Information Technology and Financial Services Competition

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We analyze how two dimensions of technological progress affect competition in financial services. While better technology may result in improved information processing, it might also lead to low-cost or even free access to information through, for example, informational spillovers. In the context of credit screening, we show that better access to information decreases interest rates and the returns from screening. However, an improved ability to process information increases interest rates and bank profits. Hence predictions regarding financial claims' pricing hinge on the overall effect ascribed to technological progress. Our results generalize to other financial markets where informational asymmetries drive profitability, such as insurance and securities markets.

Informational considerations have long been recognized to determine not only the degree of competition but also the pricing and profitability of financial services and instruments. However, recent technological progress has dramatically affected the production and availability of information, thereby changing the nature of competition in such informationally sensitive markets. This article investigates how advances in information technology (IT) affect competition in the financial services industry, in particular, credit, insurance, and securities markets.[1] We focus on two aspects of improvements in IT: better processing and easier dissemination of information.[2]

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[1] The consequences of advances in IT can be seen in the birth of on-line banking, the lowering of economic barriers to entry through better means of communication, and in modern credit and insurance risk assessment techniques such as scoring methods.

[2] Shapiro and Varian (1999) also single out these two dimensions of the IT revolution in their discussion of network economics and the role of information in competition. The Federal Reserve Bank of Dallas (1999) estimates that, in the last 30 years, processing power, storage capacity, and transmission speed have multiplied by tens to hundreds of thousands with usage costs falling dramatically.

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To fix ideas and illustrate the basic intuition, we formulate our model in the context of credit market competition. In our model, differentially informed financial intermediaries compete for borrowers of varying credit quality. These intermediaries can obtain a privately informative signal by conducting credit assessments whose success depends on the state of the IT and the effort expended in gathering and interpreting borrower-specific data.[3] We show that the two dimensions of technological progress, as defined by advances in the ability to process and evaluate information, and in the ease of obtaining information generated by competitors, can have very different impacts on the competitiveness of lending markets.

In situations where banks have established business relationships with borrowers, our model delivers sharp predictions. We find that advances in IT that improve the ability to *process* information make markets less competitive. This decrease in competition occurs because such improvements widen the informational gap between competitors who invest resources in gathering information and those who do not. Consequently, informed intermediaries obtain higher rents as a result of technological progress and informationally captured borrowers suffer through higher interest rates. Moreover, as returns to processing information increase, banks exert more effort in this direction, compounding the original impact of technological change.

At the same time, technological progress also facilitates the dissemination of information. Other market participants may freely observe part or all of any information collected so that second-hand *access* to proprietary information becomes less costly or even free.[4] We show that easier access to information levels the playing field for competitors and erodes banks' rents, helping borrowers avoid informational capture by informed intermediaries. Faster dissemination of information increases competition among lenders and benefits borrowers through lower interest rates. Informational spillovers, however, by decreasing the returns to acquiring information, also decrease banks' incentives to screen borrowers and gather information.

We also allow for competition between banks to establish business relationships. We find that, for a wide set of parameter values, our earlier results concerning improved information processing carry over to situations where intermediaries compete to be an informed lender. Specifically we show that as long as the information obtained by lenders is not too

[3] Recent literature has argued that the special nature of bank lending, relative to other forms of credit, provides banks with private information over their borrowers; see, for example, James (1987) and Lummer and McConnell (1989) for evidence to this effect. See Sharpe (1990), Rajan (1992), and von Thadden (1998) for theoretical models illustrating this point.

[4] An article that makes a similar assumption on the information-gathering activity of banks is Cetorelli and Peretto (2000), who focus on the feedback between competition among banks and the incentives to gather information.

accurate, technological progress raises the expected interest rates for borrowers. Hence, even such ex ante competition between banks does not necessarily imply that all gains from technological progress will be passed along to customers in the guise of lower borrowing costs.

Our results suggest that technological advances have the potential to undermine property rights over information. If so, intermediaries may find it worthwhile to invest resources in asserting these rights. Hence we extend our model to consider efforts by an information-gathering intermediary to protect its proprietary intelligence. We show that, if outside access to private information is not too widespread, technological advances lead to more effort being spent on decreasing spillovers and preventing expropriation of information. However, when property rights over private information are very weak, further advances will erode bank profits to a point where intermediaries reduce both screening and spillover prevention effort.

We apply our model to insurance and securities markets and find the same effects of technological improvements at work. For example, who most benefits from the wider availability of information through the new SEC Regulation fair disclosure (FD) depends on the ability to obtain and process company-specific facts. Hence our results show that predictions regarding IT's impact on financial service providers and their customers, for a variety of markets, largely depend on the overall effect ascribed to the technological progress.[5] It is often claimed that technological progress is likely to erode intermediaries' profits and force them to alter their business strategies.[6] To the extent that improvements in IT level the playing field among competitors, this prediction may be true. However, we point out that other types of improvements may further increase the informational gap between competitors and yield very different predictions.

To our knowledge, the impact of IT on the incentives to collect and process information in financial markets has been little studied. Instead, the debate has traditionally focused on the consequences of insider trading

[5] Two recent articles explicitly consider improved processing capacity and informational spillovers in financial services. Passmore and Sparks (2000) analyze the impact of automated underwriting as a technological innovation on the mortgage market. Investments in mortgage scoring technology by Fannie Mae and Freddie Mac are claimed to reduce screening costs not only for the companies themselves, but also, through spillover effects, for other market participants. Wilhelm (1999) discusses how technological progress has affected incentives for information acquisition through informational spillovers in the initial public offering (IPO) process. He suggests that traditional relationship-based intermediation created large asymmetries between the informed and the uninformed, which may be eroded with improvements in the storage and dissemination of information.

[6] Evans and Wurster (1997) argue in the *Harvard Business Review* that the value of relationships in banking is likely to drop due to the changes in IT, necessitating a change in banks' strategies. Similarly a survey in *The Economist* makes the case that the IT revolution should lower barriers to entry and make markets more competitive by improving access to "knowledge" and information (*The Economist*, September 3, 2000).

[Diamond (1985), Fishman and Haggerty (1992)] or, more recently, on the type of information to disclose [Boot and Thakor (2001)]. While the latter focuses on the kind of information disclosed rather than incentives to collect and process information, their analysis nevertheless shows the importance of access to and diffusion of information in financial markets. Bhattacharya and Chiesa (1995) and Yosha (1995) are among the first to consider information spillovers as a consequence of disclosure. However, in their models the information externality benefits the firm's competitors and is therefore harmful. In our analysis, informed investors generate a positive information externality that benefits other investors. Hence our focus is on the collection of relevant information rather than its supply.

In addition to the analysis of the issues raised above, one of our main contributions is the development of a simple, tractable model of competition under asymmetric information. While we limit our focus to the consequences of changes in information-gathering technology, we believe that the simple expressions this model delivers can be easily adapted to the study of related topics. The theoretical treatments closest to our own are Rajan (1992), von Thadden (1998), and Hauswald and Marquez (2000). Rajan (1992) analyzes how information advantages generate rents for incumbent banks, while von Thadden (1998) investigates the degree to which borrowers might be captured by their inside bank. Neither article, however, analyzes how changes in the technology for acquiring information affects the competitive nature of lending markets. Hauswald and Marquez (2000) study intermediaries' incentives to allocate information-gathering resources across different markets, but do not address improvements in their ability to gather information.

Petersen and Rajan (2000) provide evidence on the consequences of technological progress in credit markets. They find that the physical distance between banks and borrowers has increased over the last two decades, and attribute this phenomenon to improvements in banks' ability to collect and process large amounts of "hard" information. However, their results are also consistent with improved networks for the transmission of such information, allowing banks to obtain information gathered about borrowers located farther away, and to compete for these borrowers. Hence, it is likely that both aspects we highlight in this article are at work. Their simultaneous presence may explain why there has been improved availability of credit but ambiguous implications for the pricing of loans.

The article proceeds as follows. In Section 1 we describe the theoretical framework and carry out some preliminary analysis. Section 2.1 characterizes the impact of an improvement in information processing ability. Section 2.2 contrasts the previous results to those obtained if, instead, information creates a positive externality for other lenders. In Section 3 we discuss extensions to the basic model and endogenize the information acquisition decision. Section 4 applies our results to insurance and securities markets and discusses determinants of the state of IT. Section 5 concludes. Most of the proofs are relegated to the appendix.

1. A Model of Lending Competition

1.1 Description of model

Let there be a continuum of borrowers of measure 1. Each potential borrower has an investment project that requires an initial outlay of \$1 and generates a terminal cash flow X. This cash flow X can be an amount R with probability p_θ and 0 with probability $1-p_\theta$, where $\theta \in \{l, h\}$ denotes the borrower's type. We assume that the success probability for the borrower with the better investment opportunity is higher: $p_h > p_l$. Final cash flows are observable and contractible, but borrower type θ is unknown to either borrower or lender.[7] The probability that a borrower is of high quality is q and this distribution of borrower types is common knowledge. We also assume that borrowers have no private resources, and that $p_l R < 1 < p_h R$, so that it is efficient to finance good borrowers but not bad ones. Moreover, letting $\overline{p} \equiv qp_h + (1-q)p_l$ denote the average success probability, we assume that $\overline{p}R > 1$, so that it is ex ante efficient to grant a loan.

Two banks compete for borrowers in this market. We will refer to the first intermediary as the *inside* or informed bank because it has access to a screening technology ϕ that generates borrower-specific information. The other intermediary, which we call the *outside* bank, does not have access to such technology and therefore remains uninformed.[8] Screening of borrowers leads to better credit assessments that provide the inside bank with an informative signal about a borrower's type. In particular, loan screening yields a signal $\eta \in \{l, h\}$ about the borrower's repayment probability, with the probability of successful and erroneous credit assessments given by, respectively,

$$\begin{aligned} \Pr(\eta = h \mid \theta = h) = \phi = \Pr(\eta = l \mid \theta = l) \\ \Pr(\eta = h \mid \theta = l) = 1 - \phi = \Pr(\eta = l \mid \theta = h). \end{aligned} \tag{1}$$

Credit analysis is not perfect and depends on the effort the inside bank puts into evaluating the information gathered and on the state of IT.

[7] Alternatively, we could assume that there are no self-selection or sorting devices such as collateral available because, for example, the borrower is wealth constrained and the project cannot serve as collateral.

[8] This setup captures the notion that some banks may be early adopters of technology and consequently have an edge over competitors. Similarly we would expect some lenders to have established business relationships with certain customers and hence to be in a better position to acquire proprietary information about such borrowers.

For concreteness, suppose that loan screening produces information according to

$$\phi = \frac{1 + Ie}{2}, \quad I \in (0, 1), \ \ e \in [0, 1], \tag{2}$$

where the parameter I represents the state of the information processing technology and e the bank's effort in generating information and interpreting the results of the credit assessment. This setup ensures that the screening technology is informative, so that $\phi \geq \frac{1}{2}$. Note that effort and technology are complementary, so that effort is more productive when the state of technology is high. Hence Ie represents the inside bank's total information processing capabilities. Effort e, however, is costly. We assume that this cost is given by a function $c(e)$, where $c' > 0$ and $c'' > 0$ for $e > 0$, and $c'(0) = 0$, $c'(1) = \infty$.

The timing is as follows. The inside bank must first decide whether or not to screen a loan applicant, and how much costly effort e to exert in evaluating the information gathered. Both banks compete in a second stage by simultaneously making interest rate offers. Borrowers choose last by accepting a loan from the bank quoting the lowest rate.

1.2 Preliminary analysis

As a preliminary step, we derive a potential borrower's success probability in light of the inside bank's credit assessment. By Bayes' rule, the probability of a project being of high or low quality given a credit assessment of $\eta = h$ or $\eta = l$ is

$$\Pr(\theta = h | \eta = h) = \frac{\phi q}{\phi q + (1 - \phi)(1 - q)} \equiv H$$
$$\Pr(\theta = l | \eta = l) = \frac{\phi(1 - q)}{\phi(1 - q) + (1 - \phi) q} \equiv L.$$

We obtain the project's success probability conditional on the screening result $p(\eta)$ as

$$p(h) \equiv \Pr(X = R | \eta = h) = H p_h + (1 - H) p_l \in [\overline{p}, p_h]$$
$$p(l) \equiv \Pr(X = R | \eta = l) = (1 - L) p_h + L p_l \in [p_l, \overline{p}].$$

The inside bank's strategy has two components: its effort in screening applicant borrowers, and its interest rate offer, which can be conditioned on the results from screening. The outside bank, by contrast, has no information and can only decide on its interest rate offers knowing that the inside bank has screened, but not the outcome of such screening.

We index the inside lender by i and the outside or uninformed lender by u. Let $\pi_i(\eta)$ represent the expected profits, gross of the cost of effort $c(e)$, of an inside bank after observing a signal $\eta \in \{h, l\}$. We next characterize the equilibrium in the lending subgame after the inside bank has made its effort decision, where informed and uninformed banks compete in interest rate offers. The proof is sketched in the appendix.

Proposition 1. *While a pure strategy equilibrium in the lending game does not exist, there exists a unique mixed strategy equilibrium, given by the distribution functions over interest rates* $\{F_i, F_u\}$ *for the informed and uninformed bank, respectively. Equilibrium expected profits for the uninformed bank are zero. Equilibrium expected profits before observation of the signal for the informed bank are given by*

$$E[\pi_i(\eta)] - c(e) = \Pr(\eta = h)\pi_i(h) + (1 - \Pr(\eta = h))\pi_i(l) - c(e)$$
$$= \frac{1}{\overline{p}}(p_h - p_l)q(1-q)[2\phi - 1] - c(e). \quad (3)$$

The result that no pure strategy equilibrium exists when bidders have asymmetric information is standard [see Engelbrecht-Wiggans, Milgrom, and Weber (1983) and von Thadden (1998)]. This outcome is a consequence of the winner's curse: the fact that an interest rate offer from an uninformed bank is accepted by a customer suggests that other lenders judged this borrower to be a poor credit risk and therefore did not bid very aggressively. The proposition also shows that, in our model of lending competition under asymmetric information, we obtain a very simple expression for expected profits to an inside bank which only depends on the ex ante borrower quality $\overline{p}$, the heterogeneity of borrowers $\Delta_p \equiv p_h - p_l$, their distribution q, and on the quality of the screening (information) technology ϕ.

2. Technological Progress in Credit Markets

In this section we analyze the consequences of improved information processing and easier access to information on credit markets and discuss some empirical implications of our results.

2.1 Improvements in information processing

Having characterized the equilibrium in the screening and lending game, we next study the impact of an improvement in technology I on the inside bank's profits and the competitiveness of the credit market. By substituting the expression for ϕ into Equation (3), expected profits of the inside lender simplify to

$$E[\pi_i(\eta)] - c(e) = \frac{1}{\overline{p}}(p_h - p_l)q(1-q)Ie - c(e)$$

We can see at once that $\partial E[\pi_i(\eta)]/\partial I > 0$ and $\partial E[\pi_i(\eta)]/\partial e > 0$. An increase in I, all other things being equal, increases the profits earned by an inside bank. Similarly, increasing the effort expended in evaluating borrower-specific information also increases a bank's profits (gross of its cost of effort). Both effects occur because better technology increases the relative information advantage of an informed bank. The uninformed bank, therefore, does not gain from technological improvements. In fact, the opposite is true: an increase in I causes it to face a larger adverse selection problem.

We next study the impact of an improvement in information processing technology on borrowers. While banks obtain higher profits as a result of the improvement, this outcome might be due to their more efficient screening of low-quality borrowers. An important question, therefore, is whether the interest rate borrowers expect to pay increases or decreases with the state of technology I. The actual interest rate that a borrower pays on a loan when both banks make an offer is $\min\{r_i, r_u\}$, where r_i is the rate offered by the informed bank and r_u is that of the uninformed bank. From the proof of Proposition 1, we know that the informed bank only bids upon observing a high signal. Consistent with our focus on direct competition between the banks, we concentrate on this case. Hence we need to calculate $E[\min\{r_i, r_u\}]$. Define $\hat{r} = \min\{r_i, r_u\}$, and let $F(\hat{r})$ be the distribution function for this minimum given that both banks make a loan offer. Since both banks bid simultaneously, F_i and F_u are independent, and so, for a given interest rate r, $F(r) = F_i(r,h) + F_u(r) - F_i(r,h)F_u(r)$, where $F_i(r,h)$ is the inside bank's distribution function over interest rate offers upon a positive credit assessment outcome $\eta = h$. Therefore

$$E[\min\{r_i, r_u\}] = E[\hat{r}] = \int_{\underline{r}}^{R} r dF(r) = \int_{\underline{r}}^{R} [1 - F(r)]dr + \underline{r}.$$

From the construction of the equilibrium (see the proof of Proposition 1 in the appendix), we know that the mixing distributions for each bank can be expressed as

$$F_i(r,h) = \frac{p(h) - p(l)}{\overline{p} - p(l)} \frac{\overline{p}r - 1}{p(h)r - 1}$$
$$F_u(r) = \frac{p(h)}{\overline{p}} \frac{\overline{p}r - 1}{p(h)r - 1}.$$

From these distribution functions we obtain the following result:

Lemma 1. *F_i and F_u are decreasing in I so that $F(r) = F_i(r,h) + F_u(r) - F_i(r, h)F_u(r)$ is also decreasing in I.*

Proof. See the appendix. ■

This lemma implies the following result for expected interest rates paid by borrowers.

Proposition 2. *Expected interest rates, $E[\hat{r}]$, are increasing in processing capacity I.*

Proof. Since $E[\hat{r}] = \int_{\underline{r}}^{R} [1 - F(r)]dr + \underline{r}$, the result follows from the preceding lemma. ■

This proposition shows that an improvement in banks' information processing ability, while increasing bank profits and improving their screening ability, also increases the interest rates borrowers pay. Rather than leveling the playing field, superior ability to screen can actually make lending markets *less* competitive by increasing the information asymmetries across banks. This effect occurs for two reasons. First, increasing I increases the return to screening for a bank. Second, since only one bank obtains any information while the other bank remains uninformed, this latter bank faces a larger winners' curse problem and in equilibrium bids less aggressively. The response by the informed bank is to bid less aggressively as well, leading to higher expected interest rates for the borrower.

In this context, Lemma 1 has an interesting further implication. As part of its equilibrium strategy, the outside bank only makes a loan offer with probability $F_u(R) < 1$ and refrains from bidding otherwise. By Lemma 1, the probability that a borrower obtains a competing loan offer from the uninformed bank is decreasing in I, once again suggesting that the market becomes less competitive as I increases. We should also point out that Proposition 2 continues to hold even when the inside bank observes a low signal, abstains from bidding, and only the outside bank makes a loan offer. Hence the restriction to the case in which both banks bid is innocuous.

There is a second channel through which changes in technology I affect our results: the indirect effect through the effort choice e. Notice that since processing ability and effort are complementary, we obtain from Equation (3) that $\partial^2 E[\pi_i(\eta)]/\partial I \partial e > 0$: an increase in I increases the marginal return to exerting effort. Therefore an inside bank should adjust its effort decision with changes in I, as follows.

Corollary 1. *The optimal level of screening effort e^* is increasing in I.*

Proof. From Proposition 1 we obtain the first-order condition for optimal effort as

$$\begin{aligned}
&\frac{1}{\overline{p}}(p_h - p_l)q(1-q)2\frac{\partial \phi}{\partial e}(e^*) - \frac{\partial c}{\partial e}(e^*) \\
&\quad = \frac{1}{\overline{p}}(p_h - p_l)q(1-q)I - \frac{\partial c}{\partial e}(e^*) = 0.
\end{aligned}$$

Applying the implicit function theorem we can solve for $\partial e^*/\partial I$ as

$$\frac{\partial e^*}{\partial I} = \frac{(1/\overline{p})(p_h - p_l)q(1-q)}{c''(e^*)},$$

which is greater than zero since $c''(e^*) > 0$. ■

The corollary suggests that the effect of an increase in banks' ability to process information is further compounded by its impact on banks' effort in gathering information. As banks become better at processing information, the return to exerting effort increases, so that banks choose a higher effort level. Hence an inside bank's information advantage should increase as well. Together with the result of Proposition 2, this induces a further increase in interest rates as a consequence of the increase in I. Corollary 1, therefore, provides a theoretical counterpart to the observation that technological progress leverages human capital in banking [e.g., Wilhelm (2001)] and leads to greater effort provision.

It should be mentioned that while borrowers pay higher interest rates as a result of the improved credit assessments by informed banks, they might also benefit from advances in information technology. One obvious benefit is that improved screening reduces the likelihood that a good borrower is mistakenly turned down for a loan. Hence improvements in IT could expand the credit market, if there were previously un- or underserved borrowers [see, e.g., Emmons and Greenbaum (1998)]. Evidence in Petersen and Rajan (2002) supports this view. They find that the usefulness of geographical distance between borrowers and lenders as a predictor of credit quality has decreased over time. The implication is that superior ability to obtain information about borrowers has allowed banks to lend to *observably* worse borrowers but whose credit quality may be equally good on the basis of privately observed characteristics.

2.2 Information externalities

So far we have only focused on the case where an advance in IT improves an inside bank's ability to acquire and process information. A second aspect of technological improvements is that intermediaries might gain easier access to information. In this scenario, banks can acquire some information even without screening or investing resources. One reason is that a certain portion of any collected information disseminates quickly and becomes freely available to all other lenders. In other words, there are informational spillovers as a result of technological progress.

We capture this effect by assuming that an information externality implies that outside banks costlessly observe a public signal about borrower type, $\eta_p \in \{l, h\}$. The probability of a successful credit assessment based on the public signal is

$$\phi_p = \frac{2 - \frac{1}{t}}{2}, \quad t \in [1, \infty), \tag{4}$$

where $\phi_p = \Pr(\eta_p = h|\theta = h) = \Pr(\eta_p = l|\theta = l)$. As t increases, the quality of the publicly available signal improves. For $t = 1$, the public signal has no information content. As $t \to \infty$, the public signal becomes perfectly informative. Hence an improvement in IT, in the sense of providing easier access to information, corresponds to an increase in t. Assuming that any inside bank also observes the public signal η_p in addition to the result of its own private appraisal η, we can solve the model of competition with asymmetric information as in the previous section. The key difference now, however, is that outside banks have some information about borrowers rather than being completely uninformed. For simplicity, we assume that t is sufficiently high so that observing a negative signal provides enough information to deny credit.

The general effect of informational spillovers is to erode the competitive advantage of an informed bank. In essence it reduces the returns to screening, since competing lenders can obtain some borrower-specific information for free. Hence an equivalent approach is to treat an information externality as decreasing the quality of an inside bank's credit assessment. We therefore redefine the screening technology from the previous section so as to incorporate this effect, and assume once again that only the inside bank obtains any information:

$$\phi = \left(\frac{1 + \frac{Ie}{t}}{2}\right), \quad I \in (0, 1), \;\; e \in [0, 1], \;\; t \in [1, \infty). \tag{5}$$

We demonstrate in the appendix that this more tractable specification is, indeed, equivalent to assuming that other potential lenders have access to a public signal such as the one in Equation (4). As t increases, the relative informational advantage of an inside bank diminishes, precisely because other banks can gain access to at least some of its privately generated information.

Using this framework, we now investigate the impact of improved access to information on bank profits and expected interest rates. In particular, we analyze the effect of an increase in t on the equilibrium that obtains from the competition over borrowers between one inside and one outside bank.

Proposition 3. *Expected interest rates, $E[\hat{r}]$, are decreasing in the quality of the public signal t.*

Proof. The proof of this result is identical to that of Proposition 2 and Lemma 1, where we replace $\partial p(\eta)/\partial I$ by $\partial p(\eta)/\partial t$. Since $\partial p(\eta)/\partial t$ is negative for $\eta = h$ and positive for $\eta = l$, both F_i and F_u must be increasing in t. The result now follows from observing that $F(r) = F_i(r, h) + F_u(r) - F_i(r, h)F_u(r)$ is also increasing in t. ■

In contrast to the previous case, Proposition 3 establishes that the expected interest rate paid by borrowers, $E[\min\{r_i, r_u\}]$, must be decreasing in t, the parameter describing ease of access to information. In other words, by decreasing the relative information advantage of an inside bank, bank profits not only diminish ($\partial E[\pi_i(\eta)]/\partial t < 0$), but lending rates are also lower.[9]

Improvements in IT that reduce the asymmetries of information across lenders have beneficial competitive effects for their customers. Unlike the previous case, this aspect of technological progress does in fact serve to level the playing field. Easier access to information allows competing banks to better sort borrowers and therefore reduces some of the problems associated with competition under asymmetric information. In particular, it leads to more competitive loan rate offers by lowering the winner's curse faced by a less-informed bank. Hence better dissemination of information limits an inside bank's ability to use its information advantage to informationally capture its clients.

There also exists an additional effect through banks' effort decisions, as lowering the return to screening activities also decreases the amount of information banks are willing to gather about borrowers.

Corollary 2. *The optimal level of screening effort e^* is decreasing in t.*

Proof. With a minor change to Corollary 1, the first-order condition for optimal effort becomes

$$\frac{1}{\bar{p}}(p_h - p_l)q(1-q)\frac{I}{t} - c'(e) = 0.$$

We can apply the implicit function theorem to solve for $\partial e^*/\partial t$ as

$$\frac{\partial e^*}{\partial t} = -\frac{\frac{1}{\bar{p}}(p_h - p_l)q(1-q)\frac{I}{t^2}}{c''(e)},$$

which is less than zero since $c''(e) > 0$. ■

[9] In contrast to our results, Rajan (1992) finds that the informed bank's rents are unaffected by an increase in the precision of public information when a perfectly informed bank competes with an outside lender that observes a public signal. This result holds when the range of precision for the public signal is restricted so that observing a negative public signal does not provide the outside lender sufficient information to abstain from lending. In our model, the inside bank is not necessarily perfectly informed and observing a negative signal provides sufficient information to rule out lending.

Since increased spillovers of information decrease the returns to effort spent on gathering and interpreting information, banks exert lower levels of effort when such effort is costly. Note that this consequence of easier information dissemination also implies that inside banks' informational advantage shrinks even further. Again, coupled with Proposition 3, this indirect effect of technology improvements means that borrowers should obtain more competitive interest rate offers on loans.

The above result can lead to the perverse outcome that easier access to information, by preventing banks from profiting from previously private information, results in less borrower screening. Hence markets could potentially become less efficient to the extent that information acquisition is beneficial: less precise information in the wake of its faster dissemination may lead banks to turn down more high-quality loan applicants. This observation is particularly true if, as suggested below, the amount of information that spills out depends on how much was gathered in the first place.

We should also emphasize that we are only analyzing situations where information advantages over competitors generate rents for the bank. There may, however, be situations where the incentives of the intermediary are aligned with those of its client, so that the release of information might be beneficial. An example can be found in the underwriting of public equity offers. Here an investment bank may prefer to disclose information it has gathered about its client in order to lower investors' information asymmetries and obtain a higher price for the equity issue.[10]

2.3 Implications for financial services

While we think of improved information processing and easier access to information as two different dimensions of technological progress, they might simultaneously be present in practice. In recent years we have seen dramatic increases in both the ability to process information as well as the ease with which information can be transmitted. Which effect is likely to dominate depends on the specific circumstances and the market in question, as well as the relative magnitudes of these changes. Whenever the ability of clients to disseminate information increases, we would expect competition to become more intense as intermediaries in those markets operate on a more level playing field. Conversely, when most of the progress lies in the use of computing and processing equipment, for example, for proprietary pricing, risk assessment, or credit scoring models, we should expect the gulf between those who are informed and those

[10] See Milgrom and Weber (1982) for a general result, Diamond (1985) for an application to financial markets, and Benveniste *et al.* (2003) for empirical evidence in the context of IPOs.

who remain uninformed to increase. Determining which effect is more important is an empirical matter.

There is a second, more subtle reason why disentangling these two effects may prove delicate. While we have treated I and t as distinct, it seems plausible that much of the information that spills over is second hand and depends on the amount of privately generated information, which is a function of both the state of technology I as well as the effort spent on acquiring and processing information. This effect can be captured by allowing the quality of the publicly observed signal, ϕ_p, to be an increasing function of ϕ, the quality of the privately generated signal. In our reduced-form model, we could equivalently assume that the spillover parameter t is a function of the variables that define the amount of information generated, that is, $t = t(Ie)$. More stringent disclosure standards for both publicly quoted firms (SEC's Regulation (FD)), or borrowers and lenders (credit bureaus, regulatory disclosure) might justify this specification.[11]

Improvements in IT now have a direct and indirect effect on the informed intermediary's informational advantage: $d\phi/dI = \partial\phi/\partial I + (\partial\phi/\partial t)(\partial t/\partial I)$. Since the direct effect $\partial\phi/\partial I$ is positive and $\partial\phi/\partial t$ is negative, the indirect effect reduces the competitive advantage from information processing improvements through spillovers ($\partial t/\partial I > 0$). While it is unlikely that the indirect effect would dominate, intermediaries may not be able to fully appropriate the gains from improved processing ability. Moreover, there is a similar effect stemming from increases in effort, in that part of the increased proprietary information generated may also dissipate with the public signal ($\partial t/\partial e > 0$). Taken together, these effects could further reduce the incentives for intermediaries to spend resources on generating information.

While an empirical examination of the two effects' relative magnitudes is beyond the scope of this article, our analysis offers some testable implications for such an endeavor. In particular, we would expect increasing IT investments in markets with captive customers, such as small business lending, to be accompanied by rising loan rates *ceteris paribus*. At the same time, one should observe more dispersed loan pricing[12] and an expanded customer base, as conjectured by Emmons and Greenbaum (1998). Conversely, financial markets characterized by spillovers and wider information dissemination initiated by regulation or customers should exhibit less disperse and falling prices as IT improves [e.g., securities underwriting; see Wilhelm (1999)].

[11] Information sharing mechanisms in the insurance and credit markets could not have acquired their present prominence without modern technology for collecting, processing, and disseminating information; see Padilla and Pagano (1997) for an analysis of such mechanisms.

[12] Passmore and Sparks (2000) conjecture that this effect might exist in the context of mortgage markets.

3. Extensions and Generalizations

This section extends our model in several dimensions. We first consider efforts by the inside bank to prevent informational spillovers and protect its proprietary information. We then endogenize a bank's decision to become an inside lender.

3.1 Preventing expropriation of information

In our model, intermediaries face the threat that they cannot fully appropriate the gains from customer-specific informational investments. In practice, we would expect banks to react to technological advances that undermine their property rights over information by exerting effort to protect these rights. In their analysis of the public good aspects of private information in banking, Anand and Galetovic (2000) show how repeated interaction can lead to self-enforcing agreements by intermediaries not to poach private information, nor the human capital behind it. In this section we focus on actions that intermediaries can take to directly protect their investments in the generation of information, and provide an alternative channel for intermediaries to assert their property rights over information.[13]

Suppose that, in addition to the effort e spent on generating information, the inside bank can exert costly effort $\tilde{e} \in [0, 1]$ to prevent information leakage or expropriation. Such effort might include signing and enforcing confidentiality agreements with clients and employees, building secure systems and firewalls, and taking legal action against competitors to protect intellectual property. Let the spillover variable $t \geq 1$ be given by

$$t(\tilde{e}, \alpha) = \frac{1}{1 - \alpha(1 - \tilde{e})}, \quad \alpha \in [0, 1),$$

so that it decreases in preventive effort $\tilde{e}$ and increases in the externality parameter α which, in light of the preceding section, might itself be a function of information processing capacity I. For $\tilde{e} = 0$, this specification is the same as in the preceding section: as α increases toward 1, which represents greater informational spillovers, t approaches infinity as before. Borrower screening is then successful with informativeness,

$$\phi = \frac{1 + (Ie/t)}{2} = \frac{1 + [1 - \alpha(1 - \tilde{e})]Ie}{2}.$$

For concreteness, we take effort costs to be quadratic, that is, $c(e, \tilde{e}) = (e^2 + \tilde{e}^2)/2$. Ex ante expected net profits are therefore

$$E[\pi_i(\eta)] - c(e, \tilde{e}) = \frac{1}{\bar{p}}(p_h - p_l)q(1 - q)[1 - \alpha(1 - \tilde{e})]Ie - \frac{e^2 + \tilde{e}^2}{2}. \qquad (5)$$

[13] As Wilhelm (2001) observes, advances in IT have the potential to disrupt existing mechanisms for protecting intermediaries' property rights over information. Intermediaries, therefore, have an incentive to pursue alternative strategies that enforce their property rights and ensure an adequate return on their investments in innnovation and information gathering.

The inside bank chooses productive and preventive efforts e and $\tilde{e}$ so as to maximize the preceding expression given the information processing and leakage-state variables I and α. We now characterize its optimal response to technological progress that fosters informational externalities.

Proposition 4. *In equilibrium, both types of effort are strictly positive. There exists a threshold $\hat{\alpha} \in (0,1)$ so that optimal effort in spillover prevention $\tilde{e}^*$ increases in α for $\alpha \leq \hat{\alpha}$, and decreases otherwise. Optimal screening effort e^* decreases in α.*

Proof. See the appendix. ■

As IT improvements weaken the hold of informed banks over proprietary information, these banks allocate more resources to protecting their informational advantage. Initially, optimal spillover prevention effort $\tilde{e}^*$ increases with leakage α. However, when property rights over information become very weak because access to proprietary information has become widespread ($\alpha > \hat{\alpha}$), additional technological progress reduces banks' provision of spillover prevention effort. This reduction occurs because very large informational spillovers erode profitability to a point where inside banks can no longer afford, at the margin, to spend the additional effort it would take to stem this flow. The second result reprises Corollary 2 for the new specification of t and is included for completeness only: when, due to technological progress (α increases), private information becomes harder to protect, inside banks cut back on screening effort e^*. It is easily verified that both types of effort increase in I, as before (see Corollary 1).

We next turn to the incidence of borrower heterogeneity $\Delta_p = p_h - p_l$ to see how one of the underlying economic factors characterizing the population of borrowers affects screening incentives.

Corollary 3. *Both screening and leakage prevention effort increase in borrower heterogeneity Δ_p: $\partial e^*/\partial \Delta_p > 0$ and $\partial \tilde{e}^*/\partial \Delta_p > 0$.*

Proof. The result follows by simple differentiation of the expressions for e^* and $\tilde{e}^*$ with respect to Δ_p in the proof of Proposition 4 [Equations (8) and (9) in the appendix]. ■

As borrowers become more heterogeneous, an informed bank earns higher profits on those borrowers with good signals. The intuition for this result lies in the adverse selection problem faced by the outside bank, which increases in the heterogeneity of borrowers (large Δ_p). In such markets, the returns to generating and protecting proprietary information are correspondingly large. Consequently both types of effort increase in borrower heterogeneity. We next focus on how the threshold $\hat{\alpha}$ for preventive effort depends on the state of technology and borrower heterogeneity.

Corollary 4. *As information processing I improves or borrower heterogeneity Δ_p increases, the threshold $\hat{\alpha}$ also rises: $\partial\hat{\alpha}/\partial I > 0$ and $\partial\hat{\alpha}/\partial\Delta_p > 0$.*

Proof. From the proof of Proposition 4, $\hat{\alpha} \in (0, 1)$, so that taking derivatives of $\hat{\alpha}$ with respect to I and Δ_p establishes the result. ■

The more information processing capacity is available or the more heterogeneity there is in the market, the more valuable proprietary intelligence becomes because ex ante profits from screening increase in I and Δ_p: $\partial E[\pi_i(\eta)]/\partial I > 0$ and $\partial E[\pi_i(\eta)]/\partial\Delta_p > 0$. Again, higher profits from privately generated information translate into both more resources and incentives for the inside bank to protect its informational advantage. Hence it will only scale back its leakage prevention effort when informational externalities are more significant, that is, for higher values of the threshold $\hat{\alpha}$.

3.2 Endogenous screening

We next extend our model by endogenizing the bank's decision to become the inside bank and acquire borrower-specific information. Two ex ante symmetric banks have access to the screening technology and simultaneously decide whether to become informed or not. To focus on technology adoption, we slightly simplify the setup from the previous sections. In particular, we assume that banks can only exert discrete screening effort $e \in \{0, 1\}$ in the first stage. Otherwise, the intermediation game proceeds exactly as before. Exerting screening effort $e = 1$ in the first stage incurs a cost $c > 0$ but allows intermediaries to observe a creditworthiness signal with informativeness $\phi = (1 + Ie/t)/2$, as before.

We assume that signals are perfectly correlated so that if both banks decide to screen, they come to the same credit assessment.[14] This assumption captures the fact that all banks ultimately attempt to analyze the same set of data so that the information obtained essentially depends on whether or not effort is exerted. Bertrand competition ensures that they offer break-even loan rates $r_h = 1/p(h)$ only to borrowers deemed of high quality. Similarly, if no bank screens, they both offer ex ante break-even interest rates $\underline{r} = 1/\overline{p}$. If only one bank screens, we are back in the ex post information monopoly setting of the previous sections and the banks make loan rate offers according to the mixing distributions F_i and F_u we calculated earlier. Table 1 lays out the reduced form of the game's information acquisition stage and summarizes strategies and net payoffs.

[14] If the signals were instead conditionally independent, the construction of the equilibrium would slightly change; see Broecker (1990) or Thakor (1996) for frameworks in which more than one bank screens but all intermediaries use the same technology and signals are conditionally independent.

Table 1
Information acquisition decision

		Bank 2	
		$e_2 = 1$	$e_2 = 0$
Bank 1	$e_1 = 1$	$-c, -c$	$E[\pi_1(\eta)] - c, 0$
	$e_1 = 0$	$0, E[\pi_2(\eta)] - c$	$0, 0$

Lemma 2. *The screening game has two pure strategy equilibria* $\{(1, 0), (0, 1)\}$, *in which one of the banks enjoys an* ex post *informational monopoly, and a unique mixed-strategy equilibrium in which each bank screens with probability*

$$\sigma = 1 - \frac{c}{E[\pi(\eta)]} = 1 - \frac{c}{(1/\overline{p})(p_h - p_l)q(1-q)(I/t)}. \tag{6}$$

Proof. See the appendix. ■

The two pure-strategy equilibria correspond to the information monopoly case of Proposition 1, except that effort is now a discrete choice variable. In these equilibria, only one bank chooses to exert effort in screening. The second bank chooses not to screen because it would not recoup the cost of evaluating the information. For these equilibria, all our earlier results continue to hold. The mixed-strategy equilibrium represents the case where both banks compete to acquire information and dissipate their rents in the process. Note that $\partial\sigma/\partial I > 0$ so that technological progress leads to higher probabilities of information acquisition. Similarly the more heterogenous borrowers are, that is, the higher is $\Delta_p = p_h - p_l$, the more likely banks will screen.

In the mixed screening strategy equilibrium, expected interest rates paid by borrowers are

$$E[r] = \sigma^2 r_h + (1-\sigma)^2 \underline{r} + 2\sigma(1-\sigma)E[\hat{r}],$$

where, as previously defined, $\hat{r} = \min\{r_i, r_u\}$ is the actual interest rate paid if only one bank screens. With probability σ^2, both banks screen and offer high-quality borrowers a rate of r_h. With probability $(1-\sigma)^2$, neither bank screens and borrowers pay the ex ante break-even rate $\underline{r}$. Finally, with probability $2\sigma(1-\sigma)$, one bank enjoys an information monopoly so that expected interest rates are $E[\min\{r_i, r_u\}]$ as in the preceding sections.

Proposition 5. *There exists a screening probability* $0 < \hat{\sigma} < 1$ *such that*

$$\frac{\partial E[r]}{\partial I} > 0 \quad \text{for } \sigma \in [0, \hat{\sigma})$$
$$\frac{\partial E[r]}{\partial I} < 0 \quad \text{for } \sigma \in (\hat{\sigma}, 1].$$

Proof. See the appendix. ■

Proposition 5 shows that the mixed-strategy equilibrium shares the same properties as the pure strategy equilibria for certain parameter values. In particular, the earlier result that expected interest rates increase with improvements in information processing continues to hold for low equilibrium screening rates σ, even when banks compete to acquire information. This result obtains because the benefits of increases in I are only passed on to bank customers when both banks in fact screen. If the probability of screening for each bank is relatively low, the probability of an ex post information monopoly is greater than the probability that both banks will be informed, and the effect stemming from the ex post monopoly dominates. When the probability of screening is high, however, increased competition among informed lenders forces intermediaries to pass on the benefits of improvements in IT to customers, and interest rates fall.

Equation (7) indicates that a broad range of parameter values yields low screening probabilities σ. For instance, high screening costs c deter either bank from acquiring information because duplicated screening is then very costly. Hence we can restate Proposition 5 in terms of effort cost: there exists a value $0 < \tilde{c} < E[\pi(\eta)]$ such that increases in I lead to rising interest rates if and only if $c > \tilde{c}$. Similarly we see that low values of I translate into low screening probabilities because profits from information acquisition are correspondingly low (Proposition 1). Initial improvements in information processing now imply higher expected interest rates as banks begin to make use of their informational advantage. Only as information processing becomes very efficient (high I) does information duplication translate into competitive gains for borrowers.

Finally, it should be noted that ex ante expected profits for both banks are zero in this mixed-strategy equilibrium. Hence we might expect that most of the benefits from technological improvements are passed on to customers as banks compete away their rents. However, this setting is most likely to apply to banks either entering new markets or serving new customers. Once business relationships are established, it is unlikely that the benefits to an inside bank of any subsequent technological improvements will be entirely bid away because we are, once again, in the ex post monopoly setting of the previous sections. Hence the mixed-strategy equilibrium from Proposition 5 probably applies best to situations where no intermediary has a market presence, whereas Section 2.1 covers the case of technological progress in established markets.

4. Applications and Discussion

Improvements in information technology also affect other financial markets so that we now generalize our model and present examples from the insurance and securities industries. We also discuss determinants of the IT state variables in light of our results.

4.1 Insurance

Medical and computer science advances have given rise to new data storage and risk assessment technologies that allow much more detailed insurance classifications. Examples of this trend can be found in the advent of genetic screening and the computerization of medical records. To study their impact, consider differentially informed insurance companies that compete for customers of low- or high-risk type $\theta \in \{l, h\}$. Outcomes (losses) for policy holders can be $X = -V$ with probability p_θ and $X = 0$ with complementary probability. Insurance companies compete in loss payouts v per \$1 of premium income.[15] All our earlier results carry over, but the conclusions of Propositions 2 and 3 are reversed: expected payout rates decrease in the state of technology I and increase in t. As improvements in information processing lead to lower payout rates and higher profitability for informed insurers, their screening effort increases and policy holders become informationally more captured. However, much of the data collected by insurance and related companies routinely finds its way into the public domain, too. In the presence of significant informational spillovers, insurance customers benefit and we would expect payout rates to rise and insurer profitability to fall with technological progress.

4.2 Underwriting securities

The recently adopted SEC Regulation FD bars the selective dissemination of nonpublic information by listed companies. As a result, publicly quoted companies have started to use electronic news media (Internet) to disclose much more information and, especially, more detailed financial (statement) information to investors.[16] To illustrate the consequences of the Regulation FD in the context of our model, suppose that a firm of unknown quality $\theta \in \{l, h\}$ is going public. Institutional (informed) as well as less-informed (retail) investors bid for a dollar amount s in the firm.[17] The market agrees that the firm is worth $X = S > 0$ with probability p_θ and $X = 0$ otherwise.

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[15] Insurance premia ρ are usually set per \$1 insured with payoffs $\rho - p_\theta \cdot 1$ so that one can equivalently use the payout rate $v = 1/\rho > 1$ per \$1 of premium. This formulation preserves our payoff structure as $\pi(v, \theta) = -(p_\theta v - 1)$.

[16] In Boot and Thakor (2001), firms can choose what to disclose to which party. Regulation FD makes this much harder so that firms might find it advantageous to disclose as much as possible to all investors through, for example, their websites. Investors are now responsible for downloading, sorting, and processing all this company-specific information.

[17] This setup is equivalent to the more usual case where investors bid for a certain number of shares, or a fraction of the firm's equity: simply define the fraction of the firm to be purchased as s/S, and assume that bidders compete for this fraction. Net profits per \$1 investment to an informed investor are $\pi(\hat{s}, \theta) = p_\theta \hat{s} - 1$, where $\hat{s} = \frac{s}{b}$ for the offered price b.

By Propositions 2 and 3, the value of cash flow rights to informed investors such as large mutual funds or investment banks increases in the state of technology I, but decreases in information dissemination t. Since the latter prevents informed investors from fully appropriating the gains from screening, such an improvement raises IPO prices and diminishes information rents because of a reduction in the winner's curse. This result shows how technology can also be responsible for the "crowding out effects" demonstrated by Diamond (1985) or Fishman and Haggerty (1992) in the context of insider trading. As spillovers reduce the informed investors' informational advantage, their incentives to gather costly information fall.

4.3 Determinants of the state of technology

Our analysis shows how economic factors such as borrower heterogeneity, screening cost, competition in information acquisition, and the state of IT determine the intermediaries' optimal choice of screening and leakage prevention efforts ϵ and $\tilde{\epsilon}$ through their impact on bank profitability. Throughout we have treated I and t as IT state variables so that banks view them as exogenously given when choosing their effort levels and lending strategies. However, these variables, while fixed at any moment in time, constantly evolve, which is consistent with our focus on how changes in these variables affect credit markets. Here we discuss how certain underlying economic factors might drive the evolution of these state variables over time.

Intermediaries themselves may be leaders in the development of new information processing capabilities (e.g., development of credit scoring systems, automated loan pricing, and underwriting). Current and past profitability often determine the resources spent on research and development for the next generation of IT in financial services. At the very least, financial intermediaries create a market for IT (storage, processing, dissemination) and generate a large part of the demand for such improvements that, in turn, may lead to greater profits. Hence there is a compounding effect in the development of information processing ability: improvements (increases in I) raise the profits of banks that make use of technological progress, which then provides greater resources for the further development of such technologies. The upshot is a cycle where initial improvements and early adoption may translate into significant IT improvements through higher profitability as intermediaries allocate more resources toward research and development.

These feedback effects between informational rents and IT development might be intensified by other economic factors that reinforce the use of technology. For example, as we point out in Section 3.1, greater borrower heterogeneity Δ_p leads to greater screening effort as credit assessments become more important when borrowers are more dissimilar. From

Equation (6), we also see that $\partial^2 E[\pi_i(\eta)]/\partial\Delta_p \partial I > 0$, so that technological improvements have a greater impact when borrower heterogeneity is high. Hence we might expect to see more resources being devoted to the development of improved processing technology when the return to doing so is higher, which is precisely when borrowers have widely divergent characteristics.

5. Conclusion

In our analysis of how changes in the state of IT affect financial markets, we differentiate between two possible effects. One aspect of technological progress is that financial service providers can better process information. In this scenario, resources invested toward gathering and analyzing information become more productive as processing ability improves. Consequently, an advance in IT increases the informational advantage of intermediaries that gather information relative to competitors who remain uninformed. As the scope for information rents improves, financial markets ultimately become less competitive. In the context of credit markets, for example, this translates into higher interest rates for borrowers.

A competing view holds that improved access to information makes data much more widely and readily available. Proprietary information gathered by one intermediary quickly disseminates to its competitors. An improvement in IT that generates spillovers has the opposite implications to one that affects processing ability. Improved access to information or greater information leakage erodes informational advantages and serves to level the playing field for all market participants. The net result is that markets may become more competitive so that customers benefit from technological progress.

In practice, one would expect both aspects of advances in IT to affect financial services competition. While determining the importance of each effect is an empirical question, this article suggests that advances in IT need not necessarily be beneficial for customers. Hence it is important to carefully identify the relevant type of technological improvement one has in mind for any analysis of its expected consequences.

While there are other aspects of technological progress that might be of relevance to the study of competition and price formation in financial services, we believe that our model can easily be adapted to a more general analysis of competition under asymmetric information. For example, Rajan (1992) argues in the context of credit markets that the potential for information monopoly on the side of a lender may lower a borrower's incentive to exert effort. Padilla and Pagano (1997) show how information sharing, that is, voluntary informational spillovers, can mitigate such effort problems. Our specification might be useful in this context to analyze the incidence of technological progress which, however, is beyond the scope of this article.

Appendix A: Proofs

Proof of Proposition 1 (Sketch). For a proof of the nonexistence of a pure-strategy equilibrium in a similar framework, see von Thadden (1998) and Hauswald and Marquez (2000). A mixed-strategy equilibrium over interest rate offers does, however, exist. The above articles show that the equilibrium distribution functions, F_i and F_u, are continuous and strictly increasing over an interval $[\underline{r}, R)$. Moreover, it is a standard result in models of competition under asymmetric information that a bidder, all of whose information is known by some other competitor, cannot make positive expected profits [see, e.g., Engelbrecht-Wiggans, Milgrom, and Weber (1983)]. Therefore we can conclude that the uninformed lender must make zero expected profits in equilibrium.

To calculate profits for the informed bank, we proceed as follows. Define π_u as the expected profits to the uninformed bank. Since the uninformed bank must make zero profit for every one of its possible bids, it must make zero profits also at the lowest possible bid, $\underline{r}$. Offering that rate must guarantee the uninformed bank of having the lowest rate and winning the interest rate auction. Hence $\pi_u(\underline{r}) = 0 \Leftrightarrow \underline{r}\overline{p} - 1 = 0 \Rightarrow \underline{r} = 1/\overline{p}$. Upon observation of a low signal ($\eta = l$), the informed bank abstains from making a loan offer and its profits are $\pi_i(l) = 0$.[18] However, upon observing a high signal ($\eta = h$), the informed bank bids and obtains expected profits

$$\pi_i(h) = \underline{r}p(h) - 1 = \frac{1}{\overline{p}}p(h) - 1 = \overline{\pi} > 0.$$

Note that, in equilibrium, all its loan offers conditional on a high-quality credit assessment yield the same profit. The calculation of ex ante expected profits as stated in the proposition then follows directly by substituting for $\pi_i(l) = 0$ and $\pi_i(h)$ from the above expression, and simplifying.

Finally, the distribution functions can be obtained by solving the following expression for expected profits, where $\pi_i(r, h)$ represents the profits to an informed bank of bidding a rate of r:

$$\begin{aligned} \pi_u(r) &= 0 = (1 - F_i(r))(r\overline{p} - 1) + F_i(r)(rp(l) - 1) \\ \pi_i(r, h) &= \overline{\pi} = (1 - F_u(r))(rp(h) - 1). \end{aligned}$$

Substituting for $\overline{\pi}$ and solving for F_i and F_u yields the expressions in the text. ■

Proof of Lemma 1. Recall the definition of $F_i(r,h) = [(p(h) - p(l))/(\overline{p} - p(l))] \times (\overline{p}r - 1)/(p(h)r - 1)$ and $F_u(r) = [p(h)/\overline{p}](pr - 1)/(p(h)r - 1)$. Differentiation of F_i with respect to I yields

$$\begin{aligned} \frac{\partial F_i(r,h)}{\partial I} = \frac{(\overline{p}r - 1)}{(\overline{p} - p(l))^2(p(h)r - 1)^2}\big[&p'(l)(p(h) - \overline{p})(p(h)r - 1) \\ &+ p'(h)(\overline{p} - p(l))(rp(l) - 1)\big] < 0, \end{aligned}$$

[18] This represents simply a restriction on the pair (I, $c(e)$), to ensure that enough information is always gathered so that lending to a borrower with a low signal is unwarranted.

where $p'(\eta) = \partial p(\eta)/\partial I$. Similarly for F_u,

$$\frac{\partial F_u(r)}{\partial I} = p'(h)\frac{(1-\overline{p}r)}{\overline{p}(p(h)r-1)^2} < 0.$$

Since

$$F(r) = F_i(r,h) + F_u(r) - F_i(r,h)F_u(r),$$

we have that

$$F(r) = (1 - F_u(r))\frac{\partial F_i(r,h)}{\partial I} + (1 - F_i(r,h))\frac{\partial F_u(r)}{\partial I} < 0,$$

since $(1 - F_u(r))$, $(1 - F_i(r, h)) > 0$ and $\partial F_i(r,h)/\partial I$, $\partial F_u(r)/\partial I < 0$ a.s. ■

Proof of Proposition 4. By Equation (6), the inside bank solves the following maximization problem:

$$\max_{(e,\tilde{e}) \in [0,1]^2} \left\{ \frac{1}{\overline{p}}(p_h - p_l)q(1-q)[1 - \alpha(1-\tilde{e})]Ie - \frac{e^2 + \tilde{e}^2}{2} \right\}.$$

The first-order conditions for screening and preventive effort are, respectively,

$$\frac{1}{\overline{p}}(p_h - p_l)q(1-q)[1 - \alpha(1-\tilde{e})]I - e = 0$$
$$\frac{1}{\overline{p}}(p_h - p_l)q(1-q)\alpha Ie - \tilde{e} = 0.$$

We can solve these directly for optimal effort levels. Define $A \equiv (1/\overline{p})(p_h - p_l)q(1-q)$. Then

$$e^* = \frac{1-\alpha}{1-\alpha^2A^2I^2}AI \in (0,1) \tag{8}$$

$$\tilde{e}^* = \frac{1-\alpha}{1-\alpha^2A^2I^2}A^2I^2\alpha \in (0,1). \tag{9}$$

Differentiating the optimal effort levels with respect to the spillover parameter α yields

$$\frac{\partial e^*}{\partial \alpha} = -AI\frac{\alpha^2A^2I^2 - 2\alpha A^2I^2 + 1}{(\alpha^2A^2I^2 - 1)^2}$$
$$\frac{\partial \tilde{e}^*}{\partial \alpha} = A^2I^2\frac{\alpha^2A^2I^2 - 2\alpha + 1}{(\alpha^2A^2I^2 - 1)^2}.$$

Defining the numerator of $\partial e^*/\partial\alpha$ as $g(\alpha) \equiv \alpha^2A^2I^2 - 2\alpha A^2I^2 + 1$, we see that $g(\alpha)$ is quadratic in α and has a minimum at $\alpha = 1$; also, $g(0) = 1$ and $g(1) = 1 - A^2I^2 > 0$ since $A, I \in (0, 1)$, so that $\alpha^2A^2I^2 + 1 - 2\alpha A^2I^2 > 0$ for $\alpha \in (0, 1)$. Hence we find $\partial e^*/\partial\alpha < 0$. Repeating a similar argument for $\partial\tilde{e}^*/\partial\alpha$, we have that the numerator and hence the derivative changes in sign. Solving the quadratic equation $\alpha^2A^2I^2 - 2\alpha + 1 = 0$ for the critical value $\hat{\alpha} = (1/2A^2I^2)(2 - 2\sqrt{1 - A^2I^2}) \in (0,1)$ establishes that $\partial\tilde{e}^*/\partial\alpha > 0$ for $\alpha < \hat{\alpha}$ and $\partial\tilde{e}^*/\partial\alpha < 0$ for $\alpha > \hat{\alpha}$, as desired. ■

Proof of Lemma 2. Without loss of generality, suppose bank 1 decides to become an inside bank ($e_1 = 1$) at cost $c > 0$. If bank 2 does not screen ($e_2 = 0$), bank 1 enjoys an informational monopoly and its expected profits in the next stage, gross of the cost of effort, will be $E[\pi_1(\eta)] = (1/\overline{p})(p_h - p_l)q(1-q)[2\phi - 1] = (1/\overline{p})(p_h - p_l)q(1-q)I/t$, as before. If bank 2 does screen, the assumption of perfectly correlated signals ensures that Bertrand competition ensues, so that both banks break even with loan rate offers $r_h = 1/p(h)$. If bank 1 decides not to become informed ($e=0$), then it makes zero profits independently of whether bank 2 is an inside bank or not.

From Table 1, it is immediate that the game has two pure-strategy equilibria $\{(1,0),(0,1)\}$ in which one of the banks enjoys an ex post informational monopoly. However, the game also has a symmetric mixed-strategy equilibrium in screening probabilities. We construct this equilibrium next. Let σ be the probability of screening a borrower for either bank. From Table 1 we have

$$\text{Payoff to screening } (e_i=1) \qquad (1-\sigma)\frac{1}{\overline{p}}(p_h-p_l)q(1-q)\frac{I}{t}-c$$

$$\text{Payoff to not screening } (e_i=0) \quad 0.$$

In equilibrium, each bank must be indifferent between screening and not screening. Therefore setting these expressions equal to each other and solving for σ yields

$$\sigma = 1-\frac{c}{\frac{1}{\overline{p}}(p_h-p_l)q(1-q)\frac{I}{t}} = 1-\frac{c}{E[\pi(\eta)]}.$$

Proof of Proposition 5. Since expected interest rates paid by borrowers are

$$E[r] = \sigma^2 r_h + (1-\sigma)^2 \underline{r} + 2\sigma(1-\sigma)E[\hat{r}],$$

taking the derivative with respect to the state of technology I yields

$$\frac{\partial E[r]}{\partial I} = 2\frac{\partial \sigma}{\partial I}\{\sigma(r_h+\underline{r}-2E[\hat{r}])+E[\hat{r}]-\underline{r}\}+\sigma^2\frac{\partial r_h}{\partial I}+2\sigma(1-\sigma)\frac{\partial E[\hat{r}]}{\partial I}.$$

This expression cannot be signed unambiguously because $\partial\sigma/\partial I,\ \partial E[\hat{r}]/\partial I>0$, but $\partial r_h/\partial I<0$ from $\partial p(h)/\partial I=(p_h-p_l)\partial H/\partial I>0$. However, taking limits we see that

$$\lim_{\sigma\to 0}\frac{\partial E[r]}{\partial I} = 2\frac{\partial\sigma}{\partial I}\{E[\hat{r}]-\underline{r}\}>0$$
$$\lim_{\sigma\to 1}\frac{\partial E[r]}{\partial I} = 2\frac{\partial\sigma}{\partial I}\{r_h-E[\hat{r}]\}+\frac{\partial r_h}{\partial I}<0,$$

since $\hat{r}\in[\underline{r},\overline{r}]$ by the construction of the mixing strategies in the lending subgame, and since $r_h<\underline{r}$ from $p(h)>\overline{p}$ and $\partial r_h/\partial I<0$. Furthermore, $\partial E[r]/\partial I$ as a function of σ is quadratic in σ, strictly concave and continuous on [0, 1]. Appealing to the Intermediate Value Theorem, we obtain that there exists a unique mixing probability $\hat{\sigma}\in(0,1)$ so that $\partial E[r]/\partial I|_{\sigma=\hat{\sigma}}=0$. Consequently we find that the interest rate effect of technological progress depends on screening probabilities as claimed:

$$\frac{\partial E[r]}{\partial I}>0 \quad \text{for } \sigma\in[0,\hat{\sigma})$$
$$\frac{\partial E[r]}{\partial I}<0 \quad \text{for } \sigma\in(\hat{\sigma},1].$$

Appendix B: Equivalence of Approaches

In this section we demonstrate that using a model where increased access to information erodes the advantage of the screening bank is equivalent to assuming that less-informed banks observe a public signal about borrowers' types. As in the text, suppose that all banks observe a *public* signal about borrower type, $\eta_p\in\{l,h\}$, that is correct with probability ϕ_p given by

$$\phi_p = \frac{2-\frac{1}{t}}{2}, \quad t\in[1,\infty). \tag{10}$$

In addition, a screening bank observes the private signal η defined in the text, with precision $\phi=(1+Ie)/2$. We show that this specification is equivalent to one where the screening bank instead observes a private signal with precision $(1+Ie/t)/2$ and there is no public signal.

As with the private signal, observing ϕ_p allows each bank to update its prior over borrower type as follows. By Bayes' rule, the probability of a project being of high or low quality given a credit assessment of $\eta_p=h$ or $\eta_p=l$ is

$$\Pr(\theta=h|\eta_p=h)=\frac{\phi_p q}{\phi_p q+(1-\phi_p)(1-q)}\equiv H_p$$
$$\Pr(\theta=l|\eta_p=l)=\frac{\phi_p(1-q)}{\phi_p(1-q)+(1-\phi_p)q}\equiv L_p.$$

We obtain the project's success probability conditional on the result from screening $p(\eta_p)$ as

$$p(h_p)\equiv\Pr(X=R|\eta_p=h)=H_p p_h+(1-H_p)p_l\in[\overline{p},p_h]$$
$$p(l_p)\equiv\Pr(X=R|\eta_p=l)=(1-L_p)p_h+L_p p_l\in[p_l,\overline{p}].$$

Effectively, the observation of the public signal allows nonscreening banks to divide the market in two: those borrowers for whom $\eta_p=h$, and those for whom $\eta_p=l$. We assume that the public signal is sufficiently informative (ϕ_p sufficiently high) so that lending to a borrower with a negative signal is not worthwhile: $Rp(l_p)<1$.[19] We can treat these markets separately in what follows.

For the informed (screening) bank, the observation of two signals, the public and its private signal, allows a further refinement of its prior. Specifically we define

$$p(h_p,h)\equiv\Pr(X=R|\eta_p=h,\eta=h)$$
$$p(h_p,l)\equiv\Pr(X=R|\eta_p=h,\eta=l)$$
$$p(l_p,h)\equiv\Pr(X=R|\eta_p=l,\eta=h)$$
$$p(l_p,l)\equiv\Pr(X=R|\eta_p=l,\eta=l).$$

Since both signals are informative, it is clear that $p(h_p, h)>p(h_p)>p(h_p, l)$ and $p(l_p,h)>p(l_p)>p(l_p,l)$.

We focus on expected profits conditional on the public signal η_p, but before the private signal is observed. We write this as

$$E[\pi(\eta)|\eta_p=h]=\Pr(\eta=h|\eta_p=h)\pi(h_p,h)+\Pr(\eta=l|\eta_p=h)\pi(h_p,l).$$

By analogy to the results with just the private signal, the screening bank should make zero profits if it observes a low signal, whether it bids or not, which depends on whether $p(h_p,l)R-1>0$. This implies that $\pi(h_p, l)=0$. We also know that, at the lower bound of the mixing distribution (which now depends on the public signal), expected profits for the nonscreening bank are zero. In other words, $\pi(h_p)=0\Leftrightarrow \underline{r}(h_p)p(h_p)-1=0\Rightarrow \underline{r}(h_p)=1/p(h_p)$. Therefore profits to the screening bank, upon observing a high signal, must be

$$\pi(h_p,h)=\underline{r}(h_p)p(h_p,h)-1=\frac{p(h_p,h)-p(h_p)}{p(h_p)}>0.$$

[19] This condition is simply a restriction that the precision of the public signal ϕ_p be sufficiently high. Relaxing this condition merely increases the number of separate cases we need to consider, but does not change in any way our results.

We therefore need to calculate $p(h_p, h)$. The posterior distribution on borrower type after the observation of two high signals is

$$HH \equiv \Pr(\theta = h | \eta_p = h, \eta = h) = \frac{\phi H_p}{\phi H_P + (1-\phi)(1-H_p)}$$
$$= \frac{\phi\phi_p q}{\phi\phi_p q + (1-\phi)(1-\phi_p)(1-q)}.$$

We can now define $p(h_p, h) = HH \cdot p_h + (1 - HH) \cdot p_l$.

The last item we need for our expected profits expression is $\Pr(\eta = h | \eta_p = h) = \Pr(\theta = h | \eta_p = h)\Pr(\eta = h | \theta = h) + \Pr(\theta = l | \eta_p = h)\Pr(\eta = h | \theta = l) = H_p\phi + (1 - H_p)(1-\phi)$. Therefore, expected profits for an informed bank can be written as

$$E[\pi(\eta) | \eta_p = h] = [H_p\phi + (1-H_p)(1-\phi)]\left[\frac{p(h_p, h) - p(h_p)}{p(h_p)}\right].$$

Some algebraic manipulation shows that this can be further written as

$$E[\pi(\eta) | \eta_p = h] = (p_h - p_l)\left(\frac{1}{\phi_p q p_h + (1-\phi_p)(1-q)p_l}\right)\left(\frac{\phi_p(1-\phi_p)q(1-q)(2\phi - 1)}{\phi_p q + (1-\phi_p)(1-q)}\right).$$

For $\phi_p \geq \frac{1}{2}$, this expression for profits is monotonically decreasing in the precision of the public signal, which is measured by t. In other words, a more precise public signal erodes the information advantage of the screening bank, as desired.

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