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Interbank competition and information production: Evidence from the interest rate difference ☆

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ABSTRACT

In this paper, using firm-level cross-sectional data in the US, we report that interest rates on loans extended by inside banks are significantly lower than those on loans extended by outside banks for younger firms in concentrated loan markets, while such loan rate differences are not clearly observed in competitive loan markets. The analytical model presented in this paper predicts that an inside bank is more likely to quote rates lower than those of outside banks to capture a customer in order to gain time to establish exclusive access to the customer's private information, counting on the consequent future rent from informational advantages over rival banks, if the inside bank intends to acquire private information about the borrower's creditworthiness. In light of this prediction, we conclude that the above empirical finding is consistent with the hypothesis that increased competition discourages banks from collecting borrower-specific private information.

1. Introduction

Is harsher interbank competition detrimental to information production by banks? The available theoretical literature provides mixed answers to this question. On the one hand, several theorists

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predict that harsher lending competition discourages bankers from information production by decreasing the expected payoff from acquiring borrower-specific private information in future lending competition (Mayer, 1988; Petersen and Rajan, 1995; Boot and Thakor, 2000; Hauswald and Marquez, 2006). On the other hand, a number of theoretical analyses predict that harsher lending competition may drive bankers to make use of their given information advantage over rivals so as to reduce the competitive pressure by differentiating themselves from rivals with superior consulting and monitoring abilities or reputations for having better screening abilities (Boot and Thakor, 2000; Dinç, 2000; Yafeh and Yosha, 2001; Dell'Ariccia and Marquez, 2004; Anand and Galetovic, 2006).[1] Thus, the impact of lending competition on the production or usage of borrower-specific private information remains an empirical question.

The discrepancy in theoretical predictions comes from the difference in the prediction about the impact of the number of competing banks or other market-structure factors on the rent generated by an informational advantage over rival banks resulting from collecting borrower-specific private information. This rent renders banks more willing to extend loans to new firms to preempt the rent-seeking opportunity (Sharpe, 1990; Petersen and Rajan, 1995; Von Thadden, 2004), but it can result in economic inefficiency because it is a result of such information asymmetry among competing banks (Sharpe, 1990; Rajan, 1992). At this point, it is an essential task to measure the rent from obtaining private information and to examine the impact of lending competition on the rent. One of the challenges in doing so is that such rent is not readily observable from survey data. In this study, we propose an empirical strategy to overcome this difficulty on the basis of an analytical model that takes into account the time-to-build assumption in terms of an information advantage. We apply it to small-business financing data in the US, which has been used in many existing empirical studies.

The analytical part of this paper shows that the interest rate of a loan extended by an inside bank is lower than that of a loan extended by an outside bank in the perfect Bayesian equilibrium when the inside bank has invested in borrower-specific private information but the outcome of the investment, i.e., the information advantage over rival banks, has not yet been realized. It is also shown that this interest rate difference is an increasing function of the expected rent from obtaining private information exclusively.

Once a bank has established an informational advantage over rivals, the bank is more likely to win competitive future lending if the borrower turns out to be sufficiently creditworthy and captures the entire payoff from its information production in the standard setup of the existing literature. However, if it takes a while to acquire private information and there is an interim stage at which an inside bank has invested in private information but has not yet obtained it, the inside bank is willing to give up some of the expected rent from future lending to the borrower in order to gain time to acquire private information by continuing the lending relationship. This provides an opportunity for the borrower to capture some of the expected rent, which would otherwise be entirely appropriated by the inside bank. Indeed, our analytical model shows that the borrower imposes a *handicap* on a potentially informed inside bank's interest offer in the equilibrium. This strategy results in a negative difference between the expected interest rate of loans extended by inside banks and that of loans extended by outside banks. Such an interest rate difference does not emerge if an inside bank is not at all willing to invest in private information. Thus, the interest rate difference for firms that have not yet fully established a relationship with a bank serves as the measure of the inside bank's expected rent resulting from private information acquisition. The model also shows the possibility that the inside bank's investment in private information decreases and the interest rate difference diminishes as the number of competing banks increases.

Based on the above analytical model and using micro-data collected from the 2003 National Survey of Small Business Financing in the US, we test the impact of lending competition on the average interest rate difference between inside banks and outside banks by focusing, in particular, on firms that have a single *inside bank*, which is defined as a bank that holds more than one half of a firm's total checking account balances and maintains a relationship with a firm for more than one year. Our

[1] Here, we include Boot and Thakor (2000) in both classes of the literature, because their analysis shows that the ex ante investment in relationship banking decreases, while the usage of the existing relationship lending technology increases, as the number of competing banks increases.

regression analysis and the propensity score matching analysis verify that the impact of borrowing from the inside bank on interest rates is negative and significant for firms less than 10 years old in concentrated credit markets, while such a difference is not observed in competitive credit markets. We also find that this result is reasonably robust across subsamples and against sample selection bias. Thus, the data support the proposition that stronger interbank competition is detrimental to information production by banks. The estimated mean interest discount by borrowing from the inside bank in concentrated markets is 1.42% for five-year-old firms and 0.74% for seven-year-old firms. These interest discounts can be interpreted as, at least, a part of the net present value of acquiring borrower-specific private information, according to our analytical model.

In the existing empirical literature, Elsas (2005) and Degryse and Ongena (2007) using a firm-level micro-dataset of larger firms in Germany and that of small firms in Belgium, respectively, found that the probability of a firm receiving relationship banking is U-shaped against the concentration measures of lending markets. Using survey data of German manufacturing firms, Fischer (2000) finds that banks in more concentrated markets collect more borrower-specific information. The seminal study by Petersen and Rajan (1995) finds that loan interest rates for younger firms are higher in competitive loan markets than in concentrated loan markets and that they decrease more slowly in concentrated markets as borrowing firms get older.[2] They interpret this as evidence that relationship banking is more prevalent in more concentrated markets in the US. Our paper provides additional evidence for this result by using recent data and a new measure; namely, the interest rate difference between loans extended by inside banks and those by outside banks.

The benefit of using this measure is, first, that it enables us to measure the existence of private information that is not accessible from outsiders, including researchers, and is not directly measurable by definition. Second, the measure enables us to test the impact of lending competition on information production after controlling for other potential impacts of lending competition on interest rates, such as the winner's curse (Broecker, 1990; Riordan, 1993; Shaffer, 1998) because it is designed to compare the interest rates of loans extended by inside banks and outside banks within each competitive loan market and concentrated market.

In terms of switching banks, Kim et al. (2003) and Ioannidou and Ongena (2008) find significant switching costs in lending markets from Norwegian banking sector data and the firm panel data collected from a Bolivian public credit registering system, respectively. Black (2009) finds that a firm becomes less likely to borrow from outside banks as its credit information becomes more publicly available from the US survey data, which we also use. Degryse and Van Cayseele (2000) find a positive correlation between the length of a bank–firm relationship and loan interest rates using Belgian firm-level micro-data. Our empirical finding is not contradictory to their results, because the interest rates on loans extended by outside banks are lower than those by inside banks for older firms on average in our dataset. However, our result, in which the opposite is true for younger firms, suggests that the impact of strategic information acquisition by inside banks is predominant for these informationally opaque young firms.

The remainder of this paper is organized as follows. In Section 2, we present an analytical model to show the validity of the average interest rate difference between an inside bank and an outside bank in the earlier stage of a bank–firm relationship as a measure of the intensity of information production by an inside bank. In Section 3, we describe the dataset. Our identification strategy and the empirical specification are described in Section 4. The main results of the empirical analysis are presented in Section 5. Section 6 checks the robustness of the main results. Section 7 is the conclusion.

2. Theory

The structure of our model is based on those in Sharpe (1990) and Von Thadden (2004). The key difference from their models is that it takes time and costs for the inside bank to obtain private information about the borrower's creditworthiness from a lending relationship and that there is a stage in which a firm refinances its operating cost before the inside bank establishes an information advantage

[2] Montoriol-Garriga (2006) finds from the same dataset that this tendency is observed only in firms borrowing from multiple banks.

over outside banks. In this interim stage, the inside bank that has already invested in private information is willing to offer lower interest rates than the outside banks in order to prevent the investment from being interrupted before establishing the information advantage over outside banks. The borrower, anticipating the inside bank's intention, imposes an implicit handicap against the inside bank to capture a part of the rent resulting from the information advantage over outside banks. Thus, this type of time-to-build assumption yields the average interest rate difference between potential inside banks and outside banks.

2.1. Model

We consider four-period lending competition in which each of the continuum of mass one of firms apply for a loan to n banks at the beginning of each period. In each period, the firm needs to invest I to continue its business. In order to keep the analysis as simple as possible, we assume that the owner of the firm consumes all residual returns after repaying a loan at the end of each period and never saves for the future. We assume that the owner finances the firm's costs by bank loans at the beginning of each period. The financing costs of banks and the discount rate are normalized to zero. Firms and banks are all risk neutral.

If the firm is a good firm ($type = G$), then it always yields a positive revenue V strictly greater than I at the end of each period. If the firm is a bad firm ($type = B$), it can yield a positive revenue V strictly greater than I with a probability of β, but it can also yield zero revenue with a probability of $1 - \beta$. We assume that:

$$\beta V - I < 0, \tag{1}$$

i.e., no banks are willing to extend a loan if the firm turns out to be a bad firm. At the beginning of the first period, all banks believe that a potential borrower is G with a probability of γ and B with a probability of $1 - \gamma$. We also assume that:

$$\mu V - I \geqslant 0, \tag{2}$$

where $\mu \equiv \gamma + \beta(1 - \gamma)$, i.e., every bank is willing to extend a loan *ex ante*, irrespective of the possibility of obtaining private information about the borrower's creditworthiness.

The loan contract is assumed to be a standard debt contract (Townsend, 1979; Gale and Hellwig, 1985; Williamson, 1987); i.e., the value of the contract is equal to $\min[v, R]$, where $v = \{0, V\}$ and R is the face value of the loan (principal I plus interest) offered by a bank. Each bank competitively bids R at the beginning of each stage after receiving a loan application from the firm. The firm is assumed to have the same belief about its type as the most informed bank in each period. Both the firm and the banks maximize their own expected return given available information at each period. Under this basic setup, the repeated competition proceeds as follows (see also Fig. 1).

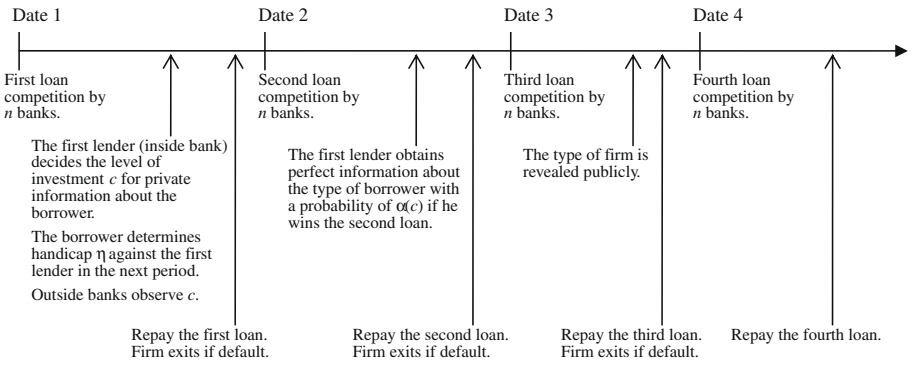

Fig. 1. Timing of actions.

(i) First period. A firm that is new to a loan market applies for a loan to n banks. There is no asymmetry among competing banks at this stage. Each bank competitively bids a loan interest rate. The firm chooses to borrow from the bank that offers the cheapest rate.

After extending the first loan, the lender chooses the level of investment in private information about the borrower's creditworthiness, which is not accessible from outside banks. This investment cost is denoted by c. We call this first lender the *inside bank* and the other banks *outside banks*. We assume that the inside bank always wins in the subsequent lending competition if a bid by the inside bank and that by an outside bank tie. If the inside bank successfully keeps the lending relationship in the second lending competition, the inside bank can obtain perfect information about the firm at the end of the second period with a probability of $\alpha(c)$, where α is twice-continuously differentiable, $\alpha' > 0$, $\alpha'' < 0$, $\alpha(0) = 0$, $\lim_{c\to\infty}\alpha(c) = 1$, $\alpha'(0) \to \infty$, and $\lim_{c\to\infty}\alpha'(c) = 0$. The investment in private information is carried out by the end of the first period. To keep the model tractable, we assume that c is observable from outside banks.

As is shown in later sections, the inside bank expects to earn a positive rent from the information advantage over rivals in the third lending competition if it invests in private information and wins the second lending competition again. Given this expected rent, the optimal strategy for the firm is to extract some of this expected rent by committing to impose a handicap $\eta \geqslant 0$ against the inside bank in the second lending competition. More precisely, the firm continues to borrow from the inside bank only if it offers a rate lower than that of the lowest rival bid minus η in the second competition. We assume that the firm determines η at the same time as the inside bank chooses the information investment level c. Outside banks can detect η by calculating it from the observable c in the equilibrium.

At the end of the first period, we assume that every bank can observe whether a borrowing firm survives the first period.[3] If the borrower cannot repay the first loan, then the borrower is a bad firm with a probability of one under our assumptions. Therefore, the inside bank never offers a loan to the firm for forbearance, and the firm exits. If the borrower successfully repays the first loan, it survives the first period, and every bank updates its subjective probability that the firm is a good firm from γ to $\gamma' \equiv \gamma/(\gamma + (1-\gamma)\beta)$ by Bayesian updating.[4]

(ii) Second period. A firm that successfully survives the first period applies for another loan to n banks at the beginning of the second period to continue its business. The inside banks and outside banks competitively bid loan rates. The inside bank is handicapped by η, which is determined by the borrower in the previous period. If the inside bank wins a loan again in the second period despite this handicap, it can obtain perfect information about the type of borrower at the end of the second period with a probability of $\alpha(c)$. We assume that outside banks cannot observe both whether the inside bank has successfully obtained perfect information or not and the content of the private information. If an outside bank successfully intercepts the existing lending relationship, no informational asymmetry among competing banks arises.

At the end of the second period, outside banks and the inside bank that failed to get private information updates its subjective probability that the firm is a good one from γ' to $\gamma'' \equiv \gamma'/(\gamma' + (1-\gamma')\beta)$ if the borrower successfully repays the second loan. The firm must exit the market otherwise.

(iii) Third period. A firm that successfully survives the second period applies for another loan to n banks again at the beginning of the third period. The banks competitively bid interest rates. If the inside bank invested in private information; i.e., $c > 0$, then the banks play a first-price auction with asymmetric information (Engelbrecht-Wiggans et al., 1983; Rajan, 1992). If an outside bank

[3] This assumption reflects the fact that public or private credit reporting systems or companies are established in many countries (Jappelli and Pagano, 2002; Miller, 2003). For example, Dun and Bradstreet, the largest credit reporting company in the US, provides subscribers with information on the payment performance of 70 million businesses, including small businesses (as of 2002), collected by D&B's own correspondents, who gather data on firms by visiting and telephoning the firm's principals, or from public filings and information provided by other corporations (Kallberg and Udell, 2003).

[4] If we assume that outside banks cannot observe whether a firm has survived or not, only the inside bank can update its belief about the creditworthiness of the borrower. In this case, the inside bank can achieve an information advantage over outside banks without paying any costs. Nonetheless, the inside bank is still willing to invest in additional private information, because more accurate information increases the expected return of the inside bank from the future lending competition. Thus, the assumption of public observability of a firm's survival is not crucial to our analytical model. We maintain this assumption throughout our theoretical analysis in order to keep the exposition as simple as possible.

intercepted the lending relationship in the previous period, private information is not produced, and the banks play standard Bertrand competition. We assume that the type of firm is publicly revealed at the end of this period. A bad firm exits.

The assumption that the type of firm is publicly revealed at the end of the third period is an abbreviation of the learning process from the fact that the firm survives. As the length of firm survival increases, the lender's subjective probability that the firm is a good one approaches 1. This alternate assumption makes the problem much simpler, although the problem is not as restrictive as it appears. This assumption precludes the possibility that the interceptor in the second period invests in private information after a successful intercept. If we drop this assumption, the interceptor may be willing to invest in private information after the intercept. However, the expected return from winning in the second competition, including the return from such investment, is smaller than that for the first mover if we take into account the gradual information revelation by the survival of the firm. Therefore, an intercept by an outside bank in the second period cannot be successful in the equilibrium, as is evident in the next subsection. Thus, the equilibrium does not change qualitatively even if this assumption is dropped.

(iv) Fourth period. The surviving firm applies for a loan to n banks. Banks operate according to standard Bertrand competition.

2.2. Analysis

The perfect Bayesian equilibrium of this game is derived backwardly. We focus on a symmetric equilibrium in the stages in which there is no asymmetric information among banks. In the equilibrium in the fourth period, it is obvious that each bank is expected to win with equal probability $1/n$ and to earn zero profit if the firm is good and that no bank extends a loan otherwise. Given this result, we start the analysis from the third period.

Third period. An outside bank and an uninformed inside bank are always willing to extend a loan, because the inequality (2) implies that $\mu''V - I \geqslant 0$, where $\mu'' \equiv \gamma'' + \beta(1-\gamma'')$ and $\mu''V - I$ is the expected value of the loan in the third period. If the inside bank does not invest in private information in the first stage, the stage game is reduced to standard Bertrand competition. The expected return of each bank when it wins the third competition by bidding the face value of the third loan R_3 is equal to $\mu''R_3 - I$. In the equilibrium, their expected return is zero, and the interest rate is equal to $1/\mu'' - 1$. Each bank is expected to win with an equal probability of $1/n$.

If the inside bank invests $c^* > 0$ in acquiring private information, then it may obtain perfect information about the type of firm with a probability of $\alpha(c^*)$. Because the outside banks cannot observe whether or not the inside bank has successfully obtained perfect information or the content of the private information, the competition becomes a first-price auction under asymmetric information whether or not the inside bank succeeds in the acquisition of information. By applying the methodology of Engelbrecht-Wiggans et al. (1983), we can show that the informed inside bank's expected return from the third competition π_3^i, conditional on the inside bank's information at the beginning of the third period, is equal to:

$$\begin{cases} \dfrac{(1-\mu'')I}{\mu''} & \text{if the inside bank obtains perfect information and } type = G, \\ 0 & \text{if the inside bank obtains perfect information and } type = B, \\ \dfrac{(1-\mu'')I}{\mu''}\dfrac{\mu''V - I}{V - I} & \text{if the inside bank could not obtain perfect information.} \end{cases} \tag{3}$$

An outside bank's expected return is equal to zero (see Appendix A for the derivation).

The key observation is that the informed inside bank can earn a positive profit as long as outside banks are not sure whether the firm is good or bad. The intuition of this standard result is as follows: the informed inside bank can economize the cost of mispricing a loan better than outside banks. From this cost advantage, the inside bank attracts a borrower by bidding down interest rates to the point at which the outside banks can expect, at most, zero profit, while the inside bank can expect a positive

profit, given its more precise information. Thus, the informed inside bank can earn a positive rent from the informational advantage.

However, it is possible to show that this rent is not generated at the cost of the borrower. Indeed, the proof in Appendix A.2 shows that the borrower's expected interest cost in the third period is equal to $I/\mu'' - I$ irrespective of the inside bank's investment c^* in private information in the first period. On the other hand, the borrower has a chance to exploit some of this rent in the second period.

Second period. An inside bank and outside banks are always willing to extend a loan, because the inequality $\mu V - I \geqslant 0$ implies that $\mu' V - I \geqslant 0$, where $\mu' \equiv \gamma' + \beta(1-\gamma')$. If the inside bank does not invest c^* in private information, then the problem is reduced to standard Bertrand competition. In the equilibrium, their expected return is zero and the interest rate is equal to $1/\mu' - 1$, and each wins with an equal probability of $1/n$.

If the inside bank invests $c^* > 0$ in private information in the first period, the expected returns for the inside bank and an outside bank are, respectively:

$$\pi_2^i = \{(1 - K(R_2^i))p + 1 - p\}^{n-1}\{\mu'(R_2^i - \eta^*) - I + E_2[\pi_3^i(c^*)]\}, \tag{4}$$

$$\pi_2^o = \{(1 - K(R_2^o))p + 1 - p\}^{n-2}\{(1 - L(R_2^o))q + 1 - q\}\{\mu' R_2^o - I\}, \tag{5}$$

where R_2^i is the face value bid by the inside bank, R_2^o is that by the outside bank, $K(\cdot)$ is the mixed strategy or the cumulative distribution function of R_2^o, $L(\cdot)$ is that of R_2^i, p is the outside bank's participation probability, and q is the inside bank's participation probability. The last term of π_2^i is the expected return from the third competition conditional on the inside bank's information at the beginning of the second period; i.e.:

$$\begin{aligned} E_2[\pi_3^i(c^*)] &= \alpha(c^*)\gamma' \frac{(1-\mu'')I}{\mu''} + (1 - \alpha(c^*))\mu' \frac{(1-\mu'')I}{\mu''}\left(\frac{\mu'' V - 1}{V - 1}\right) \\ &= \frac{(1-\mu'')I}{\mu''}\left\{\gamma'\alpha(c^*) + (1 - \alpha(c^*))\mu' \frac{\mu'' V - 1}{V - 1}\right\}. \end{aligned} \tag{6}$$

The first term of the first line is the return when the inside bank obtains perfect information and the firm is a good firm. The second term is the return when the inside bank cannot obtain perfect information. The level of investment in private information c^* is determined by the inside bank in the first period after extending the first loan. Clearly, $E_2[\pi_3^i(c^*)]$ is increasing in c^* under our assumptions. The borrower, to maximize his future expected return, attempts to exploit a part of this expected rent by committing to impose the penalty η^*, which was determined in the first period. The borrower continues to borrow from the inside bank only if the offer by the inside bank is cheaper than the cheapest offer by outside banks minus η^*.

If $E_2[\pi_3^i(c^*)] - \mu'\eta^* > 0$, then the inside bank can enjoy a type of cost advantage over rivals. Standard analysis of Bertrand competition with asymmetric costs shows that the outside banks' expected profit is equal to zero in the equilibrium. It also shows that the inside bank almost surely wins by bidding $R_2^i = I/\mu' - \eta^*$ and that its expected return in the equilibrium is:

$$\pi_2^i = E_2[\pi_3^i(c^*)] - \mu'\eta^*. \tag{7}$$

Because the counterpart must be indifferent to any action for which an equilibrium mixed strategy assigns a positive probability, the equilibrium $K(\cdot)$ is determined by setting Eq. (4) equal to $E_2[\pi_3^i(c^*)] - \mu'\eta^*$ and replacing R_2^i with R_2^o. p is determined by setting $K(V) = 1$. q is always equal to 1 because the expected payoff to the inside bank is positive.

If $E_2[\pi_3^i(c^*)] - \mu'\eta^* = 0$, then the problem returns to standard Bertrand competition. The inside bank bids $I/\mu' - \eta^*$, and the outside banks bid I/μ'. Each of them wins with equal probability $1/n$ and expects zero profit. If $E_2[\pi_3^i(c^*)] - \mu'\eta^* < 0$, then the inside bank never wins. The inside banks bid I/μ', and one of them wins with a probability of $1/(n-1)$. The expected return for the inside bank and the outside banks is equal to zero. These latter two cases are not realized in the equilibrium.

First period. After extending the first loan, the inside bank determines the level of investment c in private information. Meanwhile, the borrower simultaneously decides the penalty η. The inside bank expects a return from future loans equal to:

$$\frac{\mu\{E_2[\pi_3^i(c)] - \mu'\eta^*\}}{n} - c. \tag{8}$$

1/n appears in this expression, because each bank symmetrically wins 1/n firms out of the continuum of mass one of firms in the first lending competition. The first-order condition to maximize this return with respect to c is:

$$\frac{\mu}{n}\frac{(1-\mu'')I}{\mu''}\left(\gamma' - \frac{\mu''V - I}{V - I}\mu'\right)\alpha'(c^*) - 1 = 0. \tag{9}$$

The expected interest cost of a borrower based on the information right after the first loan is equal to:

$$\mu\left(\frac{(1-\mu')I}{\mu'} - \eta\right) + \mu\mu'\frac{(1-\mu'')I}{\mu''}. \tag{10}$$

The first term is the expected interest cost in the second period; the second term is that in the third competition. The interest cost in the fourth competition is zero, as we saw in the previous paragraph. The firm chooses η by solving the following problem:

$$\min_{\eta} \mu\left(\frac{(1-\mu')I}{\mu'} - \eta\right) + \mu\mu'\frac{(1-\mu'')I}{\mu''}, \quad \text{s.t. } \frac{\mu\{E_2[\pi_3^i(c^*)] - \mu'\eta\}}{n} \geqslant c^*. \tag{11}$$

The participation constraint for the inside bank is required, because an η that violates this condition is never realized. Clearly, the borrower sets η at the level at which the participation constraint binds; i.e.:

$$\eta^* = \frac{\mu E_2[\pi_3^i(c^*)] - nc^*}{\gamma + \beta^2(1-\gamma)}. \tag{12}$$

The borrower sets η^* so that the inside bank, which can acquire private information, continues to be willing to do so and exploits all the expected rent from the resulting informational advantage.

Because the banks' expected returns from future lending are equal to zero, the competition for the first loan is reduced to standard one-shot Bertrand competition. In the equilibrium, each bank bids I/μ and wins with equal probability $1/n$. The banks' expected returns from the first loan are equal to zero.

2.3. Interest rate difference between an inside bank and an outside bank

In the first period, both the inside bank and outside banks bid the gross interest rate of I/μ. The first lender almost certainly wins in the second period by bidding $I/\mu' - \eta^*$, while the outside banks never win if $c^* > 0$. However, outside banks may win by bidding I/μ' if $c^* = 0$. In the third period, both the expected gross interest when the inside bank wins and that when an outside bank wins are equal to I/μ'', irrespective of the investment in private information by the inside bank. In the fourth period, both the inside bank and outside banks bid I.

Thus, the difference between the interest rate of a loan extended by the inside bank and that extended by an outside bank emerges only in the second period (Fig. 2). This difference is equal to $-\eta^*$, which is given by Eq. (12). Clearly, it is a linear decreasing function of the expected rent from private information in the third period $E_2[\pi_3^i]$. Therefore, this interest rate difference serves as a measure of the rent from private information.

In our model, the investment level c^* decreases with the number of competing banks n from the first-order condition (9). We can easily verify that the gap η^* also decreases with n by substituting the first-order condition (9) (see Appendix B). The numerical example in Fig. 2(A) illustrates this point. The prediction to be tested from our model is summarized in the next hypothesis.

Hypothesis 1. *The average interest rate difference, {(interest rates of loans extended by inside banks) – (those of loans extended by outside banks)}, is negative before an inside bank establishes the informational advantage over outside banks. This gap becomes smaller as the number of competing banks increases.*

If the latter part of this hypothesis is not statistically rejected, it implies that interbank competition is more likely to hinder the information production by inside banks.

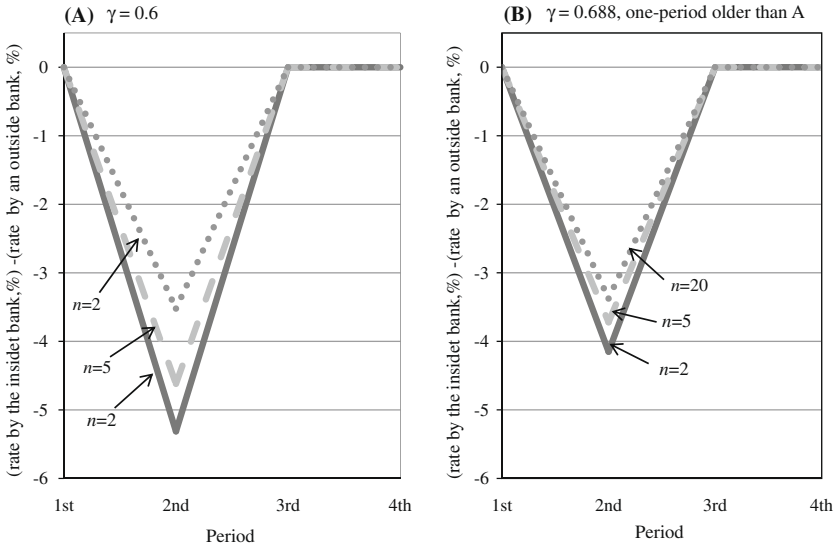

Fig. 2. Number of banks and the interest rate difference.
Notes. A numerical example of the difference between the rate offered by the inside bank and an outside bank, which is equal to $-\eta^*/I$ (Eq. (12)) in the second period and zero in other periods, is depicted. n is the number of competing banks. In the calculation, it is assumed that $\alpha(c)=1-\exp(-c^{0.9})$, $\beta = 0.68$, $I = 1000$, and $V = 1150$. $\gamma = 0.688$ in (B) corresponds to the Bayesian-updated belief by an outside bank from the observation of the firm's one-period survival when the initial prior belief is equal to 0.6. c is set equal to the solution of Eq. 9.

A bank perceives that an older firm is more creditworthy than a younger firm because the fact that the firm survives for a longer period indicates that it is more likely to be a good type of firm. Indeed, this is the case in our model, in which banks can observe whether a firm survives for one period. Both inside and outside banks update their subjective probabilities that the borrowing firm is a good type from γ to $\gamma' = \gamma/\{\gamma + \beta(1-\gamma)\}$ if a firm survives for one period. Clearly, γ' is greater than γ. If a firm survives for t periods, then the repetition of this updating reaches $\gamma_t = \gamma/\{\gamma + \beta^t(1-\gamma)\}$. This converges to 1 as $t \to \infty$. Thus, as a firm becomes older, the uncertainty regarding the type of firm becomes negligible, and the effect presented in Hypothesis 1 diminishes, as verified in Appendix B. Fig. 2 illustrates this point. Fig. 2(A) is the theoretical interest rate difference when $\gamma = 0.6$, while Fig. 2(B) is that when $\gamma = 0.688$, which is equivalent to the subjective probability that is updated from $\gamma = 0.6$ given that the firm survives for one period longer and that $\beta = 0.68$. Clearly, the interest gap is smaller in (B) than in (A). Thus, in the empirical test of Hypothesis 1, we need to take into account the possibility that the effect stated in Hypothesis 1 may not be clearly observed for older firms. We summarize this point in the following hypothesis.

Hypothesis 2. *The impact of the number of competing banks stated in Hypothesis 1 diminishes as a borrowing firm becomes older.*

2.4. Notes on the analytical model

2.4.1. Multiple bank relationships

In the analysis, we assumed that a firm borrows from a single bank in the first period. However, a firm may borrow from multiple banks in the first period in order to prevent a single bank from establishing a predominant status in terms of information acquisition. However, even if multiple banks lend to the firm in the first period, the only Nash equilibrium in the information-acquisition game in our model is an asymmetric one, in which a single bank invests in private information and others do not invest at all (Schnitzer, 1999).

This point can be verified by the following logic. If multiple banks invest the same amount of costs in private information, then the lending competition in the third period is simple Bertrand competition among these banks, and their expected return is then equal to zero. Thus, these banks conjecture that their investments are meaningless and never choose this level of investment. If multiple banks invest different positive amounts of costs, then the banks that invest less than the largest investment expect a zero return from the third lending competition. These banks never invest positive amounts in private information. If no inside banks invest in private information, then an inside bank will choose to do so alone, because it can increase its expected return in this way. The remaining case is the case in which a single bank invests positive amounts of effort in private information while the others do not invest at all. Each bank cannot increase its return by deviating from this equilibrium strategy. Therefore, the last combination of strategies is the Nash equilibrium.

Thus, multiple relationships, in the sense that multiple banks invest in the private information of a borrower, are not supported as a Nash equilibrium in our model. Nonetheless, multiple bank relationships are chosen for other reasons, such as the diversification of the liquidity risk on the side of borrowers (Detragiache et al., 2000) and the diversification of the credit risk on the side of banks (Ongena and Smith, 2000; Farinha and Santos, 2002). Moreover, banks are willing to share private information among themselves in order to ensure proper management efforts by borrowers by committing to not exploiting the information advantage over rival banks (Padilla and Pagano, 1997). In order to control for these effects in our empirical analysis, we focus on a class of firms that presumably maintains a single bank relationship on the basis of the criterion illustrated in the next section.

2.4.2. Observability of the first stage for econometricians

In the model, we assume that the first competition that gives the lender an opportunity to invest in private information about the borrower is competition for the first loan; however, competition for a checking account could be the first step to start a firm–bank relationship in reality. In our setup, it does not alter the hypotheses to assume that the first competition is for a checking account. If this is the case, however, the first stage in our model is unlikely to be observed in the actual lending data.

3. Data

The dataset used in this study was collected from the US National Survey of Small Business Financing (NSSBF) in 2003. Older versions of this survey data (from 1987, 1993, and 1998) are widely used in empirical analyses for relationship banking. The survey targeted for-profit, nonfarm, nonsubsidiary business enterprises that had fewer than 500 employees and were in operation as of year-end 2003 and on the date of the interview. Sample firms were chosen by random sampling stratified by employment-size groups, census divisions, and urban or rural locations. In the 2003 version of the database, five types of imputed values were inserted for missing values, but we treated these as missing values in our analysis. We used observations from urban areas, i.e., in metropolitan statistical areas (MSA), for our statistical analysis to prevent unobservable differences between urban and rural areas from affecting our statistical inference.

The dataset contains financial statement information and other basic characteristics of each firm, such as industry, age, census region, owner's education as of the last fiscal year-end before June 2004, and information about the most recent loan application of each firm as of the survey period from June to December 2004. This includes the application date, loan type, maturity,[5] loan amounts applied for, and the result of the application; i.e., approved or not. If the application was approved, information on rates and other terms of the loan, including whether or not it was secured and whether or not it was a fixed-rate loan, are also available. The dataset also contains the length of the relationship with each bank, the distance in miles from each bank, the types of services received from each bank, and the institutional type of each lender.

We merged the monthly short-term prime rate, default premium, which is defined by the difference in the yield between BAA corporate bonds and US Treasury bonds, and term premium, which

[5] Maturity is often unavailable for lines of credit. We assume that the terms of the lines of credit are equal to the mean maturity of those for which maturity information is available (25.27 months) for such observations.

is calculated from US Treasury securities with various maturities, to the above dataset by the date of the most recent loan application. The descriptive statistics and definition of each variable used in the regression analysis are presented in Table 1.

Table 1
Description of the variables.

Variable	# obs.	Mean	S.D.	Min.	Med.	Max.	Definition
Interest rate of the most recent loan (MRL)	890	5.74	2.80	0.00	5.50	30.00	Interest rate of the most recent loan approved (%)
MRL lender is the inside bank	1043	0.72	0.45	0	1	1	1 if the most recent lender is the inside bank of the firm, 0 otherwise
MRL application is approved	1043	0.91	0.29	0	1	1	1 if the most recent loan application is approved by a bank, 0 otherwise
Prime rate	1043	4.33	0.59	4.00	4.01	9.05	Average majority prime rate charged by banks on short-term loans to business
Term premium	890	1.24	0.99	−0.48	0.83	3.68	Moody's yield on BAA seasoned corporate bond minus the market yield on US Treasury securities at 10-year constant maturity (%)
Default premium	1043	2.38	0.40	1.92	2.19	3.79	The market yield on US Treasury securities of the closest term of the most recent loan minus the market yield on US Treasury securities at 3-month constant maturity
MRL is fixed rate	939	0.43	0.50	0	0	1	1 if the most recent loan is of fixed rate, 0 otherwise
Firm age	1043	17.41	12.88	1.08	14.83	102.92	Age of the firm (years)
Debt/asset of the firm	1043	1.19	5.65	0.00	0.60	161.97	Debt/asset of a firm
Asset of the firm	1043	3.50	11.20	0.00	0.71	196.00	Total assets of a firm (m USD)
Firm is a corporation	1043	0.78	0.41	0	1	1	1 if the firm is an LLP/LLC (tax filed as corporation) or a corporation, 0 otherwise
Owner is a college graduate	1006	0.56	0.50	0	1	1	1 if the owner of the firm is a college graduate, 0 otherwise
MRL lender is a commercial bank	1043	0.81	0.40	0	1	1	1 if the most recent lender is a commercial bank, 0 otherwise
Years of relationship with MRL lender	1043	8.09	8.41	0.00	5.42	56.92	Years of relationship between the firm and the most recent lender
Firm has a checking account at MRL lender	1043	0.77	0.42	0	1	1	1 if the firm has a checking account at the most recent lender
Mile distance to MRL lender	1014	0.48	2.07	0.00	0.04	24.57	Mile distance to the office of the most recent loan lender (100 miles)
Mile distance to the inside bank	1041	0.10	0.45	0.00	0.03	6.35	Mile distance to the office of the inside bank (100 miles)
Mile distance to the secondary bank	704	0.89	2.61	0.00	0.04	23.02	Mile distance to the office of the nearest outside bank (100 miles)
Years of relationship with the inside bank	1043	9.96	8.56	1.08	7.67	57.00	Years of relationship between the firm and the inside bank
Years of relationship with the secondary bank	1043	9.92	9.51	0.00	7.08	88.33	The longest years of relationship between the firm and outside banks
# of institutions for loan transactions	1043	1.97	1.49	0	2	12	Number of financial institutions that extended loans to the firm as of the MRL application
HHI dummy	1043	0.39	0.49	0	0	1	1 if the Herfindahl–Hirschman index of commercial bank deposits $\geqslant$ 1800, 0 otherwise

Notes. The sample consists of firms that have a single inside bank. An inside bank is a bank that maintains a relationship with a firm for longer than 1 year as of the most recent loan application and holds more than half of the total amount of all checking account balances of that firm.

4. Identification strategy

4.1. Construction of the key variables

In order to test Hypothesis 1 statistically, first we need to identify the loans extended by inside banks. For this purpose, we define the *inside bank* of a firm as a bank that satisfies the following two criteria:

1. The amount deposited in the checking account at the bank accounts for more than half of the total amount of all checking accounts the firm holds, and
2. The length of the relationship with the bank exceeds one year as of the loan application date.

In theory, the inside bank is assumed to be in the position where it can *exclusively* acquire private information about the creditworthiness of a borrower. The first criterion about the share of the checking account comes from the observation that the cash flow in checking accounts is one of the most important information sources for inside banks (Fama, 1985; Nakamura, 1993; Mester et al., 2007). The second criterion is added because the inside bank is supposed to have experienced at least a transaction with the firm.

Based on this definition of an inside bank, we construct a dummy variable that is equal to 1 if a firm applied to the inside bank for its most recent loan and 0 otherwise; this is labeled in Table 1 as "MRL lender is the inside bank." Of the firms in our dataset, 72.1% report that they had applied to their inside bank.

We primarily use the firms that have an inside bank that satisfy these criteria in our empirical analysis. By dropping the firms without an inside bank from our dataset, the firms with multiple relationships, and those within one year of starting a lending relationship with a bank, i.e., the firms in the first period in our analytical model, are dropped from our dataset. The number of observations for which an application for a loan had been made to a financial intermediary from 2001 to 2004 before the survey date is 1898 out of 4240 firms in the 2003 NSSBF database. Of the 1898 firms, 1474 are located in the metropolitan statistical area. The information required for our data analysis is fully available for 1245 out of these 1474 firms. Among them, 202 firms do not have an inside bank, while 1043 firms do. We focus primarily on the latter 1043 firms.

In terms of credit market concentration, the public version of the 2003 NSSBF data include a dummy variable that is equal to 1 if the county/MSA-level Herfindahl–Hirschman index (HHI) of commercial bank deposits is $\geqslant$1800 (concentrated) and 0 otherwise (competitive). We use this dummy variable as the proxy for the number of competing banks. Our dataset shows that 95% of firms have their inside bank within a 25-mile radius, and 90% of firms applied for their most recent loans to banks within a 35-mile radius. Therefore, a county or an MSA is a reasonable unit of a loan market.

4.2. Estimated specification

4.2.1. Baseline regression

Given the firm-level cross-sectional data containing information about firm age, the interest rate of the most recent loan determined as a result of lending competition, and the strength of the relationship with the most recent lender, our first objective is to examine statistically whether the interest rate difference, or the average treatment effect of borrowing from an inside bank, shows a tendency that is consistent with Hypothesis 1, as depicted in Fig. 2. The ideal dataset for this statistical analysis is panel data that contain information about both the loan extended by an inside bank and one extended by an outside bank to an identical firm; however, such a dataset is not publicly available. Therefore, as the second-best strategy, we investigate the interest rate gap between a loan extended by the inside bank to a firm and one extended by an outside bank to another firm that shares the same or similar characteristics with the firm.

We estimate the following specification by OLS with robust standard errors as a baseline estimate to test Hypotheses 1 and 2:

$$r_i = \beta_0 + \beta_1' x - \eta_i^* D_i + \epsilon_i, \tag{13}$$

where r_i is the most recent interest rate for a loan to firm i, x is a vector of control variables, including firm, market, loan, and bank–firm relationship characteristics, and year, industry, and region dummies, D_i is the inside-bank dummy, which is equal to 1 if the lender is the inside bank and 0 otherwise, η_i^* is the average treatment effect of borrowing from an inside bank on a loan interest rate, which conceptually corresponds to the handicap defined by Eq. (12), and ϵ_i is an error term with a mean of zero.

In the baseline estimation, we assume that η_i^* is linearly dependent on the HHI dummy as the proxy for the number of competing banks so as to test the second statement in Hypothesis 1. As stated in Hypothesis 2, the impact of lending competition on the size of the handicap diminishes as the borrowing firm survives for longer periods and becomes less uncertain. To address this effect, we include the interaction term of a firm's age and the HHI dummy in the explanatory variables:

$$-\eta_i^* = \gamma_0 + \gamma_1 \mathrm{HHI}_i + \gamma_2 \mathrm{HHI}_i \times \text{firm's age}_i. \tag{14}$$

Hypothesis 1 states that the handicap η_i^* is significantly greater than zero if an inside bank has not yet established an informational advantage over outside banks; i.e., a firm is in the stage of the second period in our analytical model. Because we do not have information available about how long it takes to establish an information advantage, we also estimate a specification that is based on the firm's relationship length with an inside bank:

$$-\eta_i^* = \gamma_0 + \gamma_1 \mathrm{HHI}_i + \gamma_2 \mathrm{HHI}_i \times \text{relationship length}_i. \tag{15}$$

If the estimated γ_1 is significantly negative and the estimated γ_2 is significantly positive in specifications (14) and (15), or both, then the handicap η^* is positive only for firms that are younger or those in which the relationship with the inside bank is shorter in a concentrated loan market. If this is the case, we can conclude that the data are consistent with Hypotheses 1 and 2, and that harsher interbank competition is detrimental to the information production of banks.

A potential problem is that the simple regression results can be contaminated with the sample selection problem because the interest rate is not observable for those who were rejected by a potential lender. To address this potential problem, we apply the Heckman two-step procedure (Heckman, 1976) in the robustness check.

4.2.2. Propensity score matching

As noted in the first paragraph in this section, $-\eta^*$ in the baseline regression is the estimator of $E[r_{1i}|D_i = 1,x] - E[r_{0j}|D_j = 0,x]$, where r_{1i} is the interest rate when firm i obtains a loan from the inside bank and r_{0j} is that when firm j obtains one from an outside bank, while what we would like to estimate is $E[r_{1i}|x] - E[r_{0i}|x]$; i.e., the average treatment effect conditional on x. Thus, the above estimator could be biased in general. However, if the following condition is satisfied:

$$(r_1, r_0) \perp D \quad \text{conditional on } x, \tag{16}$$

where $\perp$ means "stochastically independent," then $E[r_{1i}|D_i = 1,x] - E[r_{0j}|D_j = 0,x] = E[r_{1i}|x] - E[r_{0i}|x]$ (note that the distribution of the interest rate is assumed to be independently and identically distributed across firms), and the bias disappears. In addition to this assumption, if:

$$0 < Prob(D = 1|x) < 1, \tag{17}$$

it follows that:

$$(r_1, r_0) \perp D \quad \text{conditional on } Prob(D = 1|x), \tag{18}$$

(Rosenbaum and Rubin, 1983). This implies that $E[r_1|D = 1,Prob(D = 1|x)] - E[r_0|D = 0,Prob(D = 1|x)]$ is an unbiased estimator of $E[r_1|x] - E[r_0|x]$. Thus, we can estimate legitimately the average treatment effect of borrowing from the inside bank by matching a loan extended by the inside bank with one extended by an outside bank at the same level of the propensity score $Prob(D = 1|x)$ (nearest-neighbor matching), or with the weighted average of those extended by outside banks, where the weight is set so that it decreases in the distance between the propensity score of matching observations (kernel density matching).

Assuming that the conditions (16,17) are satisfied, we estimate the average treatment effect of borrowing from the inside bank by applying the nearest-neighbor propensity score matching, and the Gaussian and Epanechkov kernel density matching (Heckman et al., 1997; Heckman et al., 1998), in order to obtain evidence for the hypotheses after controlling for the probability that a firm is more likely to apply to the inside bank compared with the baseline regression.

The average treatment effect is calculated for each of the following four categories: (1) firms in a competitive credit market and less than 10 years old, (2) firms in a competitive market and more than 10 years old, (3) firms in a concentrated market and less than 10 years old, and (4) firms in a concentrated market and more than 10 years old. The propensity score is estimated by logit. If Hypotheses 1 and 2 are supported by the data, the average treatment effect should be significantly negative only in category (3).

5. Results

5.1. Preliminary univariate analysis

Table 2 shows the mean spread over the short-term prime rate sorted by market concentration, whether the lender is the inside bank or an outside bank, and whether a firm is more or less than 10 years old (panel 1) or whether the relationship with the inside bank is longer or shorter than 10 years (panel 2). The lower part of panel 1 shows that the mean of the spreads of loans extended by inside banks is significantly lower than that by outside banks for younger firms in concentrated loan markets. On the other hand, this tendency is not observed in competitive loan markets (the lower side

Table 2
Spread difference.

	Firm age ⩽ 10 years		Firm age > 10 years	
	Mean (S.D.)	# of obs.	Mean (S.D.)	# of obs.
Panel 1. Sorted according to whether a firm's age ⩽ or > 10				
[Competitive market]				
MRL lender is the inside bank	1.742	108	1.054	290
	(0.246)		(0.125)	
MRL lender is an outside bank	1.908	60	1.065	91
	(0.524)		(0.307)	
[Concentrated market]				
MRL lender is the inside bank	2.155**	66	1.090	189
	(0.255)		(0.150)	
MRL lender is an outside bank	4.358	32	0.952	54
	(1.267)		(0.379)	
	Relation with the inside bank ⩽ 10 yrs.		Relation with the inside bank > 10 yrs.	
	Mean (S.D.)	# of obs.	Mean (S.D.)	# of obs.
Panel 2. Sorted according to whether the years of a relationship with the inside bank ⩽ or > 10				
[Competitive market]				
MRL lender is the inside bank	1.280	263	1.165	135
	(0.143)		(0.188)	
MRL lender is an outside bank	1.558	100	1.090	51
	(0.383)		(0.346)	
[Concentrated market]				
MRL lender is the inside bank	1.504***	169	1.094	86
	(0.165)		(0.219)	
MRL lender is an outside bank	3.036	55	0.772	31
	(0.798)		(0.512)	

Notes. Mean spread over the prime rate sorted by HHI ⩽ or > 1800, firm age ⩽ or > 10, and whether the most recent lender is the inside bank or not is presented. ** and *** indicate that the mean spread offered by the inside bank is smaller than that offered by an outside bank at the 5% and 1% significance level (two-tailed test), respectively.

of panel 1). Panel 2 shows that a similar phenomenon is observed when we split the sample by the length of the relationship with the inside bank instead of a firm's age. These preliminary results are consistent with Hypotheses 1 and 2.

5.2. Multivariate regression analysis

The baseline regression result is reported in Table 3. Column (1) shows the estimated coefficients in the base specification adopted from Petersen and Rajan (1994). The estimated coefficients show that the interest rate decreases as the firm becomes older and larger. This is consistent with our assumption that the survival of a firm works as a signal of the good quality of the firm for banks. The coefficient for the HHI dummy is positive and significant at the 5% level. This indicates that the standard notion that market concentration has a positive impact on interest rates is valid in our sample.

Column (2) shows the estimated coefficients of the simplest version of the specification (13) including additional control variables. The inside-bank dummy has a positive coefficient, but it is not significantly different from zero. However, if we include the interaction term of the inside-bank dummy and the HHI dummy in the explanatory variables (column (3)), it turns out that the interest rates of loans extended by inside banks are lower than those extended by outside banks in more concentrated markets (HHI dummy = 1), while the opposite is true in more competitive markets. This suggests the existence of a sort of switching cost that is not explicitly modeled in our analytical model. However, this positive impact of borrowing from the inside bank in competitive markets is less robust as this effect is observed less frequently in other specifications discussed in the next section on the robustness check. The estimated coefficients by the specification (14) (column (4)) show that this negative impact of borrowing from the inside bank in a more concentrated credit market is larger for younger firms and diminishes as the firm survives longer. This finding is consistent with Hypotheses 1 and 2. A similar tendency is observed in the estimation of specification (15), but the impact is less significant (column (5)). This result possibly reflects the effect that the value of private information for an inside bank becomes smaller as a firm survives longer, because the fact that it survives longer signals publicly the good quality of the firm, as stated in Hypothesis 2. Column (6) shows that the impact of a firm's age is linear rather than nonlinear.

By estimating the specification (13) after splitting the sample into two subsamples, one that exclusively includes those in competitive loan markets and one that exclusively includes those in concentrated loan markets, we can see these effects more clearly (Table 4). Thus, our dataset supports the hypothesis that interbank competition discourages competing banks from information production.

The results in Table 4 suggest that the interest rate difference between an inside bank and an outside bank is economically and statistically negligible in a competitive credit market but statistically and economically significant for firms less than 10 years old in a concentrated credit market (Fig. 3). The estimated mean interest discount associated with borrowing from the inside bank is 1.42% for five-year-old firms and 0.74% for seven-year-old firms. Because the sample mean of the interest rate of 5–6-year-old firms is 6.19% and that of 7–8-year-old firms is 5.80%, the rate of the interest discount is 22.9% and 12.8%, respectively. Clearly, the interest discount by borrowing from an inside bank is economically significant.

5.3. Propensity score matching

In order to calculate the propensity score with respect to the probability of a firm applying to the inside bank instead of an outside bank, we estimated a logit model. The estimated coefficients in this preliminary logit are reported in Table 5. Firms tend to apply to outside banks when market interest rates are high, probably because of the tight aggregate supply of loanable funds. Older firms are more likely to apply to the inside bank. A firm is more likely to apply to outside banks when it has transacted with more banks and one of them is located in a closer neighborhood.

We estimate the average treatment effect of borrowing from the inside bank on interest rates by applying nearest-neighbor matching, and Gaussian and Epanechkov kernel density matching with respect to this estimated propensity score to the residuals of the interest rate regression (13) excluding D_i and its interaction terms.

Table 3
Pooled regression.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
MRL lender is the inside bank (0,1)		0.551*	1.065**	1.078**	1.104**	1.078**
		(0.408)	(0.533)	(0.536)	(0.544)	(0.536)
MRL lender is the inside bank × HHI dummy (0,1)		−1.208*	−2.619**	−1.654*	−2.408*	
			(0.646)	(1.094)	(0.884)	(1.620)
MRL lender is the inside bank × HHI dummy × firm age (log of +1)				0.506*		0.324
				(0.262)		(1.076)
MRL lender is the inside bank × HHI dummy					0.207	
× Yrs. of relationship with the inside bank					(0.229)	
MRL lender is the inside bank × HHI dummy × firm age^2						0.036
						(0.202)
Prime rate (%)	−0.029	−0.045	−0.080	−0.091	−0.084	−0.091
	(0.151)	(0.151)	(0.151)	(0.154)	(0.152)	(0.154)
Term premium (%)	−0.076	−0.005	−0.010	−0.004	−0.013	−0.005
	(0.097)	(0.128)	(0.128)	(0.127)	(0.129)	(0.127)
Default premium (%)	0.104	0.122	0.186	0.218	0.195	0.219
	(0.212)	(0.216)	(0.209)	(0.209)	(0.210)	(0.210)
MRL is fixed rate (0,1)	1.150***	1.380***	1.407***	1.423***	1.408***	1.423***
	(0.171)	(0.197)	(0.199)	(0.200)	(0.199)	(0.200)
Firm age (log of +1)	−0.590***	−0.504***	−0.514***	−0.649***	−0.523***	−0.649***
	(0.145)	(0.146)	(0.147)	(0.174)	(0.148)	(0.175)
Asset of the firm (log of USD)	−0.342***	−0.321***	−0.314***	−0.316***	−0.313***	−0.316***
	(0.056)	(0.061)	(0.060)	(0.060)	(0.060)	(0.060)
Debt/asset of the firm	−0.029	−0.027	−0.022	−0.016	−0.021	−0.016
	(0.034)	(0.037)	(0.037)	(0.035)	(0.036)	(0.037)
Firm is a corporation (0,1)	−0.085	−0.126	−0.090	−0.079	−0.083	−0.078
	(0.251)	(0.250)	(0.247)	(0.246)	(0.248)	(0.247)
Owner is a college graduate (0,1)		−0.593***	−0.596***	−0.590***	−0.606***	−0.590***
		(0.191)	(0.189)	(0.188)	(0.189)	(0.189)
MRL lender is a commercial bank (0,1)	−0.090	−0.253	−0.273	−0.279	−0.281	−0.280
	(0.289)	(0.310)	(0.313)	(0.311)	(0.314)	(0.311)
Years of the relationship with MRL lender (log of +1)	0.184	0.075	0.088	0.081	0.039	0.081
	(0.117)	(0.121)	(0.121)	(0.121)	(0.147)	(0.121)

Firm has a checking account at MRL lender (0,1)	−0.144	−0.746	−0.823*	−0.775	−0.809*	−0.775
	(0.291)	(0.471)	(0.490)	(0.491)	(0.491)	(0.492)
Mile distance to MRL lender (log of +1)		0.045	0.058	0.061	0.059	0.061
		(0.099)	(0.101)	(0.101)	(0.101)	(0.101)
Number of institutions for loan transactions (log)	−0.050	−0.015	−0.021	0.008	−0.017	0.009
	(0.192)	(0.200)	(0.199)	(0.201)	(0.200)	(0.201)
HHI dummy (0,1)	0.390**	0.470**	1.409**	1.424**	1.415**	1.424**
	(0.188)	(0.200)	(0.634)	(0.631)	(0.634)	(0.632)
Industry dummy	Yes	Yes	Yes	Yes	Yes	Yes
Type of the MRL dummy	No	Yes	Yes	Yes	Yes	Yes
Type of the collateral dummy	Yes	Yes	Yes	Yes	Yes	Yes
Region dummy	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.174	0.204	0.211	0.214	0.211	0.213
Number of observations	889	822	822	822	822	822
[Marginal effects of key variables]						
HHI dummy	0.390**	0.470**	0.201	0.277	0.256	0.263
when the MRL lender is the inside bank	(0.188)	(0.200)	(0.170)	(0.198)	(0.182)	(0.195)
HHI dummy	Same as above	Same as above	1.409**	1.424**	1.415**	1.424**
when the MRL lender is an outside bank			(0.634)	(0.631)	(0.634)	(0.632)
Firm age	−0.590***	−0.504***	−0.514***	−0.143	−0.523***	−0.116
when the MRL lender is the inside bank	(0.145)	(0.146)	(0.147)	(0.314)	(0.148)	(0.251)
Firm age	Same as above	Same as above	Same as above	−0.649***	Same as above	−0.649***
when the MRL lender is an outside bank				(0.174)		(0.175)

Notes. Dependent variable: Interest rate on the most recent loan (%). OLS with the robust standard errors. Estimated coefficients are listed. The sample includes the firms that have a single inside bank, which maintains a relationship with a firm for longer than 1 year as of the most recent loan application and holds more than half of the total amount of all checking account balances of that firm. In each set of parentheses is the standard error of each estimated coefficient. The estimated constant term and the estimated coefficients of the dummies of industries (SIC 1 digit), regions (New England/Middle Atlantic, East North Central, West North Central, South Atlantic, South Central, Mountain/Pacific), the type of the most recent loan (line of credit, vehicle loan, mortgage, equipment loan, and others), and the type of the collaterals of the most recent loan (inventory/account receivable, business equipment/vehicle, business security/deposit, business real estate, personal real estate, and others) are omitted from the table. In the calculation of the marginal effects of HHI dummy (the lower part of the table), we assume firm age = 17.41 years (sample mean) and years of relationship with the inside bank = 9.96 years (sample mean). In the calculation of that of firm age, we set HHI dummy = 1. *, **, and *** indicate that the coefficient is significantly different from zero at a significance level of 10%, 5%, and 1%, respectively (two-tailed test).

Table 4
Separate regression.

	Competitive market (HHI dummy = 0)			Concentrated market (HHI dummy = 1)		
Variables	(1)	(2)	(3)	(1)	(2)	(3)
MRL lender is the inside bank	0.363	−0.300	0.207	0.856	−5.703**	−1.050
	(0.540)	(1.271)	(0.712)	(0.737)	(2.399)	(1.202)
MRL lender is the inside bank × Firm age		0.244			2.389***	
		(0.411)			(0.847)	
MRL lender is the inside bank × Yrs. of relation with the inside bank			0.087			1.202*
			(0.299)			(0.696)
Adjusted R^2	0.202	0.200	0.190	0.223	0.266	0.259
Number of observations	511	511	511	311	311	311

Notes. Dependent variable: Interest rate on the most recent loan (%). The estimated coefficients are estimated by OLS with the robust standard errors by using the dataset split by HHI ⩾ or < 1800. The set of the control variables is the same as that of the specification (4) in Table 3. The estimated coefficients of these control variables are omitted from the report. *, **, and *** indicate that the coefficient is significantly different from zero at a significance level of 10%, 5%, and 1%, respectively (two-tailed test).

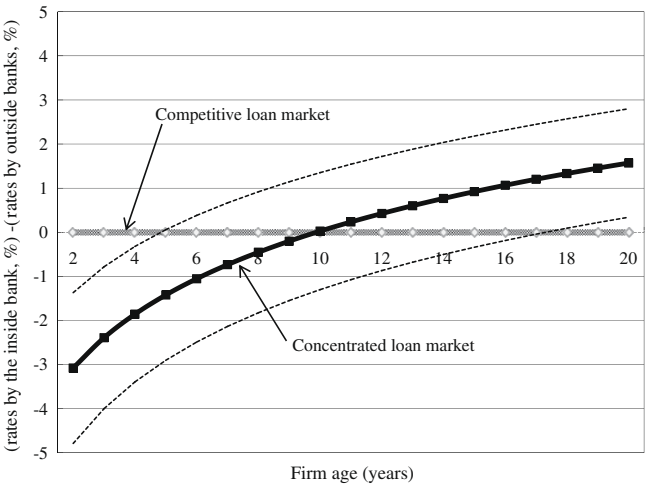

Fig. 3. Estimated rate difference.
Notes. The solid line is the mean rate difference between inside banks and outside banks in concentrated market (HHI ⩾ 1800). The area between two broken lines is the 95% confidence interval. The grey line is the mean rate difference in competitive market (HHI < 1800). The calculation is based on the estimates in the specification (2) in Table 4. The coefficients with *p*-values above 0.1 are set to be equal to zero.

Panel 1 in Table 6 lists the estimated average treatment effect for each of four classes; (1) firms in a competitive credit market and less than 10 years old, (2) firms in a competitive market and more than 10 years old, (3) firms in a concentrated market and less than 10 years old, and (4) firms in a concentrated market and more than 10 years old. The average treatment effect of borrowing from the inside bank is significantly negative only in class (3); i.e., firms in a concentrated market and less than 10 years old. This point is consistent with Hypotheses 1 and 2. The average treatment effect is significantly positive for firms more than 10 years old, and this effect does not differ by credit market concentration. However, when we classify the data according to whether the relationship with the inside bank was longer than or equal to 10 years or shorter than 10 years, rather than according to a firm's age, we cannot find any treatment effect that was significantly different from zero. The results of our baseline multivariate regression analysis and the propensity score matching analysis are generally supportive of Hypotheses 1 and 2, i.e., lending competition discourages banks from investing in private information, although the support is somewhat weak in some specifications.

Table 5
Preliminary logit.

Independent variables	Estimated marginal effect (standard error)
Prime rate (%)	−0.0603**
	(0.0239)
Term premium (%)	−0.0539***
	(0.0173)
Default premium (%)	−0.0089
	(0.0385)
Firm age (log of +1)	0.0914***
	(0.0258)
Asset of the firm (log of USD)	0.0176*
	(0.0090)
Debt/asset of the firm	0.0037
	(0.0058)
Firm is a corporation (0,1)	0.0425
	(0.0400)
Years of relationship with the inside bank (log of +1)	−0.0023
	(0.0022)
Years of relationship with the secondary bank (log of +1)	−0.0696
	(0.0673)
Inverse of the mile distance to the inside bank	−0.0002
((100 mile distance + 0.01)$^{-1}$)	(0.0005)
Mile distance to the nearest bank except the inside bank	−0.0018***
((100 mile distance + 0.01)$^{-1}$)	(0.0005)
Number of institutions for loan transactions (log)	−0.1593***
	(0.0381)
HHI dummy (0,1)	0.0294
	(0.0309)
Industry dummy	Yes
Type of the most recent loan dummy	Yes
Region dummy	Yes
Ratio of correctly predicted observations (50% cutoff point)	78.63%
Pseudo R^2	0.1734
Log likelihood	−425.27
Number of observations	889

Notes. Logit analysis with respect to the probability for a firm to apply for the most recent loan to the inside bank. The marginal effect of each coefficient is listed. The estimated constant term and the estimated coefficients of the dummies of industries (SIC 1 digit), regions (seven census regions), and the type of the most recent loan (line of credit, vehicle loan, mortgage, equipment loan, and others) are omitted from this table. *, **, and *** indicate that the coefficient is significantly different from zero at a significance level of 10%, 5%, and 1%, respectively (two-tailed test).

6. Robustness check

In order to check the robustness of the results of the baseline regression analysis in the previous section or to sharpen them up, we estimate the above model with various versions of key variables and various subsamples. We also control for the sample selection bias by applying Heckman's two-stage procedure. We summarize the results of these additional analyses in this section.

6.1. Various construction of key variables

Narrower definition of an inside bank. So far, we defined an inside bank of a firm as a bank that holds more than half of the total amount of all checking account balances of that firm and that has maintained a relationship with the firm for more than one year as of the loan application date. To check that our result in the previous section is robust against changes in this definition, we redefine the inside bank as one that monopolizes the checking account of the firm and maintains a relationship with the firm for more than one year as of the loan application date; we then estimate the same specification as in column (4) in Table 3. The estimated coefficients of the key variables are listed in column (1)

Table 6
Propensity score matching.

	Competitive market (HHI=0)				Concentrated market (HHI=1)			
	(1) Firm age ⩽ 10		(2) Firm age > 10		(3) Firm age ⩽ 10		(4) Firm age > 10	
Matching methods	Number of obs. up: treatment low: control	Average treatment effect (s.e.)	Number of obs. up: treatment low: control	Average treatment effect (s.e.)	Number of obs. up: treatment low: control	Average treatment effect (s.e.)	Number of obs. up: treatment low: control	Average treatment effect (s.e.)
Panel 1. Sorted by whether firm age is younger than 10 years or not								
Nearest neighbor	108	−0.668	290	0.843**	66	−1.092	189	0.783*
	29	(0.708)	53	(0.494)	22	(1.259)	32	(0.576)
Kernel density	108	−0.494	290	0.552	66	−1.159	189	0.488
(Gaussian)	57	(0.638)	77	(0.513)	31	(1.082)	50	(0.554)
Kernel density	108	−0.201	290	0.633*	66	−2.382**	189	0.301
(Epanechkov)	57	(0.750)	77	(0.489)	31	(1.408)	50	(0.530)
Panel 2. Sorted by whether the years of relationship with the inside bank is less than 10 years or not								
	(1) Years of relationship with the inside bank ⩽ 10		(2) Years of relationship with the inside bank > 10		(3) Years of relationship with the inside bank ⩽ 10		(4) Years of relationship with the inside bank > 10	
Nearest neighbor	263	−0.351	135	0.699	169	−0.203	86	0.577
	51	(0.551)	30	(0.690)	30	(0.692)	17	(0.768)
Kernel density	263	−0.024	135	0.834	169	−0.042	86	0.579
(Gaussian)	96	(0.496)	41	(0.798)	53	(0.634)	29	(0.507)
Kernel density	263	−0.059	135	0.767	169	−0.441	86	0.387
(Epanechkov)	96	(0.554)	41	(0.790)	53	(0.719)	29	(0.765)

Notes. Average treatment effect of borrowing from the inside bank estimated by the propensity score matching is listed in each of four categories: (competitive, young), (competitive, old), (concentrated, young), and (concentrated, old). Standard errors are calculated by bootstrapping with 100 repetitions. The bandwidth is set equal to 0.01 in kernel density matching. *, **, and *** indicate that the average treatment effect is significantly different from zero at a significance level of 10%, 5%, and 1%, respectively (one-tailed test). The test statistics are calculated by dividing the estimated average treatment effect by the estimated standard error. *P*-values are calculated from the standard normal distribution, according to the asymptotic normality of the test statistics.

in Table 7. The coefficient of the inside-bank dummy is now insignificant, while the interaction terms of the inside-bank dummy and the HHI dummy are negative and significant again. The tendency that this negative impact on the interest rate diminishes as a firm survives longer is more clearly observed than the estimates in the previous section. Thus, this result adds evidence supportive of Hypotheses 1 and 2.

Finer HHI dummies. We also include another HHI dummy, HHI dummy 2, which is equal to 1 if $1000 \leqslant \text{HHI} < 1800$, into our regression in addition to the HHI dummy used in the previous section, which is equal to 1 if $\text{HHI} \geqslant 1800$. Column (2) in Table 7 is the list of the estimated coefficients of the key variables, including the interaction terms. The estimates indicate that the extent of the interest discount by the inside bank for younger firms is larger for firms in a more concentrated market. Thus, this result adds evidence to support Hypothesis 1.

6.2. Subsample regression

Length of relationship. In our definition of the inside bank, we do not take into account the difference in the length of a relationship with a potential inside bank from that with outside banks. To address the resulting measurement error, we run a regression analysis with two subsamples: (1) The subsample that contains loans provided by the inside bank and those provided by an outside bank with a relationship shorter than or equal to one year, and (2) The subsample that contains loans provided by the inside bank and those provided by an outside bank with a relationship longer than one year. A negative interest difference is observed in the former subsample (column (3) in Table 7), but it is less significant in the latter subsample (column (3)' in Table 7). Because the former subsample possibly represents more closely those firms that have a single inside bank, this result reinforces the support for Hypotheses 1 and 2.

Firms with multiple bank relationships. In the baseline regression analysis, we dropped from our sample those firms whose checking account balances are so diversified that no bank accounts for more than half of a firm's total checking account holdings. Column (4) in Table 7 shows the estimated coefficients of key variables when we run the same regression as in column (4) in Table 3

Table 7
Regressions with various measures and subsamples.

Key variables	(1)	(2)	(3)	(3)′	(4)	(5)
	Strict inside bank	HHI dummy2	Yrs. of relation with outside lender ⩽ 1	Yrs. of relation with outside lender >1	Multiple relations	Heckman two-step procedure
MRL lender is inside bank	1.094	1.150	2.071**	0.368	0.293	1.104**
	(1.092)	(1.206)	(1.040)	(0.582)	(0.608)	(0.539)
MRL lender is inside bank	−3.550**	−4.092**	−3.228**	−1.163	−0.553	−2.671**
× HHI dummy	(1.400)	(1.789)	(1.586)	(1.013)	(1.386)	(1.093)
MRL lender is inside bank	0.605**	1.010***	0.299	0.351	−0.638*	0.524**
× HHI dummy × firm age	(0.299)	(0.380)	(0.253)	(0.248)	(0.467)	(0.260)
MRL lender is inside bank		−2.665*				
× HHI dummy2		(1.447)				
MRL lender is inside bank		0.939***				
× HHI dummy2 × firm age		(0.351)				
Inverse Mill's Ratio						−1.218
						(1.426)
Adjusted R^2	0.244	0.224	0.222	0.211	0.264	0.213
Number of observations	651	822	700	744	153	822

Notes. Dependent variable: Interest rate on the most recent loan (%). The coefficients are estimated by OLS with the robust standard errors. Estimated coefficients and standard errors of them are listed. The set of the control variables is the same as that of the specification (4) in Table 3. The estimated coefficients of these control variables are omitted from the report. *, **, and *** indicate that the coefficient is significantly different from zero at a significance level of 10%, 5%, and 1%, respectively (two-tailed test).

with the subsample containing only firms with diversified checking accounts after redefining the inside bank as one that maintains the largest checking account of a firm and keeps a relationship with the firm for longer than one year. As expected, we did not find any significant coefficients in this sample.

6.3. Sample selection bias

In the interest rate regression, we drop firms whose loan applications were rejected because interest rate information is not available for these firms, although the fact that a loan application was rejected should be informative about the lending behavior of banks. To utilize this wasted information, we applied Heckman's two-stage procedure (Heckman, 1976).[6] The coefficient of the inverse Mill's ratio is not statistically significant, and the estimated coefficients of the key variables do not differ qualitatively from the baseline result, as reported in the last column in Table 7.

6.4. Size of inside banks

The result in the baseline regression could be driven by the tendency that larger banks that are not productive in producing private information (Stein, 2002; Cole et al., 2004; Berger et al., 2005) are located in a more competitive area. We cannot control for this factor because the public version of the NSSBF database does not provide us with information about bank size. However, we can determine whether a bank is affiliated with a bank holding company from the NSSBF database. In our dataset for the regression analysis, 419 of 591 firms in competitive markets have an inside bank affiliated with a bank holding company, while 274 of 369 firms in concentrated markets have an inside bank affiliated with a bank holding company. The ratio of these BHC-affiliated inside banks is about 70% in either market. In other words, whether a bank is affiliated with a bank holding company is independent of the credit market concentration. Thus, it is not plausible that our regression results are driven by the correlation between bank size and market concentration if we are allowed to assume that those affiliated with a bank holding company are large banks.

7. Concluding remarks

The analytical model in this paper showed that a negative gap between the interest rates of loans extended by an inside bank and those of loans extended by an outside bank in the equilibrium emerges only when the inside bank is willing to collect private information about the borrower. This gap is larger in more concentrated credit markets, in which the expected rent from the informational advantage over rivals and the efforts to acquire private information about the borrower are larger than they are in more competitive credit markets. In theory, this gap is particularly pronounced at earlier stages, when the inside bank has started information acquisition but has not yet accumulated sufficient information to establish an advantage over rivals. In this earlier stage, expecting the future rent for the inside bank, the borrower tries to retrieve some of or all of it up front by treating the inside bank less favorably in competitive bidding. This borrower's strategy brings about a benefit of relationship banking: lower interest costs.

In the empirical part of this study, we found that the above interest difference between a potentially informed inside bank and an inside bank is negative and statistically significant only with respect to firms less than 10 years old in concentrated loan markets after controlling for the borrower's characteristics, firm–bank-specific characteristics, and market characteristics as much as possible. This result is consistent with the above prediction from our analytical model and implies that banks in more concentrated markets invest more in private information about their borrowers. This result is also consistent with some existing analytical results (Hauswald and Marquez, 2006) and

[6] The result of the first-stage probit with respect to loan approval is omitted from the tables but is available upon request from the author.

existing empirical studies based on data from the US (Petersen and Rajan, 1995). At this point, our results provide more evidence for the hypothesis that competition is detrimental to information acquisition from a different viewpoint using a different dataset.

Of course, these results from our statistical analysis are not readily applicable to other countries, given several competing theories that show the possibility of a positive correlation between lending competition and relationship banking (Boot and Thakor, 2000; Dinç, 2000; Yafeh and Yosha, 2001). Indeed, Elsas (2005) and Degryse and Ongena (2007) found that, in Germany and in Belgium, respectively, the probability of a firm receiving relationship banking is U-shaped against the loan-market concentration measure. An empirical study to detect clearly the cause of this variation in the correlation between lending competition and relationship banking would be an interesting future research subject.

Appendix A. The analysis in the third period

A.1. 1. The equilibrium in the third period

The inside bank's expected return π_3^i is equal to:

$$\begin{cases} \left\{(1-G(R_3^i))r+1-r\right\}^{n-1}(R_3^i-I) & \text{if the inside bank knows that } type=G,\\ 0 \quad \text{if the inside bank knows that } type=B,\\ \left\{(1-G(R_3^i))r+1-r\right\}^{n-1}(R_3^i\mu''-I) & \text{if the inside bank is uninformed,}\end{cases} \tag{19}$$

where R_3^i is a face value bid by the inside bank in the third period, $G(\cdot)$ is the cumulative distribution function of an outside bank's bid R_3^o, and r is the outside bank's participation probability.

An outside bank's expected return π_3^o is equal to:

$$\begin{aligned}&\left\{(1-G(R_3^o))r+1-r\right\}^{n-2}\left\{(1-H(R_3^o))(R_3^o-1)\mu''-(1-\mu'')\right\}\alpha(c^*)\\ &\quad+\left\{(1-G(R_3^o))r+1-r\right\}^{n-2}\left\{(1-J(R_3^o))s+1-s\right\}(R_3^o\mu''-1)(1-\alpha(c^*)),\end{aligned}$$

where $H(\cdot)$ is the cumulative distribution function of R_3^i when the inside bank obtains private information, $J(\cdot)$ is that of R_3^i when it cannot obtain private information, and s is the inside bank's participation probability.

The outside bank never bids $R_3^o < I/\mu''$, because the outside bank's expected return is negative if it does so. We denote this lower bound of the outside bank's bid by $\underline{R}_3^o \equiv I/\mu''$. If the inside bank has perfect information that the type of the borrower is G and it bids $R_3^i = \underline{R}_3^o$, then it will win with a probability of one under our tie-breaking assumption, in which the inside bank wins if the inside bank and outside banks tie. Therefore, the expected return of the inside bank in this case is equal to:

$$\left\{(1-G(\underline{R}_3^o))r+1-r\right\}^{n-1}(\underline{R}_3^o-1)=\frac{(1-\mu'')I}{\mu''}. \tag{20}$$

In the mixed strategy equilibrium, the expected return of the inside bank that could not obtain private information must be equal to this expression for any R_3^i that is assigned with a positive probability in the equilibrium mixed strategy. Thus, we obtain:

$$\left\{(1-G(R_3^o))r+1-r\right\}^{n-1}=\frac{(1-\mu'')I/\mu''}{R_3^o-I}. \tag{21}$$

Substituting this into the expected return of the inside bank when it cannot obtain private information, the third expression in (19), gives:

$$\frac{R_3^i\mu''-I}{R_3^i-I}\,\frac{(1-\mu'')I}{\mu''}. \tag{22}$$

Because this is increasing in R_3^i, the inside bank always bids the highest possible bid V when it cannot obtain private information. Therefore:

$$(1-J(R_3^o))s+1-s=1, \quad \forall\, R_3^o \in [\underline{R}_3^o, V].$$

By Theorem 2 in Engelbrecht-Wiggans et al. (1983), $\pi_3^o = 0$ in the equilibrium; thus, the equilibrium mixed strategy by the inside bank is expressed by the following cumulative distribution function after substituting in the previous expressions:

$$\alpha(c^*)\left\{1-H(R_3^i)\right\}+1-\alpha(c^*)=\frac{(1-\mu'')I}{\mu''(R_3^i-I)}, \quad \forall\, R_3^i \in [I/\mu'', V]. \tag{23}$$

By substituting $R_3^i = V$, we can show that the inside bank bids V with a probability of $\max\left[\frac{(1-\mu'')I}{\alpha(c^*)\mu''(V-I)}-\frac{1-\alpha(c^*)}{\alpha(c^*)}, 0\right]$. From Eqs. (20) and (22) at $R_3^i = V$, the expected return to the inside bank in the equilibrium is summarized as follows:

$$\pi_3^i=\begin{cases}\frac{(1-\mu'')I}{\mu''}, & \text{if the inside bank knows that } type = G,\\ 0, & \text{if the inside bank knows that } type = B,\\ \frac{V\mu''-I}{V-I}\,\frac{(1-\mu'')I}{\mu''}, & \text{if the inside bank is uninformed.}\end{cases} \tag{24}$$

A.2. The interest difference in the third period under asymmetric information

Because:

$$\left\{(1-G(R_3^i))r+1-r\right\}^{n-1}(R_3^i-I)=\frac{(1-\mu'')I}{\mu''},$$

both when the inside bank knows that the borrower is G and when the inside bank cannot obtain the private information, the expected interest rate to the inside bank is equal to:

$$\frac{(1-\mu'')I}{\mu''}. \tag{25}$$

We can verify that the expected interest rate to an outside bank is also equal to:

$$\left\{(1-H(R_3^o))\alpha(c^*)+((1-J(R_3^o))s+1-s)(1-\alpha(c^*))\right\}(R_3^o-I)=\frac{(1-\mu'')I}{\mu''},$$

by substituting (23) into the first expression. Thus, there is no difference between the expected interest rates to the inside bank and outside banks in the third competition regardless of informational asymmetry between the inside bank and outside banks. □

Appendix B. Comparative statistics of the interest rate difference

The effect of the increase in the number of competing banks is:

$$\frac{d\eta^*}{dn}=\frac{\partial\eta^*}{\partial c^*}\frac{dc^*}{dn}+\frac{\partial\eta^*}{\partial n}=-\frac{c^*}{\gamma+\beta^2(1-\gamma)}\leqslant 0. \tag{26}$$

The first term in the second expression is equal to zero from the first-order condition (9). The effect of the increase in a firm's age, which is represented by the increase in γ, on this impact is given by:

$$\frac{d^2\eta^*}{dn\,d\gamma}=-\frac{1}{\gamma+\beta^2(1-\gamma)}\frac{dc^*}{d\gamma}-c^*\frac{\partial}{\partial\gamma}\left(\frac{1}{\gamma+\beta^2(1-\gamma)}\right)\geqslant 0. \tag{27}$$

$dc^*/d\gamma \leqslant 0$ is easily verified by applying the implicit function theorem to the first-order condition (9). □

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