of the literature in Section 2.

are binding for a very small minority of banks and yet seem to influence the behaviour of other banks. Moreover, as suggested by Blum (1999), the impact of more stringent capital requirements may sometimes be surprising, once intertemporal effects are taken into account. The modeling cost is obviously additional complexity, due in particular to transitory effects. In order to minimize this complexity, we will assume a stationary liability structure, and rule out those transitory effects. Also for simplicity, we will only consider one type of assets, allowing to derive a Markov model of banks' behavior with only one state variable: the value of the bank's assets (or, up to a monotonic transformation, the bank's capital ratio).

In this paper, we adopt the view, consistent with the approach of Dewatripont and Tirole (1994) that capital requirements should be viewed as intervention thresholds for banking supervisors (acting as representatives of depositors' interest) rather than complex schemes designed to curb banks' asset allocation. This means that we will not discuss the issue of how to compute risk weights (it has already received a lot of attention in the recent literature), but focus instead on intervention thresholds, a topic that seems to have been largely neglected.

We build on a series of recent articles that have adapted continuous time models used in the corporate finance literature to analyze the impact of the liability structure of firms on their choices of investment and on their overall performance. We extend this literature by incorporating features that we believe essential to capture the specificities of commercial banks.

First of all, we get rid of the Modigliani Miller paradox, not by introducing taxes and liquidation costs as usual, but by considering that banks have the unique ability to finance investments with a positive net present value. Liquidation costs arise endogenously, due to the imperfect transferability of this ability. Moreover, profitability of the investments requires costly monitoring by the bank. Absent the incentives for the banker to monitor, the net present value of the investments becomes negative. This incentive compatibility condition creates the need for the regulator, acting on behalf of depositors, to limit banks' leverage and to impose closure well before the net present value of the bank's assets become negative. This gives rise to a fundamental property, namely the commitment problem of the regulator : from a social welfare perspective, it is almost always optimal to let a commercial bank continue to operate, even if it is severely undercapitalized. Of course, this generates bad incentives for the owners of the bank from an ex-ante point of view, unless the bank' supervisors find a commitment device, preventing renegotiation.

Thus there are two reasons why the Modigliani Miller theorem is not valid in our model: the value of the bank is indeed affected both by closure decisions and by moral hazard, which we capture in a very simple way by assuming that bankers can shirk, i.e.

stop monitoring their investments or else invest in dominated projects that provide them with private benefits. We show that this occurs when the value of the bank's assets falls below a certain threshold. Assuming that the net present value of these "bad" projects is so low that the regulator wants to prevent this behavior under all circumstances, we derive the minimum capital requirement that is needed to ensure this.

The rest of the paper is organized as follows. After a brief review of the literature in Section 2, we describe our model in Section 3. In Section 4 we analyze the objectives and limits of banking regulation: a minimum capital requirement is needed to avoid moral hazard, but closure is not credible ex-post given that the continuation value of the bank is positive. In Section 5 we introduce market discipline through compulsory subordinated debt. We show that it reduces the minimum capital requirement. This is also true if the possibility of regulatory forbearance is introduced (Section 6). Section 7 discusses possible extensions of our model, in order to deal with procyclicality issues and prompt corrective action.

2 Related Literature

We will not discuss in detail the enormous literature on the Basel Accord and its relation with the "credit crunch" (good discussions can be found in Thakor (1996), Jackson et al. (1999), Santos (2000)). Let us briefly mention that most of the theoretical literature (e.g., Furlong and Keeley (1990), Kim and Santomero (1988), Koehn and Santomero (1980), Rochet (1992), Thakor (1996)) has focused on the distortion of banks' assets allocation that could be generated by the wedge between market assessment of asset risks and its regulatory counterpart in Basel I. A large empirical literature (e.g. Bernanke and Lown (1991); see also Thakor (1996), Jackson et al. (1999) and the references therein) has tried to relate these theoretical arguments to the spectacular (yet apparently transitory) substitution of commercial and industrial loans by investment in government securities in US banks in the early 1990s, shortly after the implementation of the Basel Accord and FDICIA.[8,9] Even if these authors seem to have established a positive correlation between bank capital and commercial lending, causality can only be examined in a dynamic framework. Blum (1999) is one of the first theoretical papers to analyze the consequences of more stringent capital requirements in a dynamic framework. He shows that more stringent capital requirements may paradoxically induce increasing risk taking by the banks who anticipate having difficulty meeting these capital requirements in the future.

[8]Peek and Rosengren (1995) find that the increase in supervisory monitoring had also a significant impact on bank lending decisions, even after controlling for bank capital ratios.

[9]Blum and Hellwig (1995) is one of the few theoretical papers to analyze the macroeconomic implications of bank capital regulation.

Hancock et al. (1995) study the dynamic response to shocks in the capital of US banks using a Vector Auto Regressive framework. They show that US banks seem to adjust their capital ratios must faster than they adjust their loans portfolios. Furfine (2001) extends this line of research by building a structural dynamic model of banks behavior, which is calibrated on data from a panel of large US banks on the period 1990-97. He suggests that the credit crunch cannot be explained by demand effects but rather by raising capital requirements and/or increasing regulatory monitoring. He also uses his calibrated model to simulate the effects of Basel II and suggests that its implementation would not provoke a second credit crunch, given that average risk weights on good quality commercial loans will decrease if Basel II is implemented.

Our objective here is to design a tractable dynamic model of bank behavior where the articulation between the three pillars of Basel II can be analyzed.

Our model builds on two strands of the literature:

- Corporate finance models à la Leland and Toft (1996) and Ericsson (2000), who analyze the impact of debt maturity on asset substitution and firm value;
- Banking models à la Merton (1977), Fries et al. (1997), Bhattacharya et al. (2000), Milne and Whalley (2001) who analyze the impact of solvency regulations and supervision intensity on the behaviour of commercial banks.

Let us briefly summarize the main findings of these articles.

Leland and Toft (1996) investigate the optimal capital structure which balances the tax benefits and the bankruptcy costs coming with debt. They extend Leland (1994) by considering a coupon bond with finite maturity T. They maintain the convenient assumption of a stationary debt structure by assuming a constant renewal of this debt at rate $m = \frac{1}{T}$. Leland and Toft (1996) are able to obtain closed form (but complex) formulas for the value of debt and equity. In addition, using numerical simulations, they show that risk shifting disappears when $T \to 0$, in conformity with the intuition that short term debt allows to discipline managers.

Ericsson (2000) and Leland (1998) also touch on optimal capital structure, but are mainly concerned with the asset substitution problem where a firm can modify the volatility of its assets' value. They show how the liability structure influences the choice of assets' volatility by the firm. Both consider a perpetual debt but Ericsson (2000) introduces a constant renewal rate which serves as a disciplining instrument.

Mella-Barral and Perraudin (1997) characterise the consequences of the capital structure on an abandonment decision. They obtain an underinvestment (i.e. premature abandonment) result. This comes from the fact that equityholders have to inject new cash in the firm to keep it as an ongoing concern. Similarly, Mauer and Ott (1998) consider the investment in a growth option by equityholders of a leveraged company and also exhibit an underinvestment result for exactly the same reason. These papers thus offer a continuous time version of the debt overhang problem first examined in Myers (1977): the injection of new cash by equityholders has a positive externality on debtholders' claims and the continuation (or expansion) decisions are under-optimal because equityholders do not internalise this effect. Anderson and Sundaresan (1996) and Mella-Barral (1999) elaborate on this aspect by studying the impact of possible renegotiation between equityholders and debtholders. They also allow for the possibility of strategic default.

In the other strand of the literature, Merton (1977) is the first to use a diffusion model for studying the behaviour of commercial banks. He computes the fair pricing of deposit insurance in a context where supervisors can perform costly audits. Fries et al. (1997) extend Merton' s framework, by introducing a withdrawal risk on deposits. They study the impact of the regulatory policy of bank closures on the fair pricing of deposit insurance. The optimal closure rule has to trade-off between monitoring costs and costs of bankruptcy. Under certain circumstances, the regulator may want to let the bank continue even when equity-holders have decided to close it (underinvestment result).

Following Leland (1994), Bhattacharya et al. (2000) derive closure rules that can be contingent on the level of risk chosen by the bank. Then they examine the complementarity between two policy instruments of bank regulators : the level of capital requirements and the intensity of supervision. In the same spirit, Dangl and Lehar (2000) mix random audits as in Bhattacharya et al.(2000) with risk shifting possibilities as in Leland (1998) so as to compare the efficiency of Basle Accords (1988) and VaR regulation. They show that VaR regulation is less costly in audits to prevent risk shifting for ailing banks.

Calem and Rob (1996) design a dynamic (discrete time) model of portfolio choice, and analyse the impact of capital based-premia under the perfect audit hypothesis. They show that regulation may be counterproductive : a tightening in capital requirement may lead to an increase in the risk of the portfolios chosen by banks, and similarly, capital-based premia may sometimes induce excessive risk taking by banks. However, this never happens when capital requirements are stringent enough.

Froot and Stein (1998) model the buffer role of bank capital so as to absorb liquidity risks. They determine the capital structure that maximizes the bank's value when there are no audits nor deposit insurance. Milne and Whalley (2001) develop a model where banks can issue subsidized deposits without limit in order to finance their liquidity needs. The cost to society is limited by the threat of regulatory closure. Milne and Whalley (2001) study the articulation between two regulatory instruments: the intensity of costly auditing and the level of capital requirements. They also allow for the possibility of banks recapitalization. They show that banks'optimal strategy is to hold an additional amount of capital (above the regulatory minimum) used as a buffer against future solvency shocks. This buffer reduces the impact of solvency requirements.

3 The Model

Following Merton (1974), Black and Cox (1976) and Leland (1994), we model the value x of the bank's assets by a diffusion process:

$$\frac{dx}{x} = \mu dt + \sigma dW. \tag{1}$$

We also assume all agents are risk neutral with a discount rate $r > \mu$. However, we depart from standard assumptions in several important ways.

First, we introduce explicitly a genuine economic role for banks: equation (1) is only satisfied if the bank monitors its assets. Monitoring has a fixed cost per unit of time, equivalent to a continuous monetary outflow b.[10] In the absence of monitoring, the value of assets satisfies instead:

$$\frac{dx}{x} = \mu_B dt + \sigma_B dW, \tag{2}$$

where B stands for "bad" technology and $\mu_B = \mu - \Delta\mu \leq \mu$ and $\sigma_B^2 = \sigma^2 + \Delta\sigma^2 \geq \sigma^2$.

Second, the net expected present value of banks' assets is not zero,[11,12] which eliminates the Modigliani-Miller paradox without having to resort to taxes or government subsidies. We assume

$$\mu + \beta > r > \mu_B + \beta, \tag{3}$$

where $\beta > 0$ is the pay-out rate of the bank's assets. As a result, the "bad" technology is always dominated by closure:

$$E_{x_0}\left[\int_0^{+\infty} e^{-rt}\beta x_t dt \middle| \text{ bad technology }\right] = \frac{\beta x_0}{r - \mu_B} < x_0.$$

On the other hand the net present value of a bank who continuously monitors its assets is:

$$E_{x_0}\left[\int_0^{+\infty} e^{-rt}(\beta x_t - b) \middle| \text{ good technology }\right] = \frac{\beta x_0}{r - \mu} - \frac{b}{r},$$

[10] If monitoring cost has also a variable component, it can be substracted from μ.

[11] Genotte and Pyle (1991) were the first to analyze capital regulations in a framework where banks have an explicit monitoring role and make positive NPV loans. In some sense, our paper can be viewed as a dynamic version of Genotte and Pyle (1991).

[12] This implies that banks' assets are not traded and thus markets are not complete. In a complete markets frameworks, the moral hazard problem can be solved by risk-based deposit insurance premia and capital regulation becomes redundant.

so the “good” technology dominates closure whenever x_0 is not too small:

$$\frac{\beta x_0}{r-\mu} - \frac{b}{r} > x_0 \quad \Leftrightarrow \quad x_0 > \frac{b}{r\nu_G},$$

where

$$\nu_G = \frac{\beta}{r-\mu} - 1 > 0,$$

while we denote by analogy:

$$\nu_B = \frac{\beta}{r-\mu_B} - 1 < 0.$$

Notice that our modeling of moral hazard encompasses the classical risk shifting problem ($b = \Delta\mu = 0$) and the first order stochastic dominance pure effort problem ($\Delta\sigma^2 = 0$).

In the absence of a closure threshold (i.e. assuming that banks continue forever), the surpluses generated by the good (G) and the bad (B) technologies would be as represented in Figure 1 below:

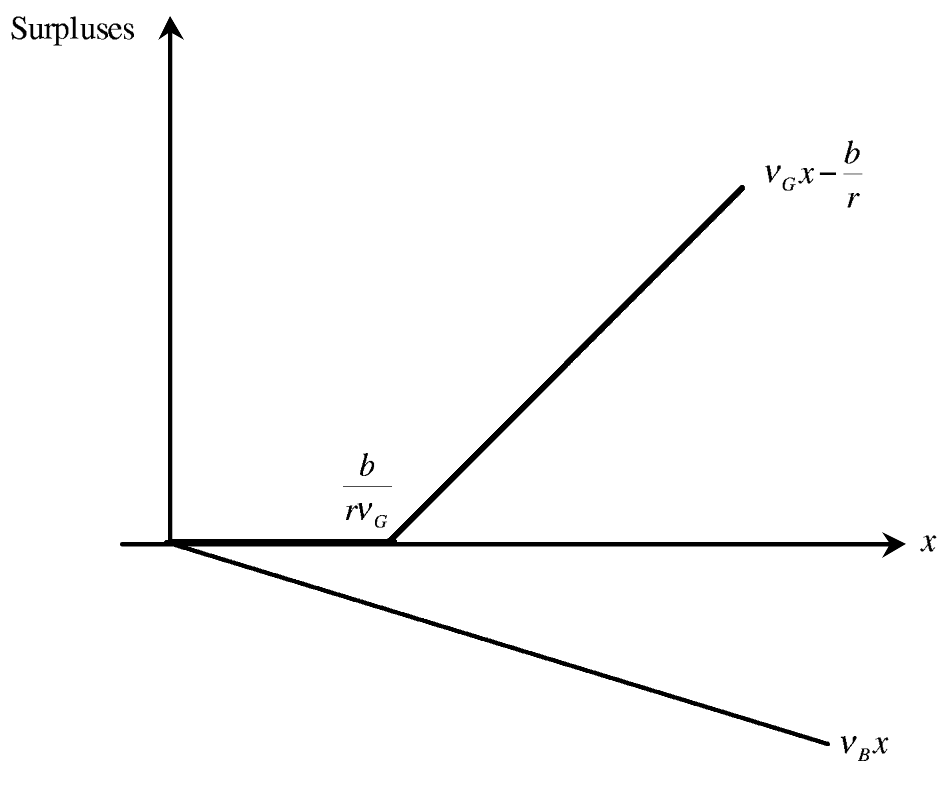

Figure 1: Economic surpluses generated
by the good (G) and the bad (B) technologies.

The economic surplus generated by the good technology is therefore positive when x is larger than the NPV threshold $\frac{b}{r\nu_G}$, while the surplus generated by the bad technology is always negative. We now introduce a closure decision, determined by a liquidation threshold x_L.

Assuming for the moment that the bank always monitors its assets, its continuation value $V_G(x)$ is thus determined by the liquidation threshold x_L, below which the bank is closed:

$$x + V_G(x) = E_x \left[\int_0^{\tau_L} e^{-rt}(\beta x_t - b)dt + e^{-r\tau_L} x_L \right], \tag{4}$$

where τ_L is a random variable (stopping time), defined as the first instant where x_t (defined by (1)) equals x_L, given $x_0 = x$.

Using standard formulas[13], we obtain:

$$V_G(x) = \nu_G x - \frac{b}{r} + \left(\frac{b}{r} - \nu_G x_L\right)\left(\frac{x}{x_L}\right)^{1-a_G}, \tag{5}$$

where

$$a_G = \frac{1}{2} + \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma^2}} > 1. \tag{6}$$

The continuation value of the bank is thus equal to the net present value of perpetual continuation $\left(\nu_G x - \frac{b}{r}\right)$ plus the option value associated to the irreversible closure decision at threshold x_L. Interestingly this option value is proportional to x^{1-a_G}, thus it is maximum for a value of x_L that does not depend on x, namely

$$x_{FB} = \frac{b}{\nu_G r}\frac{a_G - 1}{a_G}. \tag{7}$$

Proposition 1 *: The first best closure threshold of the bank is the value of x_L that maximizes the option value associated to the irreversible closure decision. This value is equal to $x_{FB} = \frac{b}{\nu_G r}\frac{a_G-1}{a_G}$. It is smaller than the NPV threshold $\frac{b}{\nu_G r}$.*

The continuation value of the bank as a function of x is represented below for different values of x_L:

[13] see for instance Karlin and Taylor (1981).

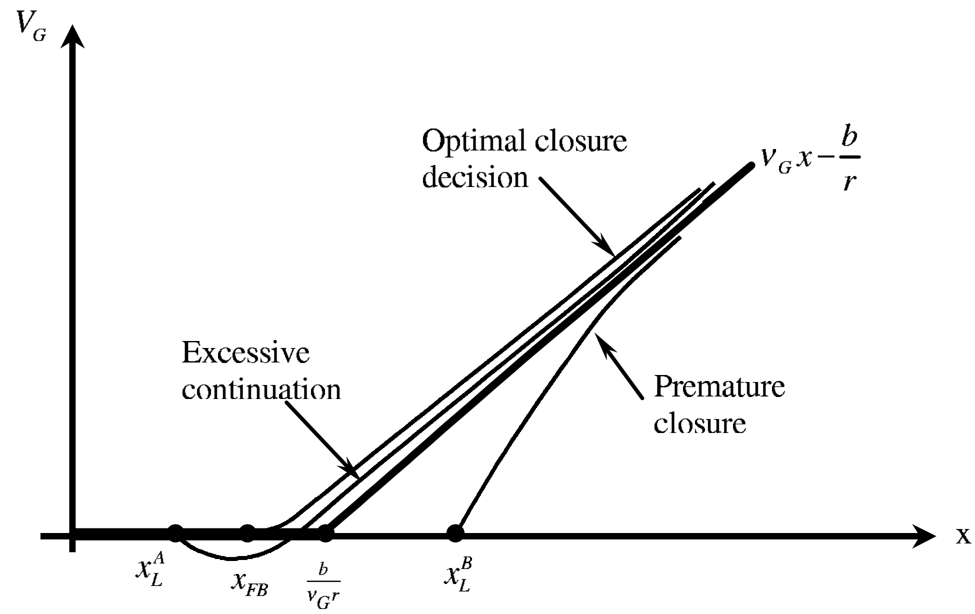

Figure 2: The continuation value of
the bank for different closure thresholds:

- x_L^A corresponds to excessive continuation ($V_G'(x_L^A) < 0$),
- x_L^B corresponds to premature closure ($V_G'(x_L^B) > 0$),
- x_{FB} corresponds to the optimal threshold ($V_G'(x_{FB}) = 0$),
- $\frac{b}{\nu_G r}$ corresponds to the positive NPV threshold.

We now introduce the second characteristic feature of commercial banking, namely deposit finance: a large fraction of the bank's liabilities consist of insured deposits,[14] with a volume normalized to one. For the moment, we assume that these deposits are the only source of outside funds for the bank: (we later introduce subordinated debt) and that issuing equity is prohibitively costly.[15] In the absence of public intervention,[16] the liquidation of the bank occurs when the cash flows βx received from its assets are insufficient to repay the interest r on deposits. The liquidation threshold is thus:

$$x_L = \frac{r}{\beta}, \tag{8}$$

[14]For simplicity, we assume that these are long term deposits. It would be easy to introduce a constant frequency of withdrawals, as in our treatment of subordinated debt in Section 5.

[15]Bhattacharya et al. (2000) make instead the assumption that the bank can costlessly issue new equity. In that case, the closure threshold is chosen by stockholders so as to maximize equity value.

[16]Public intervention can consist either of liquidity assistance by the Central Bank, or on the contrary closure by the banking supervision authorities.

which we assume is less than 1, the nominal value of deposits. As a result, the NPV of deposits $D(x)$ is less than their nominal value 1, the difference corresponding to the liability of the Deposit Insurance Fund.[17]

The NPV of deposits is computed easily:

$$D_G(x) = 1 - (1 - x_L)\left(\frac{x}{x_L}\right)^{1-a_G}, \tag{9}$$

leading to the value of equity:

$$E_G(x) = x + V_G(x) - D_G(x),$$

or

$$E_G(x) = (1+\nu_G)x - \frac{b}{r} - 1 + \left[\frac{b}{r} + 1 - (1+\nu_G)x_L\right]\left(\frac{x}{x_L}\right)^{1-a_G}. \tag{10}$$

If instead the bank ceases to monitor its assets, the value of equity becomes, by a simple adaptation of the above formula (replacing ν_G by ν_B and b by zero):

$$E_B(x) = (1+\nu_B)x - 1 + [1 - (1+\nu_B)x_L]\left(\frac{x}{x_L}\right)^{1-a_B}, \tag{11}$$

where

$$a_B = \frac{1}{2} + \frac{\mu_B}{\sigma_B^2} + \sqrt{\left(\frac{\mu_B}{\sigma_B^2} - \frac{1}{2}\right)^2 + \frac{2r}{\sigma_B^2}}. \tag{12}$$

By comparing the value of equity in the two formulas, it is easy to see that in general $E_B(x) > E_G(x)$ for x in some interval $]x_L, x_S[$, as suggested by the following figure:

[17]This liability is covered by an insurance premium $1 - D(x_0)$ paid initially by the bank. We could also introduce a flow premium, paid in continuous time, as in Fries et al. (1997).

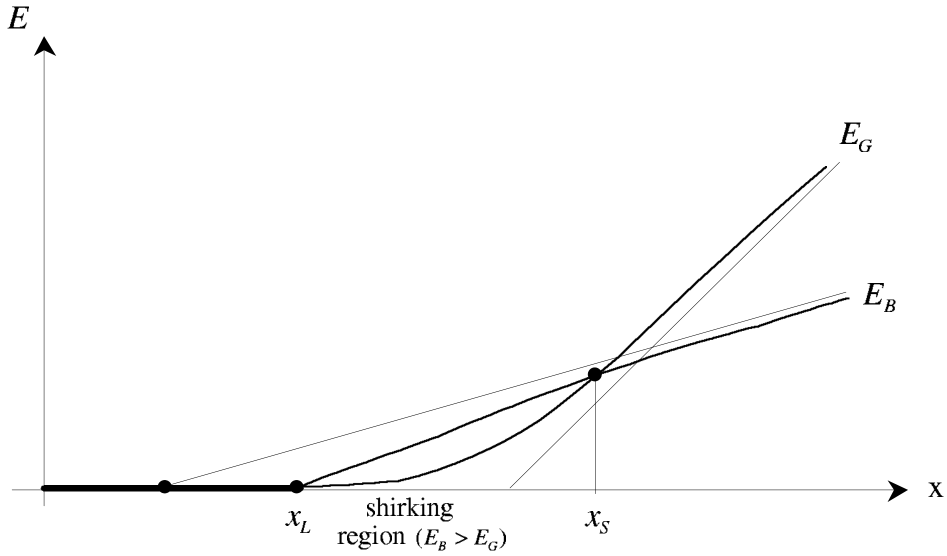

Figure 3: Comparing equity values
under good and bad technology choices.

4 The Objective and Limits of Banking Regulation

Figure 3 illustrates the basic reason for imposing a capital requirement in our model: as long as $E'_G(x_L) < E'_B(x_L)$, there is a region $[x_L, x_S]$ where, in the absence of outside intervention, the bank "shirks" (i.e. chooses the bad technology) which reduces social welfare, and ultimately provokes failure, the cost being borne by the Deposit Insurance Fund (DIF). In order to avoid shirking, banking authorities (which could be the Central Bank, a Financial Service Authority or the DIF itself) set a regulatory closure threshold x_R (which we interpret as a minimum capital requirement) below which the bank is closed. When the cost of monitoring is very large, x_R is greater than the nominal value of deposits (normalized to 1) and deposits becomes riskless. In this case the incentives of banks'stockholders are not distorted by the limited liability option: they optimally decide to close the bank when x hits the first best threshold x_{FB} and the moral hazard constraint does not bind (i.e. $x_{FB} > x_R$). A more realistic configuration occurs when

$$b < b^* = \frac{r a_G \nu_G}{a_G - 1} \left[\frac{a_G - a_B}{a_G(1+\nu_G) - a_B(1+\nu_B)} \right],$$

in which case $x_{FB} < x_R < 1$ and x_R is defined by the minimum value of x_L such that $E_G(x) \geq E_B(x)$ for all x, when x_L is replaced by x_R in formulas (10) and (11).

Proposition 2 *: When $b < b^*$, the second best closure threshold of the bank is the smallest* *value x_R of the liquidation threshold such that shirking disappears. It is given by:*

$$x_R = \frac{(a_G - 1)\frac{b}{r} + a_G - a_B}{a_G(1+\nu_G) - a_B(1+\nu_B)}. \tag{13}$$

Proof: Since by construction $E_G(x_R) = E_B(x_R) = 0$, a necessary condition for elimination of shirking is $E'_G(x_R) \geq E'_B(x_R)$. The minimum value of x_R that satisfies this inequality is defined implicitly by $\Delta(x_R) = 0$ where

$$\Delta(x_R) = x_R[E'_G(x_R) - E'_B(x_R)].$$

But formulas (10) and (11) (with x_R replacing x_L) imply

$$\begin{aligned} x_R E'_G(x_R) &= (1+\nu_G)x_R + (a_G - 1)\left[(1+\nu_G)x_R - 1 - \frac{b}{r}\right], \\ x_R E'_B(x_R) &= (1+\nu_B)x_R + (a_B - 1)\left[(1+\nu_B)x_R - 1\right]. \end{aligned}$$

Therefore

$$\Delta = \left[a_G(1+\nu_G) - a_B(1+\nu_B)\right] x_R - \left[(a_G - 1)\frac{b}{r} + a_G - a_B\right],$$

which establishes formula (13). We have to prove now that

$$\phi(x) \stackrel{\text{def}}{=} (E_G - E_B)(x)$$

is indeed non negative for all x when x_R is given by formula (13). Simple computations show that:

$$\begin{aligned} x\phi'(x) &= (\nu_G - \nu_B) - (a_G - 1)\left[1 + \frac{b}{r} - (1+\nu_G)x_R\right]\left(\frac{x}{x_R}\right)^{1-a_G} \\ &\quad + (a_B - 1)[1 - (1+\nu_B)x_R]\left(\frac{x}{x_R}\right)^{1-a_B}, \end{aligned}$$

and

$$\begin{aligned} x^2\phi''(x) &= a_G(a_G - 1)\left[1 + \frac{b}{r} - (1+\nu_G)x_R\right]\left(\frac{x}{x_R}\right)^{1-a_G} \\ &\quad - a_B(a_B - 1)\{1 - (1+\nu_B)x_R\}\left(\frac{x}{x_R}\right)^{1-a_B}, \end{aligned}$$

or

$$\begin{aligned} x^2\phi''(x) &= \left(\frac{x}{x_R}\right)^{1-a_G}\Bigg[a_G(a_G - 1)\left\{1 + \frac{b}{r} - (1+\nu_G)x_R\right\} \\ &\quad - a_B(a_B - 1)\{1 - (1+\nu_B)x_R\}\left(\frac{x}{x_R}\right)^{a_G - a_B}\Bigg]. \end{aligned}$$

Now $b < b^*$ implies that $x_{FB} < x_R < 1$, so that $\{1 - (1+\nu_B)x_R\} > 0$. Moreover, the facts that $\phi'(x_R) = 0$ and $a_B > 1$ imply that

$$(a_G - 1)\left(1 + \frac{b}{r} - (1+\nu_G)x_R\right) > (a_B - 1)\{1 - (1+\nu_B)x_R\} > 0.$$

Thus $\phi''(x)$ is positive for x small, and negative for x large, which implies that $\phi'(x)$ is single peaked. Given that

$$\lim_{x \to +\infty} \phi'(x) = \nu_G - \nu_B > 0,$$

we have established that ϕ is increasing on $[x_R, +\infty[$ and therefore always greater than $\phi(x_R) = 0$, which finishes the proof of Proposition 2. ■

Within the relevant set of parameters, we have that $x_{FB} < x_L < x_R$, which expresses the fundamental dilemma faced by banking authorities: regulation is needed because undercapitalized banks shirk (this is because $x_L < x_R$)[18] but closure is not credible given that the ex-post continuation value of the bank (from a social welfare point of view) is positive (this is because $x_R > x_{FB}$). When $x \in [x_{FB}, x_R]$ the ex-ante optimal policy would be to close the bank, but from an ex-post perspective, it is optimal to recapitalize it by injection of taxpayers' money (at least when fiscal distortions are neglected). We are now going to see how market discipline can be used to modify this fundamental dilemma faced by banking authorities.

5 Market Discipline

There are several reasons why market discipline can be useful. First it can produce additional information that the regulator can exploit. Consider for example a set up à la Merton (1978) or Bhattacharya et al. (2000) where x_t is only observed through costly and imperfect auditing. As a result, there is a positive probability that the bank may continue to operate in the region $[x_L, x_R]$ (because undetected by banking supervisors). If shirking is to be deterred, a more stringent capital requirement (i.e. a higher x_R) has to be imposed, to account for imperfect auditing (see Bhattacharya et al. (2000) for details). In such a context, imposing the bank to issue a security (say subordinated debt) whose pay-off is conditional on x_t, and that is traded on financial markets, would indirectly reveal the value of x_t and dispense the regulator from costly auditing. This is explored further in Section 7.2. Of course, if the bank's equity is already traded, then this advantage disappears and the question becomes more technical: which security prices reveal more information about banks' asset value?

[18] If $x_L > x_R$, it would be legitimate for banking authorities to provide liquidity assistance to banks in the region $[x_R, x_L]$. Unregulated banking would be optimal only in the unlikely case where $x_L = x_R$.

We will not follow this route here, because our focus is on the articulation between market discipline and bank regulation. The question of whether financial markets know more or less than regulators is irrelevant, given that regulators can in principle use all market information (which is publicly available) in their closure decisions. What is relevant is the impact of market discipline on the intervention threshold of regulators and on their credibility.

We introduce market discipline in our model by assuming that banks are required to issue a certain volume s of subordinated debt, renewed with a certain frequency m. Both s and m are policy variables of the regulator. To facilitate comparison with the previous section, we keep constant the total volume of outside finance. Thus the volume of insured deposits becomes $d = 1 - s$. To simplify the analysis, and obtain simpler formulas than Leland and Toft (1996), we assume (as in Ericsson, 2000) that subordinated debt has an infinite maturity, but is renewed according to a Poisson process of intensity m. The average time to maturity of subordinated debt is thus:

$$\int_0^{+\infty} td[e^{-mt}] = \frac{1}{m}.$$

In this section, we consider that the regulator can commit to a closure threshold x_R. We focus on the case where $x_R < d$, so that deposits are risky, while sub-debt holders (and stockholders) are expropriated in case of closure. We use the same notation as before (for any technology choice $k = B, G$):

$$\begin{aligned} V_k &= \text{continuation value of the bank,} \\ D_k &= \text{NPV of insured deposits,} \\ E_k &= \text{value of equity,} \end{aligned}$$

while S_k denotes the value of sub-debt.

Starting with the case where the bank monitors its assets ($k = G$), the values of V_G and D_G are given by simple adaptations of our previous formulas:

$$\begin{aligned} V_G(x) &= \nu_G x - \frac{b}{r} + \left[\frac{b}{r} - \nu_G x_R\right] \left(\frac{x}{x_R}\right)^{1-a_G}, \\ D_G(x) &= d - (d - x_R) \left(\frac{x}{x_R}\right)^{1-a_G}. \end{aligned}$$

S_G is more difficult to determine. It is the solution of the following Partial Differential Equation, taking into account the fact that, with instantaneous probability m, subordinated debt is repaid at face value s:

$$\begin{cases} rS_G(x) &= sr + m(s - S_G(x)) + \mu_G S_G'(x) + \frac{1}{2}\sigma_G^2 S_G''(x) \\ S_G(x_R) &= 0, \end{cases}$$

leading to:

$$S_G(x) = s\left[1 - \left(\frac{x}{x_R}\right)^{1-a_G(m)}\right], \tag{14}$$

where

$$a_G(m) = \frac{1}{2} + \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + 2\frac{r+m}{\sigma^2}}. \tag{15}$$

We immediately notice a first effect of market discipline: the exponent $1 - a_G(m)$ decreases when m increases. Thus the value of S_G increases in m. The value of equity becomes:

$$\begin{aligned} E_G(x) &= x + V_G(x) - D_G(x) - S_G(x) \\ &= (1+\nu_G)x - 1 - \frac{b}{r} + \left[d + \frac{b}{r} - (1+\nu_G)x_R\right]\left(\frac{x}{x_R}\right)^{1-a_G} + s\left(\frac{x}{x_R}\right)^{1-a_G(m)} \end{aligned} \tag{16}$$

When $m = 0$, we obtain the same formula as in the previous section (no market discipline): this is due to our convention to keep constant the total volume of outside finance ($s + d = 1$).

A simple adaptation of formula (16) gives E_B, the value of equity when the bank shirks:

$$E_B(x) = (1+\nu_B)x - 1 + [d - (1+\nu_B)x_R]\left(\frac{x}{x_R}\right)^{1-a_B} + s\left(\frac{x}{x_R}\right)^{1-a_B(m)}, \tag{17}$$

where

$$a_B(m) = \frac{1}{2} + \frac{\mu_B}{\sigma_B^2} + \sqrt{\left(\frac{\mu_B}{\sigma_B^2} - \frac{1}{2}\right)^2 + 2\frac{r+m}{\sigma_B^2}}. \tag{18}$$

Thus a necessary condition for shirking to be eliminated is: $\Delta \geq 0$, where

$$\Delta = x_R[E_G'(x_R) - E_B'(x_R)].$$

A simple computation gives:

$$\begin{aligned} x_R E_G'(x_R) &= a_G(1+\nu_G)x_R - (a_G - 1)\left(d + \frac{b}{r}\right) - s[a_G(m) - 1], \\ x_R E_B'(x_R) &= a_B(1+\nu_B)x_R - (a_B - 1)d - s[a_B(m) - 1]. \end{aligned}$$

Thus

$$\Delta = [a_G(1+\nu_G) - a_B(1+\nu_B)]x_R - \left[(a_G - a_B)d + (a_G - 1)\frac{b}{r} + s\{a_G(m) - a_B(m)\}\right], \tag{19}$$

from which we deduce immediately:

Proposition 3 *: The minimum capital requirement that prevents bank shirking is*

$$x_R(m) = \frac{(a_G - 1)\frac{b}{r} + (a_G - a_B)d + (a_G(m) - a_B(m))s}{a_G(1+\nu_G) - a_B(1+\nu_B)}.$$

When $\sigma_B^2 > \sigma_G^2$ this is a U-shaped function of m, with a minimum in m^*. When $\sigma_B^2 = \sigma_G^2$ (pure effort problem) it is decreasing in m (i.e., $m^* = +\infty$). When $m \leq m^*$, market discipline reduces the need for premature bank closures.

Thus, in the absence of regulatory forbearance, market discipline reduces the level of regulatory capital. We now study the consequences of market discipline in the more realistic case where banking authorities have a commitment problem.

6 Regulatory Forbearance

We assume in this section that banking authorities are subject to political pressure for supporting the banks who hit the closure threshold x_R. Given our irreversibility assumption, it is indeed always suboptimal to let banks go below this threshold. On the other hand, closure is (ex-post) dominated by continuation, at least when net fiscal costs are not too high. Therefore, we consider that whenever a bank hits the boundary $x = x_R$, it receives liquidity assistance from the government.

Technically, x_R becomes a reflecting barrier (see for example Dixit, 1993) and the boundary condition for V_k becomes:

$$V_k'(x_R) = \lambda,$$

where $\lambda > 0$ represents the net welfare cost of liquidity assistance (due for example to distortions created by the fiscal system). The new formula for V_G is:

$$V_G(x) = \nu_G x - \frac{b}{r} - \left(\frac{\lambda - \nu_G}{a_G - 1}\right) x^{1-a_G} x_R^{a_G}.$$

We could have considered more generally that the government injects a lump sum in the bank (recapitalization). However, provided such a recapitalization does not entail a fixed cost (but only a marginal welfare cost λ), it is easy to see that it is dominated by liquidity assistance (or infinitesimal recapitalization) whenever $\lambda > \nu_G$, which we assume from now on.[19] Notice that regulatory forbearance implies that $V_G(x_R)$ is now different from 0, given that banks are allowed to continue after they hit x_R. To see the impact

[19] When $\lambda < \nu_G$, an infinite recapitalization is optimal.

of regulatory forbearance on the value of bank equity, we have to specify the penalties imposed on equity holders and sub-debt holders when the bank hits $x = x_R$.

We assume that sub-debt-holders are wiped out (i.e. $S_k(x_R) = 0$) while equity holders are only required to pay a fraction α of the cost of liquidity assistance ($E_k'(x_R) = \alpha$). In this case, it turns out that the value of sub-debt is the same as before:

$$S_G(x) = s\left[1 - \left(\frac{x}{x_R}\right)^{1-a_G(m)}\right],$$

while the new formula for E_G is:

$$\begin{aligned} E_G(x) &= (1+\nu_G)x - \frac{b}{r} - 1 + s\left(\frac{x}{x_R}\right)^{1-a_G(m)} \\ &\quad + \frac{1+\nu_G - \alpha - s(a_G(m)-1)}{a_G - 1}\left(\frac{x}{x_R}\right)^{1-a_G}. \end{aligned}$$

Similarly:

$$\begin{aligned} E_B(x) &= (1+\nu_B)x - 1 + s\left(\frac{x}{x_R}\right)^{1-a_B(m)} \\ &\quad + \frac{1+\nu_B - \alpha - s(a_B(m)-1)}{a_B - 1}\left(\frac{x}{x_R}\right)^{1-a_B}. \end{aligned}$$

The necessary condition for no shirking becomes

$$\Delta = E_G(x_R) - E_B(x_R) \geq 0,$$

where

$$\Delta = (\nu_G - \nu_B)x_R - \frac{b}{r} + \frac{1+\nu_G-\alpha-s(a_G(m)-1)}{a_G-1} - \frac{1+\nu_B-\alpha+s(a_B(m)-1)}{a_B-1}. \tag{20}$$

Thus we deduce:

Proposition 4 *: In the presence of regulatory forbearance, the minimum capital requirement that eliminates bank shirking becomes:*

$$\hat{x}_R(m) = \frac{1}{(\nu_G - \nu_B)}\left[\frac{b}{r} + \frac{1+\nu_G-\alpha}{a_G-1} - \frac{1+\nu_B-\alpha}{a_B-1} + s\left(\frac{a_G(m)-1}{a_G-1} - \frac{a_B(m)-1}{a_B-1}\right)\right].$$

It is a decreasing function of m: market discipline reduces the cost of regulatory forbearance.

Proof: The formula for $\hat{x}_R(m)$ results directly from formula (20). The fact that $\hat{x}_R(m)$ decreases in m results from the comparison of the derivatives of $\frac{a_k(m)-1}{a_k-1}$ for $k = G, B$:

$$\frac{a_k(m) - 1}{a_k - 1} = \frac{t_k + \sqrt{t_k^2\sigma_k^2 + 2(r+m)}}{t_k + \sqrt{t_k^2\sigma_k^2 + 2r}},$$

where

$$t_k = \frac{\mu_k}{\sigma_k} - \frac{\sigma_k}{2},$$

$$\frac{\dot{a}_k(m)}{a_k - 1} = \left[t_k + \sqrt{t_k^2\sigma_k^2 + 2r}\right]^{-1} (t_k^2\sigma_k^2 + 2(r+m))^{-1/2}.$$

Given that $t_G > t_B$ and $t_G\sigma_G > t_B\sigma_B$, it is clear that

$$\frac{\dot{a}_G(m)}{a_G - 1} < \frac{\dot{a}_B(m)}{a_B - 1}$$

and thus that $\hat{x}_R(m)$ decreases in m. ■

7 Extensions and Concluding Remarks

7.1 Macro Shocks and Procyclicality

Several commentators (see for example Borio et al., 2001) have expressed the concern that risk sensitive capital requirements might exacerbate business cycles by forcing more bank closures (or at least reducing aggregate bank lending) during recessions. A simple extension of our model allows to shed light on this question. Consider indeed that the pay-out ratio β of banks' assets fluctuates according to a Markov chain with an instantaneous transition probability q. This Markov chain can take two values: $m = \underline{m}$ (interpreted as a recession) and $m = \overline{m}$ (interpreted as a boom). Accordingly, the pay-out ratio is $\underline{\beta}$ in state $\underline{m}$ and $\bar{\beta}$ in state $\overline{m}$, with $\underline{\beta} < \bar{\beta}$. Consider first the limit case $q = 0$, where the states are permanent. An immediate adaptation of our previous results allows to understand the impact of macroeconomic condition on banks' closure thresholds. Recall indeed the formulas for the first best and second best closure thresholds:

$$x_{FB} = \frac{a_G - 1}{a_G}\frac{b}{r\nu_G},$$

and

$$x_R = \frac{(a_G - 1)\frac{b}{r} + a_G - a_B}{a_G(1+\nu_G) - a_B(1+\nu_B)},$$

where

$$\nu_G = \frac{\beta}{r - \mu}$$

and

$$\nu_B = \frac{\beta}{r - \mu_B} - 1.$$

Adapting these formulas for the case where β can take two values (we assume that m, the macroeconomic state, is common knowledge) we obtain a higher closure threshold in case of a recession than in case of a boom, both for the 1st best and 2nd best cases:

$$\bar{x}_{FB} < \underline{x}_{FB} \qquad \text{and} \qquad \bar{x}_R < \underline{x}_R.$$

Notice however that the relative variation of the regulatory threshold is smaller than that of the first best threshold.

Indeed:

$$\frac{\underline{x}_R - \bar{x}_R}{\bar{x}_R} = \frac{\bar{\beta} - \underline{\beta}}{\underline{\beta}} < \frac{\underline{x}_{FB} - \bar{x}_{FB}}{\bar{x}_{FB}} = \frac{\underline{x}_{NPV} - \bar{x}_{NPV}}{\bar{x}_{NPV}} = \frac{\bar{\beta} - \underline{\beta}}{\underline{\beta} - r + \mu}.$$

This property comes from the fact that the capital requirement is related to the present value of future cash flows, which vary less (in relative terms) than the continuation value of the bank, which determines the first best threshold.

The same qualitative feature emerges when q is positive (but small).[20] In this case, the determination of closure thresholds is more complex but the basic conclusion remains true: capital requirements should be stricter during recessions.

This being said, the dependence of banks' capital requirements on the macroeconomics state of the economy creates (at least) two difficulties:

- **Procyclicality:** The aggregate value of banks' assets (that can be interpreted as the volume of outstanding credit to the economy) depends negatively of x_R and positively of β. Since x_R increases during recessions, this aggregate value fluctuates more than it would if capital requirements were fixed in absolute terms (i.e. independent of the macro state).

- **Credibility:** In theory, when a recession occurs, all the banks with asset values in the range $[\bar{x}_R, \underline{x}_R]$ should be immediately closed. This is not particularly credible, especially if the government has stabilization objectives (see our previous remark on procyclicality).

This should be the topic of further research.

[20] In this case both V_k and E_k depend on β as well as x. They can be determined by solving couples of PDE. First and second best closure thresholds can be determined as before.

7.2 Prompt Corrective Action

Following Merton (1978), a branch of the academic literature has studied the complementarity between capital requirements and regulatory audits (a recent reference is Bhattacharya et al., 2000). In this literature, the value x of the bank's assets is privately known to the banker. It can only be observed by the regulator if a costly audit is performed, which is modeled by a Poisson process, the intensity of which is chosen by the regulator. Bank closure can then result either from a regulatory decision (following an audit revealing that $x \leq x_R$) or a decision of stockholders (who have a lower closure threshold), when the profitability of the bank's assets becomes too low.[21] Since the regulator wants to avoid excessive continuation, he has to set a higher closure threshold than if x was publicly observable.[22] However this threshold can be reduced by an increase in the intensity of auditing, thus suggesting substitutability between supervision and capital requirements.

Our model allows to extend this literature by integrating the 3rd pillar of Basel II, namely market discipline, in this picture. Suppose indeed that the equity of the bank is publicly traded and that the price of the stock $E(x)$ can be used by the regulator to condition its intervention policy. By inverting the function $x \to E(x)$, the regulator can infer the value of the bank's assets from the stock price E (as before, we assume that financial markets are efficient). In such a context, the role of bank supervisors has to be re-examined: instead of a constant probability of audit across all banks, bank supervisors can adopt a gradual intervention policy (in the spirit of the US regulatory reform following the FDIC Improvement Act). For example, the regulator can set two thresholds x_R and x_I (with $x_R < x_I$), where x_R is as before a closure threshold, but x_I is only an inspection threshold: whenever $x < x_I$, the bank is inspected,[23] and it is closed if and only if the bank has chosen the bad technology ($k = B$).

With this regulatory policy, the value of equity when $k = G$ is the same as in Section 3 (with x_R replacing x_L):

$$E_G(x) = (1 + \nu_G)x - \frac{b}{r} - 1 + k_G x^{1-a_G},$$

with

$$k_G = \left[\frac{b}{r} + 1 - (1 + \nu_G)x_R\right] x_R^{a_G - 1}.$$

However the value of equity when $k = B$ now depends on x_I:

$$E_B(x) = (1 + \nu_B)x - 1 - k_B x^{1-a_B},$$

[21] Contrarily to us, this literature assumes that bankers are not liquidity constrained: new equity can be issued without cost. In that case, bankers are biased toward excessive continuation.

[22] Here also, the regulator faces a credibility problem.

[23] We assume that the regulatory audit policy is deterministic. It would be easy to consider the more general case of stochastic audits.

with

$$k_B = [1 - (1 + \nu_B)x_I]x_I^{a_B - 1}.$$

For a given value of x_I (and thus for a given function E_B) there is a minimum value of x_R such that E_G remains above E_B. It is obtained when the two curves are tangent, as suggested by the figure below.

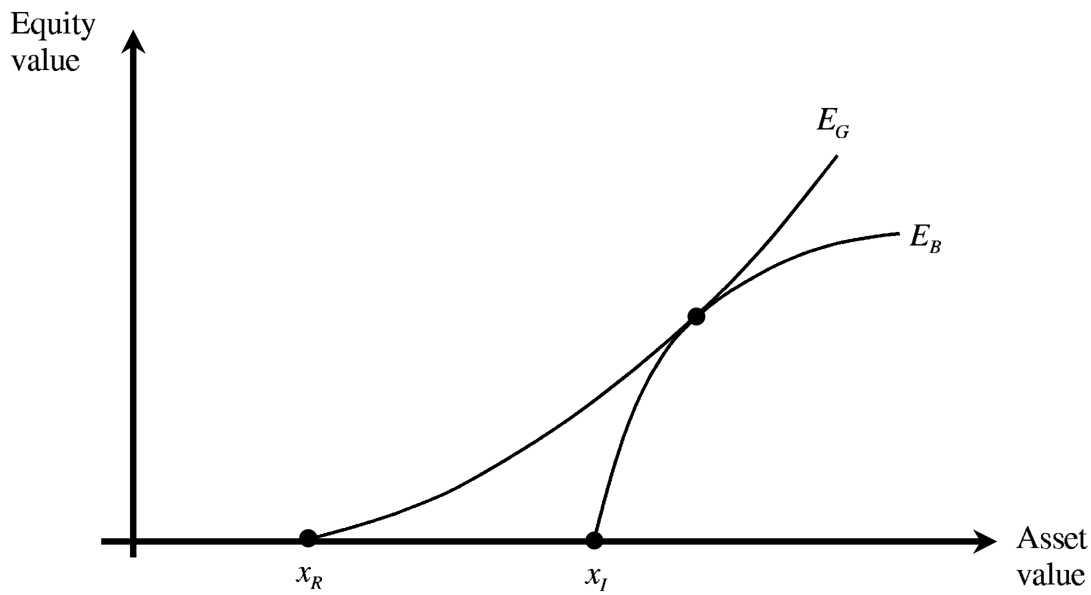

Figure 4: Optimal capital requirement x_R for a given inspection threshold x_I.

It can be proven that this minimum level of x_R decreases with x_I, which establishes that the substitutability between capital requirements and supervision is maintained when market discipline is introduced.

7.3 Concluding Remarks

Our objective in this article was to design a simple dynamic model of a bank, where the articulation between the 3 pillars of Basel II can be analyzed. We interpret the first pillar (capital adequacy requirement) as a closure threshold rather than an indirect mean of influencing banks' asset allocation. We show that market discipline (the 3rd pillar) can be used to reduce this closure threshold, even if the possibility of regulatory forbearance is introduced. We also re-examine the traditional view on the supervisory role (stochastic auditing) by introducing prompt corrective action. A more complete analysis of intervention thresholds in a context of macroeconomic uncertainty remains to be done.

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