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# Innovation in Banking and Excessive Loan Growth

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## Abstract



The volume of credit extended by a bank can be an informative signal of its abilities in loan selection and management. It is shown that, under asymmetric information, banks may therefore rationally lend more than they would otherwise in order to demonstrate their quality, thus negatively affecting financial system soundness. Small shifts in technology and uncertainty associated with new technology may lead to large jumps in equilibrium outcomes. Prudential measures and supervision are therefore warranted.
16B

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## I. INTRODUCTION

Recent credit market turmoil has come as a shock. Whereas in the middle of the decade macroeconomic conditions were viewed as unusually benign and financial systems were seen as exceptionally sound, major financial institutions have recently come under extreme pressure, and some markets have collapsed. Why did so many banks with solid reputations and risk management capacity extend themselves much too far? An understanding of this phenomenon is a necessary precondition for the determination of a policy response to deal with immediate concerns and to forestall a recurrence.

One of the most striking financial sector developments in the years leading up to the turmoil has been the acceleration of credit growth. Bank lending has been growing much fast than nominal GDP in a wide variety of countries (Figure 1). Rapid credit growth has been especially striking in many European emerging market countries; after a sharp contraction in intermediation during the transition process, credit aggregates rebounded once macroeconomic stability was restored and certain supporting infrastructure was in place. In some countries, ratios of credit to GDP already exceed levels that one would expect based on fundamentals such as per capita income (see e.g., Backé, Égert, and Zumer, 2006). Similar rapid expansion in credit is seen in emerging market and developing countries in other regions, such as South Africa and India.

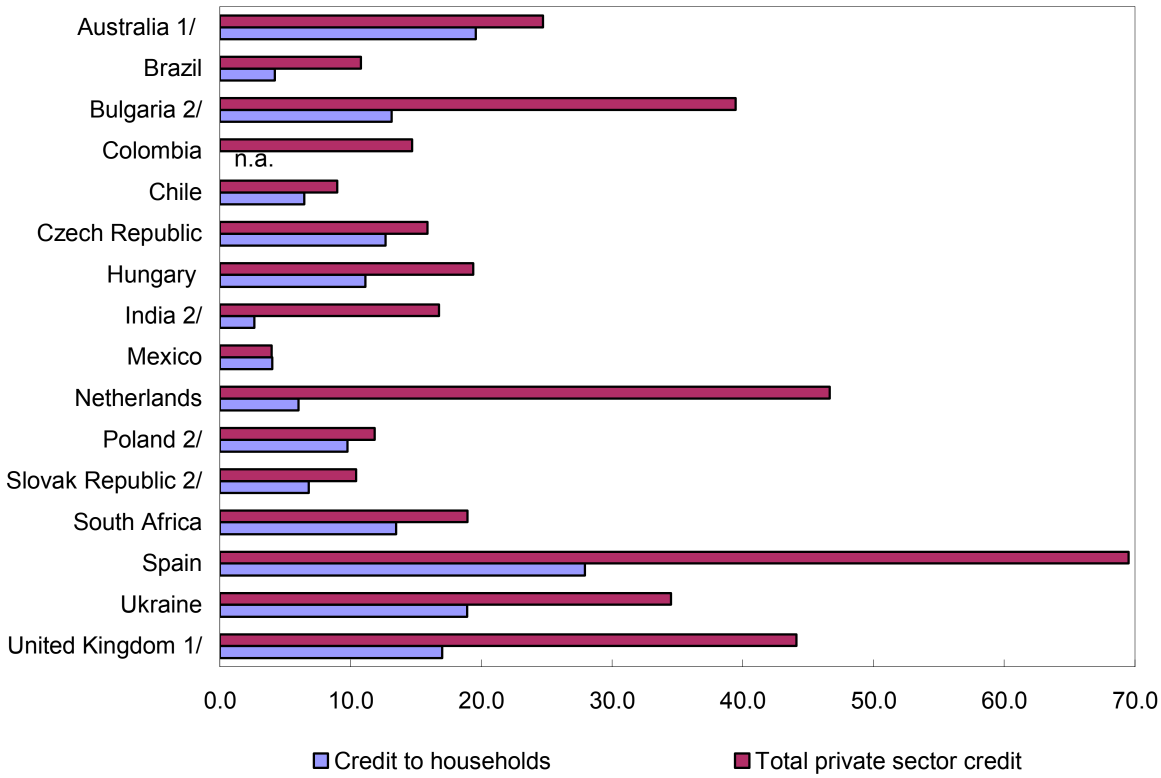
Also striking has been the composition of credit: traditional borrowers, notably larger corporates, have displayed modest demand for credit. Rather, small and medium-sized enterprises and especially households have expanded their use of credit. Sections of the population that traditionally relied on savings to finance major purchases and to smooth income now make use of loans for these purposes.[1] In many countries, a very large proportion of net credit growth has gone to these sectors.

In large part, rapid credit growth can be explained by improved economic prospects. Many countries have enjoyed rapid and relatively stable growth and lower inflation in recent years. Higher expected income and profitability, and higher levels of wealth have led households to consume more (including consumption of housing), corporates to expand output and (in many regions) invest more. Hence, there is higher demand for credit.

The supply of credit appears seems to have shifted outwards also. Many banks and other intermediaries are ready to extend credit to sectors that were previously under-serviced, and in amounts that would in the past have been considered exuberant. Part of the explanation relates to favorable macroeconomic conditions. For much of the earlier part of this decade, real interest rates on safe assets were relatively low, so financial intermediaries may have been ready to offer more credit to riskier borrowers as part of their "search for yield."

[1] At a macroeconomic level, there has been in many countries a fall in household savings and, often, a rise in savings by the corporate sector and government (see International Monetary Fund (2006), Chapter IV).

Figure 1. Change in the ratio of credit to GDP, 2003–2007
(Percentage points)




Source: International Financial Statistics, national authorities, and staff estimates.
1/ Credit to households comprises total household financial liabilities.
2/ For credit to households, change is over 2004–2007.

At the same time, there is evidence that banks have developed much more sophisticated techniques for selecting good borrowers, evaluating collateral, and managing risks in general—all of which might be termed "loan technology." The very rapid expansion of securitization and the use of credit derivatives such as credit default swaps are elements of this trend. Perhaps equally importantly, improvements in information technology and the compilation of massive databases on borrowers have allowed banks to assess creditworthiness in new ways and offer new loan products. Relationship banking, based on borrowers establishing a long history of prudent behavior with their "house bank," have been replaced by quasi-automated credit scoring systems.[2] On this basis, financial institutions have become willing to offer financing with very high loan to value ratios and even such products as zero or negative-amortization mortgages—many of which in the U.S. constitute sub-prime lending. More than ever, the (proprietary) information base on borrowers has become a major component of a bank's comparative advantage and a basis of its business strategy. Connected with these technological innovations is an intensification of competition between banks, to

[2] This process began earlier in some sectors than in others. For example, British building societies (mortgage lenders) traditionally required borrowers to save with them for an extended period as a means of rationing credit and establishing financial probity. The practice disappeared rapidly following liberalization in the 1980s.

whom clients are less closely tied than in the past. Furthermore, cross-border linkages between banks have been deepened, for example, through direct investment by banks from mature economies in the emerging market economies of Central and Eastern Europe or of Latin America. One of the advantages these banks bring with them is their expertise in credit evaluation and risk management.

These supply-side factors represent generally welcome developments, but also give rise to stability concerns. Even where credit growth is motivated by higher expected future income and profitability, there is a risk that these expectation will not be fulfilled, or that external constraints become binding before the improvement is realized. Better loan technology or more intense competition between banks should to an extent help ensure that credit is efficient allocated, but they may also give rise to certain risks.

With regard to financial sector stability, the main worry is that rapid expansion in credit is associated with a lowering of credit standards. Many financial crises have been preceded by rapid credit growth, and a sudden halt to credit expansion is often associated with the onset of crisis. (Enoch and Otker-Robe, 2007, and Kraft and Jankov, 2005, contain both empirical evidence and a discussion of policy issues; see also Barajas et. al., 2007 and Cottarelli et. al., 2005). The most alarming circumstance is where both borrowers and lenders are seized by over-optimism, so that neither is filtering loan applications with due care. Even without cognitive biases, market structure may tend to make loan standards pro-cyclical; Jimenez and Saurina (2005) provides some recent evidence, and a survey of the literature. Dell'Ariccia and Marquez (2005) addresses theoretical issues in more depth. Dell'Ariccia, Igan and Laeven (2008) find that falling credit standards are associated with accelerating expansion in sub-prime lending, and with the entry of new lenders.

Changes in loan technology may in themselves lead to a loosening of loan standards. For example, an improvement in loan technology may open up new market segments, such as poorer households, that were previously under-serviced. If clients tend to display loyalty towards banks, it may be worthwhile for banks to "invest" in a client base in the new market segments, even if that involves initially under-pricing risk.[3]

But new technology is also intrinsically less well understood by the companies that use it and by those who finance them. New lines of business may be in some regards intrinsically riskier than traditional business: banks may be most familiar with lending to government and large corporate clients, for example, but have little experience and a limited database with consumer and mortgage lending. Then there would be little evidence of how probabilities of default and losses given default for these sectors would behave in the event of a recession. The sub-prime mortgage crisis in the U.S. in 2007 can be interpreted as an instance where such risks were realized (see, e.g., Dell'Ariccia et. al, 2008). Already in the early part of that year, it became apparent that many lenders had under-estimated that repayment capacity of many borrowers, especially when housing prices ceased in rise. Models had been used to price mortgages, estimate default and loss-given default rates, and correlations among risks

[3] There is an academic literature on firm behavior when clients face "switching costs."

factors, but these models turned out to be less reliable than thought. With hindsight, it appears that model uncertainty was under-estimated, and too much reliance was placed on data gathered in a period of unusually favorable macroeconomic conditions. One may legitimately ask whether the same applies to credit risk assessments for emerging market based just on data from recent years.

One element of this increase in risk may lie in a kind of winner's curse, where the most optimistic borrowers get funding from the most optimistic banks, as illustrated in, e.g., Bolt and Tieman (2004) or Schaffer (1998), and the bias in their expectations is revealed only much later when conjunctural conditions deteriorate. However, there may be more going on.

Innovations in loan technology may lead even reputable, good banks to expand lending excessively in order to demonstrate their confidence in their loan technology, and weaker banks may be tempted to imitate then in order not to reveal their weaknesses. Because a bank's financers (depositors or other creditors such as participants in wholesale money markets) may be skeptical of the reliability of novel credit evaluation and risk management techniques, it has a strong incentive to demonstrate confidence in its own "loan technology." A bank may be especially loath to reveal that it has less confident in its skills than its rivals by being reluctant to extend large amounts of credit on this basis. Thus, credit volume becomes a signal of a bank's confidence in its loan technology, and funding costs increase for banks that do not demonstrate this confidence.

Credit volume is a useful and effective signal, because it is costly (in terms of probability of default and loss given default) for a bank to expand credit more than is warranted by its own risk assessments, and the cost is especially high for a bank with poor loan technology.[4] At the same time, loan technology is not directly observable. Banks regards their databases on the creditworthiness of their borrowers and their credit scoring algorithms as highly confidential information that encompass much of their competitive advantage. A bank cannot divulge such information without destroying the rents that accrue to its informational monopoly over its borrowers, and providing its competitors with very valuable information.[5] Thus, a bank cannot reveal this information directly, but must use a signals (credit volume) to convey to sources of finance that it offers high and safe returns.

The provision of excessive credit volumes as a signal to financiers can be mitigated by regulation and supervision. Specifically, detailed inspection of the quality of a banks' loan technology, combined with supervisory action to improve the quality if necessary, can play an important role. In addition, regulation encouraging increased transparency with respect to the quality of loan technology (without reveling proprietary methodologies or data) would

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[4] The need to send credible signals can explain a range of behaviors. Famous examples include Spence (1973) on signaling in education choices, Rothschild and Stiglitz (1976) on insurance, and Milgrom and Roberts (1982) on limit pricing to deter entry. There is a voluminous literature on the theoretical basis of signaling games, including Riley (1979) and Mailath (1987).

[5] One consequence is that there is little aggregation of information, which limits the reliability of statistical inferences.

reduce the incentive for using credit volume as a signal, and as such would reduce over-extension of credit.

The next section lays out the general model. The following section describes possible signaling equilibria under various conditions. Extensions of the model are then described, The last section concludes.

## II. The Model

Consider a bank with a certain loan technology characterized by a parameter α ($0 \geq \alpha \geq 1$). The bank seeks to maximize its expected profits from providing an amount $C$ of credit; the amount of credit extended is the choice variable. The bank operates as a price taker on the market for loans.[6] The economy can be in one of three states, which are realized independently from the bank's actions: good, slowdown, or recession.

- With probability $p_1$ the economy performs well (the good state obtains) and the credit yields (one plus the rate of return) $u$;

- However, with probability $p_2$ the economy performs less well and the credit yields only $\alpha v(C)u$, such that

$$1 \geq \alpha v \geq 0 \text{ and } v' < 0. \tag{A1}$$

  Thus, the more credit the bank extends, the more of it goes bad if the economy slows, and the less is recovered from impaired loans.[7] However, better loan technology (a higher α) implies that the portfolio is more resilient to a slowdown.

- Furthermore, the economy can go into severe recession (with probability $1 - p_1 - p_2$), where the credit portfolio yields only $g(\alpha)w(C)u$, such that

$$\alpha \geq g(\alpha),\ g'(\alpha) > 0,\ 1 \geq \alpha v(C) \geq g(\alpha)w(C) \geq 0, \text{ and } w' < 0. \tag{A2}$$

  Again, expanding credit leads to a deterioration in credit quality, but good loan technology is beneficial even in a recession.

The bank finances its credit portfolio through borrowing from financers at a rate $i$. We assume that the parameters of the model are such, that the bank cannot meet its obligations only if a severe recession occurs, that is, for all α,

$$\alpha v(C)u > i > g(\alpha)w(C)u. \tag{A3}$$

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[6] Our model is hence partial in the sense that it models the decisions only of individual banks that are not large enough to have their actions affect the market conditions (price).

[7] The bank should make provisions equivalent to a proportion ($1 - \alpha v(C)$) of its loans.

Financers have only an estimate $\tilde{\alpha}$ of the true loan portfolio parameter. Thus, the expected payoffs are as in Table 1 below:

**Table 1. Expected Payoffs in Different States**

| State | Probability | Bank's expected payoff | Financers' expected payoff |
|---|---|---|---|
| Good | $p_1$ | $uC–iC$ | $iC$ |
| Slowdown | $p_2$ | $\alpha v(C)uC–iC$ | $iC$ |
| Recession | $1– p_1 – p_2$ | 0 | $g(\tilde{\alpha})w(C)uC$ |
| Total | | $p_1uC+p_2\alpha v(C)uC–(p_1+p_2)iC$ | $(p_1+p_2)iC+(1– p_1 – p_2)g(\tilde{\alpha})w(C)uC$ |

The bank's financers are risk neutral but aware that the bank's credit portfolio is risky (other forms of financing, such as capital or non-risk sensitive deposits, are discussed below). Let *s* denote one plus the rate of interest on a safe alternative investment. Therefore, the financers will require that *i* be at a level where

$$(p_1 + p_2)iC + (1 - p_1 - p_2)g(\tilde{\alpha})w(C)uC = sC \tag{1}$$

It follows that the expected profits *V* (the value function) for a bank providing *C* in credit using loan technology α is

$$V(\alpha, \tilde{\alpha}, C) = p_1uC + p_2\alpha v(C)uC + (1 - p_1 - p_2)g(\tilde{\alpha})w(C)uC - sC \tag{2}$$

when the providers of financing believe that the bank has loan technology $\tilde{\alpha}$.

In the model, we employ three rather than the more standard two states of the economy, because we need to distinguish two separate effects. First, the banks need to obtain positive but differing payoff in at least two states: a 'good' state in which loan defaults and workouts are at a (very) low level, and in which consequently all banks make good profits, and a 'slightly worse' state, in which the loan defaults are higher, and the beneficial effect of investing in loan technology show.[8] However, since the banks' profits remain positive in both states, the financiers' payoff are the same in both states. In order for a risk premium to be associated with loan technology, one needs a third state in the model, in which the banks go bankrupt, receive zero payoff through limited liability, and return to the financiers is only partial. Still, the partial payoff to financiers is higher the better loan technology is implemented by the banks.

It is easy to verify that the first order condition for maximizing *V* with respect to *C*, given a fixed $\tilde{\alpha}$ is

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[8] Note that differences in loan technology are not revealed in good times; the test of a bank's technology comes when conditions worsen.

$$V_3 = p_1 u + p_2 \alpha (v(C) + v'C)u + (1 - p_1 - p_2) g(\tilde{\alpha})(w(C) + w'C)u - s = 0, \tag{3}$$

where $V_n$ will be used to denote the partial derivative of $V$ with respect to the $n$-th argument. We assumed for now that

$$2v' + v''C < 0, \quad 2w' + w''C < 0, \tag{4}$$

which is sufficient to ensure that the second order condition is met. It is also assumed that

$$v + v'C > 0,\ w + w'C > 0 \tag{A4}$$

in the relevant range, which is a regularity condition to ensure that a solution exists with a positive volume of credit.

Inspection of (2) and (3) shows that both $V$ and $V_3$ are increasing in α; better loan technology increases the value of the bank, and increases the marginal value of extending credit. This latter feature is the basis of the signaling equilibrium because it ensures that a bank with good technology is always more willing to extend credit than a bank with worse technology. However, it is also clear that both $V$ and $V_3$ are increasing in $\tilde{\alpha}$, and therefore a bank has an incentive to make its financers have a favorable belief about its loan technology. If those providers of finance can be persuaded that the bank will be able to meet a high proportion of its obligations even in the worst state of the economy, it will have a better credit rating and lower costs of financing.

## III. Model Analysis

### A. Full Information

It is useful to start with the situation where there are no information asymmetries, that is, where financers know the bank's loan technology. Therefore $\alpha=\tilde{\alpha}$ and the value function is given by (2) with that value inserted. Then the first order condition (FOC) for the maximum of the bank's profits is

$$V_3(\alpha, \alpha, C) = p_1 u + p_2 \alpha (v + v'C)u + (1 - p_1 - p_2) g(\alpha)(w + w'C)u - s = 0. \tag{5}$$

The optimally-chosen $C$ under full, symmetric information, denoted by $C^F(\alpha)$ will serve as a benchmark in what follows. In accordance with intuition, $C^F(.)$ depends positively on $p_1$, $p_2$, $u$ and α, and negatively on $s$. The Modigliani-Miller theorem applies because the cost of financing fully internalizes the costs of bank bankruptcy.

### B. Equilibria with Partial Information and Two Bank Types

In some situations, banks may plausibly fall into one of two categories, namely, those with relatively high-quality loan technology, and those lower-quality loan technology. Perhaps some banks have been able to import more advanced techniques from abroad, or have started earlier to build up a comprehensive database on borrowers, while others have not. Perhaps also some banks may have good technology available, but do not make full use of it because of poor management controls and governance. Thus, we first assume that banks can be of only two types, with respectively a high ($\alpha_H$) and low ($\alpha_L$) loan technology parameter. (Subsequently, we relax this analysis by looking at the case of a continuum of types.) In particular, suppose that a proportion $\theta$ of banks use high technology with $\alpha_H$, while the remainder use a lower technology $\alpha_L$, $1>\alpha_H>\alpha_L>0$.

The equilibrium behavior of banks may involve either pooling or separating. In a pooling equilibrium, all banks provide the same amount of credit, so financers cannot infer anything from credit volume; they have to rely on their ex ante estimate of the average loan technology. The good banks get to choose the credit volume, but their cost of financing is raised by the financers' fear of the intermingled low-technology banks. In a separating equilibrium, banks with good technology disburse so much credit that low-technology firms prefer not to keep up: the financers can distinguish between banks, so costs of financing reflect bank-specific risk, but the high-quality technology banks are constrained to extend more credit than they would under full information in order to discourage imitation.

**Pooling**

In the pooling equilibrium, where both types of banks disburse the same volume of credit, the objective functions for high and low technology banks are respectively

$$V(\alpha_H, \underline{\alpha}, C) = p_1 uC + p_2 \alpha_H v(C)uC + (1 - p_1 - p_2) g(\underline{\alpha}) w(C)uC - sC \tag{6}$$

$$V(\alpha_L, \underline{\alpha}, C) = p_1 uC + p_2 \alpha_L v(C)uC + (1 - p_1 - p_2) g(\underline{\alpha}) w(C)uC - sC \tag{7}$$

where $\underline{\alpha} = \theta\alpha_H + (1-\theta)\alpha_L$ is the average loan technology parameter; the presence of $\underline{\alpha}$ rather than $\alpha_H$ or $\alpha_L$ as the second argument of the value functions indicates that these are value functions under pooling. The high-technology bank chooses $C$ to maximize (6), while the low-technology banks imitates. Comparing (2) with $\alpha=\tilde{\alpha}$ to (6) and (7) reveals that pooling effectively allows the low-technology bank to transfer some of the financing cost associated with higher credit risk to the better bank. To make the problem interesting, it is assumed that the low-technology bank would have an incentive to imitate the high-technology banks, if the latter acted as if there were full information; otherwise the high-technology banks would be unconstrained. The relevant condition is:

$$V(\alpha_L, \underline{\alpha}, C^F(\alpha_H)) > V(\alpha_L, \alpha_L, C^F(\alpha_L)). \tag{8}$$

**Proposition 1 (Pooling).** *Suppose assumptions (A1)-(A4) and (4) are satisfied. Then, in a pooling equilibrium, banks of type $\alpha_H$ disburse less credit than in the full information case, while banks of type $\alpha_L$ disburse more credit than under full information.*

**Proof.** Examine the FOC derived from (6):

$$p_1 u + p_2 \alpha_H [v(C) + v'(C)]u + (1 - p_1 - p_2) g(\underline{\alpha})[w(C) + w'(C)C]u - s = 0, \tag{9}$$

which differs from the full information FOC for the high-technology bank (given by (5) with $\alpha=\alpha_H$) only in the term $g(\underline{\alpha})$ instead of $g(\alpha_H)$. As $\underline{\alpha} < \alpha_H$, and $g(.)$ is strictly increasing, $g(\underline{\alpha}) < g(\alpha_H)$. Hence, the optimum $C^P(\alpha_H) < C^F(\alpha_H)$. Analogously, (9) differs from the full information FOC for the low technology bank (given by (5) with $\alpha=\alpha_L$) by the presence of $g(\underline{\alpha}) > g(\alpha_L)$ in the third term and $\alpha_H > \alpha_L$ in the second term. Hence, (9) implies higher credit than would be optimal with low technology under full information. The low-technology bank does not choose the volume of credit under pooling (it imitates the high-technology bank), so $C^P(\alpha_H) = C^P(\alpha_L) > C^F(\alpha_L)$. □

Thus, in a pooling equilibrium, the banks with the superior technology supply less credit less than in the full information case, while the banks with the inferior technology supply more credit. Hence, the market shares are affected in favor of the low-technology banks. Whether the total credit volume would be higher or lower than under full information depends on the specific functional forms of $v(.)$, $w(.)$ and $g(.)$ and cannot be determined in general. The quality of the high-technology bank's credits improves (i.e., the proportion expected to go bad in case of slowdown or recession) because the volume shrinks, while that of the expanding low-technology bank deteriorates. The total expected volume of loan losses increases unless total credit falls appreciably (proof is provided in the appendix); intuitively, more credit is provided by banks with a higher rate of expected loan losses, and less credit it is provided by banks with lower loss rates.

**Separating**

Under some circumstances, the high-type bank might benefit from credibly signaling its type to financiers, thus creating a separating equilibrium, rather than let the low-technology bank transfer to it some financing costs. In such an equilibrium, a high-technology bank's net worth is given by (2) with $\alpha=\tilde{\alpha}=\alpha_H$ and the low technology bank's net worth in analogous but with $\alpha=\tilde{\alpha}=\alpha_L$.

However, in order for a separating equilibrium to be feasible, two incentive compatibility constraints must be met. One constraint is that the low technology bank prefers not to imitate the signal of the high-technology bank, that is, that imitating is not advantageous relative to the best obtainable outcome when financiers can infer the low-tech bank to be of the low type. Assume the high technology bank chooses its volume of credit $C^S(\alpha_H)$ such that the low-technology bank does not want to imitate:

$$V^*(\alpha_L, \alpha_L, C) \geq V(\alpha_L, \underline{\alpha}, C^S(\alpha_H)) \tag{10}$$

where an asterisk indicates that the function is maximized with respect to $C$. Condition (10) defines $C^S$ $(\alpha_H)$. Thus, the high-technology bank discourages imitation by increasing its lending; since the marginal net benefit of lending is always higher for the high-technology bank than for the low-technology bank, it will stop being worthwhile for the latter to imitate before it becomes too costly for the high-technology bank.

However, a second incentive compatibility constraints comes into play: the profits of the high-technology bank must be higher at $C^S(\alpha_H)$ than they would be under a pooling equilibrium:

$$V(\alpha_H, \alpha_H, C^S(\alpha_H)) \geq V^*(\alpha_H, \underline{\alpha}, C). \tag{11}$$

This second condition hence defines the boundary between the separating and the pooling equilibrium. Assuming (10) is satisfied, (11) ensures that the high type prefers separating over pooling. Consequently, in case (11) is not satisfied, the high type would prefer pooling, as the additional benefit from signaling its type to financiers does not outweigh the extra signaling costs of having to supply more credit than in the pooling case.

**Proposition 2 (Separating).** *Suppose assumptions (A1)-(A4), (4), and incentive compatibility constraints (10) and (11) are satisfied. Then, a separating equilibrium obtains, in which banks of type $\alpha_H$ disburse more credit than in the full information case, while banks of type $\alpha_L$ disburse the same amount of credit as under full information. Total credit is thus higher than under full information.*

**Proof.** The fact that a separating equilibrium obtains follows directly from (10) and (11), as does the fact that $C^S(\alpha_H) > C^F(\alpha_H)$. As the low technology bank's type will be revealed to financiers, this bank has no incentive to deviate from its full information supply of credit, i.e., $C^S(\alpha_L) = C^F(\alpha_L)$. Total credit hence is higher under the separating equilibrium than in the full information case, i.e., $C^S(\alpha_H) + C^S(\alpha_L) > C^F(\alpha_H) + C^F(\alpha_L)$. □

Because of the larger volume of credit extended by the high technology banks in this equilibrium, a larger proportion of its loans is at risk of going bad in case of a slowdown or recession, because both *v*(.) and *w*(.) are increasing.

We are left to verify existence of both the pooling ands separating case under the model assumptions.

**Proposition 3 (Existence).** *Suppose assumptions (A1)-(A4) and (4) are satisfied. Then, there exists functions and parameterizations of v(.), w(.), and g(.) for which pooling equilibria exists, and there exist functions and parameterizations of v(.), w(.), and g(.) for which separating equilibria exist.*

**Proof.** The second order conditions for a maximum, equation (4), and the assumption (A4) that $v+v'C>0$, $w+w'C>0$ assures that an optimum with a positive volume of credit exists. Hence, the banks can always imitate one another with a positive level of credit. Thus, pooling (i.e., imitation) is always possible. Whether pooling strategies constitute an equilibrium or not depends on whether incentive compatibility constraints (10) and (11) are satisfied.

The existence of a separating equilibrium depends on conditions (10) and (11) being met simultaneously in the relevant range. First, the conditions on *v*(.) and *w*(.) ensure that a point $\underline{C}$ exists, such that $\forall C > \underline{C}$ it holds that $V_3(\alpha_L, \underline{\alpha}, C) < V_3(\alpha_L, \alpha_L, C) < 0$ (i.e. beyond $\underline{C}$, $V(\alpha_L, \underline{\alpha}, C)$ declines more steeply than $V(\alpha_L, \alpha_L, C)$ does). Second, $V(\alpha_L, \underline{\alpha}, C) > V(\alpha_L, \alpha_L, C)$. Taken together, this implies that a point $C^S(\alpha_H) > \underline{C}$ where (10) holds with equality always exists. Because $V(\alpha_H, \alpha_H, C) > V(\alpha_H, \underline{\alpha}, C)$, at the maximum $C^F(\alpha_H)$, $V(\alpha_H, \alpha_H, C^F(\alpha_H)) > V(\alpha_H, \underline{\alpha}, C^F(\alpha_H))$. Whether (11) holds thus depends on how fast $V(\alpha_H, \alpha_H, C)$ declines between the points $C^F(\alpha_H)$ and $C^S(\alpha_H)$, i.e., the magnitude of the derivative $V_3(\alpha_H, \alpha_H, C)$ beyond its maximum $C^F(\alpha_H)$, which depends on $v$(.), $w$(.) and $g$(.). Hence, for given $v$(.) and $w$(.), choosing $g$(.) small but positive ensures that (11) is met and hence a separating equilibrium exists. Choosing $g$(.) and $w$(.) large (e.g., $g(\alpha)w(\alpha)=\alpha v(\alpha)=1$) ensures that no benefit from separating exists, and hence a pooling equilibrium will obtain. □

It is noteworthy also that the behavior of aggregate credit differs depending on the equilibrium that obtains. Under full information, how a bank reacts to changes in the interest rates it faces or the probabilities of a slowdown or recession depends just on that bank's own characteristics. Under pooling, the reaction of total credit to a shock is determined by how high-technology banks are affected $\underline{\alpha}$. The parameters θ and $\alpha_L$ still have an influence on the credit volume, but only by affecting the high technology bank. Under separating, the incentive compatibility constraint (which relates to the profitability of low-technology banks) dictates how high-technology banks will react. If the separating condition (10) is met with equality, one could even obtain "perverse" results where, for example, an increase in the expected return on lending reduces credit volumes. Thus, with certain elasticities, policies that effectively tax lending will not diminish credit volumes.

There is a range of combinations of parameters defining the boundary between the separating and the pool equilibrium This boundary is defined implicitly by the condition that the high-technology bank is indifferent between pooling and separating, where the separating level of credit is such that the low-technology bank is also indifferent. Thus:

$$V^*(\alpha_H, \underline{\alpha}, C) = V(\alpha_H, \alpha_H, C^S), \tag{12}$$

such that (10) is met with equality.

A small shift in the parameters can make the banking sector switch from one equilibrium to another. Such a shift might be caused, for example, by the introduction of new loan technology or by macroeconomic developments that affect the probability of a recession or the safe rate of interest. In particular, a small shift that lead high-technology banks to attempt to separate could generate a large and abrupt increase in credit.[9]

It is difficult to characterize fully how the boundary depends on the parameters without loss of generality, but some comparative static results can be derived. With all other parameters given, let $\alpha_L^B$ denote the level of the low-technology parameter, such that the system is on

[9] Intuitively, one can think of a series of innovations: in a banking system with little innovation, banks' true αs are eventually revealed. Then, limited innovation may lead to a pooling equilibrium. Larger, less tested innovation leads to a separating equilibrium.

the border between equilibria and (12) obtains. Let ξ denote some other parameter. Then one can show that

$$\frac{d\alpha_L^B}{d\xi}=\frac{V_\xi^*(\alpha_H,\underline{\alpha},C)-V_\xi(\alpha_H,\alpha_H,C^S)+V_3(\alpha_H,\alpha_H,C^S)\left(\dfrac{V_\xi(\alpha_L,\underline{\alpha},C^S)-V_\xi^*(\alpha_L,\alpha_L,C)}{V_3(\alpha_L,\underline{\alpha},C^S)}\right)}{V_{\alpha L}^*(\alpha_H,\underline{\alpha},C)+V_3(\alpha_H,\alpha_H,C^S)\left(\dfrac{V_{\alpha L}(\alpha_L,\underline{\alpha},C^S)-V_{\alpha L}^*(\alpha_L,\alpha_L,C)}{V_3(\alpha_L,\underline{\alpha},C^S)}\right)}. \quad (13)$$

$V_\xi$ is the derivative of $V$ with respect to the parameter ξ, which might enter both $\underline{\alpha}$ and the specification of $V$, and similarly for $V_{\alpha L}$. It has been established that $V_3$ is always increasing in α; hence the ratio $V_3(\alpha_H,\underline{\alpha},C^S)/V_3(\alpha_L,\underline{\alpha},C^S)$ is certainly greater than unity. Furthermore, if θ is not too large (so low-technology firms have a substantial presence), the denominator of (13) is positive.

One consequence is that certain differences between banks will not affect the boundary between separating and pooling. For example, suppose that one bank had more capital $K$ than the other or benefited from non-risk sensitive deposits $D$ that earn a constant return $e$ (perhaps it has an extensive retail network among non-sophisticated savers). Without loss of generality, let the low-technology bank enjoy these advantages. Then its value function becomes

$$V(\alpha_L,\tilde{\alpha},C)=p_1(uC)+p_2\alpha v(C)uC+(1-p_1-p_2)g(\tilde{\alpha})w(C)uC-s(C-K-D)-eD. \quad (14)$$

while that of the high-technology bank is unchanged. Then for a change in $K$, $D$, or $e$, the first two terms in the numerator of (13) are zero. Furthermore, $V_\xi(\alpha_L,\underline{\alpha},C^S)-V_\xi^*(\alpha_L,\alpha_L,C)=0$, so the entire numerator equals zero.

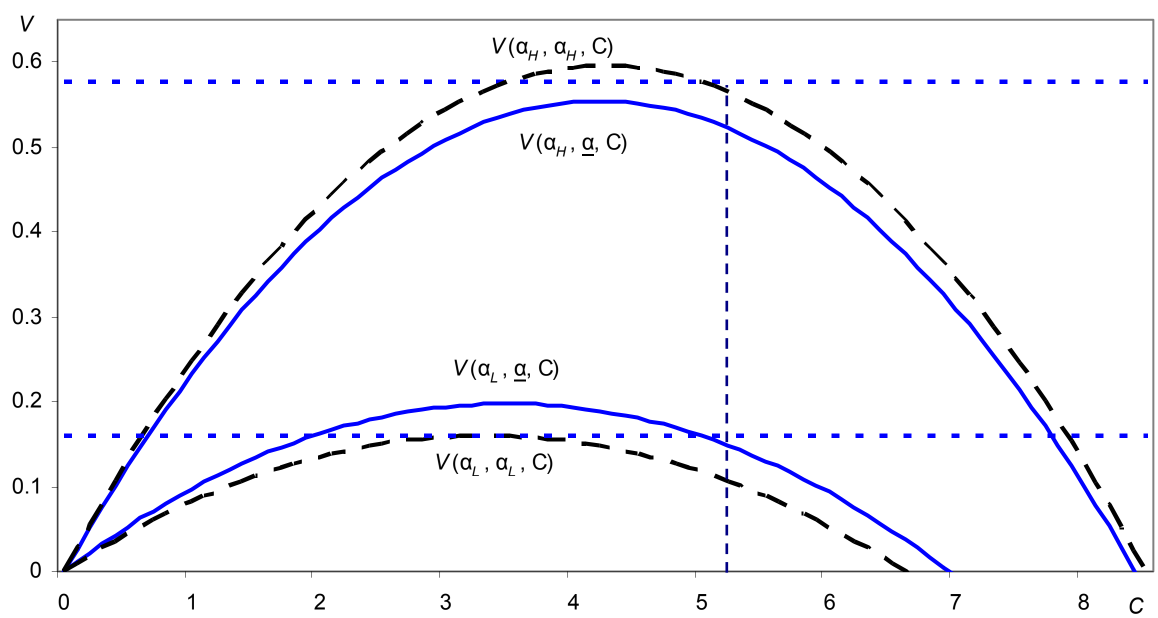
**A parameterized example**

To illustrate these possibilities, assume the two types of banks are characterized by loan technologies $\alpha_H = 0.9$ and $\alpha_L = 0.4$, respectively; a proportion $\theta = 0.5$ of banks are of the high type. The payoff functions in slowdown and recession are assumed to be $v(C) = 1 - 0.1C$ and $w(C) = 0.5 - 0.05C$, while $g(\alpha) = 0.9\alpha$. The example satisfies all regularity conditions above. Moreover, it allows for the derivation of an analytical expression can for the optimal amount of credit for a bank of type $\alpha_i$:

$$C^*=\frac{u\{p_1-p_2\alpha_i+0.45(1-p_1-p_2)\tilde{\alpha}\}-s}{u\{0.2p_2\alpha_i+0.09(1-p_1-p_2)\tilde{\alpha}\}}.$$

Figure 2 depicts the value function for different combinations of type (first argument) and financiers believes (second argument). The expected return of the project in the good state of the economy is taken to be 50 percent, so $u = 1.5$. The risk-free rate is taken to be 10 percent, so $s = 1.1$. Under the assumption that the probability of a good state of the economy is $p_1 = 0.7$, with a slowdown occurring with probability $p_2 = 0.2$, and hence a recession occurring with probability 1-$p_1$-$p_2$ = 0.1, a separating equilibrium obtains: the vertical line indicates the point $C$ = 5.0, beyond which type $\alpha_L$ prefers to be know as $\alpha_L$, rather than try to imitate $\alpha_H$ (while at this point $\alpha_L$ is indifferent between pooling and separating). At this point, however, type $\alpha_H$ still prefers to be seen as $\alpha_H$, as indicated by the fact that the value function $V(\alpha_H, \alpha_H, C)$ is above the maximum of $V(\alpha_H, \underline{\alpha}, C)$.

Figure 2. The Value Function for Different Types: Separating Equilibrium




A pooling equilibrium can result after small changes in the parameterization. Specifically, if the probability of a recession decreases, e.g. by setting $p_1$ = 0.75 instead of $p_1$ = 0.7, one quickly gets to the situation where the equilibrium consists of pooling strategies. This result is driven by the fact that the incentives to invest in loan technology are lower when the probability of a recession is lower: the benefits of good loan technology to financiers decrease, which will hence reduce the interest rate differential financiers would charge banks of the different types.

### C. Separating Equilibrium with Partial Information and a Continuum of Bank Types

While some markets might be characterized as including distinct groups of good and bad banks, in other cases it is better to think of banks as occupying locations across a continuous range of loan technologies.[10] Financers will not need to identify whether a bank falls into one or the other group, but rather, where in the range it is located. A banks will need to determine

[10] It may also sometimes be more appropriate to think of banks facing a continuous distribution of possible outcomes for their loan portfolio, rather than the discrete states considered here. However, because a distribution function typically has points of inflection, the analysis becomes much more complex.

its optimal behavior when there are always near neighbors with slightly better or slightly worse technology.

If a fully separating equilibrium exists, all banks disburse more credit than they would under full symmetric information, with the exception of the bank with the very worst technology. Each bank wants to distinguish itself from those with worse loan technology by lending more; a weaker bank would find imitation too costly in terms of deteriorating loan quality (the incentive compatibility constraint). Only the bank with the worst technology does not need to distinguish itself from yet worse banks. Instead, it would like to be conflated with a bank with better technology, but the incentive compatibility constraint is respected, so emulating the better banks is too costly in terms of additional credit risk. Hence, the volume of credit from that worst bank is the same as under full symmetric information, and all others issue more. It follows that the asymmetry of information about loan technology yields more credit and corresponding higher expected impaired loans and loan losses.

The results of Mailath (1987) provide a means of determining whether such a fully separating equilibrium could exist in such a market, and some of its characteristics. In a "fully" or "pure" separating equilibrium, there is no pooling anywhere in the range. In general, however, there may be additional equilibria, with pooling among some sub-set of banks.

In particular, assume that banks are characterized by a range of values of α such that $\alpha \in \left[\breve{\alpha}, \widehat{\alpha}\right]$. Equation (2) is the objective function for a bank with a particular α. Define C = φ(α) as the increasing function relating optimal credit volume to bank type under full, symmetric information. Under asymmetric information, Mailath shows that, if certain regularity conditions are met and a single crossing condition obtains, then there exists a strictly monotonic strategy $C = \tau(\alpha)$ that satisfies the incentive compatibility constraint, i.e., that a fully separating equilibrium exists. Strict incentive compatibility requires that

$$\{\tau(\alpha)\} = \arg\max_{y \in \tau([\breve{\alpha}, \widehat{\alpha}])} V(\alpha, \tau^{-1}(y), y), \qquad \forall \alpha \in [\breve{\alpha}, \widehat{\alpha}]. \tag{15}$$

Some stronger results are obtained when a certain initial value condition obtains; in the case here, the initial value condition is that, when subject to the incentive compatibility constraint, the bank with the worst loan technology behaves as if there were full information.[11]

Verification of the regularity conditions is presented in the appendix.

The single crossing condition is that $V_3/V_2$ is a strictly monotonic function of α. In this model

$$\frac{V_3(\alpha, \tilde{\alpha}, C)}{V_2(\alpha, \tilde{\alpha}, C)} = \frac{p_1 u + p_2 \alpha (v + v'C)u + (1 - p_1 - p_2) g(\tilde{\alpha})(w + w'C)u - s}{(1 - p_1 - p_2) g'(\tilde{\alpha}) w(C) u C}. \tag{16}$$

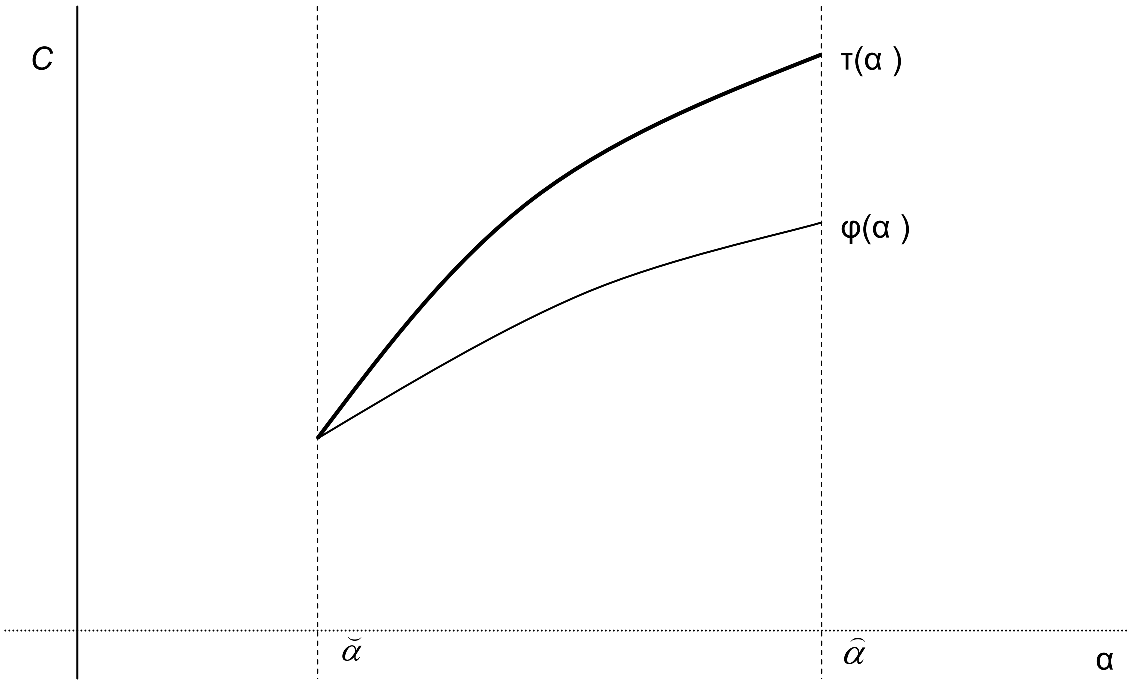
[11] In Mailath's notation, the value of C which maximizes the value function under symmetric information $V(\alpha, \alpha, C)$ is denoted by φ(α ).

The numerator of (16) contains just one term in α, which is always positive by the assumption that *v+v'C*>0. The denominator is independent of α and positive because *g*' is positive. Hence, the whole expression is monotonically increasing in α and the single crossing condition is met. Intuitively, a bank with better loan technology has higher marginal profits from extending credit than does a worse bank ($V_3$ is increasing in α), while the margin value of maintaining a good reputation among financiers is independent of actual α. Hence, the better bank can afford to extend credit until a worse bank does not wish to keep up.

The initial value condition is also met. Because $V_2 > 0$, we consider a bank with the worst loan technology, that is, with $\alpha = \breve{\alpha}$, and use *reduction ad absurdum*. Suppose first that $\tau(\breve{\alpha}) > \varphi(\breve{\alpha})$, that is, the incentive compatible level of credit for this bank is above the optimal full information level. Yet, the bank could then do better by reducing the level of its credit outstanding to $\varphi(\breve{\alpha})$, without any deterioration in financiers' estimation of its loan technology (which is already revealed); by definition $V(\breve{\alpha}, \breve{\alpha}, \varphi(\breve{\alpha})) \geq V(\breve{\alpha}, \breve{\alpha}, C), \quad C \neq \varphi(\breve{\alpha})$. Also, since this bank is at the extreme of the range of values of α, there is no worse bank that will imitate it. Hence, this level of credit is not incentive compatible. Suppose instead that $\tau(\breve{\alpha}) < \varphi(\breve{\alpha})$. Then once more the bank with the worst loan technology could do at least as well by increasing the level of its credit to $\varphi(\breve{\alpha})$ : if financiers still believe that it has the worst possible technology, that level of credit yields higher expected profits. Hence, the lower level of credit is not consistent with the incentive compatible constraint. Furthermore, if τ is continuous, higher credit from the worst bank would involve pooling with a somewhat better bank, and further increase the former's expected profits. Hence the only incentive compatible level of credit for the bank with the worst loan technology is that which is optimal under full, symmetric information.

Therefore, by Mailath's results, a unique separating equilibrium exists. Furthermore, under this equilibrium, all banks extend more credit than under full information, with the exception of the bank with the worst loan technology, which extends the same amount. Hence, the expected proportion of bad loans and the share of banks that fail is higher than under symmetric information, that is, when financiers are familiar with banks' loan technologies. The relation between *C* and α under symmetric information (φ(α )) and the separating equilibrium (τ(α )) is shown below (Figure 3).

Figure 3. Credit Volumes and Bank Characteristics for a Continuum of Types




## IV. Extensions

The model can be extended in various directions to yield plausible explanations of various other phenomena related to credit expansion and the introduction of new loan technology.

### A. Investment in Loan Technology

The value of credit volumes as a signal of loan technology will generally raise incentives to invest in that technology. The prevalence of signaling implies that an investment in better loan technology does not merely yield a direct pay-off in terms of higher returns to lending, but also reduces the cost of signaling: a high-technology bank that invests will find it cheaper to differentiate itself from a low-technology bank, and the latter will find it cheaper to imitate the former. Whether there is pooling or separating, investment may be greater than it would be under full information. This level of investment may not be socially optimal but it is good for financial sector development and stability.

To illustrate this point, suppose that a bank can invest an amount $I$ to improve its loan technology by an amount $\Delta\alpha$. Then under full information, the investment is worthwhile if the increase in the value function exceeds the cost of the investment:

$$V^*(\alpha+\Delta\alpha,\alpha+\Delta\alpha,C)-I>V^*(\alpha,\alpha,C). \tag{17}$$

The amount of credit differs in the $V$ terms on the right and left-hand sides of the equation. However, both terms are maximized with respect to C, so a first-order Taylor approximation to the condition is

$$(V_1^* + V_2^*)\Delta\alpha > I. \tag{18}$$

Consider now two banks that are initially in a pooling equilibrium. Their value functions are given in the lower-right cell of Table 2; the high-technology bank's value function is the upper-right term in the cell, and the low-technology bank's value function is the bottom-left term.

If the high-technology bank invests while the other does not, and the improvement in loan technology is sufficiently great, then the high-technology firm will be able to achieve a separating equilibrium (a move designated by an ← in the table below). It gains both because of the intrinsic value of the technology, and because financers can now distinguish it from the low-technology bank. The approximate condition for the investment to be worthwhile is

$$(V_1^* + V_2^*)\Delta\alpha + V_2^*(1-\theta)\alpha > I. \tag{19}$$

The second term on the left-hand side of (19) represents the positive gain from signally. It follows that the high-technology bank will undertake more expensive investment (higher $I$) under asymmetric information than under full information.

Moreover, the low-technology bank may react. If it anticipates that the other bank will invest, it has an extra incentive to invest to avoid being left in a separating equilibrium; an investment in loan technology may allow it to go from the bottom-left cell of the table to the upper-left cell (shown by the ↑). Given the high-technology bank is going to invest, the approximate condition for the investment to be worthwhile for the low-technology bank is

$$(V_1^* + V_2^*)\Delta\alpha + V_2^*\theta\alpha > I, \tag{20}$$

where again the left-hand side has an extra positive expression compared to (18). The banks are left in a pooling equilibrium, with both having invested in improved loan technology.

**Table 2. Investment Decision Starting From and Ending at Pooling Equilibria**

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Bank $\alpha = \alpha_H$</td></tr>
<tr><td>$I$</td><td>Not $I$</td></tr>
<tr><td rowspan="2">Bank $\alpha = \alpha_L$</td><td>$I$</td><td>$V^*(\alpha_H + \Delta\alpha, \underline{\alpha} + \Delta\alpha, C^P) - I$<br>$V(\alpha_L + \Delta\alpha, \underline{\alpha} + \Delta\alpha, C^P) - I$</td><td>$V^*(\alpha_H, \underline{\alpha} + (1-\theta)\Delta\alpha, C^P)$<br>$V(\alpha_L + \Delta\alpha, \underline{\alpha} + (1-\theta)\Delta\alpha, C^P) - I$</td></tr>
<tr><td>not $I$</td><td>↑ $V(\alpha_H + \Delta\alpha, \alpha_H + \Delta\alpha, C^S) - I$<br>$V^*(\alpha_L, \alpha_L, C^F)$</td><td>← $V^*(\alpha_H, \underline{\alpha}, C^P)$<br>$V(\alpha_L, \underline{\alpha}, C^P)$</td></tr>
</table>

Similar reasoning applies to banks starting from a separating equilibrium (see Table 3). If the investment improves loan technology enough, it may be worthwhile for the low-technology bank to undertake it in order to achieve a pooling equilibrium. However, the high-technology bank will then have an extra incentive to invest in order to maintain its lead and preserve separation. The banks arrive in a new separating equilibrium with better technology for each.

**Table 3. Investment Decision Starting From and Ending at Separating Equilibria**

| | | Bank $\alpha = \alpha_H$ | |
|---|---|---|---|
| | | *I* | Not *I* |
| Bank $\alpha = \alpha_L$ | *I* | $V^*(\alpha_H + \Delta\alpha, \alpha_H + \Delta\alpha, C^S) - I$<br>$V(\alpha_L + \Delta\alpha, \alpha_L + \Delta\alpha, C^F) - I$ | $\leftarrow$ $V^*(\alpha_H, \underline{\alpha} + (1-\theta)\Delta\alpha, C^P)$<br>$V(\alpha_L + \Delta\alpha, \underline{\alpha} + (1-\theta)\Delta\alpha, C^P) - I$ |
| | not *I* | $V(\alpha_H + \Delta\alpha, \alpha_H + \Delta\alpha, C^S) - I$<br>$V^*(\alpha_L, \alpha_L, C^F)$ | $\uparrow$ $V(\alpha_H, \alpha_H, C^S)$<br>$V^*(\alpha_L, \alpha_L, C^F)$ |

### B. Pervasive Moral Hazard and Low-Credit Outcomes

Signaling may play a role also in explaining episodes of low credit growth. Some economies, especially those that have experienced macroeconomic instability or that suffer from under-developed institutions, witness persistently low levels of credit provision. These economies may exhibit a relative low endowment of capital and variable income, and thus one would expect high returns to investment and consumption smoothing. Nonetheless, many banks may provide credit only to a small range of "cherry picked" clients. It will be shown that, in some circumstances, lower credit growth may be a sign of financial soundness and good loan technology. Therefore, high-technology banks may see an advantage in being very restrictive in their credit policy, and low-technology banks may imitate them.

To make the problem economically meaningful, we add the assumption that banks have a certain amount K of capital, and there is a capital adequacy requirement such that

$$0 < C < \rho K \tag{A.5}$$

Banks can invest in a safe asset besides making risk loans. It is also assumed that earnings in the bad state are sufficiently bad, that any bank is unable to meet its financers' demands despite the availability of capital, which then accrue to the financers along with residual earnings on credit. Then it can be shown that the value function now includes terms relating to capital:

$$V(\alpha, \tilde{\alpha}, C) = p_1 uC + p_2 \alpha v(C) uC + (1 - p_1 - p_2) g(\tilde{\alpha}) w(C) uC - s(C - K). \tag{21}$$

Suppose then that the second order conditions for the maximization of the value function $V$ are not met for any positive value of $C$. Thus, the inequalities in equation (4) are reversed, and when equation (3) is satisfied, $V$ is minimized. A variety of equilibria are possible depending on the exact configuration of parameters. For simplicity, we revert to the case with just two types of banks.

Under full, symmetric information, it is possible that both types of banks provide either zero credit or the maximum permissible amount ($\rho K$). The effects of moral hazard are so great, that either credit intermediation collapses, or banks adopt the riskiest possible strategies. It is also possible that the bank with better technology would choose a positive amount of credit but the other bank would choose to offer no risky loans.

The possibility of signaling and pooling may upset these outcomes. Generally, the amount of credit provided is reduced. The following charts illustrate certain possibilities. Figure 4 illustrates the separating equilibrium in which the high-technology bank chooses to provide no credit in order to signal its high quality: point *a* offers a higher value function (i.e., higher expected net worth) than point *b*.[12] (Where there no uncertainty about bank loan technology, this bank would lend as much as it could under the capital constraint; point *e* is above point *a*.) The low-technology bank is better off providing as much credit as possible, even though that reveals its type; point *c* offers higher expected net worth than point *d*. In this case, average loan quality is worse than it would be under full information, although the total amount of lending is less.

[12] The curves are separated vertically to clarify the figure.

Figure 4. Separating Equilibrium with Low Credit Volume

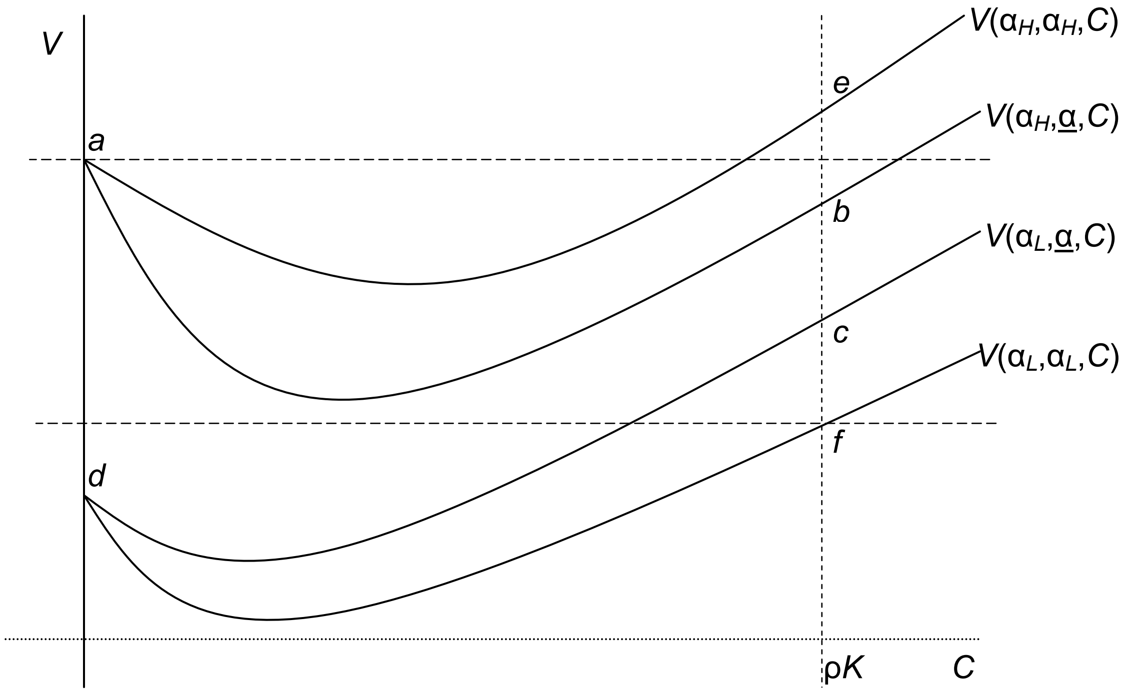
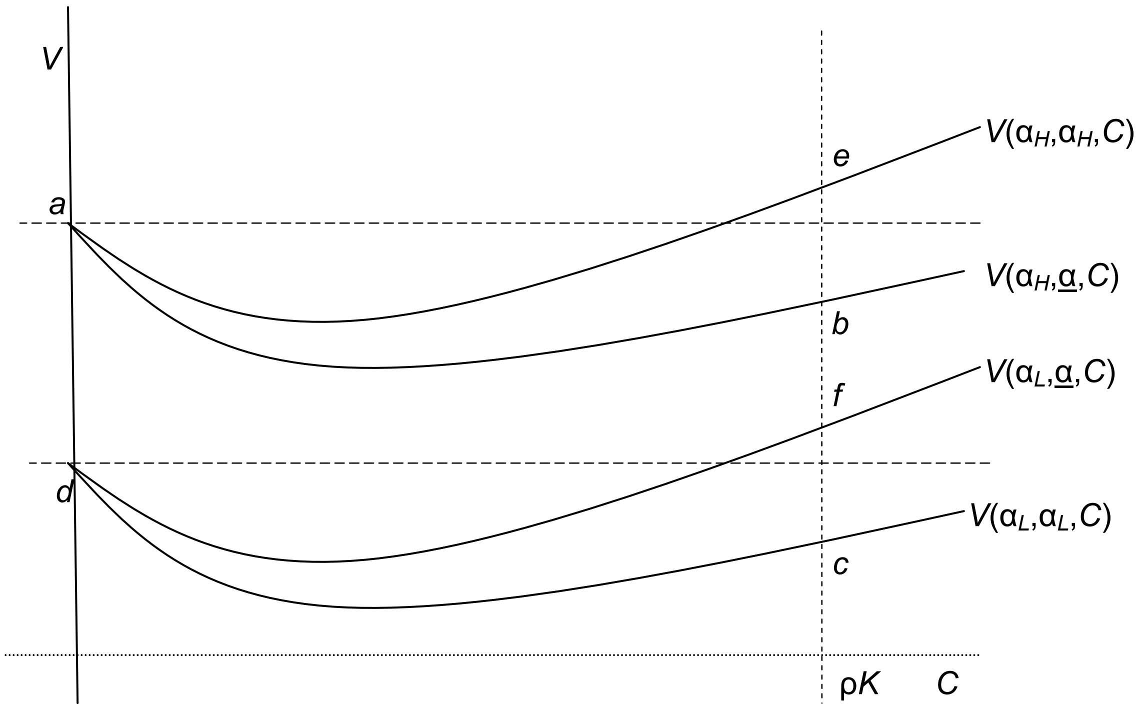



Figure 5 illustrates the possibility of a pooling equilibrium with both banks providing no credit. Given pooling, the high-technology bank prefers to offer no credit (point *a* is better than point *b*) even though it would provide credit under full, symmetric information (point *e* is better than *a*). And the low-technology bank prefers to imitate the "good" bank rather than reveal its poor loan technology (point *d* is better than point *c*). Banks are perfectly sound under this equilibrium, at the expense of under-provision of financing. With other parameter values, it is possible that both banks will provide the maximum amount of credit, even though pooling transfers some value from the high to the low-technology bank.

Figure 5. Pooling Equilibrium with Low Credit Volume




The diversity of equilibria implies that small shifts in parameters can lead to abrupt shifts across a broad range of behaviors. A slight deterioration in business conditions can result in the total collapse in intermediation. As business conditions improve, the banking system may first display a division between a few small, selective banks, and those lenders who are happy to take large risks. When conditions improve still further, the second order conditions for an interior maximum are met, and the economy jumps to an equilibrium with pooling or separating at a high level of intermediation. This evolution is consistent with the stylized facts of what has been seen in many developing and emerging market economies.

## V. Summary and Conclusions

We employ a signaling model to illustrate the point that it can be rational for a credit institution to lend more, beyond its full-information profit maximizing quantity. This over-expansion is closely connected to the introduction of new banking techniques—termed here "loan technology"—whose effectiveness is not well-tested. Banks employ different levels of loan technologies, such as credit screening and risk management models, techniques, and procedures, characterized by a general loan portfolio parameter. Assume that better loan technologies increase the marginal value of extending credit, i.e., that banks with higher loan technology parameters ("good banks") have better screening and management techniques and benefit from those by generating on average higher returns. Financiers (wholesale and depositors), however, have only an estimate of the true loan portfolio parameter, which can be informed by, e.g., reports from rating agencies and historical data. Banks perceived by financers as having a higher loan portfolio parameter are able to pay less for their funding, both on the wholesale credit markets, as well as for deposits. In these circumstances, the amount of outstanding loans is an informative and credible signal of this loan portfolio parameter, in the sense that certain levels of outstanding loans are only preferred by certain types of banks.

Then, banks have an incentive to signal good screening techniques and solid risk management practices. This holds for banks that indeed have such top-of-the-line loan technologies in place, but also for the banks that do not possess these technologies ("bad banks"). Hence, in order to distinguish itself from the signal a bad bank might produce, a good bank might need to extend more credit than it would in the full-information situation. As marginal costs for the bad bank are always higher than for the good bank, a separating point will always exist. In case the profits beyond this point remain higher than the profits the good bank could reap when the market cannot distinguish it from other bank (as is the case in a pooling equilibrium), the good bank will rationally extend credit and take on more risk over and above its full-information level. In a pooling equilibrium, it is the bad banks that extend more credit and take on more risk than they would otherwise.

Supervisors can play an important role in mitigating these effects of asymmetric information on financial system soundness. Banks will be loathe to reveal their proprietary loan technology, so a full market-based or self-regulatory approach will not be effective. Supervisors, however, have the power to investigate and assess a bank's loan technology in detail. Where they judge a bank to have weak methods and procedures for allocating credit, the supervisor can influence credit decisions through moral suasion, or by imposing additional capital and general provisioning requirements (under the so-called Pillar 2 provisions of the Basel II accord). Supervisors can also require a bank to improve its loan technology. Furthermore, supervisors can compel banks to disclose information about their loan technology, and check that this information is accurate. Even imperfect information should reduce the scope for pooling and thus the incentive to signal through over-extension of credit.

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## APPENDIX I: EXPECTED LOAN LOSSES IN A POOLING EQUILIBRIUM

Consider the expected loan losses $L$ of a bank of type $\alpha_i$ providing $C$ in credit. The total is composed of expected losses in the slowdown state and the expected losses in the recession, including accumulated interest:

$$L(\alpha_i, C) = p_2(1-\alpha_i v(C))uC + (1-p_1-p_2)(1-g(\alpha_i)w(C))uC.$$

This amount depends on the actual loan technology, not that estimated by financiers. By the definition of the value function, one can write

$$L(\alpha_i, C) = (u-s)C - V(\alpha_i, \alpha_i, C).$$

The difference between combined expected losses of both types of banks in the pooling equilibrium and expected losses in the full information equilibrium is thus

$$L(\alpha_H, C^P) + L(\alpha_L, C^P) - L(\alpha_H, C^F(\alpha_H)) + L(\alpha_L, C^F(\alpha_L)) =$$

$$2(u-s)C^P - V(\alpha_H, \alpha_H, C^P) - V(\alpha_L, \alpha_L, C^P) -$$
$$V(\alpha_L, \alpha_L, C^P) - (u-s)C_H^F + V^*(\alpha_H, \alpha_H, C_H^F) - (u-s)C_L^F + V^*(\alpha_L, \alpha_L, C_L^F).$$

The second order Taylor approximation of $V(\alpha_i, \alpha_i, C^P)$ around $C_i^F$ is

$$V(\alpha_i, \alpha_i, C^P) \approx V(\alpha_i, \alpha_i, C_i^F) + (C^P - C_i^F)V_3(\alpha_i, \alpha_i, C_i^F) + \tfrac{1}{2}(C^P - C_i^F)^2 V_{33}(\alpha_i, \alpha_i, C_i^F),$$

but because the full-information credit level is determined by FOC for a maximum, $V_3(\alpha_i, \alpha_i, C^P)=0$. Hence,

$$V(\alpha_i, \alpha_i, C^P) \approx V(\alpha_i, \alpha_i, C_i^F) + \tfrac{1}{2}(C^P - C_i^F)^2 V_{33}(\alpha_i, \alpha_i, C_i^F).$$

Substituting this expression into the expression above for the difference between expected losses yields

$$L(\alpha_H, C^P) + L(\alpha_L, C^P) - L(\alpha_H, C^F(\alpha_H)) + L(\alpha_L, C^F(\alpha_L)) \approx$$

$$(u-s)(2C^P - C_H^F - C_L^F) - \tfrac{1}{2}(C^P - C_H^F)^2 V_{33}(\alpha_H, \alpha_H, C_H^F) - \tfrac{1}{2}(C^P - C_L^F)^2 V_{33}(\alpha_L, \alpha_L, C_L^F).$$

The two last terms are certainly negative by the second order conditions for a maximum, and they enter with negative signs. Hence, only if the first expression is sufficiently negative can total expected losses be smaller in the pooling equilibrium than in the full information equilibrium, which requires that total credit volume be smaller.

## APPENDIX II: REGULARITY CONDITIONS ON THE OBJECTIVE FUNCTION WITH A CONTINUUM OF BANK TYPES

Mailath (1987, page 1352) lists a number of regularity conditions for his results to hold. They are:

1) Smoothness: assuming that $v$, $w$, and $g$ are all twice continuously differentiable, the linear equation (1) is also twice continuously differentiable.

2) Belief monotonicity: We have

$$V_2(\alpha,\tilde{\alpha},C) = (1-p_1-p_2)g'(\tilde{\alpha})w(C)uC \tag{22}$$

which is always positive (and thus never zero) because $g'$ and $w$ are always positive.

3) Type monotonicity: It is easy to show that

$$V_{13}(\alpha,\tilde{\alpha},C) = p_2(v+v'C)u \tag{23}$$

which is always positive (and thus never zero) provided that $v+v'C$ is positive, as has been assumed.

4) "Strict" quasiconcavity: The condition $V_3(\alpha,\alpha,C)=0$ is provided in equation (5). Furthermore,

$$V_{33}(\alpha,\alpha,C) = p_2\alpha(2v'+v''C)u + (1-p_1-p_2)g(\alpha)(2w'+w''C)u \tag{24}$$

is strictly negative given the assumption given in equation (4). Hence, $V_{33}(\alpha,\alpha,\varphi(\alpha))<0$, so there is a unique solution to (5).

5) Boundedness: Since $V_{33}$ is strictly negative, this condition is always fulfilled.