The Liquidity of Bank Assets and Banking Stability*

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Abstract

Recent financial innovations, such as credit derivative instruments, have increased the liquidity of bank assets by providing banks with various possibilities for selling and hedging their risks. This paper examines the consequences for banking stability.

In a simple model where liquidation of bank assets is costly, we show that increased asset liquidity benefits stability by encouraging a representative bank to reduce the risks on its balance sheet. Stability is further enhanced because the bank can now liquidate assets in a crisis more easily. However, these effects are counteracted by increased risk-taking of the bank. We find that overall, stability actually falls. This is because the improved possibilities for liquidating assets in a crisis make a crisis less costly for the bank, which induces the bank to take on an amount of risk that more than offsets the initial positive impact on stability.

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1 Introduction

Bank loans have always been considered as illiquid. Recent financial innovations, however, have substantially increased their liquidity. In particular, the various new *credit derivative* instruments have provided banks with a whole range of possibilities to transfer loan risk and to sell loans:[1] "Derivatives and the more liquid markets they encourage make possible a new discipline at commercial banks, that of active portfolio management. ...unwanted credit risks can be divested in a variety of forms, through hedges or purchases of insurance as well as outright sales in the secondary markets." (Standard & Poors, 2003) Perhaps the most significant development for the liquidity of bank assets are *portfolio products*, such as Collateralized Loan Obligations, that now enable banks to sell risks from their entire loan portfolio.[2] The ability of banks to sell their assets has further been spurred by the growing availability of ratings on bank portfolios and the build-up of credit analysis departments in non-bank institutions (such as insurance companies).

Regulators have been largely welcoming this development on the grounds that the relative illiquidity of bank assets has been considered a main source of banking fragility.[3] The intuitive reasoning is that an improved ability to sell assets should make banks less vulnerable to liquidity shocks and is further expected to reduce the level of risks on banks' balance sheets by facilitating diversification and the transfer of risk out of the banking sector.

This is clearly a static view. It ignores that banks may change their behavior as a result of the increased liquidity of their assets. In particular, banks may simply offset risks they have transferred from their balance sheet by taking on new risks. They may also be encouraged to increase their risk because a higher liquidity of loans allows them to liquidate more easily in a crisis. Recent empirical work points at the potential importance of such effects: Cebenoyan and Strahan (2004) provide evidence that banks that have access to loan sale markets hold a larger share of their portfolio in risky assets than banks inactive in loan sales. Franke and Krahnen (2005) find that following the issuance of a Collateralized Loan Obligation, the beta of a bank's share price increases, while Goderis et. al. (2005)

[1] Since its inception in 1996, the credit derivatives market has been quickly expanding, with annual growth rates of around $70-100\%$. The outstanding value of credit derivatives is currently estimated at around U\$ $5,000$ bn and the market is expected to continue to grow at a high pace (BBA 2004). For an overview of the different available instruments, see BIS (2004).

[2] There have been possibilities for banks to sell loans for a long time, such as through a loan sale market or through securitization of consumer loans and mortgages. However, this was restricted to assets with relatively low informational problems.

[3] See, for example, the various reports on the stability implications of credit derivatives (e.g., FSA 2002, IAIS, 2003, and BIS, 2004) .

find that after a CLO banks increase the amount of loans they hold in their portfolio.

The aim of this paper is to analyze whether banks' risk-taking incentives may lead to an offsetting or even a reversal of the initial beneficial stability impact of an increased liquidity of bank assets. To address this issue, we consider a simple model of an unregulated representative bank that has an incentive for taking on excessive risks because of limited liability. Crises occur because a low return on loans can trigger bank runs. Bank loans are partly illiquid in that they can only be sold at a discount to their economic value. This creates an incentive for the bank to limit the risks it retains on its balance sheet in order to avoid a crisis, in which it has to sell loans. In this framework, the bank's optimal risk-taking amounts to choosing a probability of default that balances the benefits of a higher riskiness of the bank (i.e., a higher return if the bank survives) with its costs (an increased likelihood of a crisis). Increased asset liquidity is modelled as an (exogenous) reduction in the discount at which loans can be sold, which we allow to be different in normal times and in times of crisis.

We find that an increase in liquidity in normal times does not affect stability, as measured by the bank's probability of default. The increase in liquidity initially improves stability by facilitating the transfer of risk from the bank and by increasing the bank's profits. However, it does not affect the bank's optimal probability of default. As a consequence, the bank increases risk taking in the primary markets by an amount that exactly offsets the initial impact on stability.

By contrast, an increase in asset liquidity in times of crisis, paradoxically, reduces stability. Again, there is an initial positive impact on stability, this time because it makes the bank less vulnerable to bank runs. As before, the bank would offset this through increased risk-taking. However, now the costs of a bank run for the bank are lower since the losses from selling loans in a crisis have fallen. This increases the bank's optimal probability of default and as a result the bank takes on an amount of risk that more than offsets the initial impact on stability.

Perhaps surprisingly, we therefore find that although an increased liquidity of the bank's assets reduces a main cause of fragility, stability is not increased.[4] The reason for this is that any reduction in the bank's fragility reduces the bank's costs from retaining risk on its balance sheet and causes an offsetting change in the bank's behavior in the primary markets. Stability even falls if the losses from selling assets in a crisis are reduced; the reason being that this undermines the bank's incentives to limit its risk-taking, while its incentives for taking on excessive risks due to limited liability are retained.

[4] We also find that both types of liquidity increase the loss given default, and thus the externalities associated with the bank's failure.

Financial regulators may want to address this stability problem and we study the possibilities for doing this. To this end we extend our analysis to an environment in which deposits are fully insured and regulators can impose Basel-style capital requirements. We demonstrate that a negative stability impact arising from increased liquidity can be counteracted by increasing capital requirements. However, we find that when asset liquidity becomes large, capital requirements become a less effective instrument for ensuring stability. This is because the losses from the sale or the liquidation of assets in a banking closure become then small, making banking closure less of a threat for bank owners. By contrast, we show that the impact of increased asset liquidity on stability can be directly offset by reducing the returns for bank owners in a bank closure.

The paper proceeds as follows. In the next section we relate the paper to the existing literature. Section 3 describes the model of the unregulated economy and solves for the equilibrium banking stability. Section 4 analyzes then the impact of increased liquidity. Regulation is studied in Section 5. The final section summarizes.

2 Related Literature

Several contributions have recently stressed the role of financial innovations in general (and credit derivatives in particular) in affecting the informational asymmetries in bank loans, and hence their liquidity. Duffee and Zhou (2001) have argued that the flexibility of credit derivatives can be used to mitigate adverse selection problems. Morrison (2005) has shown that credit derivative markets can reduce banks' incentives to monitor (thus reducing informational asymmetries about their assets) because it makes banks less exposed to credit risk. Arping (2005), on the other hand, develops the idea that credit risk transfer can actually improve banks' incentives to monitor by leading to a more efficient liquidation of firms. Nicolo' and Pelizzon (2005) demonstrate how different forms of credit derivatives can be used to signal the quality of bank loans under binding capital requirements. In DeMarzo (2005) it is shown how pooling and tranching, which are common in balance sheet credit derivatives, can be used to reduce informational asymmetries.[5]

The literature on banking stability has pointed out that asset liquidity has stability implications by affecting systemic risk. For example, the possibility of banks to trade assets with each other can lead to contagion because it creates informational spillovers (e.g., Aghion, Bolton, Dewatripont, 2000) and because it facilitates mutual credit exposures (e.g.,

[5] There is also a related, older, literature focusing on the scope for selling bank loans in the secondary market, which seems to contradict banks' comparative advantage in acquiring information about borrowers (e.g., Gorton and Pennacchi, 1995 and Carlstrom and Samolyk, 1995).

Freixas, Parigi and Rochet, 2000). Interbank diversification can also increase systemic risk by making individual banks less risky and thus encouraging banks to hold less liquidity (Wagner, 2005). The ability of banks to sell assets may also lead to a shift of risk between a more fragile (the banking sector) and a less fragile sectors (e.g., Allen and Gale, 2005), hence changing the overall fragility of the financial system. Increased asset liquidity can also have non-trivial stability implications by increasing the market orientation of the financial system (Fecht, 2004).

Our paper is most closely related to the strand of the literature on banking stability that emphasizes banks' risk taking incentives. Santomero and Trester (1997) consider innovations that reduce the cost of overcoming informational asymmetries when selling assets in a crisis, which correspond to our notion of an increase in crisis liquidity. They find that such innovations lead to increased risk taking by banks. However, the focus of their analysis is not on the net impact on banking stability. Instefjord (2005) analyzes risk taking by a bank that has access to credit derivatives for risk management purposes. He finds that innovations in credit derivatives markets (which correspond to an increase in liquidity in normal times in our paper) lead to increased risk taking because of enhanced risk management opportunities. Again, the paper does not focus on the net stability impact. In particular, since Instefjord considers a dynamic risk management problem with infinitesimal small shocks, there are no banking defaults in equilibrium and hence the banking sector is perfectly stable.[6]

3 The Model

An economy has the following time structure. At $t = 0$ a representative bank decides on how much to invest in a risky asset, which we interpret as extending loans. At $t = 1$, the bank has the possibility to sell off a fraction of the risky asset at a secondary market (this can be more generally interpreted as a transfer of credit risk since hedging of risk and asset sales at $t = 1$ are equivalent in the model). At $t = 2$, uncertainty about the return on the risky asset is resolved and the bank's depositors decide whether to run on the bank or not.[7] At $t = 3$ asset returns are realized and all parties are compensated.

[6] Although no explicit solution for the equilibrium risk exposure is obtained, Instefjord's paper conjectures that if the loan market is elastic, banks' retained risk can increase and that this may reduce banking stability. Our analysis qualifies this conjecture by showing that the motivation for increasing retained risk is precisely to offset an initial impact on stability. Thus, stability is not affected by such type of innovations, even if the loan market is perfectly elastic.

[7] Alternatively, our model can be interpreted along the lines of the 'modern' form of liquidity crises (e.g., Rochet and Vives, 2004), where large uninsured investors refuse to rollover credit.

The bank has an exogenously given capital structure, consisting of deposits D and equity W.[8] The return required by depositors is 1 and the interest on deposits is i. We consider an unregulated banking sector, in particular, deposits are not insured (in Section 5 we analyze deposit insurance combined with capital requirements). Deposits are made before the bank decides about its risk taking. Hence, the interest rate i is independent of the bank's *actual* risk taking. Rather, the interest rate reflects *expected* risk taking and compensates depositors for their expected losses from default.

More specifically, the bank's decision at $t = 0$ is how much of its capital to invest in the risky asset and how much to hold in reserves. Denoting the amount invested in the risky asset by X and the amount held in reserves by R we have

$$D + W = X + R \tag{1}$$

Reserves are perfectly liquid and have a return of zero. The return on the risky asset is $r = \mu + \varepsilon$, with $\mu \geq 1$. The asset shock ε is uniformly distributed on $[-1, 1]$ with probability density $\phi(\varepsilon) = 1/2$. Hence $E[\varepsilon] = 0$ and the expected return is $E[r] = \mu \geq 1$. As in Gennotte and Pyle (1991), the excess return on the risky asset is therefore not restricted to be zero. We think of this as being the result of the bank's superior ability to screen and monitor local firms, giving it a monopoly in the local loan market (as in Carlstrom and Samolyk, 1995). The counterpart of this excess return, however, is that the risky asset is partly illiquid.

At $t = 1$, the bank sells off the risky asset to investors.[9] However, because of asset illiquidity the bank cannot obtain the full value of the asset. This is interpreted as being the result of the bank's private information about its loans, which gives rise to a lemon problem (as in Duffie and Zhou, 2001), or because bank's incentives to monitor and evaluate the borrower are reduced for an asset that is not kept by the bank (Gorton and Pennacchi, 1995).[10]

The value loss due to illiquidity is specified as follows. We assume that the risky asset consists of a continuum of infinitely small loans of equal size, indexed by j, $j \in [0, X]$.

[8] The capital structure plays no role for the main results in the paper. This is because any potential impact of capital structure on stability will be undone by the bank through a change in risk taking at $t = 0$. However, in the present setting, the capital structure could be endogenized along the lines of Diamond and Rajan (2000).

[9] Note that nothing happens between $t = 0$ and $t = 1$ in the model; the two dates are to emphasize that in practice there will typically be a substantial delay between primary market risk taking and secondary markets sales.

[10] An alternative interpretation, and one that is potentially unrelated to informational problems, is that there are simply imperfections on the buyer's side, leading to *market* illiquidity. Yet another interpretation arises from limited commitment to future cash flows (as in Diamond and Rajan, 1997).

These loans differ with respect to their value loss if sold to investors at $t = 1$ but are identical otherwise. In particular, a loan j can only be sold at a proportional discount βj, where j is the measure of asset specific illiquidity and β, $\beta \geq 0$, a measure of aggregate asset illiquidity. The case where loans are perfectly liquid can then be represented by $\beta = 0$. We refer to β in the following as *risk transfer* costs; the reason being that the motivation for the bank to sell at the second market arises from the asset's riskiness (if the asset were not risky, the bank would prefer to retain it on the balance sheet and recoup the full value at $t = 3$). We furthermore assume that investors can observe the type of the loan (the index j).[11] It follows that the bank prefers to sell the loans with the lowest j. Denoting the amount sold by the bank by Y, the bank's total proceeds from selling are then

$$\int_0^Y (1 - \beta j)\mu di = (1 - \beta Y/2)\mu Y$$

At $t = 2$, uncertainty regarding the asset shock ε is resolved and r becomes known. If, as a result, depositors decide to demand their deposits back and the bank's liquidity is not sufficient to meet depositors' demands, the bank has to liquidate the risky asset. We assume that there are again proportional costs of selling the asset, for similar reasons as at $t = 1$. However, for simplicity the proportional discount is now taken to be independent of the loan type[12] and given by γ, $0 \leq \gamma \leq 1$. We term γ *liquidation costs* and assume that $\gamma > \beta(D + W)$. This ensures that $\gamma > \beta i$ for all $i \in [0, X]$, i.e., the cost of selling loans at $t = 2$ is always higher than at $t = 1$ because of the higher urgency of asset sales in a bank run.

The decision of depositors whether to run on the bank depends on their beliefs about the behavior of other depositors, giving rise to multiple equilibria. We focus in the following on the *risk dominant* equilibrium (Harsanyi and Selten, 1988), which specifies that investors have flat beliefs. Applied to our context, this means that each depositor believes that all other depositors (collectively) decide to run with probability 1/2 and simply plays its best response to this.

The use of the risk-dominant equilibrium has an appeal for several reasons. First, it has been shown that learning models often converge to the risk dominant equilibrium (Kandori, Mailath, and Rob, 1993). Furthermore, sunspot driven equilibria can be interpreted in terms of risk dominance (Ennis, 2003, p.66). Finally, when investors' signals about the fundamentals are imprecise the risk dominant equilibrium is typically obtained (Carlsson

[11] One can think of the loan type for example referring to the size of the firm, with the idea that small firms are subject to larger informational problems.

[12] A similar simplification is made in Rochet and Vives (2004). Note that introducing heterogeneity of loans at $t = 1$ only serves to ensure an interior solution for Y.

and van Damme, 1993).[13]

To solve for the risk dominant equilibrium, assume that the bank's value is shared on a pro-rata basis in a run and that if the expected pay-off from running is identical to the one from not running, depositors do not run. Assume, furthermore, that interest has already been incurred at $t = 2$. The unique risk dominant equilibrium is then to run whenever the liquidation value of the bank, denoted L, is lower than depositors' claims to the bank, $(1+i)D$, and not to run otherwise. To see this, consider first $L \geq (1+i)D$. Then, even if all other depositors decide to run on the bank, a depositor still receives the same amount as when he decides not to run. Hence, he will not run. However, when $L < (1+i)D$, a depositor's expected return from running is $1/2 \cdot L + 1/2 \cdot (1+i)D$, while his return from not running is only $1/2 \cdot 0 + 1/2 \cdot (1+i)D = 1/2 \cdot (1+i)D$ and he will therefore run.[14]

The condition for no bank run taking place ($L \geq (1+i)D$) can be written as

$$(1-\gamma)(\mu+\varepsilon)(X-Y) + (1-\beta Y/2)\mu Y + R \geq (1+i)D \tag{2}$$

i.e., the revenue from liquidating all risky assets, $(1-\gamma)(\mu+\varepsilon)(X-Y)$, plus the bank's liquid assets, $(1-\beta Y/2)\mu Y + R$, have at least to equal depositors' claims to the bank, $(1+i)D$. Using (1) and denoting with Z the amount of risk the bank has taken that remains on the balance sheet after secondary market sales ($Z = X - Y$) , (2) can be rearranged to

$$((1-\gamma)(\mu+\varepsilon)-1)\, Z + ((1-\beta Y/2)\mu - 1)Y + W - iD > 0 \tag{3}$$

From (3), we define the minimum asset shock $\widehat{\varepsilon}$ that has to prevail in order for no bank run occurring

$$\widehat{\varepsilon} = \frac{1 - [W + ((1-\beta Y/2)\mu - 1)Y - iD]\,/Z}{1-\gamma} - \mu \tag{4}$$

Because depositors run only when $L < (1+i)D$, the bank has to fully liquidate its asset in a run. Since this is not enough to fully meet depositors' claims, a run always leads to the default of the bank. If default occurs, the return on equity is zero due to limited liability and the bank simply ceases to exist.

If the bank survives, the return on equity is the value of the bank's portfolio net of payments to depositors at $t = 3$

$$\begin{aligned} \pi &= (\mu+\varepsilon)Z + (1-\beta Y/2)\mu Y + R - (1+i)D \\ &= (\mu+\varepsilon-1)Z + ((1-\beta Y/2)\mu - 1)Y + W - iD \end{aligned} \tag{5}$$

[13] In particular, our equilibrium corresponds to the one obtained in Rochet and Vives (2004), who apply the global games methodology of Carlsson and van Damme to banking crises (calculations available on request).

[14] From this follows that *any* positive probability attached to other depositors running on the bank yields the same unique equilibrium. Thus, the equilibrium is also *p-dominant* for any strictly positive p (see Morris, Rob and Shin, 1995).

The return on equity in case of survival consists thus of the excess return from loans that are retained $(\mu + \varepsilon - 1)Z$, the excess return from loans that are sold in the secondary market $((1 - \beta Y/2)\mu - 1)Y$, and bank's equity at $t = 0$ minus interest payments $W - iD$. Figure 1 depicts bank's equity as a function of the asset shock.

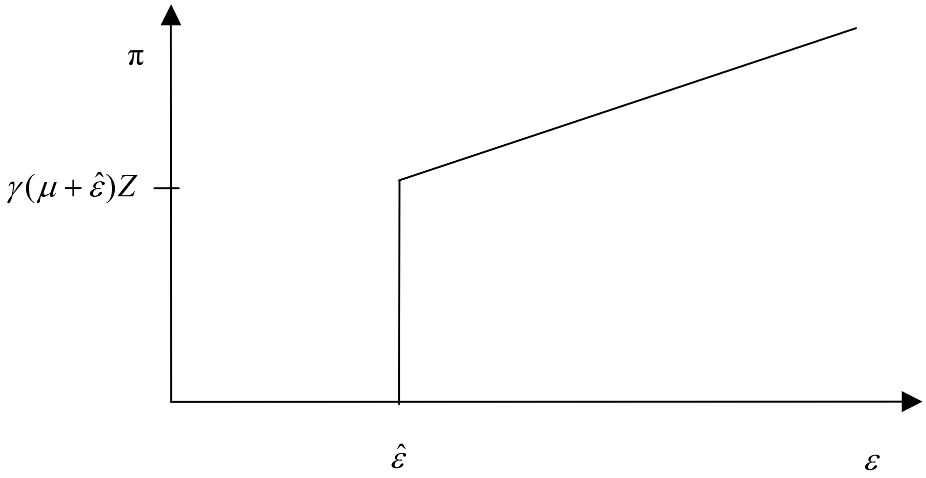

Figure 1: The Banks's Pay-Off as a Function of the Return on the Risky Asset

The *expected* return on equity is then

$$E[\pi] = \int_{\widehat{\varepsilon}}^{1} [(\mu + \varepsilon - 1)Z + ((1 - \beta Y/2)\mu - 1)Y + W - iD]\phi(\varepsilon)d\varepsilon \quad (6)$$

Depositors return when the bank survives is $(1 + i)D$. When the bank defaults ($\varepsilon < \widehat{\varepsilon}$), they receive the liquidation value L. Using (1) and (4), L can be written as

$$L = (1 + i)D - (\widehat{\varepsilon} - \varepsilon)(1 - \gamma)Z$$

Since depositors require a return of 1, the equilibrium interest rate on deposits has to fulfill

$$D = \int_{-1}^{\widehat{\varepsilon}} [(1 + i)D - (\widehat{\varepsilon} - \varepsilon)(1 - \gamma)Z]\, \phi(\varepsilon)d\varepsilon + \int_{\widehat{\varepsilon}}^{1} (1 + i)D\phi(\varepsilon)d\varepsilon$$

Rearranging for iD gives

$$iD = \int_{-1}^{\widehat{\varepsilon}} (\widehat{\varepsilon} - \varepsilon)(1 - \gamma)Z\phi(\varepsilon)d\varepsilon \quad (7)$$

Since interest payments iD compensate depositors for their losses from default, the RHS of (7) represents the expected loss from default for depositors. Note that (7) is an equilibrium condition, i.e., Z and $\widehat{\varepsilon}$ in (7) refer to depositors' expectations about the bank's choice of these variables and not to the actual choices of Z and $\widehat{\varepsilon}$. Depositors' expectations, however, may depend on β and γ. More formally, we can thus write $i = i(\beta, \gamma)$.

3.1 Equilibrium Risk Taking and Banking Stability

We measure the stability of the representative bank by its probability of default, which is given by

$$\Pr(\varepsilon < \widehat{\varepsilon}) = \int_{-1}^{\widehat{\varepsilon}} \phi(\varepsilon) d\varepsilon = (\widehat{\varepsilon} + 1)/2 \tag{8}$$

and determined by the minimum asset shock $\widehat{\varepsilon}$. We also compute the expected loss given default (LGD), which is a measure of externalities associated with banking failure. Recalling that the RHS of (7) gives the expected loss from default to depositors, the LGD is given by

$$LGD = \frac{\int_{-1}^{\widehat{\varepsilon}} (\widehat{\varepsilon} - \varepsilon)(1-\gamma) Z \phi(\varepsilon) d\varepsilon}{\Pr(\varepsilon < \widehat{\varepsilon})} = \frac{\int_{-1}^{\widehat{\varepsilon}} (\widehat{\varepsilon} - \varepsilon)(1-\gamma) Z d\varepsilon}{\widehat{\varepsilon} + 1} \tag{9}$$

We assume that the bank's managers maximize the wealth of shareholders, who are assumed to be risk-neutral. Thus managers maximize $E[\pi]$ over Y and Z, taking as given D, W, μ and the interest rate i. Note that Y and Z are independent variables, i.e., an increase in Z represents an increase in X for given Y. We focus in the following on parameter values of the model for which interior solutions for Y and Z obtain.

We turn first to the optimal choice of Y. Denoting the excess return from secondary market activity at $t = 1$ by $A(Y)$, with $A(Y)$

$$A(Y) := ((1 - \beta Y/2)\mu - 1)Y \tag{10}$$

we can write the FOC for Y (from 6) as

$$\partial E[\pi]/\partial Y = \int_{\widehat{\varepsilon}}^{1} A'(Y)\phi(\varepsilon) d\varepsilon - \pi(\widehat{\varepsilon}) \frac{\partial \widehat{\varepsilon}}{\partial A} A'(Y)\phi(\widehat{\varepsilon}) = 0 \tag{11}$$

Using the definition of the minimum shock $\widehat{\varepsilon}$ (equation 4) this can be simplified to

$$A'(Y) \left(\int_{\widehat{\varepsilon}}^{1} \phi(\varepsilon) d\varepsilon - \gamma(\mu + \widehat{\varepsilon}) Z \frac{\partial \widehat{\varepsilon}}{\partial A} \phi(\widehat{\varepsilon}) \right) = 0$$

Since $\int_{\widehat{\varepsilon}}^{1} d\varepsilon \geq 0$ and $\partial \widehat{\varepsilon}/\partial A < 0$ the expression in brackets is strictly positive, hence the FOC implies that $A'(Y) = 0$, from which follows using (10) that

$$(1 - \beta Y)\mu = 1 \tag{12}$$

Hence the optimal Y^* is given by

$$Y^* = \frac{1}{\beta \mu}(\mu - 1) \geq 0 \tag{13}$$

and is decreasing in the risk transfer costs β. Note the because $\mu \geq 1$ we have that $Y^* \geq 0$. Note also that the optimal Y it is independent of retained risk Z and liquidation costs

γ. Intuitively, this is because the bank can offset any impact of secondary market sales on stability through adjustments in the primary market. The bank therefore uses the secondary market solely to maximize excess revenues $A(Y)$.

We study next the bank's choice of Z. From (6) we obtain the FOC

$$\begin{aligned}\partial E[\pi]/\partial Z &= \int_{\widehat{\varepsilon}}^{1}(\mu+\varepsilon-1)\phi(\varepsilon)d\varepsilon-((\mu+\widehat{\varepsilon}-1)Z+A(Y)+W-iD)\,\phi(\varepsilon)\partial\widehat{\varepsilon}/\partial Z\\ &= \int_{\widehat{\varepsilon}}^{1}(\mu+\varepsilon-1)d\varepsilon-\gamma(\mu+\widehat{\varepsilon})Z\partial\widehat{\varepsilon}/\partial Z=0 \qquad (14)\end{aligned}$$

The first term in (14) is the standard expression for the marginal benefits from retaining more risk. Since $\mu \geq 1$ and $\widehat{\varepsilon} \geq -1$, this expression is always positive. The second term in (14) represents the marginal costs of retaining risk, which arise because more retained risk increases the domain of asset returns for which a bank run occurs ($\partial\widehat{\varepsilon}/\partial Z > 0$) and thus raises the probability that the liquidation costs $\gamma(\mu+\widehat{\varepsilon})Z$ have to be incurred (since at $\widehat{\varepsilon}$ the liquidation value is zero, the liquidation costs are fully incurred by equity). An interior solution for Z equates then the benefits from a higher return on equity if the bank survives with higher expected costs due to liquidation. Proposition 1 identifies conditions under which such an interior solution exists.

Proposition 1 *For $\mu < \gamma/(1-\gamma)$, $\gamma > 1/2$ and $W+A-iD > 0$ there is a unique interior solution Z^* with $Z^* \in (0,\infty)$.*

Proof. See Appendix.

The first condition, $\mu < \gamma/(1-\gamma)$, implies that for sufficiently large Z the minimum asset shock $\widehat{\varepsilon}$ becomes 1, i.e., the probability of survival is zero (this can be easily verify from 4 by letting $Z->\infty$). This ensures that as the bank increases its retained risk, the marginal benefits eventually becomes zero while the marginal costs remain positive. The second condition, $\gamma > 1/2$, ensures the concavity of the problem. For $\gamma < 1/2$, the problem becomes convex and only corner solutions exist. The third condition, $W + A - iD > 0$, ensures that an increase in retained risk Z increases the minimum asset shock. For $W + A - iD < 0$, the expected value of the bank at $t = 0$ is negative for $Z = 0$ (from 6). An increase Z would then actually increase the bank's chance of survival because of $\mu \geq 1$ ("gambling for resurrection").

The conditions in Proposition 1 and $\mu \geq 1$ ensure interior solutions for Z and Y, respectively. Additionally, for proceeding with the first order condition approach we have to ensure that $Y^*+Z^* = X^* \leq D+W$. From equations (13) and (35) (Proof of Proposition 1) it follows that for μ sufficiently close to 1 and for γ sufficiently close to 1/2, Y^* and Z^* tend to zero. Hence, for appropriate conditions on the parameter values there is an interior solution, which we from now on assume to be fulfilled.

For convenience we explicitly define for the following analysis the marginal benefits MB and the marginal costs MC from retaining risk (from 14)

$$MB = \int_{\widehat{\varepsilon}}^{1} (\mu + \varepsilon - 1)\, d\varepsilon \tag{15}$$

$$MC = \gamma(\mu + \widehat{\varepsilon}) Z \partial\widehat{\varepsilon}/\partial Z \tag{16}$$

and using the definition of $A(Y)$ (equation 10) we simplify the expression for the minimum asset shock

$$\widehat{\varepsilon} = \frac{1 - (W + A(Y) - iD)/Z}{1 - \gamma} - \mu \tag{17}$$

from which we can derive the sensitivity of $\widehat{\varepsilon}$ with respect to retained risk ($\partial\widehat{\varepsilon}/\partial Z$)

$$\partial\widehat{\varepsilon}/\partial Z = \frac{W + A(Y) - iD}{1 - \gamma} \frac{1}{Z^2} \tag{18}$$

$$= \left(\frac{1}{1 - \gamma} - \mu - \widehat{\varepsilon}\right)/Z \tag{19}$$

Using (19) we can then simplify the expression for MC (16) to yield

$$MC = \gamma(\mu + \widehat{\varepsilon})\left(\frac{1}{1 - \gamma} - \mu - \widehat{\varepsilon}\right) \tag{20}$$

4 Asset Liquidity and Banking Stability

We start by considering a reduction in the liquidation costs γ, i.e., an increase in crisis liquidity. The direct impact of the reduction in γ on stability is positive: it raises the liquidation value of the bank and thus lowers the minimum asset shock $\widehat{\varepsilon}$ that ensures that depositors do not run (equation 17). However, there is an offsetting effect because an increased liquidation value means that a bank run is less costly for the bank (the MC in 16 fall) and the bank therefore increases its retained risk Z.[15] Proposition 2 shows that Z is even increased by an amount that outweighs the initial beneficial impact on stability.

Proposition 2 *An increase in crisis liquidity increases retained risk Z and reduces banking stability.*

Proof. *See Appendix.* ■

To understand the intuition for this perhaps surprising result, consider a (hypothetical) increase in retained risk that exactly offsets the impact of the reduction in γ on the minimum asset shock $\widehat{\varepsilon}$. The resulting MB and MC would be

$$MB_1 = \int_{\widehat{\varepsilon}_0}^{1} (\mu + \varepsilon - 1)\, d\varepsilon \tag{21}$$

$$MC_1 = \gamma_1(\mu + \widehat{\varepsilon}_0) Z_1 (\partial\widehat{\varepsilon}/\partial Z)_1 \tag{22}$$

[15] Regarding secondary market activity, we have from equation (13) that the change in γ does not influence Y^*.

where subscripts 0 (1) refer to variables before (after) the change in γ. From (21) we have that $MB_1 = MB_0$, i.e., the marginal benefits from retaining risk are the same as before the change in γ. From (22) we have that the reduction in γ reduces the cost of liquidation for a given amount of assets that have to be liquidated and thus the MC_1 is lowered relative to MC_0. There are additional effects on the MC because changes in Z, γ and i (remember that interest rates may change if depositors' expectations about their expected losses change) affect $Z(\partial\widehat{\varepsilon}/\partial Z)$. However, from (19) it can be seen that the overall impact of these latter effects on the MC is negative. Hence we have $MC_1 < MC_0$.

Thus, if, following a reduction in γ, the bank would increase its risk such that it reaches the old $\widehat{\varepsilon}_0$, the marginal benefits from retaining risk would still exceed the marginal costs. The bank will therefore choose an amount of retained risk that exceeds Z_1. Hence, the $\widehat{\varepsilon}$ in the new equilibrium is higher than $\widehat{\varepsilon}_0$ and the stability of the bank is reduced.[16] Proposition 3 shows next that the reduction in γ also leads to a higher LGD.

Proposition 3 *An increase in crisis liquidity increases the LGD.*

Proof. *See Appendix.* ■

The intuition for this result can be easily understood by again considering an increase in Z that offsets the initial impact of γ on $\widehat{\varepsilon}$. We have then

$$LGD_1 = \frac{\int_{-1}^{\widehat{\varepsilon}_0} (\widehat{\varepsilon}_0 - \varepsilon)(1-\gamma_1) Z_1 d\varepsilon}{\widehat{\varepsilon}_0 + 1} \tag{23}$$

From (23) it can be seen that the LGD has now increased because of the lower γ and the increase in Z. The reason for this is that both the lower γ and the higher Z make the liquidation value more sensitive to shocks, in the sense that a shock below the minimum shock $\widehat{\varepsilon}$ leads now to higher losses for depositors. The equilibrium LGD will even be larger than LGD_1 since the bank chooses an amount of retained risk that exceeds the one that offsets the initial impact on stability (as Proposition 2 has shown).

We turn now to the analysis of increased liquidity in the secondary market, as represented by a reduction in the risk transfer costs β. A reduction in β has a direct positive impact on stability by increasing the bank's excess revenues from secondary market activity ($A(Y)$ in 10), which increases bank's equity at $t = 2$ and thus reduces the minimum asset shock $\widehat{\varepsilon}$ (equation 17). The lower β also increases sales in the secondary market (equation 13), however, this does not affect stability since Y only enters in the FOC for Z via $A(Y)$. Proposition 4 shows that overall stability is unchanged because the bank offsets the impact of increased equity on stability by increasing Z.

[16] The idea that an illiquidity of bank assets can actually be beneficial by displining bank manangers has already been emphasized by Calomiris and Kahn, 1991, and Diamond and Rajan, 2000.

Proposition 4 *An increase in liquidity in normal times increases retained risk Z but does not affect banking stability.*

Proof. *See Appendix.* ■

This result can be readily understood by noting that if the bank restores the old $\widehat{\varepsilon}$ by increasing retained risk, neither the marginal benefits MB (equation 15) nor the marginal costs MC (equation 20) have been affected by the reduction in β.

Proposition 4 modifies previous results obtained by Instefjord (2005), who analyzes the impact of an improved effectiveness of hedging (arising from credit derivatives) on bank risk. An increase in the hedging effectiveness in his paper is comparable to a reduction in β in the present paper. Although there is no explicit solution for the net effect on retained risk in Instefjord's paper, it is conjectured that if the loan elasticity is sufficiently large, the effect of additional risk taking could outweigh the reduction in risk through increased risk transfer. Our analysis confirms that retained risk increases when the loan elasticity is high (infinity in our model) but in deviation to Instefjord our results show that banking stability is unaffected. This is because the bank's incentive for increasing its retained risk is precisely to offset the initial positive stability impact.

Proposition 5 shows next that although an increase in liquidity in normal times does not affect stability, it leads to a higher LGD. This is because the increased liquidity causes the bank to retain more risk, asset shocks below the minimum asset shock $\widehat{\varepsilon}$ lead to higher losses for depositors (equation 9).

Proposition 5 *An increase in liquidity in normal times increases the LGD.*

Proof. *Follows directly from (9) since we have from Proposition 4 that $d\widehat{\varepsilon}/d\beta = 0$ and $dZ/d\beta < 0$.* ■

5 Regulation

In this section we extend our analysis to an economy in which deposits are fully insured by a deposit insurance fund and where the regulator imposes Basel-style minimum capital requirements. To this end we modify the setup as follows. We reinterpret i as the payments of the bank to the deposit insurance fund per unit of deposits, taking place at $t = 0$. Equation (7) is still assumed to hold, implying that the insurance premium is fair in that in equilibrium it compensates the deposit insurance fund for expected losses from banking failures.[17] Capital requirements are introduced in a simple fashion by assuming that if the

[17] Such a deposit insurance system potentially suffers from implementation problems when there are informational problems between bank and the regulator (see Chan, Greenbaum, Thakor, 1992, and Freixas and Rochet, 1995). Such asymmetries are, however, absent in our model.

equity of the bank at $t = 2$ falls short of a fraction k of the risky asset, the bank is closed down. To keep the analysis comparable to the previous section, both equity and the risky asset at thereby valued at their liquidation value. When the bank is shut down, its assets are liquidated. Depositors are paid out first and any remaining value is distributed to the shareholders of the bank. If the liquidation value of the bank is not sufficient to cover depositors' claims, depositors will be compensated by the deposit insurance fund.

Some comments on the modelling of the capital requirements are in order here. First, the regulator requires capital for an asset that is strictly speaking not risky anymore at $t = 2$. However, we interpret here the asset as a reduced form of an asset that is still risky (as in Blum, 1999). It should also be kept in mind that even when the asset does not bear risk anymore, there are still rationales for regulation. For example, capital requirements can be used to induce a more efficient allocation of control rights between different groups of claim-holders (Dewatripont and Tirole, 1994) or to improve managerial incentives for monitoring (e.g., Decamps et. al., 2004). Second, we rule out that shareholders recapitalize at $t = 2$ in order to meet capital requirements. The implicit assumption here is that all contracts that are made at $t = 0$ are long term and that an readjustment at $t = 2$ is too costly or not feasible. The natural justification for this is the coordination problem that arises among shareholders: while it would be collectively optimal for shareholders to inject new capital, a single shareholder has no incentive to do so. In fact, he or she will lose part of the new capital when the capital increase is not successful and the bank is closed down subsequently. Another reason is that informational asymmetries about the bank's assets make raising capital difficult, particularly in times of distress. For example, shareholders may not believe management that the bank is still solvent (since managers always have an incentive to tell so in order to make the capital increase more likely and to keep the bank going) or a bank may simply refrain from issuing equity because it serves as a bad signal about the quality of its assets (as in Myers and Majluf, 1984).[18]

The condition for no banking closure can be written as

$$((1-\gamma)(\mu+\varepsilon)-1)Z + A(Y) + W - iD \geq k(1-\gamma)Z$$

i.e., the liquidation value of the bank net of depositors' claims has to exceed k times the liquidation value of the risky assets. Denoting with $\widehat{\varepsilon}_C$ the minimum asset shock that

[18] Another issue is why the regulator would close down a bank that may still be solvent (which happens here for $k > 0$). Although we do not aim to make statements about the optimality of capital requirements, it has been shown that this is optimal when the regulator minimizes the costs for the deposit insurance fund (Mailath and Mester, 1994). A further reason for such regulation is that in an incomplete information environment, the threat of banking closure can improve ex-ante incentives for bank managers (Dewatripont and Tirole, 1994, and Decamps et. al., 2004).

ensures that the bank is not closed we get

$$\widehat{\varepsilon}_C = \frac{1 - (W + A - iD)/Z}{1-\gamma} - \mu + k \tag{24}$$

The minimum asset shock $\widehat{\varepsilon}$ that guarantees that the bank's liquidation value is sufficient to pay out depositors is unchanged and from equation (17) we get that $\widehat{\varepsilon}_C = \widehat{\varepsilon} + k$.

The bank's expected return consists now of the expected value of its portfolio net of debt if the bank is not closed down (i.e., when $\varepsilon \geq \widehat{\varepsilon}_C$) plus any remaining value that is distributed to shareholders when the bank is closed down (this value is strictly positive for $\varepsilon > \widehat{\varepsilon}$)

$$\begin{aligned} E[\pi] &= \int_{\widehat{\varepsilon}_C}^{1} [(\mu + \varepsilon - 1)Z + A(Y) + W - iD]\phi(\varepsilon)d\varepsilon + \\ & \int_{\widehat{\varepsilon}}^{\widehat{\varepsilon}_C} [((1-\gamma)(\mu + \varepsilon) - 1)Z + A(Y) + W - iD]\phi(\varepsilon)d\varepsilon \end{aligned} \tag{25}$$

The expression for iD is unchanged (equation 7).

Rearranging the FOC for Z (from 25) and using $\widehat{\varepsilon}_C = \widehat{\varepsilon} + k$, we obtain the MB and MC

$$MB = \int_{\widehat{\varepsilon}}^{1} (\mu + \varepsilon - 1)\, d\varepsilon - \int_{\widehat{\varepsilon}}^{\widehat{\varepsilon}+k} \gamma(\mu + \varepsilon)d\varepsilon \tag{26}$$

$$MC = \gamma(\mu + \widehat{\varepsilon} + k)Z\partial\widehat{\varepsilon}_C/\partial Z \tag{27}$$

$$= \gamma(\mu + \widehat{\varepsilon} + k)(\frac{1}{1-\gamma} - \mu - \widehat{\varepsilon}) \tag{28}$$

From (26), (27) and (28) we can see that compared to the unregulated economy, both MB and MC are changed because liquidation occurs already at $\widehat{\varepsilon}_C = \widehat{\varepsilon} + k$ rather than at $\widehat{\varepsilon}$. Because k increases the domain of shocks for which liquidation occurs (since $\partial\widehat{\varepsilon}_C/\partial k > 0$), the MB are lower than in the unregulated economy. By contrast, the MC are higher because the higher minimum asset shock $\widehat{\varepsilon}_C$ increases the average value of assets that are liquidated.

However, the proofs regarding the impact of asset liquidity on banking stability (analogous to the previous sections, stability refers to the probability that the bank's debt exceeds its liquidation value, i.e., $\varepsilon < \widehat{\varepsilon}$) and on the LGD can still be readily applied.

Proposition 6 *As in the unregulated economy, (i) an increase in crisis liquidity reduces stability and increases the LGD, (ii) an increase in liquidity in normal times does not affect stability and increases the LGD.*

Proof. *Analogous to Propositions 2 - 5, noting that* $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon}$ *is now* $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon} = -(\mu + \widehat{\varepsilon} - 1) - \gamma k - \gamma(\frac{1}{1-\gamma} - 2\mu - 2\widehat{\varepsilon} - k) = -(2\gamma - 1)(\frac{1}{1-\gamma} - \mu - \widehat{\varepsilon})$. ■

Proposition 7 shows next that the impact of an increase in k on banking stability is positive. Although there is no direct effect of k on $\widehat{\varepsilon}$, a higher k reduces the MB and increases the MC of retaining risk, as explained above. Thus the bank reduces its retained risk and stability increases.

Proposition 7 *An increase in capital requirements k reduces retained risk Z and increases stability.*

Proof. *See Appendix.* ■

Capital requirements can therefore be used to mitigate the impact of increased crisis liquidity. However, as the next proposition shows they become increasingly ineffective as crisis liquidity rises. This is because a banking closure is only an effective threat for banks when it is costly. When γ is low the costs of banking closure are low and, consequently, capital requirements are less effective.[19]

Proposition 8 *If the risky asset becomes perfectly liquid in times of crisis ($\gamma \longrightarrow 0$), bank stability becomes minimal regardless the size of capital requirements k.*

Proof. *For $\gamma \rightarrow 0$ we have that $MC \rightarrow 0$ (from 28 and $-1 \leq \widehat{\varepsilon} \leq 1$). From $MB \rightarrow \int_{\widehat{\varepsilon}}^{1} (\mu + \varepsilon - 1)\, d\varepsilon > 0$ for $\widehat{\varepsilon} < 1$ we have hence that $dE[\pi(Z)]/dZ > 0$ for $\widehat{\varepsilon} < 1$. Thus $\gamma \rightarrow 0$ implies $\widehat{\varepsilon} \rightarrow 1$.* ■

Suppose now that the regulator can change the cost of a banking closure for bank's shareholders. More specifically, assume that the regulator can impose a proportional penalty δ on the value of the bank's risky assets when the bank is closed down. An example for such proportional penalties (or subsidies if $\delta < 0$) are tax deductions granted to financial institutions that acquire assets of a bank that has been closed down by the regulator (as has been common practice in the U.S.). Such tax deductions increase the price at which the financial institutions are prepared to acquire the bank's assets and thus amount to a reduction in δ.[20]

For given k, this penalty does neither affect iD, $\widehat{\varepsilon}$ nor $\widehat{\varepsilon}_C$. Therefore equations (7), (17)

[19] The extreme nature of the result in Proposition 8 is due to the fact that the bank ceases to exist at $t = 3$ and thus the bank does not lose a franchise value when it is closed down at $t = 2$. When there is a franchise value, the MC of banking failure will be positive even when $\gamma = 0$ and banking stability does not become minimal. However, it is still true that, ceteris paribus, a reduction in γ reduces the costs of banking failure and makes capital requirements less effective.

[20] Similarly, allowing the acquiring institution to use goodwill on its books can also be interpreted as a reduction in δ.

and (24) still apply. The bank's expected return, however, is now

$$E[\pi] = \int_{\widehat{\varepsilon}_C}^{1} [(\mu + \varepsilon - 1)Z + A(Y) + W - iD]\phi(\varepsilon)d\varepsilon + \tag{29}$$

$$\int_{\widehat{\varepsilon}}^{\widehat{\varepsilon}_C} [(1 - \gamma - \delta))(\mu + \varepsilon - 1)Z + A(Y) + W - iD]\phi(\varepsilon) \tag{30}$$

and the expressions for MB and MC are

$$MB = \int_{\widehat{\varepsilon}}^{1} (\mu + \varepsilon - 1)\, d\varepsilon - \int_{\widehat{\varepsilon}}^{\widehat{\varepsilon}+k} (\gamma + \delta)(\mu + \varepsilon)d\varepsilon \tag{31}$$

$$MC = (\gamma + \delta)(\mu + \widehat{\varepsilon})Z\partial\widehat{\varepsilon}/\partial Z \tag{32}$$

$$= (\gamma + \delta)(\mu + \widehat{\varepsilon} + k)(\frac{1}{1-\gamma} - \mu - \widehat{\varepsilon}) \tag{33}$$

Thus δ affects the bank's optimization problem by reducing the MB and by raising the MC. As a consequence, an increase in δ leads to a reduction in risk Z, and thus $\widehat{\varepsilon}$ falls.

Proposition 9 *An increase in δ reduces retained risk Z and increases stability.*

Proof. *See Appendix.* ■

Proposition 10 shows next that penalties can be used to directly offset any impact of a reduction in γ. From (31) and (33), this is because they can directly eliminate the impact of a change in the liquidation cost γ on the MB and the MC. This suggests that penalties are a more appropriate tool for counteracting the negative stability impact of increased crisis liquidity.

Proposition 10 *The stability impact of a change in the liquidation cost $d\gamma$ can be offset by changing the penalty δ by $d\delta = -d\gamma$.*

Proof. *Follows directly from (31) and (33) by noting that $\partial MB/\partial\gamma = \partial MB/\partial\delta$ and $\partial MC/\partial\gamma = \partial MC/\partial\delta$.* ■

6 Summary

Recent financial innovations, such as the various new credit derivative instruments, have increased banks' possibilities for selling and hedging their loans. What are the consequences for the stability of the banking sector? This paper has shown that the benefits of increased liquidity, stemming from higher risk transfer in normal times and from enhanced liquidation in a crisis, are counteracted through more risk taking in primary markets. In total, stability is even reduced because the improved liquidation possibilities in a crisis reduce banks' incentives to avoid a crisis. Banks therefore take on an amount of new risks that leads to a higher probability of default.

Regulators wishing to address this stability problem can do this by increasing capital requirements. However, as asset liquidity increases, capital requirements become a less effective instrument for ensuring stability. A more direct means for undoing the impact of increased liquidity on stability is to reduce the returns for bank owners in a bank closure.

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Proof of Proposition 1. Solving the integral in the expression for $\partial E[\pi]/\partial Z$ (from 14) gives

$$\partial E[\pi]/\partial Z = \frac{1}{2}(1-\widehat{\varepsilon})(\widehat{\varepsilon}-1+2\mu) - \frac{\gamma}{(1-\gamma)Z}(\mu+\widehat{\varepsilon})(W+A-iD)$$

Substituting $\widehat{\varepsilon}$ (using the definition of $\widehat{\varepsilon}$ and A) yields

$$dE[\pi(Z)]/dZ = \frac{(2\gamma-1)(W+A-iD)^2 - (\gamma^2-\mu^2(1-\gamma)^2)Z^2}{2(1-\gamma)^2 Z^2} \tag{34}$$

Setting to zero and solving for Z, noting that $\gamma^2-\mu^2(1-\gamma)^2 > 0$ because of $\mu < \gamma/(1-\gamma)$, gives

$$Z^* = (W+A-iD)\sqrt{\frac{2\gamma-1}{\gamma^2-\mu^2(1-\gamma)^2}} \tag{35}$$

Since $\gamma^2-\mu^2(1-\gamma)^2 > 0$, $W+A-iD > 0$ and $\gamma > 1/2$ it follows that $Z^* \in (0,\infty)$. Differentiating (34) wrt. Z gives

$$\partial E^2[\pi(Z)]/\partial^2 Z = -(W+A-iD)^2\frac{2\gamma-1}{(1-\gamma)^2 Z^3}$$

hence, because of $\gamma > 1/2$, we have $\partial E^2[\pi(Z)]/\partial^2 Z < 0$ and therefore Z^* is a maximum and unique. ■

Proof of Proposition 2. We show first $d\widehat{\varepsilon}/d\gamma < 0$ and then $dZ/d\gamma < 0$. $d\widehat{\varepsilon}/d\gamma < 0$: From $E[\pi] = MB - MC$ and using (15) and (20), the total differential of $dE[\pi(Z)]/dZ = 0$ wrt. γ is

$$\frac{d\frac{dE[\pi]}{dZ}}{d\gamma} = \frac{\partial\frac{dE[\pi]}{dZ}}{\partial\gamma} + \frac{\partial\frac{dE[\pi]}{dZ}}{\partial\widehat{\varepsilon}}(d\widehat{\varepsilon}/d\gamma) = 0$$

From $\partial\frac{dE[\pi]}{dZ}/\partial\gamma < 0$ and $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon} = -(\mu+\widehat{\varepsilon}-1) - \gamma(\frac{1}{1-\gamma} - 2\mu - 2\widehat{\varepsilon}) = -(2\gamma-1)(\frac{1}{1-\gamma} - \mu - \widehat{\varepsilon}) < 0$ (because of the conditions for interior solutions $\gamma > 1/2$ and $\mu < \gamma/(1-\gamma)$ and because of $\widehat{\varepsilon} \leq 1$) it follows that $d\widehat{\varepsilon}/d\gamma < 0$. $dZ/d\gamma < 0$: Using (7) to substitute iD in (17) gives

$$\widehat{\varepsilon} = \frac{1-(W+A)/Z}{1-\gamma} + \int_{-1}^{\widehat{\varepsilon}}(\widehat{\varepsilon}-\varepsilon)\phi(\varepsilon)d\varepsilon - \mu$$

Totally differentiating wrt. γ gives

$$d\widehat{\varepsilon}/d\gamma = \frac{1-(W+A)/Z}{(1-\gamma)^2} + \frac{(W+A)/Z^2}{1-\gamma}dZ/d\gamma + \int_{-1}^{\widehat{\varepsilon}} d\widehat{\varepsilon}/d\gamma\phi(\varepsilon)d\varepsilon$$

Solving the integral and rearranging gives

$$d\widehat{\varepsilon}/d\gamma(\frac{1-\widehat{\varepsilon}}{2}) = \frac{1-(W+A)/Z}{(1-\gamma)^2} + \frac{(W+A)/Z^2}{1-\gamma}dZ/d\gamma$$

Since $d\widehat{\varepsilon}/d\gamma < 0$ and $1-(W+A)/Z \geq 0$ (from 17 with $\mu+\widehat{\varepsilon} \geq 0$ and $iD \geq 0$) it follows that $dZ/d\gamma < 0$. ■

Proof of Proposition 3. From (9) we have that

$$dLGD/d\gamma = \frac{\left(\begin{array}{c}\int_{-1}^{\widehat{\varepsilon}}\left[(1-\gamma)Zd\widehat{\varepsilon}/d\gamma+(\widehat{\varepsilon}-\varepsilon)(-Z+(1-\gamma)dZ/d\gamma\right]\phi(\varepsilon)d\varepsilon(\widehat{\varepsilon}+1)\\ -\int_{-1}^{\widehat{\varepsilon}}(\widehat{\varepsilon}-\varepsilon)(1-\gamma)Z\phi(\varepsilon)d\varepsilon d\widehat{\varepsilon}/d\gamma\end{array}\right)}{(\widehat{\varepsilon}+1)^2}$$

$$= \frac{\left(\begin{array}{c}\int_{-1}^{\widehat{\varepsilon}}\left[(\widehat{\varepsilon}-\varepsilon)(-Z+(1-\gamma)dZ/d\gamma\right]\phi(\varepsilon)d\widehat{\varepsilon}(\widehat{\varepsilon}+1)\\ +\int_{-1}^{\widehat{\varepsilon}}(1+\varepsilon)(1-\gamma)Z\phi(\varepsilon)d\varepsilon d\widehat{\varepsilon}/d\gamma\end{array}\right)}{(\widehat{\varepsilon}+1)^2} < 0$$

since $dZ/d\gamma, d\widehat{\varepsilon}/d\gamma < 0$. ■

Proof of Proposition 4. The total differential of $dE[\pi(Z)]/dZ = 0$ wrt. β is

$$\frac{d\frac{dE[\pi]}{dZ}}{d\beta} = \frac{\partial\frac{dE[\pi]}{dZ}}{\partial\widehat{\varepsilon}}(d\widehat{\varepsilon}/d\beta) = 0$$

hence $d\widehat{\varepsilon}/d\beta = 0$ because of $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon} < 0$ (which has already been shown in the Proof of Proposition 2). $dZ/d\beta < 0:$ Using (7) to substitute iD in (17) gives

$$\widehat{\varepsilon} = \frac{1-(W+A)/Z}{1-\gamma} + \int_{-1}^{\widehat{\varepsilon}}(\widehat{\varepsilon}-\varepsilon)\phi(\varepsilon)d\varepsilon - \mu$$

Totally differentiating wrt. β gives

$$d\widehat{\varepsilon}/d\beta = \frac{(W+A)/Z^2}{1-\gamma}dZ/d\beta - \frac{1/Z}{1-\gamma}dA/d\beta + \int_{-1}^{\widehat{\varepsilon}}(d\widehat{\varepsilon}/d\beta)\phi(\varepsilon)d\varepsilon$$

Since $d\widehat{\varepsilon}/d\beta = 0$ and $dA/d\beta = \partial A/\partial\beta + (dA/dY)dY/d\beta = \partial A/\partial\beta < 0$, it follows that $dZ/d\beta < 0$. ■

Proof of Proposition 7. From (26), (28) we have that

$$\frac{d\frac{dE[\pi]}{dZ}}{dk} = \frac{\partial\frac{dE[\pi]}{dZ}}{\partial k} + \frac{\partial\frac{dE[\pi]}{dZ}}{\partial\widehat{\varepsilon}}d\widehat{\varepsilon}/dk = 0$$

Since $\partial\frac{dE[\pi]}{dZ}/\partial k < 0$ and $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon} < 0$ (see Proposition 6) we have $d\widehat{\varepsilon}/dk < 0$. From $d\widehat{\varepsilon}/dk = (\partial\widehat{\varepsilon}/\partial Z)dZ/dk < 0$ and $\partial\widehat{\varepsilon}/\partial Z > 0$ it follows then $dZ/dk < 0$. ■

Proof of Proposition 9. From (31),(33) we have that

$$\frac{d\frac{dE[\pi(Z)]}{dZ}}{d\delta} = \frac{\partial\frac{dE[\pi(Z)]}{dZ}}{\partial\delta} + \frac{\partial\frac{dE[\pi(Z)]}{dZ}}{\partial\widehat{\varepsilon}}d\widehat{\varepsilon}/d\delta = 0$$

Since $\partial\frac{dE[\pi]}{dZ}/\partial\delta < 0$ we have $(\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon})d\widehat{\varepsilon}/d\delta > 0$. Since $\partial\frac{dE[\pi]}{dZ}/\partial\widehat{\varepsilon} = -(\mu+\widehat{\varepsilon}-1)-(\gamma+\delta)k-(\gamma+\delta)(\frac{1}{1-\gamma}-2\mu-2\widehat{\varepsilon}-k) = -(2\gamma+2\delta-1)(\frac{1}{1-\gamma}-\mu-\widehat{\varepsilon})+\frac{\delta}{1-\gamma} < 0$ (because of the conditions for interior solutions $\gamma > 1/2$ and $\mu < \gamma/(1-\gamma)$), it follows that $d\widehat{\varepsilon}/d\delta < 0$. From $d\widehat{\varepsilon}/d\delta = (\partial\widehat{\varepsilon}/\partial Z)dZ/d\delta < 0$ and $(\partial\widehat{\varepsilon}/\partial Z) > 0$ (from 17) it follows then $dZ/d\delta < 0$.
■