Information Acquisition Under Uncertainty in Credit Markets

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This article studies information acquisition through investment in improved risk assessment technology in competitive credit markets. A technology has two attributes: its ability to screen in productive borrowers, and its ability to screen out unproductive borrowers. The two attributes have fundamentally different effects on acquisition incentives and the structure of equilibrium informational externalities between lenders. The article also studies how uncertainty associated with the quality of superior technology affects information acquisition incentives. Uncertainty influences information acquisition even with risk-neutral banks. Increased uncertainty may raise or dampen incentives, depending on whether uncertainty is, respectively, about screening out or screening in quality.

This article studies information acquisition through investment in improved risk assessment technology in competitive credit markets. Information acquisition or screening by banks facilitates the rating of creditworthiness and drives the ability to compete in deregulated financial markets.[1] Although improvements in information technology have augmented the ability to screen borrowers and manage risk, the adoption of enhanced screening technologies has been uneven.[2] The centrality and continuation of the information technology revolution forces closer scrutiny of the decision to adopt new technology. It is generally argued that more widespread use of better information processing technology will benefit borrowers, improve credit allocation and enhance banks' competitive positions. But will new information processing products or platforms be necessarily adopted, if they are costly?

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[1] Lenders are not fully cognizant of creditworthiness of individual borrowers ex ante. Information asymmetries and gaps have been identified as the defining characteristics of credit markets. See Bhattacharya and Thakor (1993) for a survey.

[2] Some product markets have seen faster adoption than others. Consumer and small and local business lending has been significantly affected by adoption of credit scoring and other information technology-driven screening methods particularly by nontraditional lenders. Also, larger banks have tended to adopt earlier than smaller banks. See *Remarks by Chairman Alan Greenspan*, At the Conference on Bank Structure and Competition, Federal Reserve Bank of Chicago, Chicago, Illinois, May 10, 2002, available at http://www.federalreserve.gov/boarddocs/speeches/2002/20020510/default.htm and Frame, Padhi and Woolsey (2001).

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The question is of particular importance in competitive credit markets, because with limited information, decentralized markets are characterized by informational externalities across lenders. Suppose that a bank is unaware of other banks' information and decisions regarding a borrower. The act of successfully contracting with her then contains information about competitors' perceptions about her creditworthiness. If a bank invests and improves the quality of its own information, it affects the nature and extent of informational externalities imposed on its competitors. In turn, this changes a competitor's incentive structure to adopt new technology. Thus, information acquisition by banks may have substantial strategic consequences. The following questions then arise. How does information acquisition affect informational externalities and strategic interaction between financial intermediaries? In turn, how does the presence of informational externalities influence the decision to acquire information? Further, how are the incentives to acquire information in competitive credit markets affected by the characteristics of improved information processing technology?

The primary characteristic of interest is the ability to sort borrowers into risk categories. In my analysis, I distinguish between two attributes of any screening technology: its ability to *screen in* creditworthy projects, that is, how good it is in recognizing productive projects as being creditworthy, and its ability to *screen out* noncreditworthy projects, that is, how good it is in recognizing unproductive projects as being noncreditworthy. A statistical analogy can be thought of in terms of the two errors associated with a test of hypothesis. The ability to screen in creditworthy projects is related to the Type I error of a test, whereas the ability to screen out noncreditworthy projects is related to the Type II error. This separation marks a departure from the existing literature, which has assumed that the two error levels are the same.[3] Delinking the two sources of imprecision of a screening technology allows analysis of their effects separately. A new risk assessment technology may be superior either because of its enhanced screening in ability or because of its enhanced screening out ability. I show that adoption incentives and the structure of informational externalities between lenders depend critically on the nature of the superiority of new technology; assuming that the two error levels are the same, therefore, involves some loss of generality.

Further, there is uncertainty associated with the quality of new technology, even if it is known that the technology is superior. For example, uncertainty declines with maturity, or it may be lower for products from a reputed vendor, or for products which integrate better with existing platforms or represent more incremental innovation. The article explores the

[3] Broecker (1990) is a notable exception. However, that article does not analyze endogenous information acquisition.

relation between the level of uncertainty and the incentive to adopt to understand which kind of product is more likely to be adopted. I show that uncertainty about the level of benefits from a costly technology can have a substantial impact on the decision to adopt.

In my stylized duopoly model, risk-neutral banks compete in interest rates for borrowers who have indivisible fixed-size projects which can either succeed or fail. Before making offers, each bank obtains a privately informative signal on any project by conducting a credit assessment. The quality of the assessment depends on the screening technology chosen by a bank. Banks have to choose one of two technologies: an established technology or a costly superior technology. Both yield informative yet imprecise signals. However, the precision level or accuracy of the signal yielded by the costly technology is greater. Moreover, although it is known that the costly technology is superior, its exact quality (or precision level) is unknown at the time technology adoption choices have to be made.

I characterize mixed-strategy equilibrium in the interest rate offer game induced by any profile of screening or testing technologies chosen by the banks. I then analyze the *ex ante* technology choice game and show that each bank's choice of screening technology imposes an externality on the other. The logic is as follows. Suppose that a bank chooses the superior testing technology. It thereby obtains more precise information and makes better rejection and acceptance decisions. Because its decisions influence the quality of potential customers of a competitor, each bank's testing choice imposes an externality on the other.

I also show that in some cases the externality can generate strategic complementarities and result in multiple symmetric pure-strategy equilibria. Suppose that the difference in quality between the two technologies is through the screening out attribute. Then, each bank's incentive to acquire information is increasing in its competitor's information acquisition decision and multiple equilibria may emerge. Comparison of the two equilibria when they coexist shows that banks are worse off when they both adopt the superior technology, while average interest rates are lower. However, if the difference in quality between the two technologies is through the screening in attribute, a bank's incentive to acquire information is decreasing in its competitor's information acquisition decision. For some parameter values, this fact results in the existence of asymmetric pure-strategy equilibria, with one bank adopting the superior technology, and the other adopting the inferior technology.

Comparative static analysis of the effect of a change in the level of uncertainty yields similarly dichotomous results. If the two technologies differ in terms of their screening in qualities, greater uncertainty dampens the incentive to acquire superior information. The opposite result holds if the difference is in terms of the screening out qualities. Greater uncertainty *increases* the incentive to acquire superior information. The dependence of acquisition incentives on the level of uncertainty results from the presence of informational externalities. The differences across the two cases arise because the two attributes of information processing technology have opposing effects on informational externalities.

Thus, although adoption of superior processing technology by all banks can lead to benefits, the incentive to adopt is critically dependent on the properties of new technology. Information acquisition can be characterized by strategic complementarities or substitutability, and lower uncertainty can lower or raise adoption incentives, depending on whether superiority derives from improved screening out or screening in precision levels.

To my knowledge, the impact of quality uncertainty on the incentives to adopt risk screening technology and the effect of delinking different sources of imprecision of a screening technology have not been studied. The literature on costly information acquisition in financial markets has focused on the impact of competition on the incentive to invest in information acquisition. Cao and Shi (2001) show that increased competition can reduce information acquisition, which in turn can lead to lower loan availability. Hauswald and Marquez (2002) show that greater competition can lead to a refocusing of bank resources, whereby banks concentrate on gathering information on core at the expense of peripheral markets.

Closer to my article is Hauswald and Marquez (2003), who focus on a model with one informed and one uninformed bank and study the effect of exogenous technological improvement on competition in credit markets.[4] Their analysis distinguishes between two aspects of technological progress: information processing and information spillovers.[5] They show that while the latter can benefit by reducing asymmetries between banks, the former can dampen competition by increasing informational asymmetries between intermediaries. I explore a different environment. In my examination of endogenous acquisition of information processing technology, I argue that a distinction should be made between different attributes of processing technology. I show that the incentives to adopt new technology are critically dependent on the specific nature of the superiority of new technology and the level of associated quality uncertainty. None of the above papers considers uncertain information quality or the effect of different types of errors immanent in the testing process.

My study is related to the seminal work of Broecker (1990) who first studied interbank competition with independent testing in financial

[4] They briefly consider endogenous information acquisition. However, their model does not allow for private information and is of limited use in understanding adoption incentives.

[5] Boadway and Sato (1999) and Banerjee (2004) also study information acquisition with spillovers in financial markets.

markets. My modeling structure draws on this work, which only studies symmetric banks and does not allow for endogenous information acquisition. In addition, this article is related to the literature studying asymmetric competition in banking (von Thadden 2001). The connection is explored in Section 2.[6]

I present the model in the next section. Section 2 derives some preliminary results. It studies the induced interest rate game and derives mixed-strategy equilibrium. Because the effects of screening in and screening out quality are very different, I prefer to study them in isolation. Section 3 analyzes the game allowing only for difference in the screening out quality, and Section 4 investigates the game allowing only for difference in the screening in quality. The differences in the results across the two sections are discussed further in Section 4. Section 5 concludes, and proofs are collected in the Appendix.

1. Model

Consider a credit market with a continuum [0, 1] of risk-neutral firms. Each firm is endowed with an indivisible project which requires 1 unit of external funds. A project can be of one of two types, H and L. Conditional on receiving funds, H projects yield cash flow $x > 0$, whereas L projects yield 0 cash flow. $\gamma \in (0, 1)$ is the prior probability that a firm's project is of type H. Firms have no additional information on the type of their own project.

Firms submit loan applications to banks, have no collateralizable assets and can receive credit from at most one source. Further, a firm accepts the lowest-interest-rate-offer available to it as long as the offer gives it nonnegative payoff. If there are multiple offers with the lowest interest rate, a firm chooses amongst them with equal probability. Voluntary default is not allowed in the model. Firms have limited liability.

There are two risk-neutral banks that can access funds at 0 opportunity cost. Each bank can perform a *test* on a loan applicant to obtain additional information. I assume that before receiving loan applications, each bank chooses one of two *testing technologies*.[7] Information generated on a borrower by a test is independent (conditional on the true type of the borrower) across banks. Let Stage I denote the time the choice of testing technology is made by the banks. I assume that the choice is made simultaneously, irreversibly and noncooperatively. Both tests are informative but imperfect. They are also ordered in terms of precision of the information yielded. Denote the less precise test by T_c and the more

[6] I also briefly discuss the relationship with the literature on information acquisition in auctions at that point and again in Section 4.

[7] In what follows I use the words firm, borrower and project interchangeably.

precise test by T_e. I assume that T_c costs 0, while T_c costs $e > 0$, that is, higher precision comes at a cost. The cost is sunk in Stage I.[8]

Furthermore, I assume that the exact *precision level* or *quality* of T_c is known in Stage I. However, there is some uncertainty about the exact precision level of T_c at this time. The uncertainty is resolved after the testing choices have been made, in Stage II, at which time the banks' testing choices become public. I can think of T_c as an existing or incumbent testing technology whose expected benefits are perfectly known. T_c can be thought of as a new technology that is relatively immature. The formulation derives from the notion that there is often uncertainty about the level of benefits associated with new technology, though it is known that there are indeed benefits to be derived.[9]

Formally, let W be a random variable over [0, 1] with distribution function G, and let w denote a realization of W. Let $E(W) > 0$ and $V(W) > 0$. W is realized in Stage II. I assume that the precision level of T_c is independent of w, whereas the precision level of T_e is a function of w. I investigate equilibria in the interbank competition model described below when banks make strategic test choices to maximize ex ante expected profits.

After W is realized, and testing choices become public, the banks simultaneously choose two gross interest rates, about which more is described below. Each applicant is then tested. The test randomly assigns an applicant to one of two categories h and l.

Let $p_c(y|Y, w)$ denote the probability under test T_c that a firm is assigned to category $y = h, l$ given that it is truly of type $Y = H, L$, and given that $W = w$. I assume that $1 > p_c(h|H, w) = p_{Hc} = p_H > 0.5 > p_c(h|L, w) = p_{Lc} = p_L > 0$. Thus, the test is imperfect but informative. Moreover, a firm assigned to h is more likely to yield a positive cash flow than a firm assigned to l. p_H measures how good the test is in terms of its ability to screen in H projects, that is, its ability to put H projects into category h. p_H is therefore the *screening in precision level*. A higher value of p_H indicates a higher ability to screen in H projects. Similarly, p_L measures how good the test is in terms of its ability to screen out L projects, that is, its ability to put L projects into category l. A lower value of p_L indicates a higher ability to screen out L projects. p_L is therefore the *screening out precision level*. I therefore model any test as having two attributes: its ability to screen in H-borrowers and its ability to screen out L-borrowers. In terms of

[8] The model allows for a choice between two different technologies, at a discrete cost. An alternative could be to study choice over a continuum of possible technologies. Such a framework could be useful in discussing issues of the development and adoption of small versus large innovations. Preliminary analysis suggests that the general continuous case is less tractable, though some of the basic results developed in the discrete setting seem to go through.

[9] In what follows, I use the terms precision level and quality interchangeably.

the above notation, p_L is analogous to the Type II error, whereas $1 - p_H$ is analogous to the Type I error, associated with a test of hypothesis. The standard assumption in the existing literature is that the two error levels are the same for any screening technology. However, there is no a priori reason why this symmetry should hold.

Let $p_e(y|Y, w)$ denote the probability under test T_e that a firm is assigned to category $y = h, l$ given that it is truly of type $Y = H, L$, and given that $W = w$. I assume that $p_e(h|H, w) = p_{He}(w) = p_H(1 + \alpha_H w)$ and $p_e(h|L, w) = p_{Le}(w) = p_L(1 - \alpha_L w)$ with $0 \leq \alpha_H < (1 - p_H)/p_H$ and $0 \leq \alpha_L < 1$. Therefore, T_e is a more precise test than T_c. A H-firm is more likely to be assigned to h under T_e than under T_c, whereas an L-firm is less likely to be assigned to h under T_e than under T_c. $p_{He}(w)$ and $p_{Le}(w)$ are, respectively, the screening in and screening out qualities of T_e, whose exact values are unknown ex ante. I have

Assumption 1. $1 > p_{He}(\mathrm{w}) \geq p_{Hc} > 0.5 \;\; p_{Lc} \geq p_{Le}(\mathrm{w}) > 0$, *for all w.*

The interest rates quoted by the banks are then the rates charged to firms assigned to categories h and l. I assume that a bank cannot observe the results of the other bank's tests or its interest rate offers. Consider a bank applying a test T_i, $i = c, e$ to the whole population of firms. Appealing to the law of large numbers, and suppressing possible dependence on w, γp_{Hi} firms of type H are assigned to category h. Therefore, the proportion of H-type firms amongst those assigned to category h is $\gamma_i(H|h) = \gamma p_{Hi}/[\gamma p_{Hi} + (1 - \gamma)p_{Li}]$, whereas the proportion of H-type firms amongst those assigned to category l is $\gamma_i(H|l) = \gamma(1 - p_{Hi})/[\gamma(1 - p_{Hi}) + (1 - \gamma)(1 - p_{Li})]$. Hence, the average likelihood of positive returns from firms assigned to categories h and l are, respectively, $\overline{q}_{hi} = \gamma_i(H|h)$ and $\overline{q}_{li} = \gamma_i(H|l)$.

Because tests are revealing and ordered according to precision, I have that $1>\overline{q}_{he}>\overline{q}_{hc}>\gamma>\overline{q}_{lc}>\overline{q}_{le}>0$. To simplify the analysis, I shall assume that it is never profitable for banks to offer credit to those firms that are assigned to category l. Then, conditional on the bank offering credit, it will quote a single interest rate meant for firms it categorizes as h. Moreover, it will reject a firm conditional on categorizing it as l.

Assumption 2. $\dfrac{1}{\overline{q}_{lc}} > x > \dfrac{1}{\overline{q}_{hc}}$.

The assumption $(1/\overline{q}_{lc}) > x$ ensures that a firm assigned to category l will be denied credit, as lending to such a firm entails expected losses. $x > (1/\overline{q}_{hc})$ ensures that if there were only one bank, it would not make losses by charging $r = x$ to firms assigned to category h. Choice of interest rates, testing of applicants, making offers, decisions on contract acceptance and project execution and contract settlement all take place in Stage III. The division into stages acts as a convenient description of the extensive form. The time line is as below.

1. Stage I: Banks simultaneously choose which test to use. Costs are sunk at this time.
2. Stage II: The realization of W is observed, and bank choices become public.
3. Stage III: Each bank chooses an interest rate that only applies to firms it assigns to category h. It rejects firms it assigns to category l. Borrowers apply for loans. They are tested and categorized. Those who do not get any loan offers have 0 payoff. Those with at least one loan offer accept the best offer they have, provided their payoff is nonnegative. Output is obtained, contracts are settled and the game ends.

2. Preliminaries

I first analyze the subgame after banks have made testing choices. Any choice of tests induces an ex post interest rate game in Stage III. In this section, I study this induced game. I derive the induced equilibrium, which follows from the notion that interest rates must be chosen optimally, given the information of each bank and the observed profile of testing choices. The ex ante information acquisition game is discussed in later sections.

I note that an equilibrium in pure interest rate strategies does not exist.[10] The reasoning is straightforward. If such an equilibrium exists, it must be the case that both banks offer credit at the same interest rate. To see that, suppose one bank offers credit at an interest rate lower than that of the other. This cannot be an equilibrium, as the bank with the lower interest rate offer could increase payoff by increasing its offered interest rate. But, given any profile of tests chosen by the banks, if both charge the same interest rate, each has an incentive to reduce its own interest rate marginally. This arises because the bank charging the lower interest rate has a better pool of borrowers and, therefore, a higher average chance of success on any given loan. The bank charging the higher interest rate gets borrowers who have accepted its loan offer because they have been rejected by the other bank. Hence, the pool of borrowers accepting loan contracts from the bank with the higher interest rate offer contains a larger number of L-type borrowers. Each bank therefore has the incentive to charge an interest rate lower than that of the other bank. At the same time, given its own pool of borrowers, payoff is increasing in the interest rate. The combination of these two factors leads to the nonexistence of pure-strategy equilibrium. Conceptually, the externalities generated by the

[10] The nonexistence of pure strategy equilibrium in discrete private information games has been discussed before by Broecker (1990) and Wang (1991).

rejection decisions that lead to the *winner's curse* arise because tests are imperfect and are not stochastically identical, and no bank observes the rejection or acceptance decisions of the other bank. If the tests were stochastically identical, then any firm assigned to category $i \in \{h, l\}$ by one bank would also be assigned to the same category by the other. The same conclusion holds if the rejection or acceptance decisions of each bank were observable by the other. Either way, the winner's curse effect would not arise.

Although an equilibrium in pure interest rate strategies does not exist in the induced game, an equilibrium in mixed strategies does.[11] In general, if both banks always offer credit to all borrowers who are categorized as H-firms, payoffs may be negative. To guarantee existence of equilibrium, the strategy set needs to be expanded to give banks the option of withdrawing completely from the credit market (Broecker 1990) or rationing borrowers. Because the central question in this article relates to the incentives for costly information acquisition, I assume for simplicity and tractability that both banks always offer credit to firms they slot into category H and are guaranteed nonnegative equilibrium payoffs. This is not an unreasonable restriction given that banks have the option of acquiring a costly screening technology in Stage I, before the subgame is induced. Given Assumptions 1 and 2, the following assumption guarantees that equilibrium with positive payoffs exists.

Assumption 3. $x > 1 + \dfrac{e + (1-\gamma)p_L[1 - p_{Le}(w)]}{\gamma p_H[1 - p_{He}(w)]}$, *for all* $w \in [0, 1]$.

I now study mixed-strategy equilibrium in the subgame induced by the testing choices of banks. I first study the subgame induced by symmetric choices and look for symmetric equilibrium. Suppose that both banks have chosen test T_k, $k \in \{c, e\}$. Equilibrium can therefore be written as $(R_{kk}(w), F_{kk}(r; w))$, where R_{kk} and F_{kk} are, respectively, the interval of interest rates and a distribution function over this interval which a bank uses to announce interest rates.

Proposition 1. *Let the two banks choose test T_k, $k \in \{c, e\}$. A unique symmetric equilibrium in mixed interest rate strategies exists under Assumptions 1–3 in the Stage III subgame. Each bank earns payoff.*

$$u_{kk}(w) = \gamma p_{Hk}(w)[1 - p_{Hk}(w)](x-1) - (1-\gamma)p_{Lk}(w)[1 - p_{Lk}(w)] > 0$$

and chooses an interest rate from the set $R_{kk}(w) = [r^0_{kk}(w), x]$, *where*

$$r^0_{kk}(w) = 1 + [1 - p_{Hk}(w)](x-1) + \frac{(1-\gamma)p^2_{Lk}(w)}{\gamma p_{Hk}(w)}$$

[11] The interpretation of mixed-strategy equilibrium is not always clear. In the environment of this article, a mixed-strategy equilibrium can be argued to be plausible as contract offers are not publicly announced.

according to the distribution function

$$F_{kk}(r;w) = \frac{\gamma p_{Hk}(w)[(r-1) - (1-p_{Hk}(w))(x-1)] - (1-\gamma)p_{Lk}^2(w)}{\gamma p_{Hk}^2(w)(r-1) - (1-\gamma)p_{Lk}^2(w)}.$$

Proof. See the Appendix. ■

With symmetric ex ante choices, a unique symmetric equilibrium with a continuous distribution function exists in the subgame. For later reference, notice the particularly simple structure of equilibrium bank expected payoffs. A bank earns the net output for all H-firms accepted by it and rejected by its competitor. It also loses a unit of funds for every L-firm accepted by it and rejected by its competitor. I now study equilibrium in the subgame induced by asymmetric test precision choices. The proposition below shows that an equilibrium exists, and it is unique. Suppose that one of the banks (bank c) chooses T_c, whereas the other (bank e) chooses T_e. Equilibrium can be written as $(R_{ce}(w), F_{ce}(r;\ w), R_{ec}(w), F_{ec}(r;\ w))$, where R_{ce} and F_{ce} (respectively, R_{ec} and F_{ec}) are, respectively, the interval of interest rates and a distribution function over this interval which bank c (respectively, bank e) uses to announce interest rates.

Proposition 2. *Suppose one of the banks (bank c) chooses T_c, whereas the other (bank e) chooses T_e. A unique equilibrium in mixed interest rate strategies exists under Assumptions 1–3 in the Stage III subgame. Bank c chooses an interest rate from the set $R_{ce}(w) = [r_a^0(w), x)$, where*

$$r_a^0(w) = 1 + (1-p_{Hc})(x-1) + \frac{(1-\gamma)p_{Lc}p_{Le}(w)}{\gamma p_{He}(w)}$$

according to the continuous distribution function

$$F_{ce}(r;w) = \frac{\gamma p_{He}(w)[(r-1) - (1-p_{Hc})(x-1)] - (1-\gamma)p_{Lc}p_{Le}(w)}{\gamma p_{He}(w)p_{Hc}(r-1) - (1-\gamma)p_{Lc}p_{Le}(w)}$$

It obtains a payoff

$$u_{ce}^a(w) = \gamma p_{Hc}(1-p_{Hc})(x-1) - \frac{(1-\gamma)p_{Lc}[p_{He}(w) - p_{Hc}p_{Le}(w)]}{p_{He}(w)} > 0$$

Bank e obtains payoff

$$u_{ec}(w) = \gamma p_{He}(w)(1-p_{Hc})(x-1) - (1-\gamma)p_{Le}(w)(1-p_{Lc}) > u_{ce}(w)$$

and chooses an interest rate from the set $[r_a^0(w), x]$. The probability it charges x is $(p_{He}(w) - p_{Hc})/p_{He}(w)$. Over the set $[r_a^0(w), x)$, it draws interest rates according to the continuous distribution function

$$F_{ec}(r;w) = \frac{\gamma p_{He}(w)[(r-1)-(1-p_{Hc})(x-1)]-(1-\gamma)p_{Le}(w)p_{Lc}}{\gamma p_{He}(w)p_{Hc}(r-1)-(1-\gamma)p_{Le}(w)p_{Lc}} \cdot \frac{p_{Hc}}{p_{He}(w)}.$$

Proof. See the Appendix. ■

Some comments about the above result are in order here. Mixed-strategy equilibria with the winner's curse have been discussed before in the banking literature. Broecker (1990) derives such an equilibrium with symmetric banks. More recently, attempts have been made to analyze equilibrium with asymmetric banks. In Cao and Shi (2001), banks choose precision levels covertly,[12] that is, they choose precision levels and then make interest rate offers without knowing other banks' precision choices. In effect, therefore, banks play a symmetric precision choice and interest offer game, which is very different from the asymmetry analyzed above.

Von Thadden (2001), in his comment on Sharpe (1990), discusses mixed-strategy equilibrium with asymmetrically informed banks.[13] Unlike Cao and Shi's (2001) model, his duopoly model allows the two banks to be aware of each other's precision levels. He shows that the two banks bid over a common support and that the supremum of that support is equal to the output of the project (x, in my notation). Further, the more informed bank (inside bank, in his terminology) bids with an atom at x, and an atomless distribution function below x, whereas the less informed bank (outside bank, in his terminology) has a continuous distribution function below x. Although my result is similar to von Thadden's, there is one fundamental modeling difference that changes the nature of the analysis significantly. In his model, a bank is less informed because its signal is a Blackwellian garbling of the signal of the more informed bank.[14] In my model, however, the two banks merely have different precision levels and get conditionally independent signals.[15] The differences in the assumptions lead to different results as well. In this article,

[12] The terminology is due to Persico (2000), who analyzes an information acquisition problem in common value auctions. A strategic aspect of information choice is absent in the model as players choose bid functions without knowing the choice of information precision by others. See also Levin and Smith (1994), who analyze entry in common value auctions. Entry is overt in their model.

[13] Hauswald and Marquez (2002, 2003) also derive a similar result. These articles use the methodology of Engelbrecht-Wiggans, Milgrom and Weber (1983).

[14] Campbell and Levin (2000) analyze bidding in common value auctions with bidders having different, possibly commonly known, levels of information precision. My model differs from theirs because they too model inferiority of information as resulting from garbling.

[15] Kagel and Levin (1999) and Laskowski and Slonim (1999) model bidding in common value auctions with differentially informed players. They assume that the true common value V lies within some known range $[[\underline{V}, \overline{V}]]$, with each player i drawing a signal from $[V-\varepsilon_i, V+\varepsilon_i]$. The values of ε_i are common knowledge. Information precision is modeled by the value of ε_i: a bidder with a lower value of ε_i has more precise information than one with a higher value of ε_i. My model of differential information precision is, therefore, substantially different from theirs and allows for an examination of screening-out vis-á-vis screening in attributes. Moreover, these articles do not study what is a central concern of this essay: the analysis of uncertain precision.

the less informed bank gets a strictly positive payoff. By contrast, in von Thadden (2001), the model of information precision ensures it necessarily gets 0 payoff. I can now use the results of the above propositions to characterize ex ante expected payoffs conditional on any profile of testing choices by the banks. The following sections derive the characterization and also ex ante equilibrium to study bank incentives to acquire information.

3. Uncertain Screening out Quality

This article makes a distinction between the screening out and screening in properties of a testing technology. In a departure from the existing literature, I assume that a test is not necessarily symmetric in the two attributes. As shown below, studying these properties in isolation yields important benefits as their effects are not symmetric. This section studies the model under the assumption that uncertainty exists only in the screening out attribute of the better technology, T_e. For the purpose of this section, therefore, I assume that $\alpha_L > 0$, while $\alpha_H = 0$. The following section studies the incentives to adopt the improved testing technology and thereby acquire better information when there is uncertainty about the screening in benefits.[16]

From Propositions 1 and 2, I can calculate ex ante expected payoff of a bank, before the realization of W, given any testing choice profile. Given the profile of testing choices by i and j is (T_i, T_j), let u_i^{ij} and u_j^{ij} denote ex ante expected payoff of banks i and j, respectively. I have, ignoring sunk costs,

$$\begin{aligned} u_i^{ij} &= E_W u_i(T_i,T_j) \\ &= \gamma p_H(1-p_H)(x-1) - (1-\gamma)E_W p_{Li}(w) + (1-\gamma)E_W p_{Li}(w)p_{Lj}(w) \end{aligned}$$

$$\begin{aligned} u_j^{ij} &= E_W u_j(T_i,T_j) \\ &= \gamma p_H(1-p_H)(x-1) - (1-\gamma)E_W p_{Lj}(w) + (1-\gamma)E_W p_{Li}(w)p_{Lj}(w). \end{aligned}$$

To proceed, define the following:

$$\bar{e}_L = \gamma p_H(1-p_H)(x-1) - (1-\gamma)p_L[1-p_L(1-\alpha_L E(W))] > 0,$$

by Assumption 3

$$\tilde{e}_L = (1-\gamma)p_L(1-p_L)\alpha_L E(W) > 0.$$

For the rest of this section, I assume the following:

[16] Consideration of only the polar cases for the superior technology helps highlight the main points in a transparent fashion. It is not difficult to derive conditions determining the nature of equilibrium for a general superior technology. However, comparative static results pertaining to the analysis of increasing uncertainty are ambiguous in the general case.

Assumption 4. $\hat{e}_L < \overline{e}_L$.

By Assumption 3, $e < \overline{e}_L$.[17] There are potentially four different pure-strategy subgame perfect equilibria in the game: a symmetric equilibrium where both banks choose T_c (the *c*-equilibrium), another symmetric equilibrium where both banks choose T_e (the *e*-equilibrium) and two asymmetric equilibria where one bank chooses T_c, whereas the other chooses T_e. I show below that the *c*-equilibrium exists for $e \geq \tilde{e}_L$ and that the *e*-equilibrium exists for $e \leq \hat{e}_L$. In the intermediate range, I have multiple symmetric equilibria. Asymmetric equilibria do not exist. Thus, $\hat{e}_L$ and $\tilde{e}_L$ define the boundaries of parameter ranges for which different symmetric equilibria exist. Because $e \in (0, \overline{e}_L)$, Assumption 4 makes for a meaningful analysis of equilibrium existence.

Proposition 3. *Suppose α_L 0 and $\alpha_H = 0$. Given Assumptions 1–4, a c-equilibrium exists if and only if $e \in [\tilde{e}_L, \overline{e}_L)$, while an e-equilibrium exists if and only if $e \in (0, \hat{e}_L]$. Multiple symmetric equilibria coexist for $e \in [\tilde{e}_L, \hat{e}_L]$.*

Proof. See the Appendix. ■

Intuitively, if the cost of higher precision is too high, no bank invests in a more precise test. Conversely, if the cost of more precise test is low enough, both banks invest. It is easy to show that multiple symmetric equilibria exist in the intermediate range. The intuition behind the existence of multiple symmetric equilibria is as follows. By adopting the better screening technology, a bank *i* improves the pool of borrowers it offers contracts to and, therefore, worsens the pool of borrowers it rejects. Banks do not observe acceptance or rejection decisions of other banks. Thus, the other bank *j*'s pool of potential customers is worsened by *i*'s decision. Hence, each bank's testing choice imposes an externality on the other. For the presence of multiple equilibria, I need the externalities to be strong enough to generate strategic complementarities. With $\alpha_L > 0$ and $\alpha_H = 0$, it is easy to show that the value to *i* of switching from T_c to T_e when *j* uses T_e is higher than when *j* uses T_c. Thus, *i*'s incentive to acquire information is increasing in *j*'s information acquisition decision, and multiple equilibria are generated. The reason is that the use of T_e by *i* increases the number of *L*-firms in *j*'s pool of potential customers. Because the value to *j* of switching to T_e is increasing in the number of *L*-firms amongst its own pool of potential customers, *i*'s use of T_e raises *j*'s incentive to use T_e.

Can outcomes under the two equilibria be compared with, say, if one equilibrium is more desirable than the other? I study this question below

[17] Assumption 4 does not seem to have a simple economic interpretation; it is made purely for convenience and ensures there are parameter values for which the unique symmetric equilibrium is for both banks to choose Tc. Similar comments apply to Assumption 4′ made in the next section.

and also analyze how the incentives to acquire information is dependent on the level of uncertainty regarding the quality of the information. I first compare outcomes under the two symmetric equilibria.

Suppose $e \in [\tilde{e}_L, \hat{e}_L]$. Ignoring the cost of precision, net expected output is higher when both banks use test T_e. The two tests are equivalent as far as screening in H-borrowers are concerned. However, more precise screening out allows fewer L-borrowers to get loans. Thus, net expected output is higher. To see that, notice that the measure of H-projects getting a loan in any symmetric equilibrium is

$$\mu_H^k = \gamma[1 - (1 - p_H)^2],\ k = c,e.$$

However, the measure of L-projects getting loans under the c- and e-equilibria, respectively, are

$$\mu_L^c = (1 - \gamma)[1 - (1 - p_L)^2]$$

and

$$\mu_L^e = (1-\gamma)\left\{1 - (1-p_L)^2 - \alpha_L^2\, p_L^2 V(W) - \alpha_L p_L E(W)[2(1-p_L) + \alpha_L p_L E(W)]\right\} < \mu_L^c.$$

However, once the cost of precision is accounted for, I show that the net output in the e-equilibrium may or may not be higher. To see that, let Y_k denote the net expected output in the k-equilibrium, accounting for the cost of information acquisition. Thus

$$Y_c = \gamma\left[1 - (1-p_H)^2\right](x-1) - (1-\gamma)\left[1 - (1-p_L)^2\right]$$

$$Y_e = \gamma\left[1 - (1-p_H)^2\right](x-1) - (1-\gamma)E_W\left\{1 - [1 - p_{Le}(w)]^2\right\} - 2e.$$

Clearly, $Y_e - Y_c$ is decreasing in e. Straightforward calculations show that $Y_e > Y_c$ if $e = \tilde{e}_L < \hat{e}_L$ and $Y_e < Y_c$ if $e = \hat{e}_L$. Hence, I can find $e^* \in (\tilde{e}_L < \hat{e}_L)$ such that $Y_e = Y_c$ if $e = e^*$. Thus, accounting for the cost of information acquisition, if the cost is sufficiently low, net output is higher when both banks use the better screening technology. However, when the cost is sufficiently high, net output is lower under the improved test.

$$\text{If } e = \tilde{e}_L\text{:}\ Y_e - Y_c = (1-\gamma)\alpha_L^2 p_L^2 E(W^2) > 0$$

$$\text{If } e = \hat{e}_L\text{:}\ Y_e - Y_c = -(1-\gamma)\alpha_L^2 p_L^2 E(W^2) < 0.$$

I now compare bank and borrower payoffs under the two equilibria. Below, I show that banks are worse off if they use test T_e, while expected interest rates are lower.

Proposition 4. *Suppose $\alpha_L > 0$, while $\alpha_H = 0$. If $e \in [\tilde{e}_L, \hat{e}_L]$, given Assumptions 1–4, the banks are worse off in the e-equilibrium than in the* *c-equilibrium. If p_L is small, expected interest rates are lower in the e-equilibrium than in the c-equilibrium.*

Proof. See the Appendix. ■

It follows from the proposition above that fewer L-borrowers get loans and average interest rates are lower, making H-borrowers better off, when both banks adopt the superior technology, than when both adopt the inferior technology.[18] I now analyze the relation between bank incentives to invest in information acquisition, or adopt the enhanced screening technology, and the uncertainty related to the quality of the technology. The importance of this question lies in the fact that there is often uncertainty about the costs and benefits of new technology, even if it is estimated that, overall, the benefits will outweigh the costs. Below, I show that if the uncertainty pertains only to the screening out quality, the incentive to acquire information is increasing in the uncertainty associated with quality. In the next section, I show that the opposite result holds if the uncertainty pertains to the screening in quality. The following proposition also shows that net output is increasing in the level of uncertainty regarding the quality of the technology because fewer L-firms get loans in equilibrium under higher uncertainty.

For the random variable W, consider a mean preserving spread (MPS) in the distribution G.[19] This is a simple way to conceptualize an increase in uncertainty associated with a random variable. An MPS is related to the notion of second-order stochastic dominance and increases the variance of a random variable, while keeping the expectation constant.

Proposition 5. *Suppose $\alpha_L > 0$, while $\alpha_H = 0$. Given Assumptions 1–4, an increase in uncertainty raises the incentives to acquire superior information. Net output also increases, conditional on both banks using test T_e.*

Proof. See the Appendix. ■

The proof of the proposition proceeds by demonstrating that $\tilde{e}_L$ and $\hat{e}_L$ are, respectively, independent of and increasing in the variance of the random variable W. Thus, increased variance in the accuracy increases the range of parameters for which it is an equilibrium for both banks to purchase the technology. It is in this sense that the incentive to acquire superior information is increasing in the uncertainty about the quality of the information.

[18] The assumption that P_L is small allows us to discard some higher-order terms and leads to unambiguous results.

[19] See Rothschild and Stiglitz (1970) and Machina and Pratt (1997).

To see why $\hat{e}_L$ is increasing in the variance, consider a bank's ex post payoff when both banks adopt the superior technology. Banks suffer a loss from the presence of L-firms, as loans made to these firms are not recovered. The loss is concave in information quality.[20] Concavity arises for the following reason. More accurate technology allows easier detection of L-firms, implying the likelihood that a given L-borrower receives an offer from any bank i is decreasing in information quality. At the same time, because of informational externalities across banks, conditional on receiving an offer from i, the likelihood that the borrower has been rejected by bank j, and will therefore accept i's offer, is increasing in information quality. Therefore, ex post payoff is convex in information quality, and hence, ex ante payoff when both banks adopt the superior technology is increasing in the variance. Thus, higher uncertainty in information quality raises the incentive to use T_e. So if the two technologies differ in terms of their screening out qualities, lower uncertainty about the accuracy of superior technology may lead to less investment in information acquisition, higher interest rates and reduced average loan quality. The result is discussed further in the next section after I analyze comparative statics when T_e and T_c differ only in their screening in qualities.

I now study uncertainty in the screening in precision level associated with a new technology. For that purpose, I shall assume that there is no uncertainty in the screening out precision level.

4. Uncertain Screening in Quality

In contrast to the previous section, this section studies the model under the assumption that uncertainty exists only in the screening in quality of the better technology, T_e. For the purpose of this section, therefore, I assume that $\alpha_H > 0$, while $\alpha_L = 0$. I show that a change in the level of uncertainty has very different implications when the uncertainty is about the screening in quality rather than the screening out quality of the technology. I first derive equilibrium in the ex ante test choice game and then study some properties of the equilibrium.

From Propositions 1 and 2, I can calculate ex ante expected payoff of a bank, before the realization of W, given any testing choice profile. For the moment, I ignore costs of information acquisition. Suppose that ex ante choices are symmetric, that is, both banks choose some test T_k. Let u_k^k be a bank ex ante expected payoff. I have

[20] Under Assumption 1, Proposition 1 shows that if both banks choose the same test, the loss incurred from the presence of L-borrowers is increasing in the level of Type II error. Payoff increases as the quality of information improves. In the context of interdependent value auctions, Milgrom and Weber (1982) derive the linkage principle that implies that a bidder's payoff goes down if information quality improves. My analysis in the related banking environment shows that the latter result does not always hold. Other examples exist showing that the linkage principle may not always hold (see, for example, Perry and Reny, 1999, and Moscarini and Ottaviani, 2001), but the mechanisms in these studies are different from the one analyzed in this article.

$$\begin{aligned} u_k^k &= E_W u_{kk}(T_k) \\ &= \gamma(x-1)E_W\{p_{Hk}(w)[1-p_{Hk}(w)]\} - (1-\gamma)p_L(1-p_L). \end{aligned}$$

With asymmetric choices ex ante, let bank c choose test T_c and bank e choose T_e. Their respective ex ante expected payoffs are then

$$\begin{aligned} u_c^{ce} &= E_W u_{ce}^a(T_c,T_e) \\ &= \gamma p_H(1-p_H)(x-1) - (1-\gamma)p_L E_W\left(1 - \frac{p_L}{1+\alpha_H w}\right) \end{aligned}$$

$$\begin{aligned} u_e^{ce} &= E_W u_{ec}(T_c,T_e) \\ &= \gamma(1-p_H)(x-1)p_H E_W(1+\alpha_H w) - (1-\gamma)p_L(1-p_L). \end{aligned}$$

To proceed, define the following:

$$\bar{e}_H = \gamma p_H\{1 - p_H[1+\alpha_H E(W)]\}(x-1) - (1-\gamma)p_L(1-p_L) > 0,$$

by Assumption 3

$$\tilde{e}_H = (1-\gamma)p_H(1-p_H)(x-1)\alpha_H E(W)$$

$$\begin{aligned} \hat{e}_H =& \alpha_H E(W)\{\gamma p_H(x-1)[1+2p_H - \alpha_H p_H E(W)] + (1-\gamma)p_L^2[1-\alpha_H E(W)]\} \\ &- \alpha_H^2 V(W)\left[\gamma p_H^2(x-1) - (1-\gamma)p_L^2\right]. \end{aligned}$$

Note that Assumptions 1 and 2 imply $\gamma p_H^2(x-1) > (1-\gamma)p_L^2$. For the rest of the analysis, I assume the following:

Assumption 4′ $0 < \min(\tilde{e}_H, \hat{e}_H) < \max(\tilde{e}_H, \hat{e}_H) < \bar{e}_H$.

By Assumption 3, $e < \bar{e}_H$. I show below that the c-equilibrium exists for $e \geq \tilde{e}_H$, while the e-equilibrium exists for $e \leq \hat{e}_H$. With $e \in (0, \bar{e}_H)$, there are potentially four different pure-strategy subgame perfect equilibria in the game: two symmetric and two asymmetric equilibria. $\hat{e}_H$ and $\tilde{e}_H$ define the boundaries of parameter ranges for which different symmetric equilibria exist.

Proposition 6. *Suppose that α_H 0, while $\alpha_L = 0$. Suppose also that α_H is small. Given Assumptions 1–3 and 4′, a c-equilibrium exists if and only if $e \in [\tilde{e}_H, \bar{e}_H)$, while an e-equilibrium exists if and only if $e \in (0, \hat{e}_H]$. Asymmetric equilibria exist for $e \in (\hat{e}_H, \tilde{e}_H]$.*

Proof. See the Appendix. ∎

As discussed before, each bank's test adoption choice imposes an externality on the other bank. By switching from T_c to T_e, a bank i worsens the pool of borrowers forming the potential clientele of its competitor j. In the case discussed in the previous section, I saw that the externality was strong enough to generate strategic complementarities and multiple equilibria. With $\alpha_H > 0$ and $\alpha_L = 0$, it can be easily shown that the value to i of switching from T_c to T_e when j uses T_e is lower than when j uses T_c.[21] Hence, $\hat{e}_H < \tilde{e}_H$ and I do not have symmetric pure-strategy equilibrium for $e \in (\hat{e}_H, \tilde{e}_H]$. For parameter values in this range, I have asymmetric pure-strategy equilibria. If a bank believes that its competitor is choosing the superior (inferior) technology, its best response is to choose the inferior (superior) technology. Even though the banks are symmetric ex ante, equilibrium payoffs are not the same, with the bank choosing the superior technology obtaining a strictly higher payoff. I also have a symmetric mixed-strategy equilibrium. The reason why strategic complementarities are not generated in this case is as follows. The use of T_e by i reduces the number of H-firms in j's pool of potential customers. But the value of switching to T_e by j is increasing in the number of H-firms amongst its own pool of potential customers. Thus, i's use of T_e lowers j's incentive to switch to T_e.

The two tests are equivalent as far as screening out L-borrowers are concerned. However, more accurate screening in enables more H-borrowers to get loans. Thus, the likelihood of creditworthy borrowers getting loans is higher when the superior technology is adopted. Analysis of the information acquisition game shows, however, that asymmetric pure-strategy equilibria can exist for some parameter values, that is, similar banks can display very different information adoption choices.[22] Propositions 3 and 6 taken together show that although adoption decisions affect the nature of informational externalities across banks, the precise way in which the externalities are affected depends critically and very differently on whether the two tests differ in terms of their screening in or screening out qualities.

I now analyze comparative statics. Specifically, I demonstrate that increased uncertainty (regarding the quality of the superior test) reduces bank incentives to invest in information acquisition. Note that this result is the opposite to what I derived in the previous section. Thus, I show that the effect of quality uncertainty on bank information acquisition incentives is ambiguous. Higher uncertainty may increase or reduce incentives, depending on the specific properties of screening technologies. When uncertainty is primarily about how good superior screening technology is in screening out

[21] In the proposition above, I impose the restriction that α_H is small in order to obtain an approximation using a Taylor expansion and thereby derive a closed-form expression for in terms of the expectation and variance of the random variable W. The basic equilibrium characterization result can be shown to hold in the absence of this restriction. However, the comparative static analysis below becomes less tractable.

[22] In their analysis of endogenous information acquisition, Hauswald and Marquez (2003) derive that symmetric pure-strategy equilibria never exist. They assume that banks get perfectly correlated signals. Their result follows as symmetric choices then lead to 0 payoffs.

L-projects, increased uncertainty increases the incentive to acquire information. However, if the uncertainty is primarily about how good superior screening technology is in screening in H-projects, I have the opposite. The proposition below also shows that net output is decreasing in the level of uncertainty about the quality of the technology. The result obtains because fewer H-firms get loans in equilibrium under higher uncertainty. As before, increased uncertainty is assumed to result from a MPS.

Proposition 7. *Suppose that $\alpha_H > 0$, while $\alpha_L = 0$. Given Assumptions 1–3 and $4'$, an increase in uncertainty lowers the incentives to acquire superior information. Net output also decreases, conditional on both banks using test T_e.*

Proof. See the Appendix. ∎

The proof shows that $\tilde{e}_H$ and $\hat{e}_H$ are independent of and decreasing in the variance of W. Thus, increased variance in the accuracy reduces the range of parameters for which it is an equilibrium for both banks to purchase the technology. It is in this sense that the incentive to acquire superior information is decreasing in the uncertainty about the quality of the information. The result is the opposite to what I found in the previous case, when the technologies differed only in terms of their screening out qualities.

For the intuition, consider a bank's ex post payoff when both banks adopt the superior technology. Banks obtain a rent from lending to H-firms. This payoff is concave in accuracy because of informational externalities. The reason is that while with higher accuracy the likelihood that a given H-firm is offered a loan by any bank i is higher, the probability she accepts the loan is lower, as increased accuracy also increases the likelihood that the borrower receives a loan from bank j. Therefore, ex ante payoff when both banks adopt the superior technology is decreasing in the variance. Thus, higher uncertainty lowers the incentive to use T_e. So if the two technologies differ in terms of their screening in qualities, reduced uncertainty can lead to increased investment in information acquisition and improved average loan quality and make borrowers better off.

Uncertainty regarding the quality of technology may decline as a technology matures, or if it is from a more reputed producer, or if it integrates better with existing platforms. Propositions 5 and 7 together show that such products are not necessarily more likely to be adopted. Lower uncertainty can have an ambiguous effect on adoption incentives, depending on whether uncertainty relates to the screening in or screening out attribute.

5. Conclusion

New information technologies are immature and costly, and the nature and level of benefits are often uncertain. This article has studied strategic information acquisition in banking under uncertainty about the quality of information. It shows that uncertainty about quality can have an important influence on the incentive to acquire information or adopt new information gathering technology even with risk-neutral banks.

The article distinguishes between two attributes of an improved technology: how good it is in recognizing creditworthy borrowers as having productive projects and how good it is in recognizing noncreditworthy borrowers as having unproductive projects. It shows that the two attributes have very different impacts on information gathering incentives.

The analysis indicates that each bank's technology adoption decision imposes an externality on the other. When technologies are differentiated only through their screening out quality, strategic complementarities are generated and multiple symmetric equilibria may result. But if technologies are differentiated only through their screening in quality, multiple asymmetric equilibria can arise in the technology adoption game, with ex ante identical banks obtaining different payoffs in equilibrium.

A reduction in uncertainty associated with the quality of superior technology also has ambiguous effects. If the tests differ in terms of their screening out precision levels, adoption incentives are increasing in the uncertainty, whereas the opposite holds if the difference is in terms of the screening in precision levels. The results suggest that whether relatively mature products, or those from a better known vendor, or products which integrate better with existing information processing platforms, are more likely to be adopted depends on the exact nature of the improvement in information quality.

In sum, this article attempts to extend the literature on information acquisition in banking in three main ways. Firstly, the model of endogenous information acquisition allows interest rate competition to be conditioned on the profile of testing choices by banks and allows banks to draw conditionally independent signals. An investigation of the strategic nature of information acquisition and the externalities inherent in the process is thereby enabled in a natural model of competition.[23] With asymmetric testing choices by banks, the arguments show that conditional independence of signals has an impact on the market power of the superiorly informed bank. It can no longer hold the inferiorly informed banks down to zero profits, as it could if inferiorly informed banks draw a garbled signal of the superiorly informed bank's information. Secondly, the article allows the two sources of imprecision of a testing technology to be delinked. The delinkage permits the two sources, and their very different effects on the structure of informational externalities, to be analyzed sepa-

[23] Cao and Shi (2001) study endogenous information acquisition but assume that interest rate competition cannot be conditioned on the profile of testing choices. Hauswald and Marquez (2003) focus on a model with exogenously asymmetric banks who draw conditionally dependent signals. Their extension to information acquisition allows only perfectly correlated signals.

rately. Lastly, it allows for uncertainty in the quality of testing technologies and shows that the incentives to adopt superior technology are fundamentally affected by quality uncertainty and depend critically on whether uncertainty relates to the screening in or the screening out attribute.

An extension of the current work would be to study information technology adoption in a dynamic context. The results of this article suggest that the effect of uncertainty on the timing of adoption is likely to depend critically on the specific properties of new information technology. At the same time, superior information can have a significant impact on a bank's competitive position. How these effects interact with the dynamics of competition would be an important area of investigation. A dynamic analysis would also facilitate an investigation of competition with sequential adoption, an issue that the current model cannot address.

The study shows in a binary model that improvement in information quality can increase bank payoff. This contrasts with the implications of the linkage principle in common value auctions. Future research will try to understand whether the results extend to other environments. It would also be interesting to study the effect of uncertainty on information acquisition in auctions and examine the dependence on auction rules.

Appendix

Proof of Proposition 1. I drop the dependence on w in the proof for simplicity. Let R_{kk} be the set from which banks choose interest rates, and let $\inf R_{kk} = \underline{r}_{kk}$ and $\sup R_{kk} = \overline{r}_{kk}$. Without loss of generality, there cannot be an atom at any r in R_{kk}. Also, in any equilibrium, $\overline{r}_{kk} = x$. Otherwise, a bank's payoff is clearly strictly higher at $\overline{r}_{kk} + \varepsilon$ than at $\overline{r}_{kk} - \varepsilon$, which is a contradiction. Thus, I look for a symmetric equilibrium with a continuous distribution function and admissible interest rates restricted to $[r_{0k}, x]$, where

$$r_{0k} = 1 + \frac{(1-\gamma)p_{Lk}}{\gamma p_{Hk}}$$

is the zero profit interest rate for a bank using test T_k, given that its competitor is not providing credit. Let the two banks mix over this set according to some continuous distribution function $F_{kk}(r)$.

Consider any bank. Its payoff at interest rate r is

$$U_{kk}(r, F_{kk}(r)) = [1 - F_{kk}(r)p_{Hk}]\gamma p_{Hk}(r-1) - [1 - F_{kk}(r)p_{Lk}](1-\gamma)p_{Lk}.$$

In any equilibrium, it must be the case that the lowest interest rate at which F_{kk} equals 1 is x. Therefore, a bank does not make losses by setting $r = x$. Given $F_{kk}(x) = 1$, let a bank's payoff from $r = x$ be denoted as u_{kk}. Let $u_{kk} \geq 0$. Because bank i must earn the same payoff from charging any interest rate in the equilibrium support, I can use the equation $U_{kk}(r_{kk}(F_{kk}), F_{kk}) = u_{kk}$ to solve for $r_{kk}(F_{kk})$:

$$r_{kk}(F_{kk}) = \frac{u_{kk} + (1 - p_{Hk}F_{kk})\gamma p_{Hk} + (1 - p_{Lk}F_{kk})(1-\gamma)p_{Lk}}{(1 - p_{Hk}F_{kk})\gamma p_{Hk}}.$$

I note that $r_{kk}(F_{kk})$ is continuously differentiable in F_{kk}. It is easy to show that $r_{kk}(F_{kk})$ is increasing in F_{kk}. Also,

$$\underline{r}_{kk} = r_{kk}(0) = 1 + (1 - p_{Hk})(x - 1) + \frac{(1-\gamma)p_{Lk}^2}{\gamma p_{Hk}},\ \overline{r}_{kk} = r_{kk}(1) = x.$$

Let $r_{kk}(0) = r_{kk}^0$. Equilibrium is then given by $(R = [r_{kk}^0, x], F_{kk}(r))$, where F_{kk} is a distribution function which is the inverse of $r_{kk}(F_{kk})$ over the set $[r_{kk}^0, x]$.

I now have to show that $u_{kk} \geq 0$. Define

$$u_{ji} = \gamma p_{Hj}(1 - p_{Hi})(x - 1) - (1 - \gamma)p_{Lj}(1 - p_{Li}).$$

It is straightforward to show that $u_{ce} > 0$, by Assumption 3, and that $\min(u_{ee}, u_{cc}) > u_{ce}$. Therefore, u_{ee} and u_{cc} are both positive. The proof is complete as banks' payoffs are the same for all $r \in R_{kk}$, and charging an interest rate outside R_{kk} does not increase payoff. ■

Proof of Proposition 2. I drop the dependence on w for simplicity. Without loss of generality, admissible interest rates are restricted to $[r_{0c}, x]$, where

$$r_{0c} = 1 + \frac{(1-\gamma)p_{Lc}}{\gamma p_{Hc}}$$

is the zero profit interest rate for a bank using test T_c, given its competitor is not providing credit. Let $\inf R_{ce} = \underline{r}_{ce}$ and $\sup R_{ce} = \overline{r}_{ce}$ and let $\inf R_{ec} = \underline{r}_{ec}$ and $\sup R_{ec} = \overline{r}_{ec}$. It is easy to show that (a) $\underline{r}_{ec} = \underline{r}_{ce}$, (b) $\overline{r}_{ec} = \overline{r}_{ce} = x$ and (c) an equilibrium distribution function cannot have an atom at any $r \in (\underline{r}, x)$. Further, if at least one of R_{ce} and R_{ec} is closed below, then an equilibrium distribution function cannot have an atom at $\underline{r}$. Thus, let R_{ce} and R_{ec} be closed below.

I can now use a procedure similar to that found in the proof of Proposition 1 to show that an equilibrium with $R_{ce} = R_{ec}$ does not exist. Hence, any equilibrium has to have an asymmetric support, though with a common minimum. I can therefore restrict attention to the following two possibilities: $R_{ce} = [\underline{r}, x], R_{ec} = [\underline{r}, x)$ or $R_{ce} = [\underline{r}, x), R_{ec} = [\underline{r}, x]$. Let bank c's expected payoff from offering a loan at interest rate r, given $(F_{ce}(\bullet), F_{ec}(\bullet))$ be $U_{ce}(r, F_{ec}(\bullet))$ and let the corresponding expression for e be $U_{ec}(r, F_{ce}(\bullet))$.

I now show that in equilibrium, $R_{ce} = [\underline{r}, x)$ and $R_{ec} = [\underline{r}, x]$. Suppose not. Let $R_{ce} = [\underline{r}, x]$ and $R_{ec} = [\underline{r}, x)$ in equilibrium. Clearly, there cannot be any atom in $[\underline{r}, x)$. At the same time, an equilibrium without an atom at x does not exist (as otherwise the supports would be symmetric). Therefore, F_{ce} has an atom at x. I have

$$U_{ce}(x,1) = u_{ce} = \gamma p_{Hc}(1 - p_{He})(x - 1) - (1 - \gamma)p_{Lc}(1 - p_{Le}) > 0, \text{ by Assumption 3.}$$

Because c's payoff is the same for all $r \in [\underline{r}, x]$, I have

$$U_{ce}(\underline{r}, 0) = u_{ce}$$

and therefore

$$\underline{r} = r_c(0) = \frac{u_{ce} + \gamma p_{Hc} + (1-\gamma)p_{Lc}}{\gamma p_{Hc}}.$$

Finally, consider any $r \in [r_c(0), x)$. Because $U_{ce}(r, F_{ec}(r)) = u_{ce}$,

$$F_{ec}(r) = \frac{\gamma p_{Hc}(r - 1) - (1-\gamma)p_{Lc} - u_{ce}}{\gamma p_{Hc}p_{He}(r - 1) - (1-\gamma)p_{Lc}p_{Le}}.$$

$F_{ec}(r)$ is continuous in r for $r \in [r_c(0), x)$. I note that $F_{ec}(r_c(0)) = 0$ and $\lim_{r \uparrow x} F_{ec}(r) = 1$. Further, $F_{ec}(r)$ is continuously differentiable in r. I now turn to an analysis of e's payoffs. Let $U_{ec}(r_c(0), 0) = u_e$. Using the value of $r_c(0)$ derived above

$$u_e = \frac{p_{He}}{p_{Hc}} u_{ce} + \frac{(1-\gamma)(p_{He}p_{Lc} - p_{Hc}p_{Le})}{p_{Hc}} > u_{ce}, \text{ by Assumption 1.}$$

Therefore, $u_e > 0$, by Assumption 3. e's payoff is the same for all $r \in [r_c(0),x)$. Therefore, $U_{ec}(r, F_{ce}(r)) = u_e$, and

$$F_{ce}(r) = \frac{\gamma p_{He}(r-1) - (1-\gamma)p_{Le} - u_e}{\gamma p_{He}p_{Hc}(r-1) - (1-\gamma)p_{Le}p_{Lc}}.$$

$F_{ce}(r_c(0)) = 0$, and $F_{ce}(r)$ is continuously differentiable in r. Consider, therefore, the difference between the functions $F_{ce}(r)$ and $F_{ec}(r)$ over $[r_c(0),x)$.

$$F_{ec}(r) - F_{ce}(r) = \frac{(u_e - u_{ce}) - [\gamma(p_{He} - p_{Hc})(r-1) + (1-\gamma)(p_{Lc} - p_{Le})]}{\gamma p_{He}p_{Hc}(r-1) - (1-\gamma)p_{Le}p_{Lc}}.$$

By hypothesis, $F_{ce}(x) = 1$, while $\lim_{r\uparrow x}F_{ce}(r) < 1$. Because $\lim_{r\uparrow x}F_{ec}(r) = 1$, it must be that $\lim_{r\uparrow x}F_{ec}(r) > \lim_{r\uparrow x}F_{ce}(r)$. Consider $\lim_{r\uparrow x}(F_{ec}(r) - F_{ce}(r))$. Let the denominator of the above expression be $D_c(x)$.

$$D_c(x) = \gamma p_{He}p_{Hc}(x-1) - (1-\gamma)p_{Le}p_{Lc} > 0 \Leftrightarrow x < x_1 = 1 + \frac{(1-\gamma)p_{Le}p_{Lc}}{\gamma p_{He}p_{Hc}}.$$

I have $x_q > x_1$ by Assumption 1, where

$$x_q = 1 + \frac{(1-\gamma)p_{Lc}(1-p_{Le})}{\gamma p_{Hc}(1-p_{He})}.$$

Therefore, $D_c(x) > 0$ by Assumption 3. Denote the numerator by $N_c(x)$. Then

$$N_c(x) = \frac{p_{He} - p_{Hc}}{p_{Hc}} M_c(x),$$

where

$$M_c(x) = (1-\gamma)p_{Lc}p_{Le} - \gamma(x-1)p_{Hc}p_{He}.$$

Because $p_{He} > p_H$, and $M_c(x) < 0$ by Assumptions 1 and 3, I therefore have $N_c(x) < 0$. So, $\lim_{r\uparrow x}F_{ec}(r) < \lim_{r\uparrow x}F_{ce}(r) < 1$, which is a contradiction to $\lim_{r\uparrow x}F_{ec}(r) = 1$.

I now characterize equilibrium. It is easy to show, using steps similar to those above, that in equilibrium, $R_{ce} = [\underline{r},x), R_{ec} = [\underline{r},x]$. F_{ec} has an atom at x and bank e's payoff is given by

$$U_{ec}(x,1) = u_{ec} = \gamma p_{He}(1-p_{Hc})(x-1) - (1-\gamma)p_{Le}(1-p_{Lc}).$$

I have $u_{ec} > u_{ce}$, by Assumption 1. So, $u_{ec} > 0$. Because e's payoff is the same for all $r \in [\underline{r},x]$, I have $U_{ec}(\underline{r},0) = U_{ec}$. Therefore,

$$\underline{r} = r_a^0 = r_e^0 + \frac{u_{ec}}{\gamma p_{He}} = 1 + \frac{\gamma p_{He}(1-p_{Hc})(x-1)}{\gamma p_{He}} + \frac{(1-\gamma)p_{Le}p_{Lc}}{\gamma p_{He}}.$$

Assumption 2 ensures that $r_a^0 < x$. Finally, consider any $r \in [r_a^0,x)$. I can write $U_{ec}(r, F_{ce}(r)) = u_{ec}$ and hence

$$F_{ce}(r) = \frac{\gamma p_{He}[(r-1) - (1-p_{Hc})(x-1)] - (1-\gamma)p_{Le}p_{Lc}}{\gamma p_{He}p_H(r-1) - (1-\gamma)p_{Le}p_{Lc}}.$$

$F_{ce}(r)$ is continuous in r for $r \in [r_a^0,x)$. I note that $F_{ce}(r_a^0) = 0$ and $\lim_{r\uparrow x}F_{ce}(r) = 1$. Further, $F_{ce}(r)$ is continuously differentiable in r. I now turn to an analysis of c's payoffs. Let $U_{ce}(r_a^0) = u_{ce}^a$. Using the value of r_a^0 derived above

$$u_{ce}^a = \gamma p_{Hc}(1 - p_{Hc})(x - 1) - \frac{(1 - \gamma)p_{Lc}(p_{He} - p_{Hc}p_{Le})}{p_{He}} < u_{ec}.$$

It is easy to show that $u_{ce}^a > u_{ce} \Leftrightarrow x > x_1$, where x_1 has been defined above. Therefore, by Assumptions 1 and 3, $u_{ce}^a > u_{ce} > 0$. Also, c's payoff is the same for all $r \in [r_a^0, x)$. Hence

$$F_{ec}(r) = \frac{\gamma p_{He}[(r - 1) - (1 - p_{Hc})(x - 1)] - (1 - \gamma)p_{Le}p_{Lc}}{\gamma p_{He}p_{Hc}(r - 1) - (1 - \gamma)p_{Le}p_{Lc}} \cdot \frac{p_{Hc}}{p_{He}}.$$

$F_{ec}(r_a^0) = 0$, and $F_{ec}(r)$ is continuously differentiable and increasing in r. Furthermore,

$$\lim_{r \uparrow x} F_{ec}(r) = \frac{p_{Hc}}{p_{He}} < 1 \text{ and } \lim_{r \uparrow x} U_{ce}(r, F_{ec}(r)) > U_{ce}(x, 1).$$

The proof is complete as banks c and e earn the same payoff for all $r \in R_{ce}$ and $r \in R_{ec}$, respectively. Further, charging an interest rate outside R_{ce} (for bank c) or R_{ec} (for bank e) does not increase payoffs for either bank. ■

Proof of Proposition 3. First consider the c-equilibrium. Suppose both banks have chosen test T_c. For this to be an equilibrium, no bank can have an incentive to unilaterally deviate to T_e. Consider any bank i. Given that the other bank chooses T_c, if i chooses T_c, its ex ante expected payoff is

$$u^{cc} = \gamma p_H(1 - p_H)(x - 1) - (1 - \gamma)p_L(1 - p_L).$$

If it deviates, its payoff is

$$u_e^{ec} - e = \gamma p_H(1 - p_H)(x - 1) - (1 - \gamma)p_L[1 - \alpha_L E(W)](1 - p_L) - e.$$

Therefore, it does not deviate if and only if

$$u^{cc} \geq u_e^{ec} - e \Leftrightarrow e \geq u_e^{ec} - u^{cc} \Leftrightarrow e \geq (1 - \gamma)p_L(1 - p_L)\alpha_L E(W) = \tilde{e}_L.$$

Thus, a c-equilibrium exists if and only if $e \in [\tilde{e}_L, \bar{e}_L)$.

Now consider the e-equilibrium. Suppose both banks have chosen test T_e. For this to be an equilibrium, no bank can have an incentive to unilaterally deviate to T_c. Consider any bank i. Given that the other bank chooses T_e, if i chooses T_e, its payoff is

$$u^{ee} - e = \gamma p_H(1 - p_H)(x - 1) - (1 - \gamma)p_L\{(1 - p_L) - \alpha_L E(W)[1 - 2p_L + \alpha_L p_L E(W)]\}$$

$$+(1 - \gamma)\alpha_L^2 p_L^2 V(W) - e.$$

If it deviates, its payoff is

$$u_c^{ec} = \gamma p_H(1 - p_H)(x - 1) - (1 - \gamma)p_L\{1 - p_L[1 - \alpha_L E(W)]\}.$$

Therefore, it does not deviate if and only if

$$\begin{aligned} u^{ee} - e \geq u_c^{ec} \Leftrightarrow e \leq u^{ee} - u_c^{ec} \Leftrightarrow e &\leq (1 - \gamma)\alpha_L^2 p_L^2 V(W) \\ &+ (1 - \gamma)\alpha_L p_L E(W)[(1 - p_L) + \alpha_L p_L E(W)] = \hat{e}_L. \end{aligned}$$

Thus, an e-equilibrium exists if and only if $e \in (0, \hat{e}]$.

To complete the proof, it is sufficient to show that $\hat{e}_L - \tilde{e}_L > 0$. It is clear that $\tilde{e}_L$ and $\hat{e}_L$ are positive. Moreover, $\hat{e}_L < \bar{e}_L$, by Assumption 4. I have

$$\begin{aligned} \hat{e}_L - \tilde{e}_L = &(1 - \gamma)\alpha_L^2 p_L^2 V(W) + (1 - \gamma)\alpha_L p_L E(W)[(1 - p_L) + \alpha_L p_L E(W)] \\ &- (1 - \gamma)p_L(1 - p_L)\alpha_L E(W). \end{aligned}$$

Thus, $\hat{e}_L - \tilde{e}_L = (1-\gamma)\alpha_L^2 P_L^2 E(W^2) > 0.$ ■

Proof of Proposition 4. The proof uses the following lemma.

Lemma 1. *Consider two continuous random variables X_1 and X_2 with density functions f_1 and f_2, respectively. Let X_i, $i = 1, 2$ be distributed over the set $[\underline{x}_i, \overline{x}] \subset \mathrm{R}_{++}$ with $0 < \underline{x}_i < \overline{x} < \infty$ and let $\underline{x}_1 < \underline{x}_2 < \overline{x}$. Suppose the function f_i is strictly decreasing over $[\underline{x}_i, \overline{x}]$, with $f_i(\overline{x}) = 0$. Also, let $f_2(x) \geq f_1(x), \forall x \in [\underline{x}_2, \overline{x}]$, with equality if and only if $x = \overline{x}$. Then $E(X_1) < E(X_2)$.*

Proof of Lemma 1. Let F_i be the distribution function for random variable X_i. I have

$$F_2(\overline{x}) = F_1(\overline{x}) = 1.$$

Therefore,

$$\int_{\underline{x}_2}^{\overline{x}} f_2(x)\mathrm{d}x = \int_{\underline{x}_1}^{\overline{x}} f_1(x)\mathrm{d}x = \int_{\underline{x}_1}^{\underline{x}_2} f_1(x)\mathrm{d}x + \int_{\underline{x}_2}^{\overline{x}} f_1(x)\mathrm{d}x$$

or

$$\int_{\underline{x}_2}^{\overline{x}} f_1(x)\mathrm{d}x + \int_{\underline{x}_2}^{\overline{x}} g(x)\mathrm{d}x = F_1(\underline{x}_2) + \int_{\underline{x}_2}^{\overline{x}} f_1(x)\mathrm{d}x,$$

where $g(x) = f_2(x) - f_1(x)$ over the set $[\underline{x}_2, \overline{x}], g(x) \geq 0, \forall x \in [\underline{x}_2, \overline{x}]$, with equality if and only if $x = \overline{x}$. I, therefore, have

$$\int_{\underline{x}_2}^{\overline{x}} g(x)\mathrm{d}x = F_1(\underline{x}_2).$$

Consider $x^* \in (\underline{x}_2, \overline{x})$. Then,

$$F_2(x^*) < F_1(x^*) \Leftrightarrow \int_{\underline{x}_2}^{x^*} f_2(x)\mathrm{d}x = \int_{\underline{x}_2}^{x^*} f_1(x)\mathrm{d}x + \int_{\underline{x}_2}^{x^*} g(x)\mathrm{d}x < \int_{\underline{x}_2}^{x^*} f_1(x)\mathrm{d}x + F_1(\underline{x}_2).$$

Thus,

$$F_2(x^*) < F_1(x^*) \Leftrightarrow \int_{\underline{x}_2}^{x^*} g(x)\mathrm{d}x < \int_{\underline{x}_2}^{\overline{x}} g(x)\mathrm{d}x.$$

But $\int_{\underline{x}_2}^{x^*} g(x)\mathrm{d}x$ is an increasing function of x^* as $x^* \in (\underline{x}_2, \overline{x})$ and $g(x) > 0$, $\forall x \in [\underline{x}_2, \overline{x})$. Therefore, $F_2(x^*) < F_1(x^*), \forall x^* \in [\underline{x}_2, \overline{x})$. Since $\underline{x}_1 < \underline{x}_2$, F_2 first-order stochastically dominates F_1 and hence $E(X_1) < E(X_2)$. Q.E.D.

I now continue with the proof of the proposition. I first compare bank payoffs under the two equilibria. The difference in payoffs is given by

$$u^{ee} - u^{cc} - e = (1-\gamma)\alpha_L p_L E(W)[1 - 2p_L + \alpha_L p_L E(W)] - e.$$

The difference is decreasing in e. At $e = \tilde{e}_L$, the difference is

$$-(1-\gamma)\alpha_L p_L^2 E(W)[1 - \alpha_L E(W)] < 0, \text{ as } E(W) \leq 1 \text{ and } \alpha_L < 1.$$

Thus, $u^{ee} - e < u^{cc}$, for all $e \in [\tilde{e}_L, \hat{e}_L]$ and banks are worse off in the e-equilibrium than in the c-equilibrium.

I now study interest rates. Suppose both banks are using test T_k. Consider the game in Stage III when the random variable W has already been realized. Let w be the realization. Let $r_{1k}(w)$ be the interest rate faced by a borrower conditional on getting exactly one loan offer, and let $\bar{r}_{1k}(w)$ be its expectation. Also let $r_{2k}(w)$ be the interest rate on the accepted offer conditional on a borrower getting two loan offers, and let $\bar{r}_{2k}(w)$ be its expectation. Clearly, the random variable $r_{1k}(w)$ has a distribution function $F_{kk}(r; w)$ on the set $[r^0_{kk}(w),x]$. From Proposition 1,

$$r^0_{kk}(w) = 1 + (1 - p_H)(x - 1) + \frac{(1-\gamma)p^2_{Lk}(w)}{\gamma p_H} \text{ and } r^0_{cc}(w) = r^0_{cc} < x.$$

Also,

$$r^0_{cc} - r^0_{ee}(w) = \frac{(1-\gamma)p^2_L}{\gamma p_H}\left[1 - (1-\alpha_L w)^2\right] > 0 \quad \text{or } r^0_{ee}(w) < r^0_{cc}.$$

Further,

$$F_{kk}(r;w) = \frac{\gamma p_H[(r-1) - (1-p_H)(x-1)] - (1-\gamma)p^2_{Lk}(w)}{\gamma p^2_H(r-1) - (1-\gamma)p^2_{Lk}(w)}$$

$$F'_{kk}(r;w) = f_{kk}(r;w) = \gamma p_H(1-p_H)\frac{\gamma p^2_H(x-1) - (1-\gamma)p^2_{Lk}(w)}{\left[\gamma p^2_H(r-1) - (1-\gamma)p^2_{Lk}(w)\right]^2}.$$

Of course, $f_{kk}(r; w) \geq 0$, and $\gamma p^2_H(x-1) - (1-\gamma)p^2_{Lk}(w) > 0$. Given w, $f_{kk}(r; w)$ is a strictly decreasing function of r. $F_{cc}(r; w) = F_{cc}(r) = 0$ over the set $[r^0_{ee}(w), r^0_{cc}]$, whereas $F_{ee}(r; w)$ is positive. Over the set $[r^0_{cc}, x]$,

$$F_{cc}(r) - F_{ee}(r;w) = \frac{N_F}{D_F},$$

where

$$D_F = \left[\gamma p^2_H(r-1) - (1-\gamma)p^2_L\right]\left[\gamma p^2_H(r-1) - (1-\gamma)p^2_L(1-\alpha_L w)^2\right] > 0.$$

After simplification

$$N_F = -\gamma(1-\gamma)p^2_L\left[1-(1-\alpha_L w)^2\right]p_H(1-p_H)(x-r) < 0.$$

Thus, $\bar{r}_{1e}(w) < \bar{r}_{1c}$, for all w. Therefore, $E_W\bar{r}_{1e}(w) < \bar{r}_{1c}$.

I now turn attention to the random variable $r_{2k}(w) = \min(r_{ak}(w), r_{bk}(w))$, where $r_{ak}(w)$ and $r_{bk}(w)$ are two random draws of $r_{1k}(w)$. Using standard results from order statistics, the density of $r_{2k}(w)$ is, therefore,

$$\phi_k(r;w) = 2f_{kk}(r;w)[1 - F_{kk}(r;w)] \text{ over the set } \left[r^0_{kk}(w), x\right]..$$

Observe that $\phi_k(r; w)$ is a strictly decreasing function of r and $\phi_k(x; w) = 0$. Simplifying, I have

$$\phi_k(r;w) = 2\gamma^2 p^2_H(1-p^2_H)(x-r)\alpha_k(w),$$

where

$$\alpha_k(w) = \frac{\gamma p_H^2(x-1) - (1-\gamma)p_{Lk}^2(w)}{\left[\gamma p_H^2(r-1) - (1-\gamma)p_{Lk}^2(w)\right]^3}.$$

Over the set $[r_{cc}^0, x]$, I have

$$\alpha_c(w) - \alpha_e(w) = \alpha_c - \alpha_e(w) = \frac{N_\alpha}{D_\alpha},\ D_\alpha > 0.$$

After simplifying and dropping terms of the form $\beta p_L^n[1-(1-\alpha_L w)^n]$, $n \geq 4$ and β is some positive constant (since p_L is small), I obtain

$$N_\alpha = 2\gamma^3(1-\gamma)p_H^6 p_L^2\left[1-(1-\alpha_L w)^2\right](r-1)(x-1) > 0.$$

Thus,

$$\phi_c(r) > \phi_e(r;w),\ \forall r \in \left[r_{cc}^0, x\right].$$

Therefore, by Lemma 1, $\bar{r}_{2e}(w) < \bar{r}_{2c}$, for all w. Therefore, $E_W\bar{r}_{2e}(w) < \bar{r}_{2c}$. But $E_W\bar{r}_{1e}(w) < \bar{r}_{1c}$, as shown earlier. Therefore, expected interest rates are lower in the e-equilibrium compared to the c-equilibrium. ■

Proof of Proposition 5. Notice that $\tilde{e}_L$ is independent of $V(W)$. To show that the incentive to acquire information or adopt the high-quality technology is increasing in the level of quality uncertainty, it is sufficient to show that $\hat{e}_L$ is increasing in $V(W)$, given that $E(W)$ is constant. Recall,

$$\hat{e}_L = (1-\gamma)\alpha_L^2 p_L^2 V(W) + (1-\gamma)\alpha_L p_L E(W)[(1-p_L) + \alpha_L p_L E(W)]$$

which increases with $V(W)$, for constant $E(W)$.

In the e-equilibrium, net output is given by

$$\gamma\left[1-(1-p_H)^2\right](x-1) - (1-\gamma)E_W\left\{1-[1-p_L(1-\alpha_L w)]^2\right\} - 2e.$$

$1-(1-p_H)^2$ is the probability that an H-firm gets at least one loan offer, while $E_W\{1-[1-p_{Le}(w)]^2\}$ is the probability that an L-firm gets at least one loan offer. The above expression can be rewritten as

$$\gamma\left[1-(1-p_H)^2\right](x-1) - (1-\gamma)\{(2-p_L)p_L - \alpha_L^2 p_L^2 V(W) - \alpha_L p_L E(W)$$

$$[2(1-p_L) + \alpha_L p_L E(W)]\} - 2e$$

which is increasing in $V(W)$, given the value of $E(W)$. ■

Proof of Proposition 6. First consider the c-equilibrium. Suppose both banks have chosen test T_c. For this to be an equilibrium, no bank can have an incentive to unilaterally deviate to T_e. Consider any bank i. Given that the other bank chooses T_c, if i chooses T_c, its payoff is

$$u_c^c = \gamma(x-1)p_H(1-p_H) - (1-\gamma)p_L(1-p_L).$$

If it deviates, its payoff is

$$u_e^{ce} = \gamma(x-1)p_H[1+\alpha_H E(W)](1-p_H) - (1-\gamma)p_L(1-p_L) - e.$$

Therefore, it does not deviate if and only if

$$u_c^c \geq u_e^{ce} - e \Leftrightarrow e \geq u_e^{ce} - u_c^c \Leftrightarrow e \geq (1-\gamma)p_H(1-p_H)(x-1)\alpha_H E(W) = \tilde{e}_H.$$

Thus, a c-equilibrium exists if and only if $e \in [\tilde{e}_H, \bar{e}_H)$.

Now consider the e-equilibrium. Suppose both banks have chosen test T_e. For this to be an equilibrium, no bank can have an incentive to unilaterally deviate to T_c. Consider any bank i. Given that the other bank chooses T_e, if i chooses T_e, its payoff is

$$\begin{aligned} u_e^e - e = {} & \gamma p_H(x-1)\{(1-p_H) + \alpha_H E(W)[1 + 2p_H - \alpha_H p_H E(W)]\} \\ & - (1-\gamma)p_L(1-p_L) - \gamma(x-1)\alpha_H^2 p_H^2 V(W) - e. \end{aligned}$$

If it deviates, its payoff is

$$\begin{aligned} u_c^{ce} &= \gamma p_H(1-p_H)(x-1) - (1-\gamma)p_L\left(1 - p_L E_W \frac{1}{1+\alpha_H w}\right) \\ &\simeq \gamma p_H(1-p_H)(x-1) - (1-\gamma)p_L\left[1 - p_L E_W\left(1 - \alpha_H w + \alpha_H^2 w^2\right)\right] \\ &= \gamma p_H(1-p_H)(x-1) - (1-\gamma)p_L(1-p_L) \\ &\quad - (1-\gamma)\alpha_H p_L^2\{E(W)[1 - \alpha_H E(W)] - \alpha_H V(W)\}. \end{aligned}$$

The above second-order expansion utilizes the fact that α_H is small. Therefore, the bank does not deviate if and only if

$$u_e^e - e \geq u_c^{ce} \Leftrightarrow e \leq u_e^e - u_c^{ce}$$

$$\begin{aligned} \Leftrightarrow e \leq {} & \alpha_H E(W)\left\{\gamma p_H(x-1)[1 + 2p_H - \alpha_H p_H E(W)] + (1-\gamma)p_L^2[1 - \alpha_H E(W)]\right\} \\ & - \alpha_H^2 V(W)\left[\gamma p_H^2(x-1) - (1-\gamma)p_L^2\right] = \hat{e}_H. \end{aligned}$$

Thus, an e-equilibrium exists if and only if $e \in (0, \hat{e}_H]$.

I now show that $\hat{e}_H < \tilde{e}_H$. To see that, define

$$\tilde{e}_H(w) = \gamma(1-p_H)[p_{He}(w) - p_H](x-1)$$

$$\hat{e}_H(w) = \gamma[1 - p_H - p_{He}(w)][p_{He}(w) - p_H](x-1) + \frac{(1-\gamma)p_L^2}{p_{He}(w)}[p_{He}(w) - p_H].$$

I have

$$u_{cc} \geq u_{ec}(w) - e \Leftrightarrow e \geq \tilde{e}_H(w)$$

$$u_{ee}(w) - e \geq u_{ce}^a(w) \Leftrightarrow e \leq \hat{e}_H(w).$$

And

$$\tilde{e}_H(w) - \hat{e}_H(w) = \frac{p_{He}(w) - p_H}{p_{He}(w)}\left[\gamma p_{He}^2(w)(x-1) - (1-\gamma)p_L^2\right] > 0, \text{ by Assumption 2.}$$

Therefore,

$$E_W \tilde{e}_H(w) = \tilde{e}_H > E_W \hat{e}_H(w) = \hat{e}_H.$$

Consider an asymmetric pure-strategy equilibrium where one bank (bank c) uses T_c, while the other (bank e) uses T_e. For that to be an equilibrium, I need

$$e \leq u_e^{ce} - u_c^c = \tilde{e}_H \text{ and } e \geq u_e^e - u_c^{ce} = \hat{e}_H.$$

Therefore, asymmetric equilibria exist for $e \in [\hat{e}_H, \tilde{e}_H]$. ■

Proof of Proposition 7. Note that $\tilde{e}_H$ is independent of $V(W)$. To show that the incentive to adopt the high-quality technology is decreasing in the level of quality uncertainty, it is sufficient to show that $\hat{e}_H$ is decreasing in $V(W)$, given that $E(W)$ is constant. Recall,

$$\begin{aligned}\hat{e}_H = {} & \alpha_H E(W)\{\gamma p_H(x-1)[1+2p_H - \alpha_H p_H E(W)] + (1-\gamma)p_L^2[1-\alpha_H E(W)]\} \\ & - \alpha_H^2 V(W)\left[\gamma p_H^2(x-1) - (1-\gamma)p_L^2\right]\end{aligned}$$

which decreases with $V(W)$, for constant $E(W)$.

In the e-equilibrium, net output is given by

$$\gamma E_W\left\{1 - [1 - p_H(1+\alpha_H w)]^2\right\}(x-1) - (1-\gamma)\left[1-(1-p_L)^2\right] - 2e. \quad ■$$

$1-(1-p_L)^2$ is the probability that an L-firm gets at least one loan offer, while $E_W[1-(1-p_{He}(w))^2]$ is the probability that an H-firm gets at least one loan offer. The above expression can be rewritten as

$$\begin{aligned}&-(1-\gamma)p_L(1-p_L) - 2e + \gamma(x-1)p_H\{(2-p_H) - \alpha_H^2 p_H V(W) \\ &\quad + \alpha_H E(W)[2(1-p_H) - \alpha_H p_H E(W)]\}\end{aligned}$$

which is decreasing in $V(W)$, given the value of $E(W)$.

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