Information Technology and Bank Competition*

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Abstract

We consider a spatial model of bank competition to study how the diffusion of information technology affects competition in the lending market, stability of the banking sector, and social welfare. We find that the effects of an improvement in information technology depend on whether or not it weakens the influence of bank–borrower distance on monitoring/screening costs. If so, then bank competition intensifies, which reduces bank stability and brings about an ambiguous welfare effect. Otherwise, competition intensity does not vary, banks are more stable, and welfare improves. If banks have local monopolies, then technological progress always improves social welfare.

JEL Classification: G21, G23, I31

Keywords: bank stability, credit, monitoring/screening, FinTech, Big Data, price discrimination, deposit insurance, regulation

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1 Introduction

The banking industry is undergoing a digital revolution. Banks feel increasing pressure from the threat of financial technology (FinTech) companies and BigTech platforms that adopt innovative information and automation technology in traditional banking businesses. Prominent examples can be seen in China, where Alibaba and Tencent – the two largest BigTech companies – are active in a wide range of financial services that include payments, wealth management, and lending. In the United States, online FinTech lenders now account for some 8%–12% of new mortgage loan originations (Buchak et al., 2018; Fuster et al., 2019) and about a third of personal unsecured loans (Balyuk and Davydenko, 2019). The banking sector itself is transforming from reliance on physical branches to adopting information technology (IT) and Big Data in response to the increased supply of technology and to changes in consumer expectations of service, which are the two main drivers of digital disruption (FSB, 2019; Vives, 2019). Information technology allows financial intermediaries to offer personalized services and to price discriminate. The COVID-19 pandemic has accelerated this digitalization process and fosters remote loan operations; the result is stimulation of the development and diffusion of IT in the banking sector (Carletti et al., 2020).

How do the development and diffusion of information technology affect bank competition? Are banks more or rather less stable as IT develops? What are the welfare implications of information technology? To answer those questions, we build a model of spatial competition in which banks compete to provide entrepreneurs with loans. The key ingredients of our model are that price-discriminating banks are differentiated and offer personalized monitoring/screening services to entrepreneurs.

We model the lending market as a circular city à la Salop (1979), where two banks – which are located symmetrically at two endpoints of the city's diameter – compete for entrepreneurs who are distributed along the city circumference. Entrepreneurs can undertake risky investment projects, which may either succeed or fail, but have no initial capital; hence they require funding from banks. Banks have no direct access to investment projects, so their profits are derived from offering loans to entrepreneurs. Banks compete in a Bertrand fashion by simultaneously posting their discriminatory loan rate schedules. In addition to financing entrepreneurs, another critical bank function is monitoring entrepreneurs in order to increase the probability of their projects' success (see e.g. Martinez-Miera and Repullo, 2019). As an alternative, banks can screen entrepreneur projects and help identify the good ones. Either the monitoring or the screening effort of a bank increases the probability of success of a financed project. Monitoring/screening is more costly for a bank if there is more distance between its expertise and the entrepreneur's project characteristics.[1] Information technology can be of service in two ways. The first is by lowering the costs of monitoring/screening an entrepreneur without affecting banks' relative cost advantage in different locations – for example, by making improvements in the processing of hard information. The second is by reducing the effect of bank–borrower distance on monitoring/screening costs; for example, IT can facilitate transforming soft information into hard information via Big Data and machine learning techniques. In what follows, the term "monitoring" will refer both to monitoring proper and to screening.

Under the set-up just described, we study how information technology affects bank competition and obtain results consistent with the available empirical evidence. We find that by adopting more advanced IT, whatever its type, a bank can offer higher loan rates to entrepreneurs. The reason is that a bank's IT progress increases its competitive advantage. Another of our results is that a bank will become more stable as its IT progresses.

When two competing banks each make technological progress, that progress will not increase the overall competitive advantage of either bank. In this case, the different types of IT progress can yield different results. If IT progress involves only a reduction in the costs of monitoring an entrepreneur without altering banks' relative cost advantage, then banks' competition intensity will not be affected by such technology progress. In this case, the loan rates that banks offer to entrepreneurs will not vary, although banks will become more profitable and stable because monitoring is now cheaper. However, if IT progress involves a weakening in the influence of bank–borrower distance on monitoring costs, then banks' competition intensity will increase. The result follows because this type of technological progress reduces banks' differentiation. As a consequence, the loan rates offered to entrepreneurs will decline for both banks, which thereby become less profitable and less stable.

Finally, we analyze the welfare effects of information technology progress. We find that more intense competition is not always welcome from the perspective of social welfare. When competition in the lending market is at a low level, increasing competition intensity improves welfare because more competition greatly increases entrepreneurs' utility.

[1] Furthermore, there is evidence that firm–bank *physical* distance also matters for bank lending. Degryse and Ongena (2005) document spatial discrimination in loan pricing; see also Petersen and Rajan (2002) and Brevoort and Wolken (2009).

Yet too much competition can reduce social welfare because high competition intensity will decrease banks' incentive to monitor entrepreneurs, which in turn will render those projects less likely to succeed. So if IT progress weakens the influence of bank–borrower distance on monitoring costs, then that progress may or may not benefit social welfare owing to the consequent increased bank competition – which improves or reduces welfare according as whether there was a low or high level of competition to start. In fact, if information technology is cheap, banks would be trapped in a prisoner's dilemma and choose endogenously very low levels of differentiation, excessive from the social point of view. If IT progress simply means that the cost of monitoring an entrepreneur is lower (and that banks' relative cost advantage is unaffected), then there is no competition effect and social welfare will improve. This outcome arises also if, in equilibrium, banks do not compete with each other; in that case, the only effect of IT progress is to make monitoring cheaper.

Our baseline model assumes that depositors can observe the bank's monitoring effort (which determines its risk position). Our results hold also if depositors are protected by a fairly priced deposit insurance scheme and do *not* observe monitoring levels. The reason is that risk is priced fairly in both cases and so banks' payoff functions are the same. Note that insurance renders deposits riskless, so depositors will accept lower nominal deposit rates; this reduces the amount that banks must promise to depositors, thereby promoting bank stability and thus social welfare. In any case, the presence of deposit insurance does not change the effects of IT progress on bank stability and social welfare.

Related literature. This work builds on the spatial competition models of Salop (1979) and Thisse and Vives (1988); but our model focuses on bank competition. Similarly to our paper, Matutes and Vives (1996) and Cordella and Yeyati (2002) study bank competition within a spatial competition framework. Yet in their work, banks compete for deposits and can directly invest in risky assets. In contrast, the banks in our model compete to finance entrepreneurs' projects, monitor them, and are able to price discriminate. A more closely related work is that of Almazan (2002), who studies how bank capitalization, interest rates, and regulatory shocks can affect bank competition and monitoring efficiency in a spatial competition model where a bank's monitoring expertise decreases linearly with bank–borrower distance. For Almazan model, the only difference between banks is the level of their capital; banks cannot strategically choose loan rates because loan contracts are offered by entrepreneurs, who have all bargaining power vis-a-vis banks. In our work, banks differ in their IT and the strategic pricing of banks is based on their competitive advantage – which is affected by information technology.

Our study also belongs to the literature that studies information technology and bank competition. Hauswald and Marquez (2003) find that improving an informed bank's ability to process information strengthens the "winner's curse" (adverse selection) faced by an uninformed bank, decreases the intensity of bank competition, and increases the loan rate that borrowers are expected to pay. However, if both informed and uninformed banks can easily access public information, then the information gap between them becomes smaller; this softens the winner's curse, increases the intensity of bank competition, and reduces borrowers' expected loan rate. Hauswald and Marquez (2006) extend that model by allowing (a) the endogenous investment by banks in information processing technology and (b) the bank–borrower distance to have a negative effect on the precision of banks' information. These authors find that more intense bank competition reduces banks' incentive to invest in information processing and that borrowers pay lower rates when they are located farther from the bank that screens them.[2] We likewise find that borrowers located farther from the lending bank pay lower rates when there is bank competition.

However, our approach differs in several aspects. First, there is a major difference in our interpretation of screening: the Hauswald and Marquez models incorporate adverse selection whereas our model features "inverse" selection, whereby a bank by screening knows more about an entrepreneur's project than does the entrepreneur herself.[3] Screening increases the success probability of a financed entrepreneur's project, which benefits both the lender and the borrower. So when deciding on which bank to borrow from, entrepreneurs will consider not only the competing banks' loan rates but also their intensity of screening. Second, in our model the progress of IT need not affect banks' differentiation. Third, we assume that banks must borrow from depositors in order to make loans and therefore run the risk of insolvency. This assumption enables us to analyze how IT affects bank stability.

Several papers have emphasized the importance of monitoring in banking.[4] Martinez-

[2]Using a similar framework, He et al. (2020) introduce "open banking" – an information sharing mechanism that enables borrowers to share their customer data stored in a bank with a FinTech lender that has advanced information processing technology but no access to customer data. They find that open banking increases the FinTech lender's screening ability and competitiveness but that the "screening ability gap" between the bank and the FinTech lender does not necessarily shrink. In particular, open banking can soften the lending competition and so hurt borrowers if the FinTech lender is "overempowered" by the data sharing mechanism.

[3]Inverse selection is the term used by Brunnermeier et al. (2020). There are many companies (e.g., Zestfinance, Scienaptic systems, Datarobot, Underwrite.ai) that help the financial industry improve credit screening via Big Data and machine learning techniques, thus transforming soft data into hard data. See also Boot et al. (2020).

[4]The *delegated monitoring theory* of financial intermediaries was first explored by Diamond (1984), who shows that if investors can impose non-pecuniary penalties on a financial intermediary (e.g., a

Miera and Repullo (2019) examine the effectiveness of monetary and macroprudential policies in addressing a financial system's risks within a framework where bank monitoring can increase the probability that investing in an entrepreneur yields a positive return. In our work, bank monitoring increases the likelihood of entrepreneurial success, which is similar to the set-up of the Martinez-Miera and Repullo model. However, we focus on how information technology affects bank monitoring, which in turn affects bank competition, bank stability, and social welfare.

This study is also related to the literature that explores the connection between bank competition and bank stability (for a survey, see Vives, 2016).[5] In contrast to the literature, our paper focuses on how the development and diffusion of IT affect bank competition, bank stability, and social welfare.

Finally, we propose a theoretical framework relevant to the empirical literature on information technology adoption in the lending market, which has thrived owing to the rise of FinTech in recent years (Vives, 2019).[6] To start with, there is considerable evidence showing that IT makes non-traditional data – such as soft information (Iyer et al., 2016), friendships and social networks (Lin et al., 2013), applicants' description text (Dorfleitner et al., 2016; Gao et al., 2018; Netzer et al., 2019), contract terms (Kawai et al., 2014; Hertzberg et al., 2016), mobile phone call records (Björkegren and Grissen, 2020), and digital footprints (Berg et al., 2020) – useful for assessing the quality of borrowers.

Moreover, there is a wide stream of research that documents the increases in lending efficiency brought about by information technology. Frost et al. (2019) report that, in Argentina, credit-scoring techniques based on Big Data (e.g., platform transactions and the reputation of sellers) and processed with machine learning and artificial intelligence techniques have outperformed credit bureau ratings in terms of predicting the loss rates

bank) with poor performance then the optimal arrangement is to sign a deposit contract with the financial intermediary and have it monitor borrowers. Holmstrom and Tirole (1997) demonstrate that bank monitoring increases the availability of external funding to firms, but poorly capitalized firms still have no access to external funding.

[5] Gehrig (1998) finds that under certain conditions the entry of a new bank into a formerly monopolistic banking market will reduce the incumbent's screening efforts and so increase its bank risk. Boyd and De Nicolo (2005) show that more bank competition is good for bank stability because firms will take less risk when loan rates are lower; this is a favorable risk-shifting effect. However, Martinez-Miera and Repullo (2010) note that lower rates also reduce the banks' revenues from non-defaulting loans – a margin effect. Together these two effects yield a U-shaped relationship between competition and the risk of bank failure. When the number of banks is small, the risk-shifting effect dominates; but when the number of banks is sufficiently large, the margin effect (charter value) dominates.

[6] Philippon (2016) claims that the existing financial system's inefficiency can explain the emergence of new entrants that bring novel technology to the sector.

of small businesses.[7] Buchak et al. (2018) find FinTech lenders – which can be viewed as banks that adopt advanced technology – charge higher loan rates in the US mortgage market than do traditional banks; our model implies a similar result that a bank with better IT can offer higher loan rates to entrepreneurs. Kwan et al. (2021) find that banks with better IT originate more "paycheck protection program" loans – especially in areas with more severe COVID-19 outbreaks, higher levels of Internet use, and more intense bank competition; this is consistent with our finding that a higher intensity of bank competition increases the sensitivity of a bank's loan volume to its IT progress. Pierri and Timmer (2021) study the implications of IT in banking for financial stability; these authors find that pre-crisis IT adoption that was higher by one standard deviation led to 10% fewer non-performing loans during the 2007–2008 financial crisis; we provide a consistent result that a bank will become more stable as its IT progresses. Ahnert et al. (2021) document that small business lending by banks with higher IT adoption is less affected by the distance between the bank headquarters and their borrower; our model is in line with the finding by showing that a bank's geographic reach will be extended if the bank adopts better information technology.

The rest of our paper proceeds as follows. Section 2 presents the model set-up; in Section 3, we examine the lending market equilibrium. Section 4 analyzes how information technology affects bank stability, and Section 5 gives a welfare analysis of information technology progress. We conclude in Section 6 with a summary of our findings. Appendix A presents all the proofs, and the other appendices deal with extensions.

2 The model

The economy and players. The economy is represented by a circular "city", of circumference 2, that is inhabited by entrepreneurs and banks. A point on the circumference represents the characteristics of an entrepreneur (type of project, technology, . . .) at this location, and two close points mean that the entrepreneurs in those locations are similar. Entrepreneurs' types are uniformly distributed along the city.

There are two banks, labeled by $i = \{1, 2\}$, located symmetrically at the two endpoints of a diameter of the city. Hence banks are closer to some entrepreneurs than to others. This means, for example, that banks are specialized in different sectors of the economy. If the distance between an entrepreneur and bank 1 is z, we say that the entrepreneur is

[7] Furthermore, Fuster et al. (2019) estimate that technology-based lenders process mortgage applications 20% faster than do traditional lenders yet without incurring greater default risk.

located at (location) z. As a result, the distance between an entrepreneur at z and bank 2 is $1-z$. At each location (e.g. location z) there is a potential mass M of entrepreneurs. Figure 1 gives an illustration of the economy.

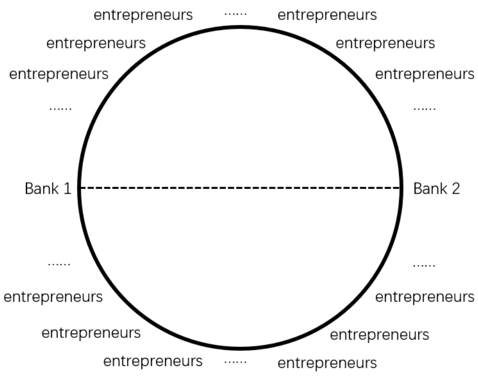

Figure 1: The Economy.

Entrepreneurs and monitoring intensity. Each entrepreneur has no initial capital but is endowed with a risky investment project that requires a unit of funding; hence entrepreneurs require funding from banks to undertake projects. The investment project of an entrepreneur at z yields the following risky return:

$$\widetilde{R}(z) = \begin{cases} R & \text{with probability } \ m(z), \\ 0 & \text{with probability } \ 1-m(z). \end{cases}$$

In case of success (resp. failure), the entrepreneur's investment yields R (resp. 0). The probability of success is $m(z) \in [0,1]$, which represents how intensely the entrepreneur is monitored by a bank. An entrepreneur at z who borrows from bank i with loan rate $r_i(z)$ will receive a residual payoff of $R - r_i(z)$ (resp. 0) from the investment when her project succeeds (resp. fails).

Bank deposits. For simplicity, we assume that banks have no initial capital and must therefore finance bank loans by attracting funds from risk-neutral depositors. Bank deposits are not insured, and the funding supply of depositors is perfectly elastic when the expected payoff of a unit of deposits is no less than the risk-free rate f. The deposit rate of bank i is denoted by d_i, which must be set so as to make depositors break even. We assume that, before d_i is determined, banks' monitoring intensities have already been observed by depositors. Hence d_i can be adjusted to reflect bank i's risk, which ensures that the bank's expected payment to a unit of deposits is no less than f regardless of how intensely the bank chooses to monitor. This situation is equivalent to the case where depositors cannot observe the monitoring intensity of loans but are protected by a fairly priced deposit insurance scheme.

Entrepreneurs' funding demand. An entrepreneur at location z can borrow and invest at most 1 unit of funding. If an entrepreneur at z borrows at loan rate $r(z)$ and is monitored with intensity $m(z)$, then her expected net return on the investment is

$$\pi^e(z) \equiv (R - r(z))m(z).$$

We assume that the entrepreneur derives utility $\pi^e(z) - \underline{u}$ by implementing the risky project and seeks funding if and only if $\pi^e(z) \geq \underline{u}$. We interpret $\underline{u}$ as the reservation utility of the entrepreneur's alternative activities. For each entrepreneur at z, $\underline{u}$ is independently and uniformly distributed on $[0, M]$. The total funding demand (which is also the measure of entrepreneurs who require funding) at location z is therefore

$$D(z) = M \int_0^M \frac{1}{M} 1_{\{\pi^e(z) \geq \underline{u}\}} \, d\underline{u} = \pi^e(z),$$

and total entrepreneurial utility at location z can be written as

$$M \int_0^M \frac{1}{M} (\pi^e(z) - \underline{u}) 1_{\{\pi^e(z) \geq \underline{u}\}} \, d\underline{u} = \frac{(\pi^e(z))^2}{2}.$$

Correlation among entrepreneurs' projects. The outcomes of projects are driven by a single aggregate risk factor θ that is uniformly distributed over the interval $[0, 1]$. The project of an entrepreneur at z under monitoring intensity $m(z)$ fails if and only if

$$\theta < 1 - m(z).$$

The risk factor θ can be viewed as a measure of economic conditions. A project with a higher θ requires less monitoring to succeed.

Monitoring and information technology. The two banks can use monitoring to increase entrepreneurs' probability of success. More specifically, if an entrepreneur at z borrows from bank i and if the bank monitors the entrepreneur with intensity m_i, then the bank incurs the non-pecuniary quadratic monitoring cost

$$C_i(m_i, z) = \frac{c_i}{2(1 - q_i s_i)} m_i^2.$$

Here $c_i > 0$, $R \geq \sqrt{2c_i f}$, $q_i \in (0, 1)$, and s_i is the distance between bank i and entrepreneur z; we have $s_i = z$ (resp., $s_i = 1 - z$) if $i = 1$ (resp., $i = 2$). The parameters c_i and q_i are inverse measures of the efficiency of bank i's monitoring technology. Parameter c_i captures how costly bank monitoring is in general, while q_i measures the influence of bank–borrower distance on monitoring costs. A bank has greater capacity to discipline nearby borrowers and must expend more effort to monitor entrepreneurs who are more distant from their expertise. The constraint $R \geq \sqrt{2c_i f}$ must hold to guarantee that bank i is willing to provide loans to at least some entrepreneurs in the market. Our assumption implies that bank i's information technology can develop in two ways: by changing c_i and/or changing q_i. For example, IT may improve the ability of bank i to process hard information, which lowers c_i; yet IT can also improve the bank's ability to deal with soft information (e.g., by using technology to harden soft information or to improve a bank's organizational structure), which reduces q_i (see Liberti and Petersen, 2019 and Degryse et al., 2009).

Remark: The cost function $C_i(m_i, z)$ has two crucial properties when $q_1 = q_2 = q$ and $c_1 = c_2 = c$. First, the ratio of the two banks' monitoring costs at location z (i.e., $C_1(m_1, z)/C_2(m_2, z)$) is independent of c for any given m_1 and m_2. This property implies that increasing c does not affect a bank's relative cost advantage (or disadvantage), although it makes monitoring more costly for both banks. The second property is

$$\frac{\partial^2 \left(\frac{C_1(m_1,z)}{C_2(m_2,z)}\right)}{\partial z \partial q} = \frac{2(1 - q(1 - z))}{(1 - qz)^3} \left(\frac{m_1}{m_2}\right)^2 > 0,$$

which means that the sensitivity of the relative cost advantage to z is increasing in q. Note that $C_1(m_1, z)/C_2(m_2, z)$ increases with z. Therefore, increasing q not only makes monitoring more costly but also magnifies the importance of entrepreneurs' locations in determining the relative cost advantage (or disadvantage) of a bank.

Interpretation of monitoring. Tirole (2010) distinguishes two forms of monitoring: active and speculative. An *active* monitor can directly intervene to prevent or correct a firm's policy, whereas a *speculative* monitor cannot. In reality, debt holders do not directly interfere in the management of a firm unless the firm defaults on its debts. Therefore, we shall interpret banks' monitoring as speculative monitoring. Although banks do not directly participate in firms' management, they can collect firm data and assess whether the firm is acting appropriately to return its loan (and, more generally, acting in the interest of debt holders), which disciplines firms' management. Speculative monitoring relies on collecting and processing information about the focal firm, so it is facilitated by any advancement in the lending bank's information technology. In our model, an important feature of monitoring is that it benefits both banks and entrepreneurs; hence we can view our monitoring (or screening) as banks' advising, mentoring or/and information production that are valuable for entrepreneurs in a relationship lending context.

Competition with discriminatory loan pricing. In extending loans, banks compete in a localized Bertrand fashion. Bank i follows a discriminatory pricing policy in which the loan rate $r_i(z)$ varies as a function of the entrepreneurial location z.[8]

The timing of the lending game is as follows (see Figure 2). First, banks post loan rate schedules simultaneously. Once the loan schedules are chosen and posted, entrepreneurs decide whether to implement their projects and which bank to approach for funding. Given entrepreneurs' decisions and the loan rates of each bank, bank i chooses its optimal monitoring intensity (i.e., $m_i(z)$), depending on the location of entrepreneurs. Finally, depositors – after observing $m_i(z)$ – put their money into banks and are promised a nominal deposit rate d_i.

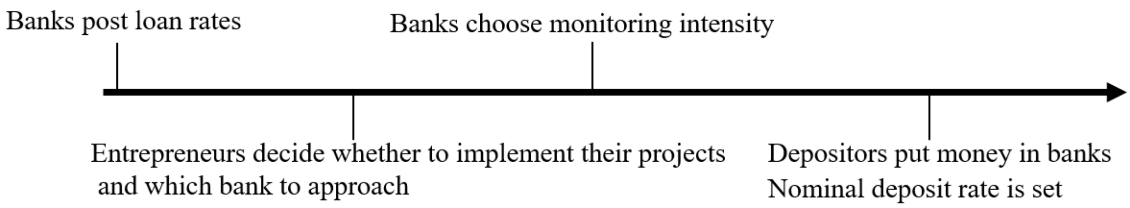

Figure 2: Timeline.

Remark: A screening interpretation. Instead of assuming that banks can monitor their borrowers and thus increase projects' probability of success, we could build our model while assuming that banks can increase the quality of their loans by screening entrepreneurs. Internet Appendix D describes the screening-based model. In this model, we assume that entrepreneurs are of two types: good or bad. The project of a good (resp. bad) entrepreneur succeeds with a positive (resp. zero) probability. Banks and

[8] Degryse and Ongena (2005) document spatial discrimination in loan pricing. See also Agarwal and Hauswald (2010).

entrepreneurs have the same prior belief about the distribution of entrepreneurial types. By screening an entrepreneur, a bank receives a signal that is either high or low and thereby reveals (in part) the entrepreneur's type. Entrepreneurs do not know their own types, so there is no adverse selection between entrepreneurs and banks in our model; rather, there is *inverse* selection whereby banks – after screening – know more about projects than do the entrepreneurs themselves. An entrepreneur can perfectly infer her signal, and therefore update her belief, based on whether or not she is able to secure bank funding. The project of an entrepreneur who receives bank financing will succeed with a higher probability when the bank's screening intensity (the equivalent of m_i in the monitoring model) is higher, from which it follows that the entrepreneur's expected utility of implementing her project will increase with the lending bank's intensity of screening. Thus screening benefits banks and entrepreneurs both, which is a key feature of our model. The cost of increasing the signal's precision by raising the screening intensity is greater for an entrepreneur located farther from the bank. The principal results of the monitoring model are robust to the screening interpretation.

3 The equilibrium

In this section we analyze the equilibrium and seek to establish how the development and diffusion of information technology can affect bank competition. Toward these ends, we consider two types of equilibria in the spatial competition model. The first type is the equilibrium with direct competition, in which case all locations are served by the two banks. The other type is the local monopoly equilibrium, where the two banks do not compete with each other and some locations are not served by either bank. We focus mostly on the equilibrium with direct competition – given that competition is our paper's main topic – but we also characterize the local monopoly equilibrium.

3.1 Equilibrium with direct competition

We start by considering the case where two banks compete with each other directly and all locations are served. Since banks' loan rates can vary with entrepreneurial location, there is localized Bertrand competition between banks at each location. So without loss of generality, we concentrate on location z and analyze how banks set loan rates to compete for entrepreneurs at z. We solve the equilibrium by backward induction and so first examine how banks choose their monitoring intensity. Bank i's loan rate and monitoring intensity for entrepreneurs at z are denoted by $r_i(z)$ and $m_i(z)$, respectively.

Optimal choice of monitoring intensity. According to the timeline, an entrepreneur at z has already decided whether to implement her project and which bank to borrow from *before* banks choose their monitoring intensity. If an entrepreneur at z approaches bank 1, then bank 1's expected profit (or payoff function) from financing the entrepreneur can be written as

$$\pi_1(z) \equiv r_1(z)m_1(z) - f - \frac{c_1}{2(1-q_1 z)}(m_1(z))^2. \tag{1}$$

The first term of $\pi_1(z)$ is the expected repayment of bank 1's loans from an entrepreneur at z, because the entrepreneur repays bank 1 the amount $r_1(z)$ with probability $m_1(z)$. The second term measures bank 1's funding costs by borrowing from depositors. Note that what determines bank 1's funding costs is the risk-free rate f, not the bank's nominal deposit rate d_1. The reason is that d_1 is determined after depositors have observed bank 1's monitoring intensity schedule and is adjusted to reflect the bank's ultimate risk. When a bank makes its decisions, it knows that its expected return to depositors will be f. Finally, the third term represents bank 1's non-pecuniary monitoring costs.

Remark: Fairly priced deposit insurance and non-observable monitoring. In this case, bank 1's payoff from financing an entrepreneur at z is the same as Equation (1) – as shown in Internet Appendix C – because risk is appropriately priced when it is observable by depositors and also when it is not observable yet there is fairly priced deposit insurance. It follows that all propositions in this section are valid also in the case with fairly priced deposit insurance.

Bank 1 chooses its optimal monitoring intensity $m_1(z)$ to maximize its expected profit $\pi_1(z)$, while taking $r_1(z)$ as given; the result is presented in Lemma 1.

Lemma 1. *Bank 1's optimal monitoring intensity for entrepreneurs at z is given by*

$$m_1(z) = \frac{r_1(z)(1-q_1 z)}{c_1}.$$

Bank 2's optimal monitoring intensity for entrepreneurs at z is symmetrically given by

$$m_2(z) = \frac{r_2(z)(1-q_2(1-z))}{c_2}.$$

Because the two banks are symmetric, we explain only the intuition behind $m_1(z)$.

First, note that $m_1(z)$ is decreasing in c_1 since bank 1 has less incentive to monitor as monitoring becomes more costly. Second, $m_1(z)$ is also decreasing in z because monitoring an entrepreneur at z is more costly for bank 1 when the entrepreneur is located farther away. Finally, $m_1(z)$ is increasing in $r_1(z)$. This statement follows because $r_1(z)$ represents bank 1's marginal benefit of monitoring an entrepreneur at z. The higher is $r_1(z)$, the more bank 1 receives from the entrepreneur's loan repayment when her project succeeds and so the more incentive bank 1 has to increase its intensity of monitoring.

Remark: According to Lemma 1, bank 1's payment d_1 to depositors does not affect $m_1(z)$. This result differs from the findings of Martinez-Miera and Repullo (2019), who assume that depositors cannot observe a bank's monitoring intensity and show that such intensity is determined by the bank's "intermediation margin", which is the bank's loan income *minus* its payment to depositors. In this case, a higher deposit rate will reduce the marginal benefit of monitoring; hence banks choose lower monitoring intensities when the deposit rate is high. Yet in our paper, d_i is adjusted to bank i's risk because its monitoring intensity is observable to depositors.

Best loan rate and monopoly loan rate. We solve the equilibrium following the method proposed by Thisse and Vives (1988). Which bank is able to attract an entrepreneur at z depends on which bank can provide a better loan rate (or "price") to the entrepreneur. Before proceeding, we introduce two concepts – *best loan rate* and *monopoly loan rate* – which are defined as follows.

Definition 1. *The best loan rate that bank i can offer to an entrepreneur at z is the loan rate that maximizes the entrepreneur's expected utility and ensures the bank a non-negative profit. The monopoly loan rate of bank i is the loan rate that bank i would choose if it faced no competition.*

In competition of the Bertrand type, a bank that wants to win the contest for an entrepreneur at z must offer a loan rate that is more attractive to the entrepreneur than its rival bank's best loan rate. The best loan rate is characterized by our next lemma.

Lemma 2. *If $R \geq \sqrt{8c_i f/(1-q_i)}$, then bank i's best loan rate is $R/2$ for any entrepreneur. Neither bank will offer a loan rate that is lower than $R/2$.*

We can best explain Lemma 2 by proving it here. Since the two banks are symmetric, we focus on bank 1. We know that the expected utility of an entrepreneur at z when she borrows from bank 1 is

$$U \equiv \pi^e(z) - \underline{u} = (R - r_1(z))m_1(z) - \underline{u};$$

here, by Lemma 1, $m_1(z) = r_1(z)(1 - q_1 z)/c_1$. The best loan rate that bank 1 could offer is the $r_1(z)$ that maximizes U, and the result is exactly $R/2$.

Bank 1's expected profit from financing an entrepreneur at z (viz. $\pi_1(z)$) is given in (1). By Lemma 1, $\pi_1(z)$ can be simplified to

$$\frac{(r_1(z))^2(1 - q_1 z)}{2c_1} - f, \tag{2}$$

which is obviously positive when $r_1(z) = R/2$ and $R \geq \sqrt{8c_1 f/(1 - q_1)}$. Therefore, the best loan rate is acceptable to bank 1. In a symmetric way, we can show that the best loan rate for bank 2 is also $R/2$ when $R \geq \sqrt{8c_2 f/(1 - q_2)}$.

Lemma 2 conveys the information that (a) simply lowering the loan rate may not increase a bank's attractiveness and (b) the lower bound for a bank's loan rate should be $R/2$. These statements follow because a lower loan rate to an entrepreneur at z implies a lower monitoring intensity and hence a higher probability of her failure, although it leaves her a higher payoff in the event of success. When bank i's loan rate is too low (as low as $R/2$), the effect of the loan rate on monitoring intensity becomes dominant; in that case, bank i cannot attract entrepreneurs by further reducing its loan rate.

When R is not large enough (i.e., when $R < \sqrt{8c_i f/(1 - q_i)}$), a loan rate as low as $R/2$ cannot ensure banks a non-negative profit at some locations. In this case, a bank's best loan rate is not always $R/2$.[9] In order to convey our ideas in the simplest way, we maintain for now the assumption that $R \geq \sqrt{8c_i f/(1 - q_i)}$ so that banks' best loan rate is always $R/2$ (the case where R is *not* large enough is relegated to Appendix B). In Section 3.2 we show that the assumption $R \geq \sqrt{8c_i f/(1 - q_i)}$ eliminates the possibility of local monopoly equilibria, so here we can focus on the equilibrium with direct bank competition.

In contrast to the best loan rate, which is the *lower* bound of a bank's loan rate, the monopoly loan rate is the *upper* bound of a bank's loan rate. The monopoly loan rate is characterized as follows.

Lemma 3. *The monopoly loan rate $r_1^m(z)$ of bank 1 for entrepreneurs at z is the largest solution of the following equation:*

$$\frac{(r_1^m(z))^2(3R - 4r_1^m(z))(1 - q_1 z)}{2c_1} + (2r_1^m(z) - R)f = 0$$

[9] A bank's best loan rate is higher than $R/2$ at some or even all locations when R is not large enough.

(a symmetric statement holds for bank 2). Both $r_1^m(z)$ and $r_2^m(z)$ are higher than the best loan rate $R/2$.

At location z, bank i would never offer a loan rate that is higher than its monopoly loan rate $r_i^m(z)$ because the total funding demand of entrepreneurs at z would be too low for bank i when the loan rate is higher than $r_i^m(z)$. Since $r_i^m(z)$ is higher than the best loan rate $R/2$ by Lemma 3, it follows that bank i's loan rate for entrepreneurs at z should be between $r_i^m(z)$ and $R/2$ in equilibrium.

Equilibrium loan rate. Given Lemmas 2 and 3, we can solve for the banks' equilibrium loan rates. The two banks are symmetric, so we look at how bank 1 chooses its loan rate for entrepreneurs at z.

If bank 1 wants to attract an entrepreneur z who is looking to undertake a project, it must offer the entrepreneur a loan rate that is more attractive than the best loan rate $R/2$ of bank 2. If bank 1 cannot do so, then the entrepreneur will instead be served by bank 2. However, if bank 1 can indeed offer a better loan rate, then its best strategy is to maximize its own profit – subject to the constraint that the entrepreneur's expected utility is no less than what she would derive by accepting the best loan rate ($R/2$) offered by bank 2. Reasoning in this way yields Proposition 1, which gives the equilibrium loan rates.

Proposition 1. *Assume that $R \geq \max\left\{\sqrt{\frac{8c_1 f}{1-q_1}}, \sqrt{\frac{8c_2 f}{1-q_2}}\right\}$. Define*

$$
\begin{aligned}
r_1^{\text{comp}}(z) &\equiv \frac{R}{2}\left(1+\sqrt{1-\frac{c_1}{c_2}\frac{1-q_2(1-z)}{1-q_1 z}}\right),\\
r_2^{\text{comp}}(z) &\equiv \frac{R}{2}\left(1+\sqrt{1-\frac{c_2}{c_1}\frac{1-q_1 z}{1-q_2(1-z)}}\right),\\
\tilde{x} &\equiv \frac{1-\frac{c_1}{c_2}+\frac{c_1}{c_2}q_2}{\frac{c_1}{c_2}q_2+q_1}.
\end{aligned}
$$

When $0 < \tilde{x} < 1$, there exists an equilibrium in which entrepreneurs located in $[0, \tilde{x}]$ (resp. $(\tilde{x}, 1]$) are served by bank 1 (resp. bank 2). The equilibrium loan rates of bank 1 and bank 2, respectively $r_1^*(z)$ and $r_2^*(z)$, are as follows:

$$
\begin{aligned}
r_1^*(z) &= \min\{r_1^{\text{comp}}(z), r_1^m(z)\}, \quad z \in [0, \tilde{x}];\\
r_2^*(z) &= \min\{r_2^{\text{comp}}(z), r_2^m(z)\}, \quad z \in (\tilde{x}, 1].
\end{aligned}
$$

Proposition 1 describes an equilibrium with direct bank competition. The restriction $0 < \tilde{x} < 1$ guarantees that both banks can attract a positive number of entrepreneurs in equilibrium. When this restriction does not hold, the result is an equilibrium in which one bank dominates the lending market. For example, if c_2 is large enough then $\tilde{x} \geq 1$; in this case, bank 1 serves all entrepreneurs. The reason is that, when c_2 is too large, monitoring is too costly for bank 2 and so bank 2's intensity of monitoring entrepreneurs is too low. As a result, bank 2 is unable to attract any entrepreneur even when it offers the best loan rate $R/2$. By the same logic, the lending market will be dominated by bank 2 if c_1 is large enough. Bank i's equilibrium loan rate for entrepreneurs at z still equals $r_i^*(z)$ even when bank i dominates the market, since rival bank j's competitive pressure still exists despite its serving no entrepreneurs. Therefore, banks' pricing policy as described in Proposition 1 is robust for a more general $\tilde{x}$. To convey our ideas better, we focus on the more standard case $0 < \tilde{x} < 1$. In this case, bank 1 (resp., bank 2) serves the region $[0, \tilde{x}]$ (resp., $(\tilde{x}, 1]$) because in this region bank 1 (resp., bank 2) has better information technology and hence can monitor entrepreneurs more efficiently.

One implication of Proposition 1 is that bank-borrower distance matters for bank lending. Specifically, bank 1 (resp. bank 2) can originate loans only in the region $[0, \tilde{x}]$ (resp. $(\tilde{x}, 0]$), and so must give up entrepreneurs who are sufficiently distant. Meanwhile, note that $\tilde{x}$ is decreasing in q_1 and c_1; this means bank 1's lending can reach farther locations if its information technology develops (i.e., if q_1 and/or c_1 decrease). This result is in line with Ahnert et al. (2021) who document that small business lending by banks with higher IT adoption is less affected by the distance between the bank headquarters and their borrowers, and with Kwan et al. (2021) who document that banks with better IT originate more "paycheck protection program" loans.

Since the two banks are symmetric, we simply look at bank 1's pricing strategy. Proposition 1 tells us that two cases may arise when bank 1 chooses its loan rate for entrepreneurs at z. In the first case, which occurs when c_1/c_2 is small enough and/or $q_2(1-z)$ is large enough, bank 2 cannot put enough competitive pressure on bank 1 and so the latter has enough market power to maintain its monopoly loan rate $r_1^m(z)$ for entrepreneurs at z. In this case, there is actually no effective competition between the banks because the existence of bank 2 does not affect bank 1's monopoly loan rate. In the second case, which occurs when c_1/c_2 is not too small and $q_2(1-z)$ is not too large, bank 2 can exert sufficient competitive pressure and so bank 1 can no longer maintain its monopoly loan rate for entrepreneurs at z. In this case, bank 1's loan rate for entrepreneurs at z is $r_1^{\text{comp}}(z)$, which is lower than $r_1^m(z)$. (The superscript "comp" is used to indicate that the bank faces effective competition.)

Because our focus here is on bank competition, we are primarily interested in $r_i^{\mathrm{comp}}(z)$. The following corollary gives a simple property of $r_1^{\mathrm{comp}}(z)$; a symmetric result holds for $r_2^{\mathrm{comp}}(z)$.

Corollary 1. *If $0 < \tilde{x} < 1$, then $r_1^{\mathrm{comp}}(z)$ is decreasing in z when $z \in [0, \tilde{x}]$. At the location $z = \tilde{x}$, we have $r_1^{\mathrm{comp}}(z) = R/2$.*

The intuition underlying Corollary 1 is that, if entrepreneurs at z are quite close to bank 1 and therefore distant from bank 2, then bank 1 can easily find a loan rate that is more attractive to the entrepreneurs than the best loan rate offered by bank 2 – that is because a long distance makes it too costly for bank 2 to monitor them. As a consequence, bank 1 has more market power to increase its own profit by raising $r_1^{\mathrm{comp}}(z)$ when competing for entrepreneurs at z. Reasoning symmetrically, we argue as follows: in the region served by bank 2 ($z \in (\tilde{x}, 1]$), the closer that entrepreneurs at z are to bank 2, the more market power bank 2 has and the higher is $r_2^{\mathrm{comp}}(z)$. The location $z = \tilde{x}$ is special because, at that point, neither bank has a cost advantage when monitoring an entrepreneur and so the competition there between banks is greatest. Hence the equilibrium loan rate is $R/2$ (i.e., the best loan rate) at this location. Figure 3 illustrates the banks' equilibrium loan rates.

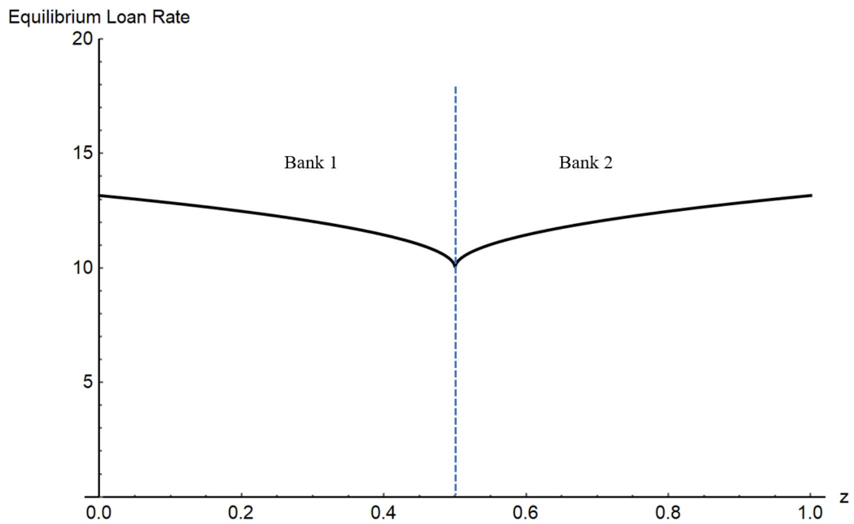

Figure 3: Equilibrium Loan Rates for Different Locations. This figure plots the equilibrium loan rate against the entrepreneurial location in the equilibrium under direct bank competition. The parameter values are $R = 20$, $f = 1$, $c_1 = 20$, $c_2 = 20$, $q_1 = 0.1$, and $q_2 = 0.1$.

The total funding demand of entrepreneurs at location z also varies with z, which is established in our next corollary.

Corollary 2. *If $0 < \tilde{x} < 1$ and if there is effective bank competition at z (i.e., if $r_i^{\text{comp}}(z) < r_i^m(z)$), the total funding demand of entrepreneurs at z is increasing (resp., decreasing) in z when $z \in [0, \tilde{x}]$ (resp., $z \in (\tilde{x}, 1]$).*

This corollary states that bank 1's loan volume for entrepreneurs at z is increasing in z within the region $[0, \tilde{x}]$, where bank 1 has the competitive advantage. A symmetric result holds in the region $(\tilde{x}, 1]$, where bank 2 has the advantage. The intuition here is that banks must compete more intensely near the "indifference location" $\tilde{x}$ and so entrepreneurs receive more attractive loan rates and thus derive greater utility, which stimulates total funding demand in the area.

Information technology and bank competition. Next we study how bank competition is affected by a change in information technology. In particular, we concentrate on the case with effective competition and analyze how r_i^{comp} varies with q_i and c_i – factors that (inversely) reflect bank i's information technology. Since the two banks are symmetric, we can restrict our attention to bank 1. Our next proposition presents the relevant results.

Proposition 2. *When $z \in (0, \tilde{x})$ and if there is effective bank competition at z (i.e., if $r_1^{\text{comp}}(z) < r_1^m(z)$), bank 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is decreasing in c_1 and q_1 but is increasing in c_2 and q_2.*

As c_1 or q_1 increases, monitoring becomes more costly for bank 1; this outcome reduces bank 1's competitive advantage and induces it to decrease its loan rate in an attempt to maintain market share. Yet as c_2 or q_2 increases, monitoring becomes more costly for bank 2 and therefore reduces bank 2's competitive advantage. As a result, bank 1 will increase its loan rate in this case. Proposition 2 is consistent with Buchak et al. (2018), who report that FinTech lenders – a suitable proxy for banks that adopt advanced technology – charge higher loan rates than do traditional banks in the US mortgage market.

In fact, we have witnessed the development and diffusion of information technology throughout the entire banking sector. We are therefore led to question how bank competition is affected by changes in the sector's information technology. To answer this question, we let $c_1 = c_2 = c$ and $q_1 = q_2 = q$ and then analyze how equilibrium loan rates vary with c and q, which can be viewed as two inverse measures of the banking sector's information technology. The following proposition gives the results.

Proposition 3. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. If there is effective bank competition at z (i.e., if $r_i^{\text{comp}}(z) < r_i^m(z)$), then bank i's equilibrium loan rate $r_i^{\text{comp}}(z)$ is increasing in q (except for $z = 1/2$) but is not affected by c.*

Proposition 3 highlights a crucial difference between c and q, although both parameters measure the bank sector's information technology. As q increases, monitoring costs become more sensitive to distance; this reduces banks' incentive to monitor far-away entrepreneurs. Then entrepreneurs are more willing to choose nearby banks because the monitoring intensity to which they are subject decreases more rapidly with distance as q increases. The result is that both banks' can post higher loan rates for their respective entrepreneurs, so $r_i^{\text{comp}}(z)$ is increasing in q. In sum: increasing q not only makes monitoring more costly but also increases banks' differentiation, and the latter effect renders bank competition less intense.[10] In contrast, if c increases then banks' monitoring costs increase but their differentiation is unaffected; hence bank i's equilibrium loan rate $r_i^{\text{comp}}(z)$ is not affected by c. Proposition 3 tells us that, when studying how changes in information technology affect bank competition, we should first specify the *type* of IT change. Finally, observe that this proposition holds for a general cost function $C_i(m_i, z) = g(c_i, q_i, s_i)m_i^2$ that satisfies

$$\frac{\partial\left(\frac{C_1(m_1,z)}{C_2(m_2,z)}\right)}{\partial c} = 0 \quad \text{and} \quad \frac{\partial^2\left(\frac{C_1(m_1,z)}{C_2(m_2,z)}\right)}{\partial z \partial q} > 0$$

when $c_1 = c_2 = c$, $q_1 = q_2 = q$, and $g(c_i, q_i, s_i)$ is an increasing function of c_i, q_i and s_i.

According to Proposition 3, parameter q inversely measures how intensely the two banks compete; this allows us to study how a bank's aggregate loan volume is affected by the intensity of bank competition. Recall that entrepreneurs' loan demand at z is $D(z)$, so bank 1's (resp. bank 2's) aggregate loan volume is equal to $L_1 \equiv \int_0^{\tilde{x}} D(z)dz$ (resp. $L_2 \equiv \int_{\tilde{x}}^1 D(z)dz$). The following proposition shows how L_i is affected by q in the case $q_1 = q_2 = q$.

[10]If $q = 0$ (and $c_1 = c_2 = c$), then banks' differentiation will disappear and the intensity of bank competition will be maximal; in this case, both banks must offer their best loan rate for all locations. If $q = 0$ and $c_1 \neq c_2$, then the bank with better IT will dominate the entire lending market and so drive out the other bank.

Proposition 4. *Let $q_1 = q_2 = q$. If there is effective bank competition at all locations (i.e., if $r_i^{comp}(z) < r_i^m(z)$ holds for all $z \in [0,1]$), then the sum of the two banks' aggregate loan volume is decreasing in q (i.e., $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q} < 0$); and the sensitivity of bank i's aggregate loan volume to c_i is decreasing in q (i.e., $\left.\frac{\partial^2 L_i}{\partial c_i \partial q}\right|_{q_i=q} > 0$).*

The first part of Proposition 4 (i.e., $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q} < 0$) states that the banking sector will originate more loans when bank competition is more intense (i.e., when q is smaller). The intuition is that banks must offer more attractive loan rates as competition intensifies; this improves entrepreneurs' utility and thus increases their funding demand. The second part (i.e., $\left.\frac{\partial^2 L_i}{\partial c_i \partial q}\right|_{q_i=q} > 0$) of the proposition states that IT progress of a bank (i.e. a lower c_i) will bring more loan volume to the bank when the intensity of bank competition is larger (i.e., when q is smaller). Two reasons contribute to the result. First of all, a bank's marginal "geographic expansion" (which is caused by the bank's IT progress) will bring more loans to the bank if q is smaller because entrepreneurs demand more funding at each location when banks compete more intensely. Second, a bank's marginal IT progress will lead to a larger geographic expansion if q is smaller (i.e., $\left.\frac{\partial^2 \tilde{x}}{\partial c_1 \partial q}\right|_{q_i=q} > 0$) because the IT progress can affect more (distant) entrepreneurs' decisions when bank differentiation is smaller. The second part of the proposition is consistent with Kwan et al. (2021) who find that banks with better IT originate more "paycheck protection program" loans especially in areas with more intense bank competition.

Comparison with Thisse and Vives (1988). A critical difference between our bank competition context and that of Thisse and Vives (1988) is that, in the latter, a firm's best price that maximizes a consumer's utility is equal to the firm's marginal costs (production cost plus transportation cost) of serving the consumer; yet in our bank competition context, a bank's best loan rate is not determined by marginal costs when R is large enough. In Thisse and Vives (1988), an increase in price is always detrimental to consumers, so a firm's best price must be its lowest acceptable (or "affordable") price. Since no firms accept negative profits, the lowest acceptable price of a firm equals its marginal costs. In the bank competition context, however, an increase in loan rate need not hurt entrepreneurs because a higher loan rate also implies a higher monitoring intensity and thus a higher probability of success. Therefore, a bank's best loan rate may not be its lowest acceptable loan rate. Lemma 2 states that, instead, the best loan rate is $R/2$ when R is large, which guarantees a positive profit for the bank.

What happens when R is not large enough? In Appendix B we consider the case when R is not large enough and so bank i cannot make a non-negative profit by posting the loan rate $R/2$. In this case, the best loan rate bank that i can offer to entrepreneurs at z equals the loan rate that exactly brings bank i zero profit at that location. Appendix B shows that bank i's best loan rate (which is also its lowest acceptable loan rate) is higher than $R/2$ and is increasing in both q_i and c_i if $R/2$ is too low to ensure bank i a non-negative profit at z.

The result of Proposition 2 is robust in this case because increasing c_i or q_i makes monitoring more costly for bank i and reduces its competitiveness – irrespective of whether or not bank i's best loan rate is $R/2$. However, the result that $r_i^{\text{comp}}(z)$ is unaffected by c (Proposition 3) does not hold when $R/2$ is not bank i's best loan rate. Appendix B reveals that $r_i^{\text{comp}}(z)$ is increasing in c (provided that $c_1 = c_2 = c$ and $q_1 = q_2 = q$) if banks' best loan rates are determined by their zero-profit conditions. This follows because, when $R/2$ is too low, bank i's best loan rate is increasing in c; in other words, the higher is c, the higher a loan rate bank i must charge in order to guarantee a non-negative profit. As c increases, the best loan rate that bank i can offer to entrepreneurs at z will also increase, which reduces the attractiveness of bank i's best loan rate. As a result, if entrepreneurs at z are located relatively closer to bank j ($j \neq i$) then bank j faces less competition pressure from bank i and is able to set a higher loan rate for entrepreneurs at z as bank i's best loan rate increases.

Remark: Endogenous bank differentiation. In our model banks are by assumption located symmetrically at the two endpoints of a diameter of the city; that is, the differentiation of banks' expertise is maximized. We find from a numerical study that such maximum bank differentiation will arise endogenously in equilibrium if banks have similar IT (i.e., if q_1 and c_1 are respectively close to q_2 and c_2), because then it is a dominant strategy for either bank to stay as distant as possible from its rival in this case. However, if a bank's IT is sufficiently better than that of the other bank (e.g., if q_1 and/or c_1 are sufficiently lower than q_2 and/or c_2), then the bank with better IT would prefer a small or even zero distance from its rival in order to obtain more market share or drive the other bank out of the market; in contrast, the bank with inferior IT would like to maximize its distance from the rival to protect its market share. In this case, there may be no pure equilibrium in locations.

3.2 Local monopoly equilibrium

In this section we consider the local monopoly equilibrium, where the two banks do not compete with each other. Studying this equilibrium requires us to abandon the previous assumption that R is large (i.e., that $R \geq \max\{\sqrt{8c_1 f/(1-q_1)}, \sqrt{8c_2 f/(1-q_2)}\}$); otherwise, there will exist no local monopoly equilibria. The reason is that such an equilibrium exists only if banks are unwilling to finance far-away entrepreneurs even when the loan rate is R, which contradicts the condition $R \geq \max\{\sqrt{8c_1 f/(1-q_1)}, \sqrt{8c_2 f/(1-q_2)}\}$ that ensures banks are willing to offer the loan rate $R/2$ to any entrepreneur.

Since the two banks are symmetric, we focus on bank 1. If entrepreneurs at z are target clients of bank 1 and if there is no bank competition, then bank 1 must guarantee that the expected profit of an entrepreneur at z who borrows from bank 1 is non-negative; otherwise, no entrepreneur at z would want to be served by bank 1. If bank 1's loan rate for entrepreneurs at z is $r_1(z)$, then an entrepreneur's expected profit at that location is

$$(R - r_1(z))\frac{r_1(z)(1-q_1 z)}{c_1},$$

which is always non-negative for $r_1(z) \in [0, R]$. In other words, bank 1 can serve all locations by offering a loan rate $r_1(z) \in [0, R]$.[11]

Yet in a local monopoly equilibrium, there must exist locations that bank 1 is not willing to serve. If entrepreneurs at z are clients that bank 1 does not want to finance, then bank 1's expected profit from financing an entrepreneur at that location must be negative even if bank 1 sets $r_1(z) = R$, which implies the following inequality:

$$R\frac{R(1-q_1 z)}{c_1} - f - C_1\left(\frac{R(1-q_1 z)}{c_1}, z\right) < 0.$$

This expression can be simplified to

$$z > \frac{R^2 - 2c_1 f}{q_1 R^2}. \tag{3}$$

Inequality (3) implies that bank 1 is willing to serve entrepreneurs in $\left[0, \frac{R^2-2c_1 f}{q_1 R^2}\right]$ if $\frac{R^2-2c_1 f}{q_1 R^2} \geq 0$. By symmetric reasoning, bank 2 is willing to serve entrepreneurs in $\left[1 - \frac{R^2-2c_2 f}{q_2 R^2}, 1\right]$ if $1 - \frac{R^2-2c_2 f}{q_2 R^2} \leq 1$. To ensure that the equilibrium is indeed of the local monopoly type, there cannot exist a location that both banks are willing to serve. Hence

[11] When $r_1(z) = R$, an entrepreneur with $\underline{u} = 0$ is willing to accept the offer of bank 1.

the local monopoly equilibrium exists if

$$\frac{R^2 - 2c_1 f}{q_1 R^2} + \frac{R^2 - 2c_2 f}{q_2 R^2} < 1.$$

In such an equilibrium, there is no competition between banks and so bank i's equilibrium loan rate for an entrepreneur at z is the monopoly loan rate $r_i^m(z)$.

We summarize the foregoing analysis in our next proposition.

Proposition 5. *Let* $\frac{R^2-2c_1 f}{q_1 R^2} \geq 0$, $\frac{R^2-2c_2 f}{q_2 R^2} \geq 0$, *and* $\frac{R^2-2c_1 f}{q_1 R^2} + \frac{R^2-2c_2 f}{q_2 R^2} < 1$. *Then there exists a local monopoly equilibrium where bank 1's and bank 2's loan rates are given by*

$$r_1^{\text{local}}(z) = r_1^m(z), \quad z \in \left[0, \frac{R^2 - 2c_1 f}{q_1 R^2}\right] \quad \text{and}$$
$$r_2^{\text{local}}(z) = r_2^m(z), \quad z \in \left[1 - \frac{R^2 - 2c_2 f}{q_2 R^2}, 1\right],$$

respectively. Bank 1 serves entrepreneurs in $\left[0, \frac{R^2-2c_1 f}{q_1 R^2}\right]$ *while bank 2 serves entrepreneurs in* $\left[1 - \frac{R^2-2c_2 f}{q_2 R^2}, 1\right]$.

According to Proposition 5, we have a local monopoly equilibrium when R is not large yet q_i and c_i are sufficiently large. When the returns of projects are not high but the costs of financing far-away entrepreneurs are high, banks will find it optimal to focus on nearby entrepreneurs. Entrepreneurs in the middle region – that is, $z \in \left(\frac{R^2-2c_1 f}{q_1 R^2}, 1 - \frac{R^2-2c_2 f}{q_2 R^2}\right)$ – are not close to either bank and therefore have no access to bank financing, which results in the local monopoly equilibrium. Corollary 3 shows how $r_1^m(z)$ varies with entrepreneurial location z; a symmetric result holds for $r_2^m(z)$.

Corollary 3. *In the local monopoly equilibrium, bank 1's equilibrium loan rate* $r_1^m(z)$ *is increasing in* z *when* $z \in \left[0, \frac{R^2-2c_1 f}{q_1 R^2}\right]$. *At the location* $z = \frac{R^2-2c_1 f}{q_1 R^2}$, *we have* $r_1^m(z) = R$.

From the perspective of bank 1, the marginal benefit of increasing its loan rate for entrepreneurs at z is that the bank could earn more profits from a given amount of loans. However, the marginal cost is that total funding demand at z would decline – and this cost is increasing in the bank's profit per unit of loans (and the value of $r_1^m(z)$ is determined by equating the marginal benefit with the marginal cost). All else equal, a greater borrower–bank distance (i.e., a higher z) makes it more costly for bank 1 to monitor entrepreneurs at z, which reduces bank 1's profit per unit of loans and thus makes bank 1 less afraid of losing total funding demand at z. So as z increases, bank 1 will set a higher loan rate and let the total funding demand at z fall in order to rebalance the marginal benefit and the marginal cost. At the location $z = (R^2 - 2c_1 f)/(q_1 R^2)$, which is the farthest place bank 1 can reach, monitoring is so costly that the bank must set its loan rate to R in order to ensure itself a non-negative profit; of course, the funding demand is zero at this extreme location.

Note that the pattern of bank 1's loan rate with respect to z in the local monopoly equilibrium is different from that in the case with bank competition (see Corollary 1). The reason is that the determinants of loan rates are completely different in the two types of equilibria. When the two banks compete for entrepreneurs at z, what determines the equilibrium loan rate is the intensity of bank competition. In this case, the equilibrium loan rate is higher at the locations where the competition is less intense. In the local monopoly equilibrium, however, banks no longer compete with each other and so the equilibrium loan rate reflects banks' costs of providing loans (monitoring and funding costs) instead of competition intensity.

Information technology and monopoly loan rates. Next we study how information technology affects loan rates in the local monopoly equilibrium. It should be clear that a bank's information technology progress is unable to affect the other bank in such an equilibrium because there is no interaction between banks. Hence we need only analyze how a bank's equilibrium loan rate is affected by its own information technology. The following proposition gives the relevant result.

Proposition 6. *In the local monopoly equilibrium, bank 1's equilibrium loan rate $r_1^m(z)$ is increasing in c_1 and q_1 when $z \in \left[0, \frac{R^2 - 2c_1 f}{q_1 R^2}\right)$.*

The effect of IT progress on bank 1's loan rate for entrepreneurs at z is completely different in the local monopoly equilibrium than in the case with competition (Proposition 2). In the local monopoly equilibrium information technology progress (i.e., reducing c_1 or q_1) simply makes monitoring cheaper for bank 1, which increases bank 1's profit per unit of loans and hence induces bank 1 to be more concerned about total funding demand at z. As a result, bank 1 decreases its loan rate in order to increase the funding demand and maximize its monopoly profit at location z.

Proposition 6 does not hold for the location $z = (R^2 - 2c_1 f)/(q_1 R^2)$ because bank 1's loan rate has already reached its upper bound R there. If c_1 increases to c_1^{new} (and/or q_1 increases to q_1^{new}), then bank 1 will no longer profit from serving an entrepreneur located at $z = (R^2 - 2c_1 f)/(q_1 R^2)$. As a result, the region covered by bank 1 shrinks from $\left[0, \frac{R^2-2c_1 f}{q_1 R^2}\right]$ to $\left[0, \frac{R^2-2c_1^{\text{new}} f}{q_1^{\text{new}} R^2}\right]$; then entrepreneurs at $z = (R^2 - 2c_1 f)/(q_1 R^2)$ lose their access to bank financing, instead of being offered a higher loan rate.

4 Bank stability

An issue of considerable importance is how the development and diffusion of information technology affects bank stability. To study this issue using our model, we exploit the probability of bank default as an inverse measure of bank stability. Our model's two banks are symmetric and so, as before, we examine only bank 1 when assessing the probability of default. First we focus on the equilibrium described in Section 3.1 – that is, when $R \geq \max\{\sqrt{8c_1 f/(1-q_1)}, \sqrt{8c_2 f/(1-q_2)}\}$. Then we look at bank stability in the local monopoly equilibrium. The probability of bank 1's default is denoted by θ^*, which can be pinned down as described in Lemma 4.

Lemma 4. *Suppose the entrepreneurs located within* $[0, \tilde{x}]$ *are served by bank 1. Let total funding demand at* $z \in [0, \tilde{x}]$ *be* $D(z)$*, and let the loan rate of bank 1 be* $r_1(z)$ *for entrepreneurs at* $z \in [0, \tilde{x}]$*. Then bank 1's default probability* θ^* *is determined by the equality*

$$\int_0^{\theta*} \int_0^{\tilde{x}} D(z) r_1(z) 1_{\left\{1 - \frac{r_1(z)(1-q_1 z)}{c_1} \leq \theta\right\}} \, dz \, d\theta \\ + (1-\theta^*) \int_0^{\tilde{x}} D(z) r_1(z) 1_{\left\{1 - \frac{r_1(z)(1-q_1 z)}{c_1} \leq \theta^*\right\}} \, dz - f \int_0^{\tilde{x}} D(z) \, dz = 0,$$

where $1_{\{\cdot\}}$ *is an indicator function that equals* 1 *if the condition in* $\{\cdot\}$ *holds and equals* 0 *otherwise.*

To see what is behind Lemma 4, we prove it here. Since the risk factor θ is assumed to be uniformly distributed on $[0, 1]$, it follows that bank 1 would default when $\theta < \theta^*$ if the bank's default probability is equal to θ^*. So for a given θ^*, the break-even condition for depositors is

$$\int_0^{\theta^*} \int_0^{\tilde{x}} D(z) r_1(z) 1_{\left\{1 - \frac{r_1(z)(1-q_1 z)}{c_1} \leq \theta\right\}} \, dz \, d\theta + (1-\theta^*) d_1 \int_0^{\tilde{x}} D(z) \, dz = f \int_0^{\tilde{x}} D(z) \, dz. \quad (4)$$

Equation (4) is interpreted to mean that bank 1's actual expected payment to depositors must equal their minimum expected payoff. To understand the equation, we start by looking at its right-hand side. Here $\int_0^{\tilde{x}} D(z) \, dz$ is the aggregate funding amount that bank 1 borrows from its depositors and f is the minimum expected return required by those depositors. Thus $f\int_0^{\tilde{x}} D(z)\,dz$ measures the minimum total expected payoff required by depositors. Next we look at the left-hand side, which represents bank 1's actual expected payment to depositors. When the economic condition θ is not lower than θ^*, bank 1 stays solvent and is able to pay all of $d_1\int_0^{\tilde{x}} D(z)\,dz$ back to the depositors. However, if $\theta < \theta^*$ then bank 1 cannot fully pay back depositors; instead, the bank repays the amount $\int_0^{\tilde{x}} D(z)r_1(z)1_{\left\{1-\frac{r_1(z)(1-q_1z)}{c_1}\leq\theta\right\}}\,dz$, which is the aggregate loan repayment that the bank receives from entrepreneurs when the economic condition is θ. The indicator function $1_{\left\{1-\frac{r_1(z)(1-q_1z)}{c_1}\leq\theta\right\}}$ appears in (4) because entrepreneurs at z have a positive loan repayment to bank 1 if and only if $1-m_1(z)\leq\theta$. Integrating the bank's payoff to depositors from $\theta=0$ to $\theta=1$ yields the bank's expected payment to depositors, which is exactly the left-hand side of Equation (4).

Furthermore, bank 1 defaults if and only if $\theta < \theta^*$ and so, when $\theta = \theta^*$, the aggregate loan repayment received by bank 1 should exactly equal the bank's promised payment to depositors. The implication is that

$$\int_0^{\tilde{x}} D(z)r_1(z)1_{\left\{1-\frac{r_1(z)(1-q_1z)}{c_1}\leq\theta^*\right\}}\,dz = d_1\int_0^{\tilde{x}} D(z)\,dz. \tag{5}$$

Equations (4) and (5) together determine d_1 and θ^*. Inserting (5) into (4) yields the equation displayed in Lemma 4.

4.1 Bank stability under direct bank competition

Here we focus on the equilibrium in which banks compete directly with each other and retain the assumptions adopted in Section 3.1; in particular, we assume that $R \geq \max\{\sqrt{8c_1f/(1-q_1)}, \sqrt{8c_2f/(1-q_2)}\}$. Lemma 4 does not yield a closed-form solution for θ^*, so we shall use numerical methods to analyze how IT change – as represented by changes in c_i or q_i – affects bank 1's default probability.

An intuitive result is that bank 1 becomes less stable as q_1 and/or c_1 increases (see Panels 1 and 3 of Figure 4), which means that more advanced information technology is good for bank stability; as stated in Section 1, this result is consistent with the empirical findings of Pierri and Timmer (2021). An increase in q_1 and/or c_1 reduces bank 1's stability by way of two channels. First, a higher q_1 or c_1 increases bank 1's monitoring cost and so decreases bank 1's incentive to monitor entrepreneurs; this factor reduces the investment projects' likelihood of success. Second, Proposition 2 establishes that an increase in q_1 and/or c_1 decreases bank 1's competitiveness (and market power) and thus forces the bank to set lower loan rates, which reduces not only bank 1's monitoring intensity but also its "profit buffer" and therefore its stability. Yet we must point out that increasing q_1 and/or c_1 also has a pro-stability *market area effect*. Namely: as q_1 and/or c_1 increases, the region that bank 1 serves will shrink (i.e., $\tilde{x}_1$ will decrease); hence bank 1 can focus more on nearby entrepreneurs (who are easier to monitor), which promotes stability. However, this pro-stability market area effect is dominated by the two opposite effects mentioned previously, so we can observe in the model that bank 1 is more (resp. less) stable when it serves a larger (resp. smaller) region; this is consistent with Goetz et al. (2016) who document that geographic expansion materially reduces bank risk.

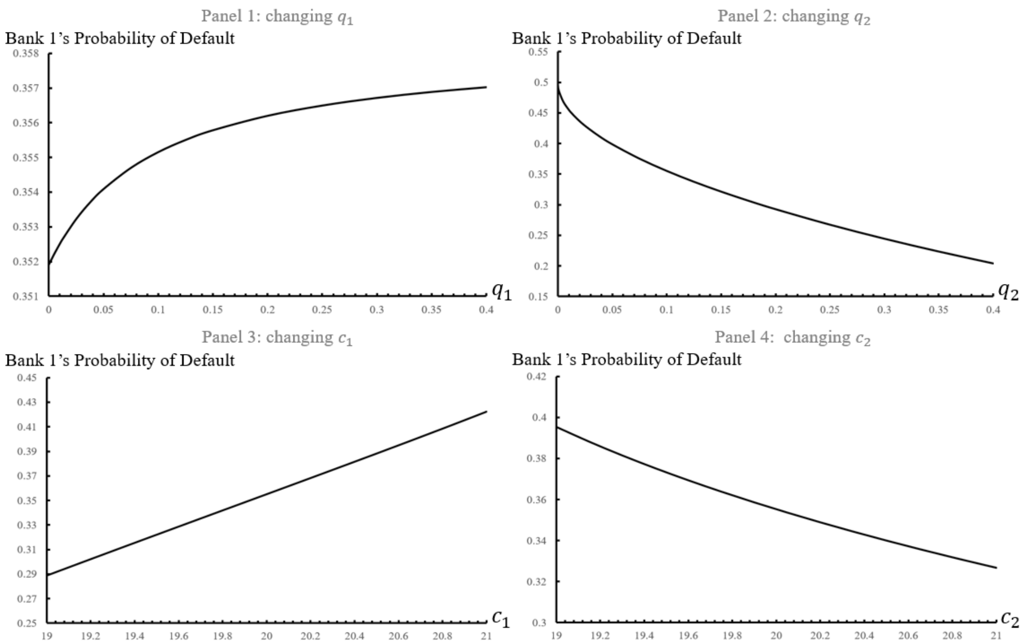

Figure 4: Bank 1's Probability of Default (w.r.t. q_i and c_i). This figure plots bank 1's probability of default against q_i and c_i in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c_1 = 20$, $c_2 = 20$, $q_1 = 0.1$, and $q_2 = 0.1$.

As q_2 and/or c_2 increase, bank 1 becomes more stable (Panels 2 and 4 of Figure 4). This occurs because a higher q_2 and/or c_2 decreases bank 2's competitive power (Proposition 2) and enables bank 1 to set a higher loan rate – which increases bank 1's monitoring intensity and also its profit buffer, thereby improving its stability. However, increasing q_2 and/or c_2 has a negative market area effect on bank 1's stability. As q_2 and/or c_2 increases, the region that bank 1 serves will expand (i.e., $\tilde{x}_1$ will increase) and so bank 1 must serve more entrepreneurs who are located far away and thus difficult to monitor, reducing the bank's stability. That being said, this market area effect is dominated by the first effect.

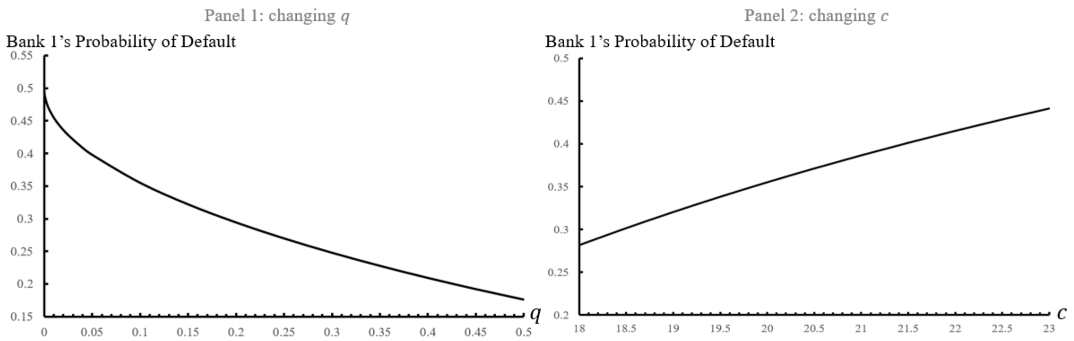

Figure 5: Bank 1's Probability of Default (w.r.t. q and c). This figure plots bank 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$ in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c = 20$, and $q = 0.1$.

Putting $q_1 = q_2 = q$ and $c_1 = c_2 = c$ allows us to analyze how the development and diffusion of information technology in the entire banking sector affect banks' stability. As before, we need only assess the bank 1 case because the two banks are symmetric. Although both q and c can be seen as inverse measures of IT in the banking sector, their effects on bank stability are different. Numerical results show that bank 1 becomes more stable as q increases but becomes less stable as c increases (see Figure 5). As q or c increases, the direct (cost) effect is that monitoring becomes more costly for banks; this effect reduces bank stability. Yet an increase in q increases banks' differentiation and so makes bank competition less intense (the indirect effect). As a result, both banks can post higher loan rates (Proposition 3), which enhances the stability of both banks. Here the indirect effect of q dominates.[12] In contrast, an increase in c does not have this kind of indirect effect because c has no influence on banks' differentiation. Therefore, the final effects of c and q are different.

4.2 Bank stability under local monopoly

Next we explore the local monopoly equilibrium. As in Section 3.2, we do not assume that R is large when studying this equilibrium. In a local monopoly equilibrium, bank 1

[12]This result is in line with Jiang et al. (2017) who document that an intensification of bank competition materially boosts bank risk by reducing bank profits, charter values, and relationship lending.

is not affected by q_2 or c_2; therefore, we need only look at the effects of q_1 and c_1 on bank 1's stability. Proposition 7 gives a relevant result.

Proposition 7. *In the local monopoly equilibrium, bank 1's probability of default is independent of q_1.*

A higher q_1 has two competing effects on bank 1's stability. The first one is a direct cost effect: increasing q_1 makes monitoring more costly, which reduces the intensity of bank 1's monitoring and thus reduces bank stability. The second effect is an indirect market area effect: the region that bank 1 serves will shrink as q_1 increases, which promotes the bank's stability because it can then concentrate more on nearby entrepreneurs (who are easier to monitor). Proposition 7, which is illustrated in Panel 1 of Figure 6, means that the market area effect exactly offsets the cost effect. The market area effect in our model is in line with empirical evidence. Acharya et al. (2006) find that geographic expansion does not guarantee greater safety for banks. Deng and Elyasiani (2008) document that increased distance between a bank holding company (BHC) and its branches is associated with BHC value reduction and risk increase. Loutskina and Strahan (2011) find that geographically concentrated lenders have higher profits and are more stable than diversified lenders because geographic diversification leads to a decline in screening by lenders.

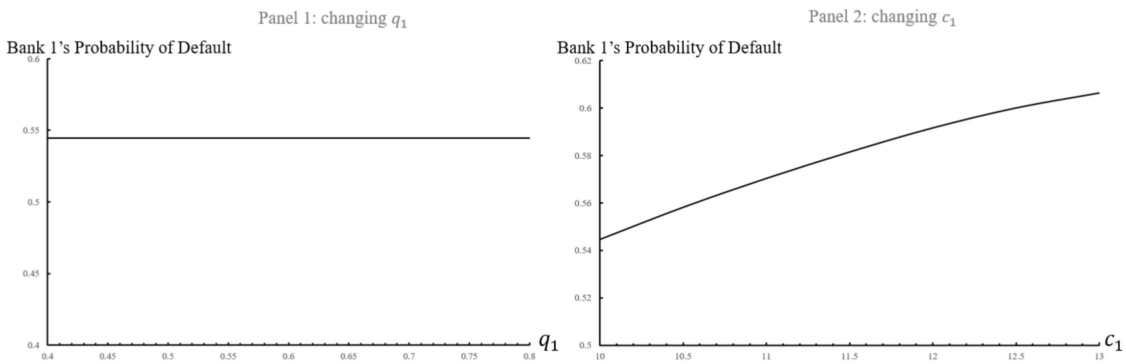

Figure 6: Bank 1's Probability of Default (w.r.t. q_1 and c_1). This figure plots bank 1's probability of default against q_1 and c_1 in the local monopoly equilibrium. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c_1 = 10$, and $q_1 = 0.4$.

Increasing c_1 induces a cost effect and a market area effect, just as changing q_1 does. Yet because c_1 significantly affects monitoring costs for all locations,[13] the cost effect of c_1

[13]In contrast, q_1 does not significantly affect bank 1's monitoring costs for given monitoring intensity when z is close to zero.

is stronger than that of q_1. A numerical study establishes that the cost effect dominates as c_1 increases, which is illustrated in Panel 2 of Figure 6.

As is shown in Proposition 5, the local monopoly equilibrium is sustained by sufficiently high q_i and/or c_i. Therefore, as q or c decreases (with $q_1 = q_2 = q$ and $c_1 = c_2 = c$), the local monopoly equilibrium may disappear and then banks may begin to compete with each other. This dynamic can reverse the net effect of IT progress on bank stability; see Panel 1 of Figure 7 for an example.

Our numerical study (see Panel 1 of Figure 7) indicates that, when banks are initially in a local monopoly equilibrium, bank 1's probability of default is constant at first; it then decreases and finally increases as q decreases. The intuition is as follows. At the beginning, a reduction in q does not change the equilibrium type; hence bank stability does not vary with q because the cost effect exactly offsets the market area effect (Proposition 7). When q declines to a certain level, the equilibrium switches to the one with bank competition. In this new equilibrium, a further reduction in q would bring a (competition) differentiation effect, which would reduce bank stability, but the market area effect of changing q disappears because banks are no longer able to extend their regions. In this case, bank 1 will be more stable as q decreases unless q is small enough. This happens because if q is not small enough then bank 1 has monopoly power over a large part of its entrepreneurs; in this case effective bank competition occurs only for entrepreneurs who are located in the middle region. As a result, the (competition) differentiation effect of q is weak and the cost effect dominates. However, when q is small enough, bank competition will be so intense that bank 1 has monopoly power over only a small (or vanishing) fraction of its entrepreneurs; then the (competition) differentiation effect of q will dominate the cost effect. As a result, the net effect of a lower q on bank stability is reversed when q is small enough.

Note that the "decrease then increase" pattern of bank 1's probability of default (as illustrated in Panel 1 of Figure 7) does not appear in Section 4.1 (see Panel 1 of Figure 5), where we assume that R is large (i.e., $R \geq \max\{\sqrt{8c_1 f/(1-q_1)}, \sqrt{8c_2 f/(1-q_2)}\}$); we do not make that assumption here. If R is large, then there is effective bank competition at most (or even all) locations. Hence the differentiation effect of q dominates and bank 1's probability of default is decreasing in q, which explains the graph in Panel 1 of Figure 5.

The net effect of reducing c is simpler. Since a reduction in c significantly lowers the monitoring costs for all locations, it follows that the cost-saving effect of decreasing c is strong and always dominates other effects – that is, regardless of whether or not bank competition arises for a large group of entrepreneurs. Therefore, bank 1's probability of

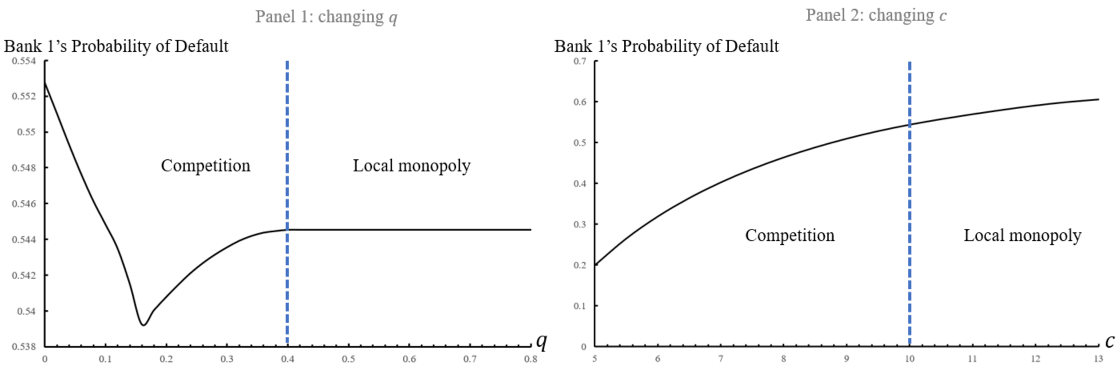

Figure 7: Bank 1's Probability of Default (w.r.t. q and c). This figure plots bank 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c = 10$, and $q = 0.4$.

default is increasing in c (see Panel 2 of Figure 7).

Remark: In Internet Appendix C we show that, if depositors are protected by a fairly priced deposit insurance scheme, then bank 1's probability of default is no longer as given in Lemma 4. The reason is that, when deposits are insured, the nominal deposit rate required by depositors is f rather than d_1. However, a numerical study shows that such deposit insurance only slightly reduces the probability of default and does not affect our results concerning the influence of information technology on bank stability.

5 Welfare analysis

In this section, we perform a welfare analysis. First we look at the relation between banks' equilibrium loan rates and socially optimal ones. We then analyze how the development and diffusion of the banking sector's information technology affect social welfare under the direct competition equilibrium described in Section 3.1 when R is large – that is, when $R \geq \max\{\sqrt{8c_1 f/(1-q_1)}, \sqrt{8c_2 f/1-q_2)}\}$. Finally, we look at the local monopoly equilibrium described in Section 3.2, where R is not large. We let $q_1 = q_2 = q$ and $c_1 = c_2 = c$, and we use changes in q and c to measure the banking sector's IT change.

5.1 Socially optimal loan rates

If entrepreneurs at location z are financed by bank i and if $\Omega \subseteq [0,1]$ is the set of locations that are served, then social welfare is given by

$$\underbrace{\int_{\Omega} D(z) R m_i(z)\, dz}_{\text{Social benefits}} - \underbrace{\left(\begin{array}{c} \int_{\Omega} D(z) f\, dz + \int_{\Omega} \frac{D(z)c}{2(1-qs_i)} (m_i(z))^2\, dz \\ + \int_{\Omega} \int_0^{D(z)} \underline{u}\, d\underline{u}\, dz + (\theta_1^* + \theta_2^*) K \end{array} \right)}_{\text{Social costs}}. \tag{6}$$

Here $r_i(z)$ (resp., $m_i(z)$) is bank i's loan rate (resp., monitoring intensity) for entrepreneurs at z, $D(z)$ is the total funding demand at z, s_i is the distance between bank i and location z, θ_i^* is the probability that bank i goes bankrupt, and K is the deadweight loss (i.e., bankruptcy costs) associated with a bank's failure. In our bank competition context, the social benefits of banks' lending behavior are measured by the expected value of all projects implemented; social costs consist of funding costs, monitoring costs, entrepreneurs' reservation utility, and bankruptcy costs. Entrepreneurs' reservation utility must be included in social costs because it measures the opportunity costs of giving up alternative activities. Bankruptcy costs can be interpreted as the costs of systemic banking sector failure given that both banks stay solvent or go bankrupt together in the symmetric case (i.e., where $q_1 = q_2 = q$ and $c_1 = c_2 = c$).

Recall $\int_0^{D(z)} \underline{u}\, d\underline{u} = (D(z))^2/2$ and $D(z) = (R - r_i(z)) m_i(z)$. Then we can reorganize (6) as follows:

$$\begin{aligned} W = & \underbrace{\int_{\Omega} \frac{\big((R - r_i(z)) m_i(z)\big)^2}{2}\, dz}_{\text{Entrepreneurs' aggregate expected utility}} \\ & + \underbrace{\int_{\Omega} D(z) \left(r_i(z) m_i(z) - f - \frac{c (m_i(z))^2}{2(1 - qs_i)} \right) dz}_{\text{Banks' expected profits}} - \underbrace{(\theta_1^* + \theta_2^*) K}_{\text{Deadweight loss of bankruptcy}}. \end{aligned} \tag{7}$$

This expression divides social welfare into three components: entrepreneurs' aggregate utility, banks' profits, and the expected deadweight loss due to banks' failure. Using Equation (7), we can analyze the relation between equilibrium loan rates and socially optimal ones. We focus on the second-best (SB) socially optimal loan rates but will also characterize the first-best (FB) case.

Definition 2. *The second-best socially optimal loan rate schedule of bank i, denoted by $\{r_i^{\mathrm{SB}}(z)\}$, maximizes social welfare (7) under the constraint that bank i's monitoring* *intensity at z (viz. $m_i(z)$) is equal to* $\frac{r_i^{\mathrm{SB}}(z)(1-qs_i)}{c}$.

This definition stipulates that, in the second-best case, a benevolent social planner can choose loan rates for banks but cannot control banks' monitoring intensities. Hence the latter must be as described in Lemma 1. Our next proposition gives the basic properties of $r_i^{\mathrm{SB}}(z)$.

Proposition 8. *If $K = 0$ and if location z is served by bank i, then the second-best socially optimal loan rate at location z (viz., $r_i^{\mathrm{SB}}(z)$) is given by*

$$r_i^{\mathrm{SB}}(z) = \frac{(2R^2(1-qs_i)+4cf) + \sqrt{(2R^2(1-qs_i)+4cf)^2 - 24cfR^2(1-qs_i)}}{6R(1-qs_i)},$$

which satisfies $R/2 < r_i^{\mathrm{SB}}(z) \leq r_i^m(z)$. (Note that the equality $r_i^{\mathrm{SB}}(z) = r_i^m(z)$ holds only when bank i's best loan rate at z is R.)

From the social planner's perspective, a higher $r_i^{\mathrm{SB}}(z)$ gives bank i more incentive to monitor, which increases the expected value of projects financed by bank i. Yet as $r_i^{\mathrm{SB}}(z)$ increases, entrepreneurs' utility will decrease (when $r_i^{\mathrm{SB}}(z) \geq R/2$). Hence a social planner must balance the social benefits and costs of increasing $r_i^{\mathrm{SB}}(z)$ – here $R/2$ is one extreme loan rate, which maximizes entrepreneurs' utility; the monopoly loan rate $r_i^m(z)$ is the other extreme, which maximizes banks' profits and also incentivizes them to choose high monitoring intensities – leading to the relation $R/2 < r_i^{\mathrm{SB}}(z) \leq r_i^m(z)$. Bank i's equilibrium loan rate in the local monopoly equilibrium exactly equals $r_i^m(z)$, so we have the following corollary.

Corollary 4. *Let $K = 0$. Then, in a local monopoly equilibrium where bank 1 serves the region $\left[0, \frac{R^2-2cf}{qR^2}\right]$, bank 1's equilibrium loan rate is higher than $r_1^{\mathrm{SB}}(z)$ when $z \in \left[0, \frac{R^2-2cf}{qR^2}\right)$ – provided that $\frac{R^2-2cf}{qR^2} > 0$ – and is equal to $r_1^{\mathrm{SB}}(z)$ ($= R$) at $z = \frac{R^2-2cf}{qR^2}$. A symmetric result holds for bank 2.*

Next we consider the relation between $r_i^{\mathrm{SB}}(z)$ and the equilibrium loan rate under effective bank competition (viz., $r_i^{\mathrm{comp}}(z)$). Proposition 9 presents a useful result.

Proposition 9. *Let $K = 0$. If $R > \sqrt{2cf}$ and if location z is served by bank i, then the inequality $r_i^{\mathrm{comp}}(z) < r_i^{\mathrm{SB}}(z)$ holds for all locations when q is small enough.*

The constraint $R > \sqrt{2cf}$ in this proposition rules out the boundary case $R = \sqrt{2cf}$.[14] In this boundary case, bank i must set its loan rate to R – even when $q = 0$ – in order

[14]Recall that, throughout the paper, we must have $R \geq \sqrt{2c_i f}$; otherwise, bank i is unwilling to serve any entrepreneur.

to ensure itself a non-negative profit; we always have $r_i^{\text{comp}}(z) = r_i^{\text{SB}}(z) = r_i^m(z) = R$ at locations served by bank i.

Apart from the boundary case $R = \sqrt{2cf}$, Proposition 9 states that if q is small then bank i's loan rates are inefficiently low as compared with the second-best loan rates.[15] This follows because the intensity of bank competition is too high when q (the differentiation between banks) is sufficiently low. From the perspective of social welfare, the benefits and costs of bank competition must be balanced. Entrepreneurs are better-off as the intensity of bank competition increases; but banks are then worse-off and monitoring intensities will decline, which reduces the expected value of investment projects.[16] Figure 8 offers a graphic presentation of this result.

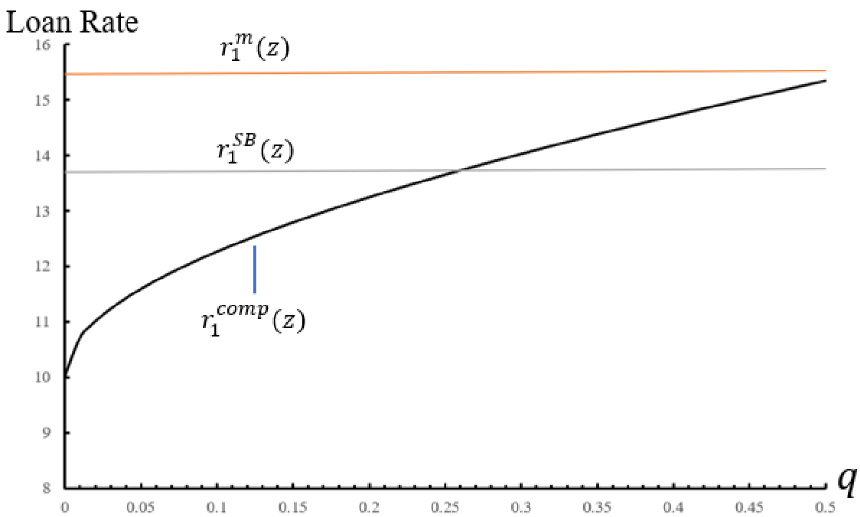

Figure 8: Comparing $r_1^{\text{comp}}(z)$, $r_1^m(z)$, and $r_1^{\text{SB}}(z)$. This figure plots $r_1^{\text{comp}}(z)$, $r_1^m(z)$, and $r_1^{\text{SB}}(z)$ against q. The parameter values are $R = 20$, $f = 1$, $c = 20$, and $z = 0.25$.

First-best outcome. Now we consider the first-best socially optimal case, where the social planner can choose not only the banks' loan rates but also their monitoring intensities. Thus banks' monitoring intensities are no longer constrained by Lemma 1. The following proposition characterizes the first-best socially optimal loan rates and monitoring intensities.

Proposition 10. *If $K = 0$ and if location z is served by bank i then, at location z, the*

[15]If $R > \sqrt{2cf}$, then there is always effective competition at z when q is small enough.

[16]Gehrig (1998) also finds that under certain conditions competition will decrease banks' screening efforts, and so reduce the quality of the overall loan portfolio.

first-best socially optimal loan rate $r_i^{\mathrm{FB}}(z)$ and monitoring intensity $m_i^{\mathrm{FB}}(z)$ are given by

$$r_i^{\mathrm{FB}}(z) = \frac{R}{2} + \frac{cf}{(1-qs_i)R},$$
$$m_i^{\mathrm{FB}}(z) = \frac{(1-qs_i)R}{c};$$

here $r_i^{\mathrm{FB}}(z) \leq r_i^{\mathrm{SB}}(z)$. (Note that $r_i^{\mathrm{FB}}(z) = r_i^{\mathrm{SB}}(z)$ only when bank i's best loan rate at z is R.)

In the first-best case, a social planner can directly choose monitoring intensities and so need not rely on loan rates to incentivize banks' monitoring; the implication is that $r_i^{\mathrm{FB}}(z) \leq r_i^{\mathrm{SB}}(z)$. Meanwhile, the planner maximizes the expected value of investment projects (net of monitoring costs) by setting the first-best monitoring intensity at z to the same monitoring intensity that bank i would choose in equilibrium if and only if its loan rate were equal to the upper bound R.

The relation between the equilibrium loan rate under effective bank competition (viz., $r_i^{\mathrm{comp}}(z)$) and the first-best socially optimal loan rate (viz., $r_i^{\mathrm{FB}}(z)$) is given by Proposition 11.

Proposition 11. *Let $K = 0$. If $R > \sqrt{2cf}$ and if location z is served by bank i, then $r_i^{\mathrm{comp}}(z) < r_i^{\mathrm{FB}}(z)$ holds for all locations when q is small enough.*

In the first-best case, the monitoring intensity $m_i^{\mathrm{FB}}(z)$ is higher than what bank i would choose in equilibrium (unless the bank's equilibrium loan rate is R). Since a higher monitoring intensity benefits entrepreneurs, the social planner must control $r_i^{\mathrm{FB}}(z)$ in order to avoid (inefficiently) excessive funding demand at location z – which means that $r_i^{\mathrm{FB}}(z)$ cannot be too low. So when bank competition is intense enough (i.e., when q is small enough), the equilibrium loan rate $r_i^{\mathrm{comp}}(z)$ will be lower than $r_i^{\mathrm{FB}}(z)$. Figure 9 illustrates the relations involving $r_1^{\mathrm{comp}}(z)$, $r_1^{\mathrm{SB}}(z)$, and $r_1^{\mathrm{FB}}(z)$ in $z \times q$ space.

5.2 Welfare analysis of the equilibrium under direct bank competition

Here we examine the equilibrium described in Section 3.1 and analyze the welfare effects of information technology progress (i.e., of changes in q and c). Figure 10 shows how entrepreneurs' utility, banks' profits, and social welfare vary with q and c.

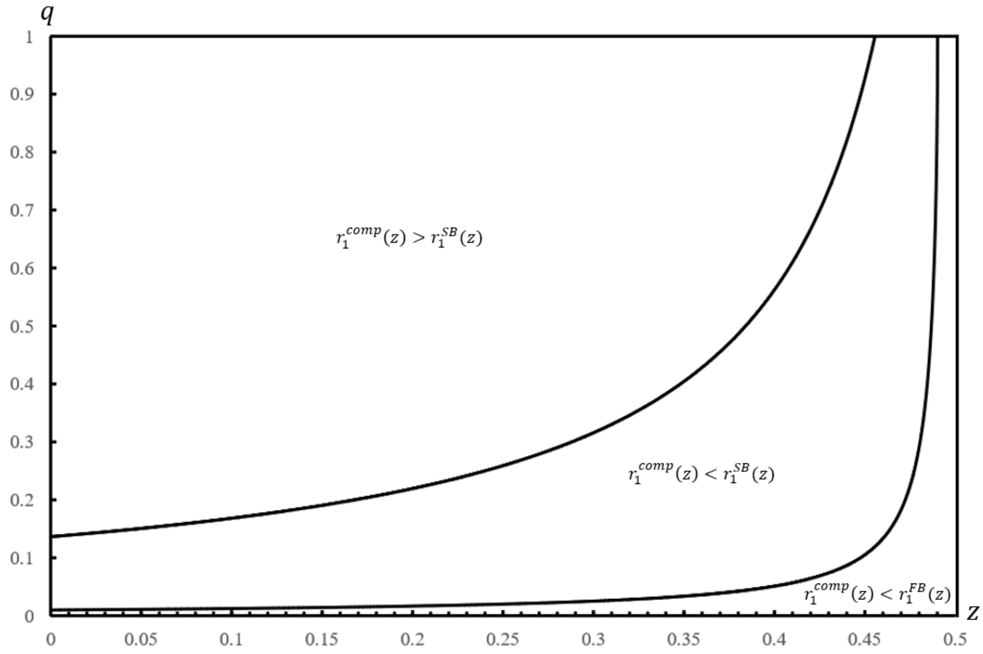

Figure 9: Relations among $r_1^{\mathrm{comp}}(z)$, $r_1^{\mathrm{SB}}(z)$, and $r_1^{\mathrm{FB}}(z)$ in $z \times q$ space. This figure compares $r_1^{comp}(z)$ with $r_1^{\mathrm{SB}}(z)$ and $r_1^{\mathrm{FB}}(z)$ in $z \times q$ space. The parameter values are $R = 20$, $c = 20$, and $f = 1$.

By Proposition 3, if q decreases then the intensity of banking competition increases because banks' differentiation will be diminished. From the perspective of entrepreneurs, greater bank competition translates into banks offering better loan rates to attract entrepreneurs, which always boosts entrepreneurs' utility. So as can be seen in Panels 1 and 2 of Figure 10, entrepreneurial utility increases as q decreases. From the bank's perspective, reducing q has two opposing effects. The first is a positive cost-saving effect: monitoring is cheaper when q is lower. Yet there is also a competition effect that banks dislike: a lower q implies more intense competition. The net effect – of decreasing q – on banks' profits is ambiguous. When q is not small, the cost-saving effect dominates and so banks' profits increase as q decreases. When q is small enough, however, the cost-saving effect is no longer significant; hence the competition effect will dominate and we see that banks' profits decrease as q decreases.

Perhaps more surprising is that decreasing q can sometimes reduce social welfare, even if there is no cost of bank failure (i.e., if $K = 0$; see Panel 1 of Figure 10). The reason is that banks' equilibrium loan rates will be excessively low (as compared with socially optimal rates) when competition is too intense (i.e., when q is small enough; Proposition 9), which can dominate the cost-saving effect of decreasing q and thereby reduce social welfare. In our model, competition determines not only the distribution

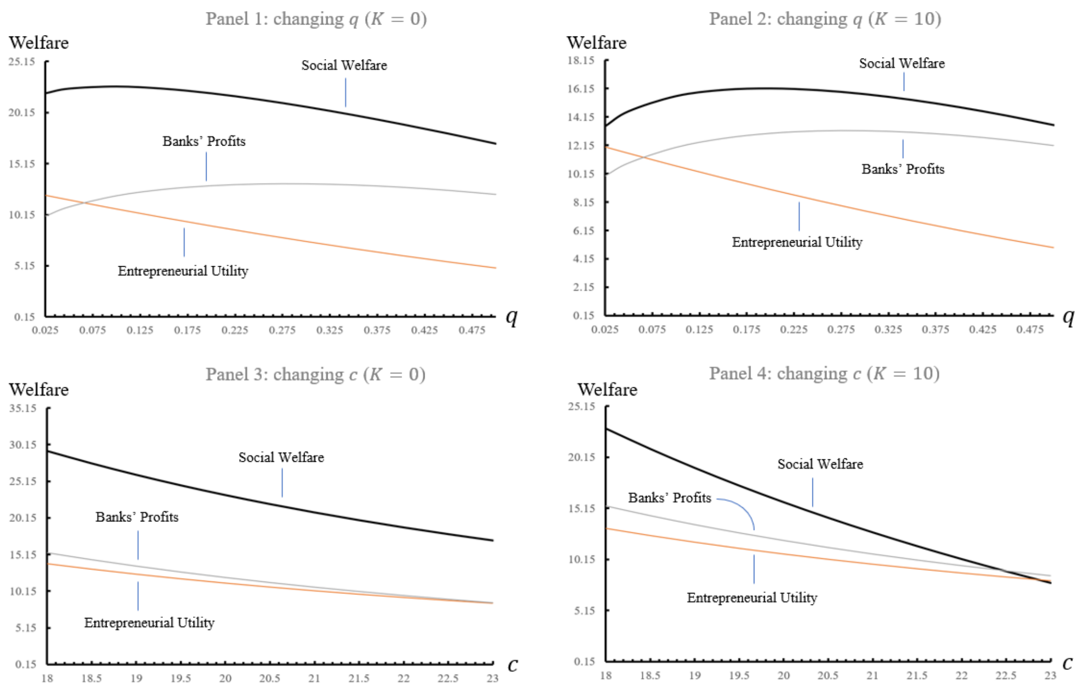

Figure 10: Social Welfare and Banking Sector's Information Technology under Competition. This figure plots social welfare, entrepreneurial utility, and banks' profits against c and q in the equilibrium under bank competition. The parameter values are: $R = 20$ and $f = 1$ in all panels; $c = 20$ in Panels 1 and 2; $q = 0.1$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 10$ in Panels 2 and 4.

of benefits between banks and entrepreneurs but also each bank's incentive to monitor entrepreneurs. As competition intensity increases, equilibrium loan rates will decline and so banks will prefer a lower monitoring intensity (Lemma 1); this dynamic reduces the expected value of the entrepreneurs' projects and hence is detrimental to social welfare. That is why, in Panel 1 of Figure 10, social welfare is not maximized at $q = 0$. When q is high, decreasing q and thus increasing competition intensity will promote social welfare because now there is insufficient competition in the lending market to start with and entrepreneurs' aggregate utility is too low. Yet when q is low enough, decreasing q diminishes social welfare because competition intensity will be excessively high. Whether a reduction in q (and the resultant increased competition intensity) is welfare-improving depends on whether we start with a low or high level of competition. Recall that K is an exogenous cost associated with banks' failure. Since a higher intensity of bank competition will increase banks' probability of default, it follows that the socially optimal level of q will be higher when K is positive than when $K = 0$ (see Panel 2 of Figure 10).

The effects of decreasing c are relatively simple because, unlike changing q, changing c

has no effect on (competition) differentiation (Proposition 3). From the perspective of entrepreneurs, changing c does not affect the equilibrium loan rates of locations under bank competition. Yet as c decreases, banks will increase their monitoring intensity and hence entrepreneurs' projects will be more likely to succeed, which increases entrepreneurs' utility. From the perspective of banks, decreasing c makes monitoring cheaper without bringing more competition, so banks' profits will also increase as c decreases. Finally, decreasing c enhances bank stability and can therefore – when K is positive – reduce the expected deadweight loss caused by banking failures. As a result, social welfare increases when c decreases (Panels 3 and 4 of Figure 10).

In short: although reducing q and reducing c can each be viewed as progress in information technology, their welfare effects are quite different. So when discussing IT progress, one must stipulate the type of information technology change involved.

Remark: Endogenous choice of q***.*** If bank i ($i = \{1, 2\}$) can choose q_i before the price competition game takes place, then a symmetric equilibrium with excessively low q can arise endogenously when the cost of decreasing q is sufficiently low for the banks. To convey the intuition in a simple way, consider a special case where bank i can freely choose its q_i without incurring any cost. Such a case can be viewed as an economy where information technology is highly advanced in non-financial sectors and it spills over the banking sector. Banks then can exploit the technology spillover with little costs. In this case, choosing $q_i = 0$ is bank i's dominant strategy because the marginal benefit of decreasing q_i is always positive for the bank, which does not internalize the negative effect of decreasing q_i on the rival bank's profit.[17] As a consequence, $q_1 = q_2 = 0$ will arise endogenously, and hence bank competition will be excessively intense from the perspective of social welfare since we know that this is the case when q is low (see Proposition 9). Note that even if both banks can make more profits when q is higher, bank i is not willing to deviate from $q_i = 0$ given the rival bank's IT; this means bank i is trapped in a prisoner's dilemma if the cost of decreasing q_i is sufficiently low.

5.3 Welfare analysis of the local monopoly equilibrium

Next we analyze how the development and diffusion of information technology affect social welfare in the local monopoly equilibrium described in Section 3.2 (where R is *not*

[17] From the perspective of bank 1, decreasing q_1 makes its monitoring cheaper without increasing the competitive pressure from bank 2, because bank 2's best loan rate at each location solely depends on q_2 and c_2. Hence the marginal benefit of decreasing q_1 is always positive for bank 1. Reasoning symmetrically, the marginal benefit of decreasing q_2 is also always positive for bank 2.

large). Figure 11 plots how entrepreneurs' utility, banks' profits, and social welfare each vary with q and c.

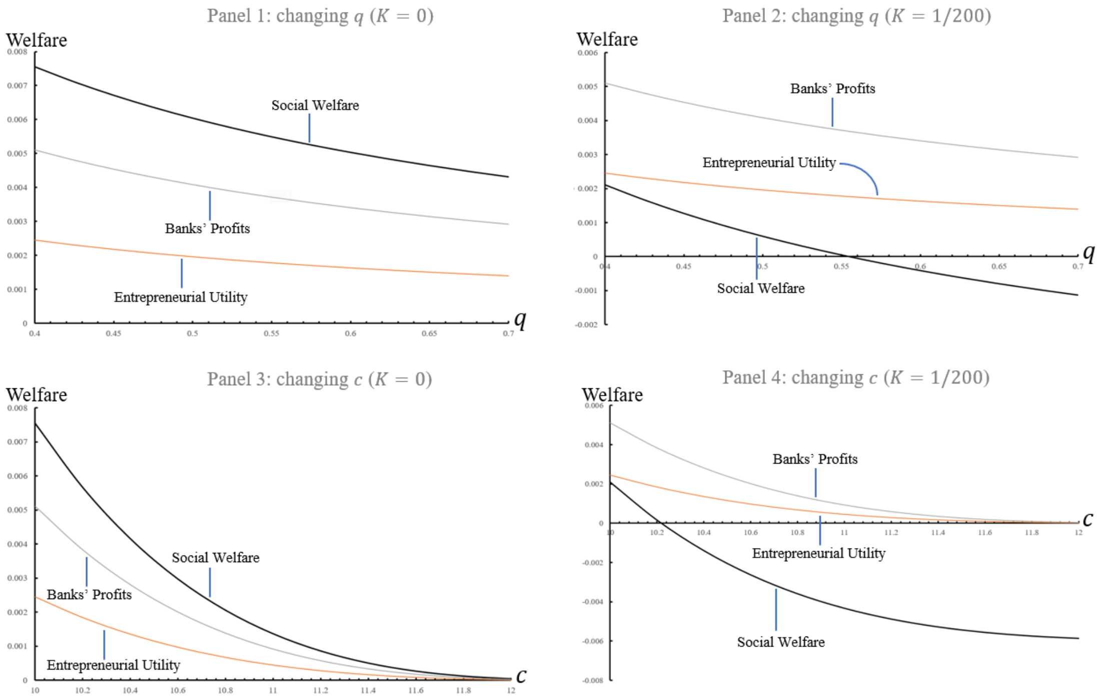

Figure 11: Social Welfare and Banking Sector's Information Technology under Local Monopoly. This figure plots social welfare, entrepreneurial utility, and banks' profits against c and q in the local monopoly equilibrium. The parameter values are: $R = 5$ and $f = 1$ in all panels; $c = 10$ in Panels 1 and 2; $q = 0.4$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 1/200$ in Panels 2 and 4.

In a local monopoly equilibrium, the welfare effects of q and c are not qualitatively different. As either q or c increases, we see that entrepreneurial utility, banks' profits, and social welfare all decline (Panels 1 and 3 of Figure 11). This concordance arises because, in the local monopoly equilibrium, banks no longer compete with each other and so there is no (competition) differentiation effect associated with the parameter changes. As q or c increases, the only effect is that monitoring becomes more expensive for the banks – which reduces their profits. And since monitoring intensity is positively associated with an entrepreneur's probability of success, an increase in monitoring costs also hurts entrepreneurs. It follows that the overall effect of increasing q and/or c is welfare-reducing. Taking bankruptcy cost K into consideration strengthens (resp., does not change) the welfare-reducing effect of increasing c (resp., q) because, when there is no bank competition, a higher c (resp., q) reduces (resp., does not affect) bank stability; see Panels 2 and 4 of Figure 11.

Remark: The formula for social welfare W, Equation (7), applies also to the case with a fairly priced deposit insurance scheme; that case is analyzed in Internet Appendix C. The claim follows because (a) the deposit insurance fund always earns zero expected profit and (b) banks' payoff functions are not affected by such insurance. However, this does not mean that deposit insurance has no effect on social welfare. Because bank stability is no longer determined by Lemma 4 when deposits are insured, fairly priced deposit insurance will increase social welfare by reducing banks' probability of default (θ_i^*) when there is a positive deadweight loss associated with bank failure (i.e., when $K > 0$). Yet as shown in Internet Appendix C, this section's results – on how IT progress affects social welfare – are robust in the case of fairly priced deposit insurance and a positive deadweight loss of bank failure.

6 Conclusion

Our study shows that whether (or not) the development and diffusion of information technology increases bank competition depends on whether it diminishes or increases differentiation among banks. In particular: if IT progress reduces the costs of monitoring/ screening an entrepreneur without altering banks' relative cost advantage (i.e., lower c), neither differentiation nor competition among banks is affected. Yet if IT progress weakens the influence of bank–entrepreneur distance on monitoring/screening costs (i.e., lower q) then differentiation among banks will decrease, bank competition will become more intense, and banks will be less stable. We must therefore be careful to identify the kind of information technology change being considered before gauging its impact. In any case, and consistently with received empirical evidence, we find that a technologically more advanced bank – regardless of how changes in IT affect differentiation – commands greater market power and is more stable.

We find that the welfare effect of information technology progress is ambiguous when it weakens the influence of bank–entrepreneur distance on monitoring/screening costs (lower q). On the one hand, increasing competition intensity always favors entrepreneurs; on the other hand, more competition reduces banks' profits (and increases expected bankruptcy costs). Whether or not increased competition intensity benefits social welfare depends on whether the lending market has not enough or too much competition at the outset. When q is low, there is always excessive competition and insufficient monitoring. This is always the case when IT technology is so advanced that it is very cheap and in equilibrium banks choose endogenously a very low q. But if banks enjoy local monopolies in equilibrium, then IT progress has no (competition) differentiation effect; it is always welfare-improving because such progress simply makes monitoring or screening less expensive.

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Appendix A: Proofs

Proof of Lemma 1

Taking $r_1(z)$ as given, maximizing $\pi_1(z) \equiv r_1(z)\, m_1(z) - \frac{c_1}{2(1-q_1 z)} (m_1(z))^2 - f$ by choosing $m_1(z)$ directly yields the following first order condition:

$$r_1(z) - \frac{c_1}{(1-q_1 z)} m_1(z) = 0 \Longrightarrow m_1(z) = \frac{(1-q_1 z) r_1(z)}{c_1}.$$

Symmetrically, we can derive $m_2(z)$.

Proof of Lemma 2

This lemma is proved in the main text.

Proof of Lemma 3

If bank 1 faces no competition, then it will choose $r_1(z)$ to maximize its expected profit from location z; such profit is equal to

$$\pi_1^{total}(z) \equiv D(z) \left(r_1(z)\, m_1(z) - \frac{c_1}{2(1-q_1 z)} (m_1(z))^2 - f \right).$$

Recall that $D(z) = (R - r_1(z))\, m_1(z)$ and $m_1(z) = \frac{r_1(z)(1-q_1 z)}{c_1}$. After inserting $D(z)$ and $m_1(z)$ into $\pi_1^{total}(z)$, the objective function bank 1 finally needs to maximize is

$$\frac{(R - r_1(z))\,(r_1(z))^3\,(1-q_1 z)^2}{2c_1^2} - \frac{(R - r_1(z))\, r_1(z)\,(1-q_1 z)}{c_1} f.$$

The monopolistic loan rate, denoted by $r_1^m(z)$, that maximizes the objective function is determined by the following first order condition:

$$f(r_1(z)) \equiv \frac{(r_1(z))^2\,(3R - 4r_1(z))\,(1-q_1 z)}{2c_1} + (2r_1(z) - R)\, f = 0.$$

It is clear that $f(-\infty) \to +\infty$, $f(0) = -Rf < 0$ and $f\left(\frac{R}{2}\right) = \frac{\left(\frac{R}{2}\right)^2 R(1-q_1 z)}{2c_1} > 0$.

Therefore, within $(-\infty, 0)$ and $\left(0, \frac{R}{2}\right)$, there exist two roots for $f(r_1(z)) = 0$. However, those two roots cannot be the profit maximizing loan rate of bank 1 because we have shown that no bank would offer a loan rate that is lower than $\frac{R}{2}$.

We can further show that $f(+\infty) \to -\infty$. So there must exist a third root, denoted by r^{3rd}, within $\left(\frac{R}{2}, +\infty\right)$. If bank 1 finds it profitable to finance entrepreneurs at z, then r^{3rd} must be no larger than R, because total finding demand and bank 1's profit will be negative at location z if the bank offers a loan rate that is higher than R, which is never optimal for the bank. As a consequence, r^{3rd}, which must be within $\left(\frac{R}{2}, R\right]$, is the solution that maximizes bank 1's profit, and we denote it by $r_1^m(z)$ in the main text. The schedule $r_2^m(z)$ can be pinned down in the same way.

Proof of Proposition 1

First we determine the cut-off (indifference) location where an entrepreneur is indifferent about which bank to approach. Because the two banks compete in a localized Bertrand fashion, both banks will offer their best loan rates at the indifference location; meanwhile an entrepreneur at the location feels indifferent. So we have the following equation for the indifference location $\tilde{x}$:

$$\left(R - \frac{R}{2}\right) \frac{\frac{R}{2}(1 - q_1\tilde{x})}{c_1} - \underline{u} = \left(R - \frac{R}{2}\right) \frac{\frac{R}{2}(1 - q_2(1 - \tilde{x}))}{c_2} - \underline{u},$$

and the result is $\tilde{x} = \frac{1 - \frac{c_1}{c_2} + \frac{c_1}{c_2} q_2}{\frac{c_1}{c_2} q_2 + q_1}$. At the point $\tilde{x}$ neither bank has a competitive advantage. On the left (resp. right) side of $\tilde{x}$, bank 1 (resp. bank 2) will have advantage in the competition with its rival. So if $0 < \tilde{x} < 1$, entrepreneurs in $[0, \tilde{x}]$ are served by bank 1, while the other locations are served by bank 2.

At location $z \in [0, \tilde{x}]$, bank 1 must offer a loan rate $r_1(z)$ to maximize its own profit from this location, subject to the constraint that an entrepreneur at z's utility is no less than what she would derive from the best loan rate $\left(\frac{R}{2}\right)$ of bank 2. If bank 1 has no monopoly power on the entrepreneur, then bank 1's optimal choice is to set $r_1(z)$ as high as possible; this implies the following equation:

$$(R - r_1(z)) \frac{r_1(z)(1 - q_1 z)}{c_1} - \underline{u} = \left(R - \frac{R}{2}\right) \frac{\frac{R}{2}(1 - q_2(1 - z))}{c_2} - \underline{u}.$$

The equation yields $r_1(z) = r_1^{\text{comp}}(z)$. However, if $r_1^{\text{comp}}(z)$ is higher than bank 1's monopoly loan rate $r_1^m(z)$, then bank 1 actually has monopoly power on entrepreneurs at z. In this case, bank 1 will simply choose $r_1^m(z)$ as its loan rate. Therefore, bank

1's pricing strategy is $r_1^*(z) = \min\{r_1^{\text{comp}}(z), r_1^m(z)\}$ for entrepreneurs located in $[0,\tilde{x}]$. Similarly, we can derive bank 2's equilibrium loan rate $r_2^*(z)$.

Proof of Corollary 1 and Proposition 2

The schedule $r_1^{\text{comp}}(z)$ is obviously decreasing in z for $z \in [0,\tilde{x}]$. When $z = \tilde{x}$, it is clear that $r_1^{\text{comp}}(z) = \frac{R}{2}$. Symmetrically, $r_2^{\text{comp}}(z)$ is increasing in z for $z \in (\tilde{x}, 1]$. For $z \in (0,\tilde{x})$, it is clear that $r_1^{\text{comp}}(z)$ is decreasing in c_1 and q_1, while increasing in c_2 and q_2.

Proof of Corollary 2

If $0 < \tilde{x} < 1$ and if there is effective competition between banks (i.e., if $r_i^{\text{comp}}(z) \leq r_i^m(z)$) at z, the loan volume provided by bank 1 to entrepreneurs at $z \in [0,\tilde{x}]$ is $D(z) = (R - r_1^{\text{comp}}(z))m_1(z)$. After some calculation, we can show that $D(z) = \frac{(1-q_2(1-z))R^2}{4c_2}$, which is increasing in z when $z \in [0,\tilde{x}]$. In the same way, we can show that the loan volume provided by bank 2 to entrepreneurs at $z \in (\tilde{x}, 1]$ is decreasing in z.

Proof of Proposition 3

If $c_1 = c_2 = c$, $q_1 = q_2 = q$ and if there is effective competition at z, bank 1's equilibrium loan rate is

$$r_1^{\text{comp}}(z) = \frac{R}{2}\left(1 + \sqrt{1 - \frac{1-q(1-z)}{1-qz}}\right), z \in [0,\tilde{x}],$$

which is obviously unaffected by c, but is increasing in q unless $z = \frac{1}{2}$.

In the same way, we can show that the same result holds for bank 2's equilibrium loan rate.

Proof of Proposition 4

First we calculate $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q}$. If there is effective bank competition at all locations, we have

$$\left.(L_1 + L_2)\right|_{q_i=q} = \int_0^{\tilde{x}} \frac{(1-q(1-z))R^2}{4c_2} dz + \int_{\tilde{x}}^1 \frac{(1-qz)R^2}{4c_1} dz,$$

because loan volume at z is equal to $\frac{(1-q(1-z))R^2}{4c_2}$ (resp. $\frac{(1-qz)R^2}{4c_1}$) if $z \in [0,\tilde{x}]$ (resp. $z \in (\tilde{x}, 1]$) according to the proof of Corollary 2. Therefore, it can be shown that

$$\begin{aligned} \left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q} &= \int_0^{\tilde{x}} \frac{-(1-z)R^2}{4c_2} dz + \int_{\tilde{x}}^1 \frac{-zR^2}{4c_1} dz \\ &\quad + \left(\frac{(1-q(1-\tilde{x}))R^2}{4c_2} - \frac{(1-q\tilde{x})R^2}{4c_1}\right)\frac{\partial \tilde{x}}{\partial q}. \end{aligned}$$

Obviously the first two terms of $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q}$ are negative. The third term of $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q}$ is zero because $\frac{(1-q(1-\tilde{x}))R^2}{4c_2}=\frac{(1-q\tilde{x})R^2}{4c_1}$ must hold to ensure that entrepreneurs are indifferent about which bank to approach at the indifference location $\tilde{x}$. As a consequence, we have $\left.\frac{\partial(L_1+L_2)}{\partial q}\right|_{q_i=q}<0$.

Next we look at $\left.\frac{\partial^2 L_i}{\partial c_i \partial q}\right|_{q_i=q}$. We need only look at L_1 since the two banks are symmetric. It can be shown that

$$\left.\frac{\partial L_1}{\partial c_1}\right|_{q_i=q}=\frac{(1-q(1-\tilde{x}))\,R^2}{4c_2}\frac{\partial \tilde{x}}{\partial c_1}=-\frac{R^2}{4c_2^2\left(\frac{c_1}{c_2}+1\right)^3}\frac{(2-q)^2}{q}<0.$$

Obviously, $\left.\frac{\partial^2 L_i}{\partial c_i \partial q}\right|_{q_i=q}>0$ because $\partial\left(\frac{(2-q)^2}{q}\right)/\partial q<0$.

Proof of Proposition 5

This proposition is proved in the main text.

Proof of Corollary 3 and Proposition 6

We have shown that $r_1^m(z)$ is the largest solution of the following equation:

$$f(r_1(z))\equiv\frac{(r_1(z))^2\,(3R-4r_1(z))\,(1-q_1z)}{2c_1}+(2r_1(z)-R)\,f=0,$$

and the solution is between $\frac{R}{2}$ and $+\infty$. Because two solutions of the equation above are lower than $\frac{R}{2}$ (see the proof of Lemma 3), the solution in $\left(\frac{R}{2},+\infty\right)$ is unique. Meanwhile, because $f\left(\frac{R}{2}\right)=\frac{\left(\frac{R}{2}\right)^2R(1-q_1z)}{2c_1}>0$ and $f(+\infty)=-\infty$, we must have $f'(r_1^m(z))<0$. When $r_1(z)$ is close to the solution $r_1^m(z)$ (i.e., when $r_1(z)\approx r_1^m(z)$), a marginal increase of z will increase $f(r_1(z))$ because $2r_1(z)-R$ is positive and $3R-4r_1(z)$ is negative (since $f(r_1(z))$ is close to 0 when $r_1(z)\approx r_1^m(z)$). A higher $f(r_1(z))$ around the third solution of $f(r_1(z))=0$ implies a higher $r_1^m(z)$ because $f'(r_1^m(z))<0$.

In the same way, we can show that a marginal increase of c_1 or q_1 will increase $f(r_1(z))$ when $r_1(z)$ is close to $r_1^m(z)$, and so will cause $r_1^m(z)$ to increase.

Inserting $z=\frac{R^2-2c_1f}{q_1R^2}$ into $f(r_1)=0$, it is easy to check that the solution in $\left(\frac{R}{2},+\infty\right)$ is $r_1=R$.

Proof of Lemma 4

This lemma is proved in the main text.

Proof of Proposition 7

If we use $\frac{x}{q_1}$ to replace z, then $r_1^m(\frac{x}{q_1})$ is determined by

$$\frac{(r_1^m(\frac{x}{q_1}))^2(3R - 4r_1^m(\frac{x}{q_1}))(1-x)}{2c_1} + (2r_1^m(\frac{x}{q_1}) - R)f = 0,$$

which means $r_1^m(\frac{x}{q_1})$ is independent of q_1. Similarly, we can show $D(\frac{x}{q_1}) = \pi^e(\frac{x}{q_1}) = (R - r_1^m(\frac{x}{q_1}))\frac{(1-x)r_1^m(\frac{x}{q_1})}{c_1}$, which is also independent of q_1.

Letting $z = \frac{x}{q_1}$, bank 1's probability of default (see Lemma 4 for the equation) in the local monopoly equilibrium is determined by

$$\left(\begin{array}{c} \int_0^{\theta^*}\int_0^{\frac{R^2-2c_1 f}{R^2}} D\left(\frac{x}{q_1}\right) r_1\left(\frac{x}{q_1}\right) 1_{\left\{1-\frac{r_1\left(\frac{x}{q_1}\right)(1-x)}{c_1}\leq\theta\right\}} dx d\theta \\ +(1-\theta^*)\int_0^{\frac{R^2-2c_1 f}{R^2}} D\left(\frac{x}{q_1}\right) r_1\left(\frac{x}{q_1}\right) 1_{\left\{1-\frac{r_1\left(\frac{x}{q_1}\right)(1-x)}{c_1}\leq\theta^*\right\}} dx - f\int_0^{\frac{R^2-2c_1 f}{R^2}} D\left(\frac{x}{q_1}\right) dx \end{array}\right) = 0,$$

which implies that θ^* is independent of q_1 because $D\left(\frac{x}{q_1}\right)$ and $r_1\left(\frac{x}{q_1}\right)$ are independent of q_1.

Proof of Proposition 8 and Corollary 4

The second-best socially optimal loan rate of bank i maximizes W under the constraint $m_i(z) = \frac{(1-qs_i)r_i^{\mathrm{SB}}(z)}{c}$. If $K = 0$, then the first order condition satisfied by $r_i^{\mathrm{SB}}(z)$ is

$$f^{\mathrm{SB}}\left(r_i^{\mathrm{SB}}(z)\right) \equiv \frac{r_i^{\mathrm{SB}}(z)\,R\left(2R - 3r_i^{\mathrm{SB}}(z)\right)(1-qs_i)}{2c} + \left(2r_i^{\mathrm{SB}}(z) - R\right)f = 0,$$

which has two solutions.

It must hold that $1 - qs_i > 0$ because the farthest location bank 1 (or bank 2) finances is $z = \frac{1}{2}$ in the symmetric case. Therefore, it is clear that $f^{\mathrm{SB}}(-\infty) \to -\infty$, $f^{\mathrm{SB}}\left(\frac{R}{2}\right) > 0$ and $f^{\mathrm{SB}}(+\infty) \to -\infty$; This means one solution of the FOC is smaller than $\frac{R}{2}$, and the other solution is larger than $\frac{R}{2}$. The second order condition (SOC), which is $\frac{R\left(2R-6r_i^{\mathrm{SB}}(z)\right)(1-qs_i)}{2c} + 2f < 0$, is satisfied by the larger solution of the FOC:

$$r_i^{\mathrm{SB}}(z) = \frac{\left(2R^2(1-qs_i) + 4cf\right) + \sqrt{\left(2R^2(1-qs_i) + 4cf\right)^2 - 24cfR^2(1-qs_i)}}{6R(1-qs_i)} > \frac{R}{2}.$$

The monopoly loan rate $r_i^m(z)$ is the largest solution (which is larger than $\frac{R}{2}$) of following equation:

$$f\left(r_i^m(z)\right) \equiv \frac{\left(r_i^m(z)\right)^2\left(3R-4r_i^m(z)\right)\left(1-qs_i\right)}{2c} + \left(2r_i^m(z)-R\right)f = 0.$$

Based on the equation above, we have $r_i^m(z) > \frac{3}{4}R$ because $f\left(\frac{3}{4}R\right) > 0$ and $f(+\infty) \to -\infty$ hold. Meanwhile, it is easy to see that $f(x) > f^{\mathrm{SB}}(x)$ if $R > x > \frac{3R}{4}$. Therefore, if $r_i^m(z) < R$, we have $f\left(r_i^m(z)\right) = 0 > f^{\mathrm{SB}}\left(r_i^m(z)\right)$, which implies $r_i^{\mathrm{SB}}(z) < r_i^m(z)$.

If $r_i^m(z) = R$, however, it must hold that $R = \sqrt{\frac{2cf}{1-qs_i}}$. In this case, bank i's best loan rate is also $\sqrt{\frac{2cf}{1-qs_i}}$, and it is easy to show that $f^{\mathrm{SB}}(R) = 0$, so $r_i^m(z) = r_i^{\mathrm{SB}}(z) = R$ in this case.

Corollary 4 directly follows from that bank i's equilibrium loan rate at z is $r_i^m(z)$, and that $r_i^m(z) = R = \sqrt{\frac{2cf}{1-qs_i}}$ holds at the farthest location served by bank i in the local monopoly equilibrium.

Proof of Proposition 9

We consider the limiting case $q = 0$. In this case, bank i must offer its best loan rate in equilibrium because there is no bank differentiation. That is, $r_i^{\mathrm{comp}}(z) = \frac{R}{2}$ if $R \geq 2\sqrt{2cf}$ and $r_i^{\mathrm{comp}}(z) = \sqrt{2cf}$ if $\sqrt{2cf} < R < 2\sqrt{2cf}$ (see Appendix B for bank i's best loan rates when R is not large). In the case $R \geq 2\sqrt{2cf}$, it is easy to see $r_i^{\mathrm{comp}}(z) = \frac{R}{2} < r_i^{\mathrm{SB}}(z)$ because $f^{\mathrm{SB}}\left(\frac{R}{2}\right) > 0$. So we need only look at the case $\sqrt{2cf} < R < 2\sqrt{2cf}$.

In the case $\sqrt{2cf} < R < 2\sqrt{2cf}$, we can show that

$$f^{\mathrm{SB}}\left(r_i^{\mathrm{comp}}(z)\right) = \frac{2\sqrt{2cf}\left(R-\sqrt{2cf}\right)^2}{2c},$$

which is positive if $R > \sqrt{2cf}$ holds. Therefore, we have $r_i^{\mathrm{comp}}(z) < r_i^{\mathrm{SB}}(z)$ if $R > \sqrt{2cf}$ and if $q = 0$; this means $r_i^{\mathrm{comp}}(z) < r_i^{\mathrm{SB}}(z)$ holds when q is small enough and $R > \sqrt{2cf}$.

Proof of Proposition 10

In the first-best case, the social planner chooses $r_i^{\mathrm{FB}}(z)$ and $m_i^{\mathrm{FB}}(z)$ to maximize W. The FOC w.r.t. $r_i(z)$ is

$$-r_i(z)\,m_i(z) + f + \frac{c}{2(1-qs_i)}\left(m_i(z)\right)^2 = 0.$$

The FOC w.r.t. $m_i(z)$ is

$$\left(R + r_i(z)\right)m_i(z) - f - \frac{3c}{2(1-qs_i)}\left(m_i(z)\right)^2 = 0.$$

Solving the two FOC equations yields:

$$r_i^{\mathrm{FB}}(z) = \frac{R}{2} + \frac{cf}{(1-qs_i)R}; m_i^{\mathrm{FB}}(z) = \frac{(1-qs_i)R}{c}.$$

We can show that

$$\begin{aligned} f^{\mathrm{SB}}\left(r_i^{\mathrm{FB}}(z)\right) &= \frac{r_i^{\mathrm{FB}}(z)\,R\left(2R - 3r_i^{\mathrm{FB}}(z)\right)(1-qs_i)}{2c} + \left(2r_i^{\mathrm{FB}}(z) - R\right)f \\ &= \frac{\frac{1}{4}\left((1-qs_i)\,R^2 - 2cf\right)^2}{2c\,(1-qs_i)\,R}, \end{aligned}$$

which is positive unless $R = \sqrt{\frac{2cf}{1-qs_i}}$. As a consequence, $r_i^{\mathrm{FB}}(z) < r_i^{\mathrm{SB}}(z)$ if $R \neq \sqrt{\frac{2cf}{1-qs_i}}$.

If $R = \sqrt{\frac{2cf}{1-qs_i}}$, then bank i's best loan rate is R at location z. In this case we have $f^{\mathrm{SB}}\left(r_i^{\mathrm{FB}}(z)\right) = 0$, so $r_i^{\mathrm{FB}}(z) = r_i^{\mathrm{SB}}(z) = r_i^m(z) = R$.

Proof of Proposition 11

We consider the limiting case $q = 0$. In this case, bank i must offer its best loan rate in equilibrium because there is no bank differentiation. That is, $r_i^{\mathrm{comp}}(z) = \frac{R}{2}$ if $R \geq 2\sqrt{2cf}$ and $r_i^{\mathrm{comp}}(z) = \sqrt{2cf}$ if $\sqrt{2cf} < R < 2\sqrt{2cf}$. In the case $R \geq 2\sqrt{2cf}$, it is easy to see $r_i^{\mathrm{comp}}(z) = \frac{R}{2} < r_i^{\mathrm{FB}}(z)$ because $r_i^{\mathrm{FB}}(z) = \frac{R}{2} + \frac{cf}{R}$. Therefore, we only need to look at the case $\sqrt{2cf} < R < 2\sqrt{2cf}$.

In the case $\sqrt{2cf} < R < 2\sqrt{2cf}$, we can show that

$$r_i^{\mathrm{FB}}(z) - r_i^{\mathrm{comp}}(z) = \frac{R^2 - 2R\sqrt{2cf} + \sqrt{2cf}\sqrt{2cf}}{2R} = \frac{\left(R - \sqrt{2cf}\right)^2}{2R} > 0.$$

Therefore, $r_i^{\mathrm{comp}}(z) < r_i^{\mathrm{FB}}(z)$ holds when q is small enough.

Appendix B: Insufficiently large R

In this part we consider bank competition under a general R that need not be large (i.e., $R \geq \max\left\{\sqrt{\frac{8c_1 f}{1-q_1}}, \sqrt{\frac{8c_2 f}{1-q_2}}\right\}$ need not hold). In this case, $\frac{R}{2}$ may not guarantee banks a non-negative profit at z. Specifically, bank 1's expected profit from financing an entrepreneur at z is given by:

$$\pi_1(z) = \frac{(r_1(z))^2\,(1-q_1 z)}{2c_1} - f$$

when bank 1 posts loan rate $r_1(z)$ for the entrepreneur. If $\pi_1(z)$ is positive when $r_1(z) = \frac{R}{2}$, then bank 1's best loan rate at location z is still $\frac{R}{2}$. However, if $\pi_1(z)$ is negative when $r_1(z) = \frac{R}{2}$, then $\frac{R}{2}$ is no longer bank 1's best loan rate. A symmetric result holds for bank 2. When $\frac{R}{2}$ is too low to be bank 1's best loan rate, the lowest acceptable loan rate for bank 1 is determined by

$$\pi_1(z) = 0,$$

which yields:

$$r_1(z) = \overline{r}_1(z) \equiv \sqrt{\frac{2c_1 f}{1 - q_1 z}}.$$

Similarly, the lowest acceptable loan rate for bank 2 equals $\overline{r}_2(z) \equiv \sqrt{\frac{2c_2 f}{1-q_2(1-z)}}$ if $\frac{R}{2}$ is too low to be the best loan rate. As a result, bank i 's best loan loan rate at location z is given by

$$r_i^b(z) = \max\left\{\frac{R}{2}, \overline{r}_i(z)\right\}.$$

Because the two banks are symmetric, we need only look at how bank 1 chooses its loan rates at locations it serves. If bank 1 does not face enough competition pressure from bank 2, then bank 1 will maintain its monopoly loan rate $r_1^m(z)$ for entrepreneurs at z.

If bank 1 faces effective competition at z, and wants to attract entrepreneurs who want to undertake investment projects at the location, then it must be able to offer entrepreneurs at z a loan rate that is more attractive than $r_2^b(z)$ offered by bank 2. If bank 1 cannot do so, then location z will be served by bank 2. If bank 1 can do so, then its strategy is to maximize its own profit, subject to the constraint that an entrepreneur at z's expected utility is no less than what she would derive from accepting $r_2^b(z)$ offered by bank 2. Following this reasoning, the equilibrium loan rate offered by bank 1, if there is effective competition between banks, is determined by the following equation:

$$(R - r_1(z))\frac{r_1(z)(1 - q_1 z)}{c_1} - \underline{u} = \left(R - r_2^b(z)\right)\frac{r_2^b(z)(1 - q_2(1-z))}{c_2} - \underline{u},$$

which yields

$$r_1^{\text{comp}}(z) = \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_1}{c_2}\frac{1 - q_2(1-z)}{1 - q_1 z}\left(R - r_2^b(z)\right) r_2^b(z)}.$$

In a similar way, bank 2's loan rate, if there is effective competition between banks, is given by

$$r_2^{\text{comp}}(z) = \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_2}{c_1}\frac{1-q_1 z}{1-q_2(1-z)}\left(R - r_1^b(z)\right) r_1^b(z)}.$$

The indifference entrepreneur is located at the point $\tilde{x}$ where an entrepreneur feels indifferent about which bank to choose and meanwhile both banks offer their best loan rate. Therefore, $\tilde{x}$ is determined by the following equation:

$$\left(R - r_1^b(\tilde{x})\right)\frac{r_1^b(\tilde{x})(1-q_1\tilde{x})}{c_1} - \underline{u} = \left(R - r_2^b(\tilde{x})\right)\frac{r_2^b(\tilde{x})(1-q_2(1-\tilde{x}))}{c_2} - \underline{u}. \quad (8)$$

Equation (8) does not yield a closed-form solution. However, at locations where both banks are willing to serve, $\frac{R}{2} \leq r_i^b(z) \leq R$ must hold, so the left hand side of Equation (8) is decreasing in $\tilde{x}$, and the right hand side is increasing in $\tilde{x}$. Therefore, whenever there exists a solution $\tilde{x} \in [0,1]$ that solves equation (8), such a solution must be unique.

It is possible that equation (8) yields no solution in the region $[0,1]$. If this occurs, then it means one bank dominates the entire lending market. We focus on the interesting case that both banks can serve a positive measure of locations in equilibrium, and so summarize our foregoing analysis with the following proposition:

Proposition 12. *Define*

$$r_1^b(z) \equiv \max\left\{\frac{R}{2}, \overline{r}_1(z)\right\}, r_2^b(z) \equiv \max\left\{\frac{R}{2}, \overline{r}_2(z)\right\},$$

$$r_1^{\text{comp}}(z) \equiv \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_1}{c_2}\frac{1-q_2(1-z)}{1-q_1 z}\left(R - r_2^b(z)\right) r_2^b(z)},$$

$$r_2^{\text{comp}}(z) \equiv \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_2}{c_1}\frac{1-q_1 z}{1-q_2(1-z)}\left(R - r_1^b(z)\right) r_1^b(z)}.$$

Assume that there exists an $\tilde{x} \in (0,1)$ solving

$$\left(R - r_1^b(\tilde{x})\right)\frac{r_1^b(\tilde{x})(1-q_1\tilde{x})}{c_1} = \left(R - r_2^b(\tilde{x})\right)\frac{r_2^b(\tilde{x})(1-q_2(1-\tilde{x}))}{c_2}.$$

Then there exists an equilibrium where entrepreneurs located in $[0,\tilde{x}]$ are served by bank 1, while the other locations are served by bank 2. Bank 1 and bank 2's equilibrium loan *rates, $r_1^*(z)$ and $r_2^*(z)$, are respectively given by the following two equations:*

$$r_1^*(z) = \min\left\{r_1^{\text{comp}}(z), r_1^m(z)\right\}, z \in [0, \tilde{x}]$$

$$r_2^*(z) = \min\left\{r_2^{\text{comp}}(z), r_2^m(z)\right\}, z \in (\tilde{x}, 1].$$

We need only focus on bank 1 because the two banks are symmetric. Note that if $r_2^b(z) = \frac{R}{2}$, then $r_1^{\text{comp}}(z)$ exactly equals

$$\frac{R}{2}\left(1 + \sqrt{1 - \frac{c_1}{c_2}\frac{1 - q_2(1-z)}{1 - q_1 z}}\right),$$

which is what we have in Proposition 1. Therefore, in this appendix, we focus on the case $r_2^b(z) = \overline{r}_2(z)$, which implies

$$r_1^{\text{comp}}(z) = \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_1}{c_2}\frac{1 - q_2(1-z)}{1 - q_1 z}\left(R - \overline{r}_2(z)\right)\overline{r}_2(z)}.$$

The following corollary characterizes $r_1^{\text{comp}}(z)$ when $r_2^b(z) = \overline{r}_2(z)$.

Corollary 5. *If $0 < \tilde{x} < 1$ and if $r_2^b(z) = \overline{r}_2(z)$, then $r_1^{\text{comp}}(z)$ is decreasing in z when $z \in [0, \tilde{x}]$. At the location $z = \tilde{x}$, $r_1^{\text{comp}}(z) = r_1^b(z)$.*

This corollary is consistent with Corollary 1 except that the best loan rate offered by bank 1 at $z = \tilde{x}$ is $r_1^b(z)$ here, instead of $\frac{R}{2}$.

Comparative statics. Now we analyze how the foregoing equilibrium is affected by parameters. The next proposition gives the result:

Proposition 13. *When $z \in (0, \tilde{x})$, if $r_2^b(z) = \overline{r}_2(z)$ and if there is effective bank competition at z (i.e., $r_1^{\text{comp}}(z) < r_1^m(z)$), then bank 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is decreasing in c_1 and q_1, but is increasing in c_2 and q_2.*

This proposition shares the same intuition with Proposition 2. So we do not repeat the intuition here.

Letting $c_1 = c_2 = c$ and $q_1 = q_2 = q$, we can study how the change of the bank sector's information technology affects the equilibrium. The following proposition gives the result:

Proposition 14. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. If there is effective bank competition at z (i.e., if $r_1^{\text{comp}}(z) < r_1^m(z)$) and if $r_2^b(z) = \overline{r}_2(z)$, then bank 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is increasing in c and q at $z \in \left[0, \frac{1}{2}\right]$. A symmetric result holds for bank 2.*

Different from Proposition 3, if $r_2^b(z) = \overline{r}_2(z)$ (i.e., if R is not large enough to make $\frac{R}{2}$ the best loan rate of bank 2 at z), then $r_1^{\text{comp}}(z)$ is increasing in c. The reason is that now the lowest loan rate bank 2 can offer is $\overline{r}_2(z)$, rather than $\frac{R}{2}$. If c increases, then $\overline{r}_2(z)$ will also increase, which decreases the competition pressure bank 2 puts on bank 1 when bank 1 chooses loan rates for its entrepreneurs. As a consequence, bank 1 is able to choose a higher $r_1^{\text{comp}}(z)$. Symmetrically, bank 2 also faces less competition from bank 1 if c increases, so $r_2^{\text{comp}}(z)$ is increasing in c at $z \in (\frac{1}{2}, 1]$.

Internet Appendix

Appendix C: Fair deposit insurance

In this appendix, we consider the case that depositors are fully insured. Whenever bank i is not able to fully repay depositors, a deposit insurance fund (DIF) would intervene and ensure that depositors are fully paid. In exchange for the insurance fund's service, bank i must pay a fraction τ of its profit to the DIF whenever the bank is solvent. We assume τ is fairly determined and so based on bank i's risk; this means bank i's expected payment to the DIF is always equal to the DIF's expected payment to depositors.

Because the two banks are symmetric, we need only focus on bank 1 and analyze how the existence of the fair deposit insurance affects the bank's optimization problem. We denote bank 1's loan rate and monitoring intensity for entrepreneurs at z by $r_1(z)$ and $m_1(z)$ respectively, and the bank's probability of default by θ^I (i.e., bank 1 cannot fully repay depositors if and only if $\theta < \theta^I$). After observing bank 1's loan rates, entrepreneurs decide whether to implement their projects and which banks to approach. The funding demand at location z is denoted by $D(z)$. The nominal deposit rate bank 1 would offer to depositors should be f in this section because deposits are riskless with the help of the DIF. If bank 1 finances entrepreneurs located in $\Omega \subseteq [0,1]$, then the bank's aggregate expected profit is

$$(1-\tau)\int_{\theta^I}^{1}\left(\begin{array}{c}\int_{z\in\Omega} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz \\ -f\int_{z\in\Omega} D(z)\, dz\end{array}\right) d\theta - \int_{z\in\Omega} D(z)\, C_1(m_1(z), z) dz. \tag{9}$$

The second term of (9) represents bank 1's aggregate monitoring costs. Those costs do not rely on the economic condition θ because they are non-pecuniary and so must be incurred no matter whether or not the bank is solvent. The first term of (9) is bank 1's expected net pecuniary income. When $\theta < \theta^I$ holds, bank 1 cannot fully repay depositors and so goes bankrupt; in this case the bank's net pecuniary income is zero. When $\theta \geq \theta^I$, the loan repayment received by bank 1 (viz., $\int_{z\in\Omega} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz$) can cover the promised payoff to depositors (viz., $f\int_{z\in\Omega} D(z)\, dz$). In this case, the bank's net pecuniary income is $(1-\tau)\left(\int_{z\in\Omega} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz - f\int_{z\in\Omega} D(z)\, dz\right)$ after paying the DIF a fraction τ. Integrating bank 1's net pecuniary income from $\theta = 0$ to $\theta = 1$ yields the expected net pecuniary income, which is exactly the first term of (9).

In order to further simplify (9), we need to determine the value of τ. The expected payment from the DIF to bank 1's depositors equals

$$EI \equiv \int_0^{\theta^I} \left(f \int_{z\in\Omega} D\left(z\right) dz - \int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz \right) d\theta. \tag{10}$$

We explain EI here. When $\theta \geq \theta^I$ holds, the DIF does not pay depositors because bank 1 is still solvent. When $\theta < \theta^I$ holds, bank 1 is insolvent and so pays depositors $\int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz$, which is the total loan repayment bank 1 receives. In the case, the DIF must pay the remaining part $f \int_{z\in\Omega} D\left(z\right) dz - \int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz$ to depositors to guarantee that they are fully paid. Integrating the DIF's payment to depositors from $\theta = 0$ to $\theta = 1$ yields EI.

The first term of (9) implies that bank 1's expected payment to the DIF is

$$\tau \int_{\theta^I}^1 \left(\int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz - f \int_{z\in\Omega} D\left(z\right) dz \right) d\theta,$$

which must equal EI because the deposit insurance is fairly priced. Therefore we must have

$$\tau = \frac{EI}{\int_{\theta^I}^1 \left(\int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz - f \int_{z\in\Omega} D\left(z\right) dz \right) d\theta}.$$

Inserting τ back to (9) yields the following simplified bank 1's expected profit:

$$\begin{aligned}
\pi_1 &= \int_0^1 \int_{z\in\Omega} D\left(z\right) r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz d\theta - f \int_{z\in\Omega} D\left(z\right) dz - \int_{z\in\Omega} D\left(z\right) C_1(m_1(z), z) dz \\
&= \int_{z\in\Omega} D\left(z\right) r_1(z) \int_0^1 1_{\{1-m_1(z)\leq\theta\}} d\theta dz - f \int_{z\in\Omega} D\left(z\right) dz - \int_{z\in\Omega} D\left(z\right) C_1(m_1(z), z) dz
\end{aligned}$$

It is easy to show that

$$\int_0^1 1_{\{1-m_1(z)\leq\theta\}} d\theta = \int_{1-m_1(z)}^1 d\theta = m_1(z).$$

Therefore, bank 1's expected aggregate profit, denoted by π_1^{DI}, takes the following simple form:

$$\pi_1^{DI} = \int_{z\in\Omega} D\left(z\right) \left(r_1(z) m_1(z) - f - C_1(m_1(z), z) \right) dz.$$

The bank's profit from an entrepreneur at $z \in \Omega$ is therefore

$$\pi_1^{DI}\left(z\right) = r_1(z) m_1(z) - f - C_1(m_1(z), z).$$

The first term of $\pi_1^{DI}(z)$ is the expected loan repayment bank 1 receives from an entrepreneur at z, because the entrepreneur repays bank 1 $r_1(z)$ with probability $m_1(z)$. To finance the loan to the entrepreneur, bank 1 must borrow one unit of funding from depositors and promise to pay back f. Moreover, bank 1 has to pay a premium to the DIF when the bank is solvent. The second term measures the sum of bank 1's expected payment to depositors and expected premium to the DIF. Because deposits are riskless, the sum of bank 1's and the DIF's payments to depositors is always f per unit of funding. Meanwhile, the expected premium received by the DIF should exactly equal the DIF's expected payment to depositors because the insurance is fairly priced. Therefore, the sum of bank 1's expected payment to depositors and expected premium to the DIF equals f when financing an entrepreneur at z. The third term represents bank 1's non-pecuniary monitoring costs.

The effects of fair deposit insurance. We note that $\pi_1^{DI}(z)$ is the same as $\pi_1(z)$ (see Equation 1), which means the presence of the fair deposit insurance does not affect banks' objective functions in the competition for entrepreneur z. Therefore, all propositions in Section 3 still hold here because they are based on the objective function $\pi_i(z)$, which is not affected by the deposit insurance.

However, the presence of deposit insurance indeed changes something. Because bank 1's (nominal) deposit rate is f instead of d_1 in the presence of the insurance, the default condition of bank 1 is no longer the same as (5). If entrepreneurs located in $[0, \tilde{x}]$ are served by bank 1 and if the economic condition is θ, then the aggregate loan repayment received by bank 1 is $\int_0^{\tilde{x}} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta\}} dz$. Meanwhile, bank 1 owes $f\int_0^{\tilde{x}} D(z)\, dz$ to depositors. Therefore, the following default condition must hold for bank 1:

$$\int_0^{\tilde{x}} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta^I\}} dz = f \int_0^{\tilde{x}} D(z)\, dz.$$

This condition reflects that the total loan repayment received by bank 1 exactly covers the bank's promised payoff to depositors when the economic condition is θ^I.

We use θ^{NI} to denote bank 1's probability of default in the case without deposit insurance. Then θ^{NI} is determined by

$$\int_0^{\tilde{x}} D(z)\, r_1(z) 1_{\{1-m_1(z)\leq\theta^{NI}\}} dz = d_1 \int_0^{\tilde{x}} D(z)\, dz.$$

It is clear that $d_1 > f$ holds if θ^{NI} is positive, so we have the following proposition that compares θ^{NI} and θ^I.

Proposition 15. *If $\theta^{NI} > 0$, then the presence of a fair deposit insurance decreases bank 1's probability of default.*

This proposition is quite intuitive. Because $\pi_1^{DI}(z)$ is the same as $\pi_1(z)$, the presence of a fair deposit insurance does not affect $\tilde{x}$, $r_1(z)$, $D(z)$ or $m_1(z)$. However, the deposit insurance decreases the payoff bank 1 promises to depositors. Meanwhile, bank 1's payment (also called premium) to the DIF does not affect the bank's solvency, because the premium is deducted only when the bank is solvent after paying depositors. Therefore, the deposit insurance makes bank 1 more stable.

Bank stability and social welfare. Because the presence of deposit insurance affects banks' probabilities of default, a natural question is whether or not our previous results about the influence of information technology on bank stability and social welfare are still robust. To answer the question, we conduct numerical analyses and find that our previous results (those in Sections 4 and 5) still hold in the presence of the fair deposit insurance (DI).

Figure 12 illustrates how information technology progress affects bank 1's stability (probability of default) when we hold the assumptions adopted in Section 3.1 (i.e., $R \geq \max\{\sqrt{\frac{8c_1 f}{1-q_1}}, \sqrt{\frac{8c_2 f}{1-q_2}}\}$). We can see that Figure 12 is quite consistent with Figure 4 that describes the case without fair deposit insurance. Letting $q_1 = q_2 = q$ and $c_1 = c_2 = c$, we can analyze how the development and diffusion of whole banking sector's information technology affects bank stability in the presence of the deposit insurance, and Figure 13 describes the result. Obviously, Figure 13 is highly consistent with Figure 5. In sum: our results in Section 4.1 are robust even if we consider the presence of a fair deposit insurance scheme.

Figure 14 shows how information technology progress affects bank 1's stability in the local monopoly equilibrium. We can see that Figure 14 is quite similar to Figure 6 that describes the case without deposit insurance. Figure 15 describes how bank stability will change as information technology progress alters the equilibrium type. We find that the Figure 15 is consistent with Figure 7 that describes the case without DI. Therefore, our results in Section 4.2 are robust even if we consider the presence of a fair deposit insurance scheme.

Figure 16 describes, when fair deposit insurance is present, how the progress of the banking sector's information technology affects social welfare in the equilibrium described in Section 3.1. We find that there is no prominent difference between Figure 16 and Figure 10 that describes the case without a deposit insurance. In the (local monopoly) equilibrium where banks do not compete with each other because R is not large while q

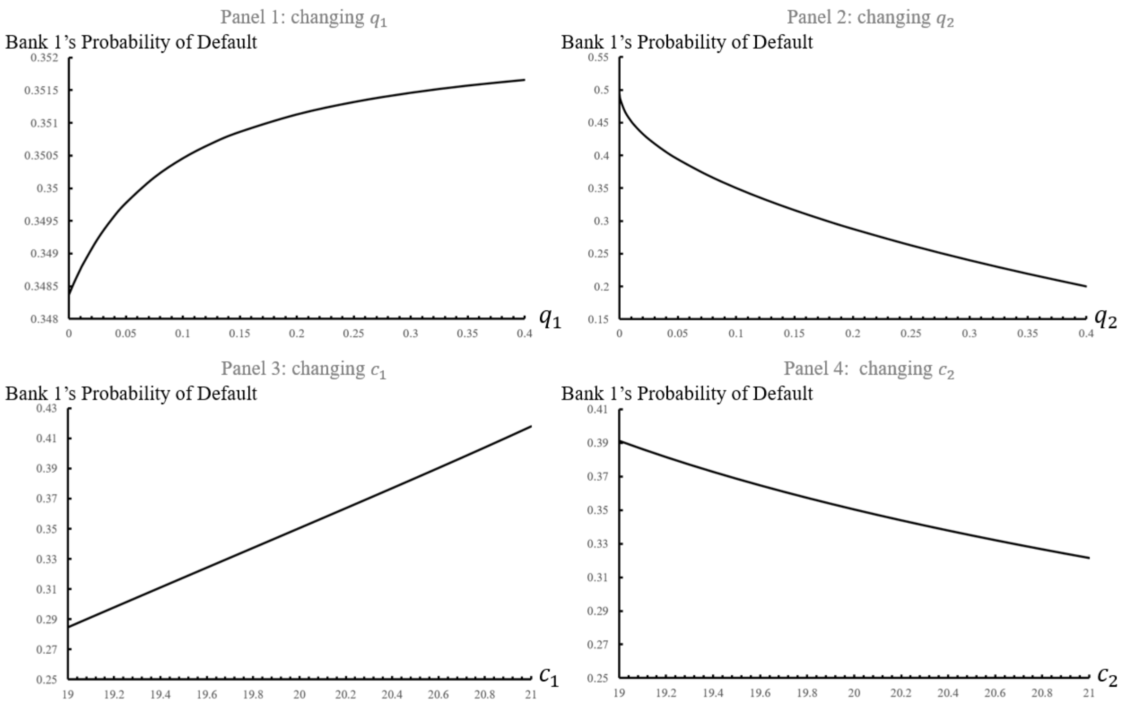

Figure 12: Bank 1's Probability of Default (w.r.t. q_i and c_i) with DI. This figure plots bank 1's probability of default against q_i and c_i in the presence of fairly priced deposit insurance (DI) in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c_1 = 20$, $c_2 = 20$, $q_1 = 0.1$, and $q_2 = 0.1$.

and/or c are large enough, Figure 17 illustrates how social welfare is affected by information technology in the presence of fair deposit insurance, and the result is consistent with that described in Figure 11. Overall, our results in Section 5 are robust after we consider the presence of a fair deposit insurance scheme.

Appendix D: Screening interpretation

Throughout the main text our model builds on the assumption that banks can increase projects' probability of success by monitoring their borrowers. However, a similar model can be built by assuming that banks can increase the quality of their loans by screening entrepreneurs. In this appendix, we provide the model set-up and main results of the screening-based model.

Entrepreneur. We assume that at each location (e.g. z) there is a potential mass N of penniless entrepreneurs. Each entrepreneur is endowed with a risky investment project that requires a unit of funding and yields R (resp. 0) in the event of success (resp. failure).

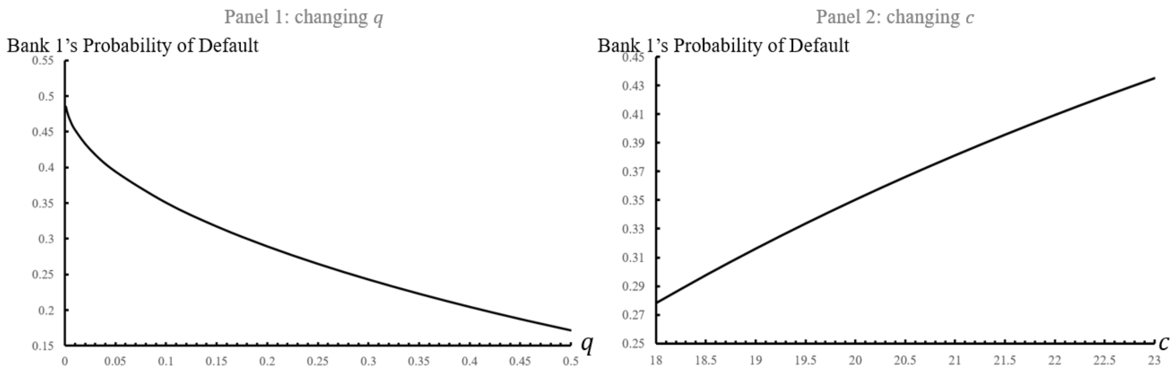

Figure 13: Bank 1's Probability of Default (w.r.t. q and c) with DI. This figure plots bank 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$ in the presence of fairly priced deposit insurance (DI) in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c = 20$, and $q = 0.1$.

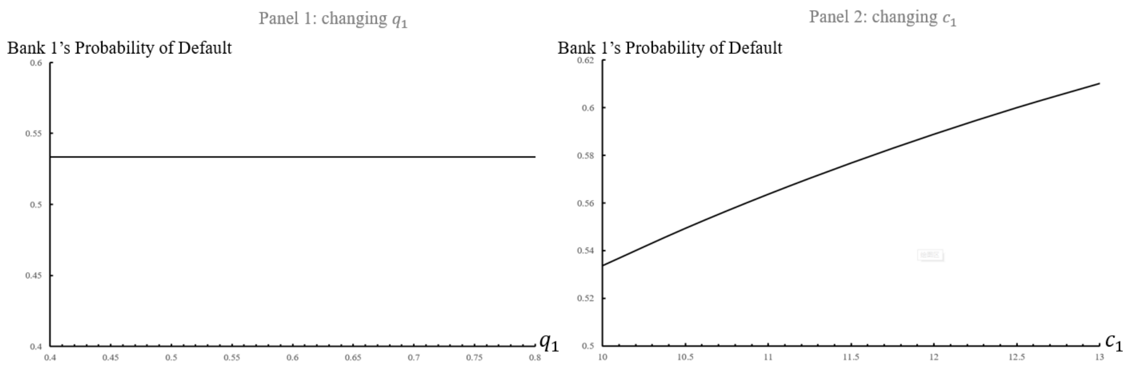

Figure 14: Bank 1's Probability of Default (w.r.t. q_1 and c_1) with DI. This figure plots bank 1's probability of default against q_1 and c_1 in the local monopoly equilibrium in the presence of fairly priced deposit insurance. Except when used an a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c_1 = 10$, and $q_1 = 0.4$.

Entrepreneurs are of two types: good (type G) and bad (type B). Projects of type G (resp. B) entrepreneurs succeed with probability $p_G > 0$ (resp. 0). An entrepreneur does not know her own type, but a bank can partially discover it by screening the entrepreneur if she applies for a loan from the bank.

Prior belief and bank screening. Banks and entrepreneurs have the same prior belief about the distribution of entrepreneurial types; the distribution is characterized by

$$prob.(type = G) = p.$$

We assume that $p \times p_G R < f$, so it is never profitable for a bank to finance an entrepreneur

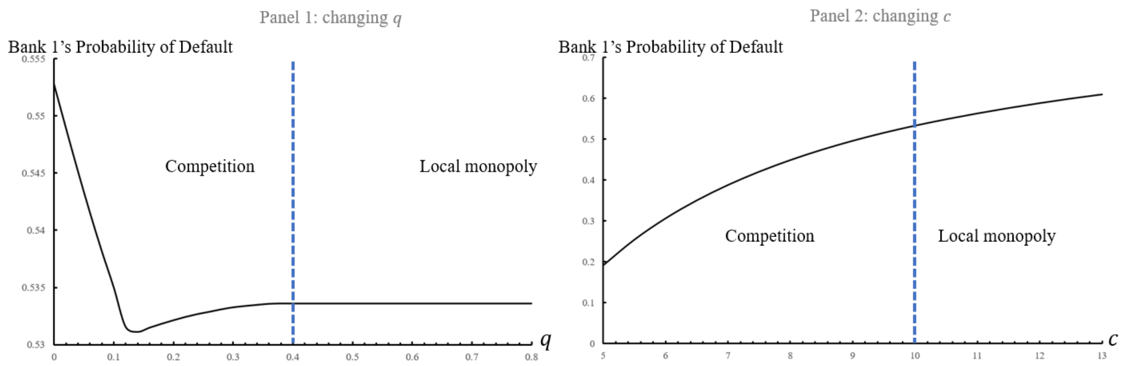

Figure 15: Bank 1's Probability of Default (w.r.t. q and c) with DI. This figure plots bank 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$ in the presence of fairly priced deposit insurance. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c = 10$, and $q = 0.4$.

simply based on the prior belief. However, if an entrepreneur applies for a loan from bank i, the bank can screen her and get a signal s that partially reveals the entrepreneur's type. The signal s of an entrepreneur is either "H" or "L" and satisfies:

$$prob.\,(s = H \mid type = G) = k + \frac{1-p}{p}\delta_i(z),$$

$$prob.\,(s = H \mid type = B) = k - \delta_i(z).$$

Here $k = prob.\,(s = H) \leq p$; The variable $\delta_i(z) \geq 0$ is determined by bank i's screening efforts.

Posterior belief. After receiving the signal of an entrepreneur, bank i will update its belief about her type based on Bayesian rules:

$$prob.\,(type = G \mid s = H) = \frac{\left(k + \frac{1-p}{p}\delta_i(z)\right)}{k} p \geq p,$$

$$prob.\,(type = G \mid s = L) = \frac{\left(1 - k - \frac{1-p}{p}\delta_i(z)\right)}{1-k} p \leq p.$$

Note that if $\delta_i(z) = 0$, then $prob.\,(type = G \mid s = H) = prob.\,(type = G \mid s = L) = p$, which means the signal is not informative; if $\delta_i(z) = k$, then $prob.\,(type = G \mid s = H) = 1$, which means the signal $s = H$ is fully revealing. Because $prob.\,(type = G \mid s = L) \leq p$, bank i will not finance an entrepreneur whose signal is L.

Screening cost and bank profit. Defining $m_i(z) \equiv \frac{pk+(1-p)\delta_i(z)}{k} p_G$, we can show

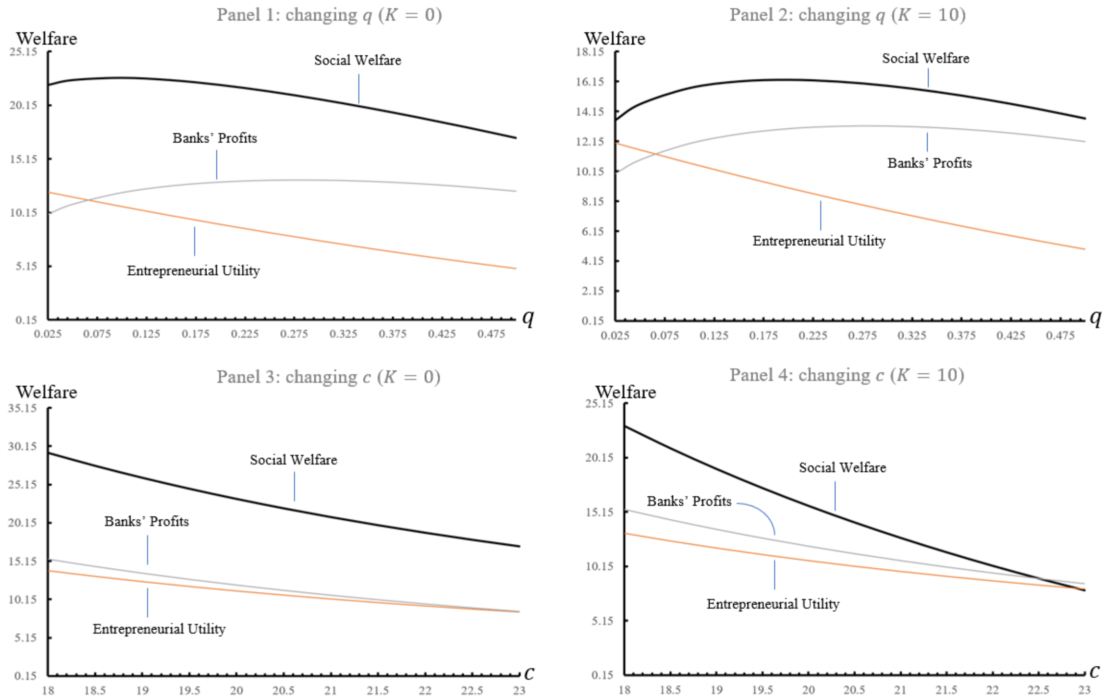

Figure 16: Social Welfare and Banking Sector's Information Technology with DI under Competition. This figure plots social welfare, entrepreneurial utility, and banks' profits against c and q in the equilibrium where banks compete directly with each other and there is fairly priced deposit insurance. The parameter values are: $R = 20$ and $f = 1$ in all panels; $c = 20$ in Panels 1 and 2; $q = 0.1$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 10$ in Panels 2 and 4.

that the project of an entrepreneur with signal $s = H$ succeeds with probability $m_i(z)$. We assume that bank i's (non-pecuniary) costs of screening an entrepreneur at z is:

$$C_i\left(m_i(z), z\right) = \frac{c_i}{2\left(1 - q_i s_i\right)} \left(m_i(z)\right)^2.$$

Here $s_i = z$ (resp. $s_i = 1 - z$) if $i = 1$ (resp. $i = 2$). We call $m_i(z)$ the "screening intensity" of bank i at z. If bank i is willing to serve location z, then the bank must be willing to finance entrepreneurs whose signal is $s = H$; hence its expected profit from screening a loan applicant at z is

$$\pi_i^{\text{screen}}(z) = k\left(r_i(z)\, m_i(z) - f\right) - \frac{c_i}{2\left(1 - q_i s_i\right)} \left(m_i(z)\right)^2,$$

where $r_i(z)$ is bank i's loan rate at z. The first term of $\pi_i^{\text{screen}}(z)$ represents bank i's expected payoff of screening a loan applicant. Note that k is the probability that an applicant's signal is H, and that $r_i(z)\, m_i(z) - f$ is the expected net payoff of financing

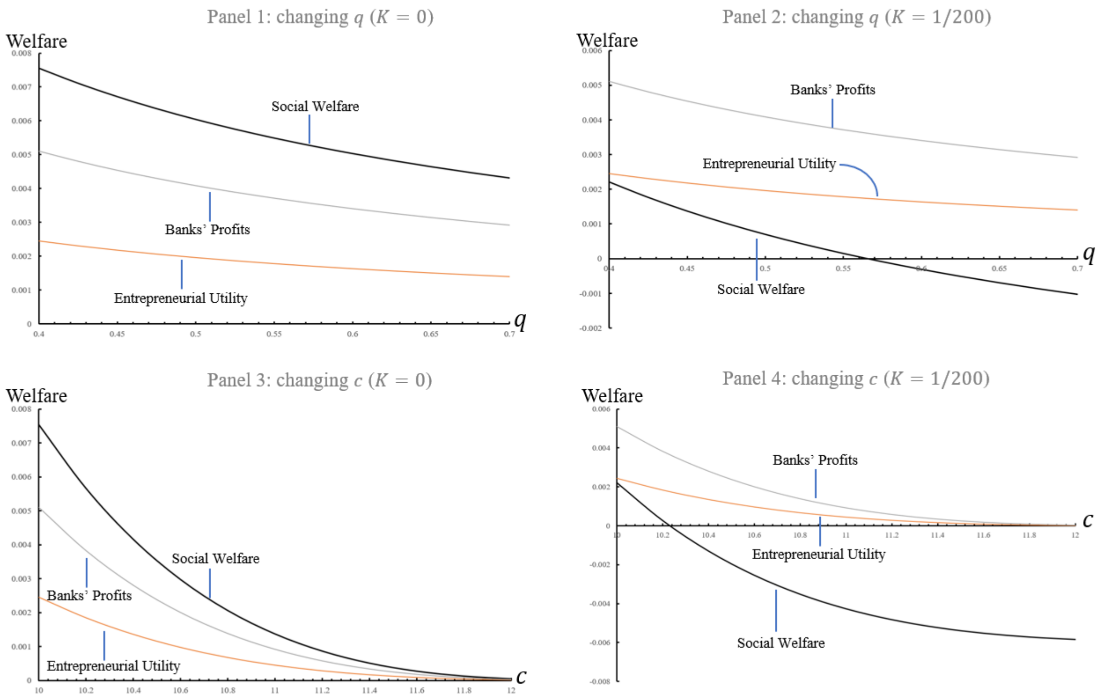

Figure 17: Social Welfare and Banking Sector's Information Technology with DI under Local Monopoly. This figure plots social welfare, entrepreneurial utility, and banks' profits against c and q in the local monopoly equilibrium with fairly priced deposit insurance. The parameter values are: $R = 5$ and $f = 1$ in all panels; $c = 10$ in Panels 1 and 2; $q = 0.4$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 1/200$ in Panels 2 and 4.

an entrepreneur with signal $s = H$ because the entrepreneur (with $s = H$) succeeds with probability $m_i(z)$ and the expected funding cost of financing her is f. The second term of $\pi_i^{\text{screen}}(z)$ is bank i's non-pecuniary screening costs.

Entrepreneurs' funding demand. We assume that location z is served by bank i. After observing bank i's loan rate $r_i(z)$ for location z, all entrepreneurs at z can expect the bank's optimal screening intensity $m_i(z)$ based on the payoff function $\pi_i^{\text{screen}}(z)$. If an entrepreneur successfully secure a loan from bank i, then she will know that her project succeeds with probability $m_i(z)$, and so the expected utility of implementing the project is $\pi^e(z) - \underline{u}$ for her; here $\pi^e(z) \equiv (R - r_i(z))m_i(z)$. For each entrepreneur at z , we assume that $\underline{u}$ is independently and uniformly distributed on $[0, M]$. Because an entrepreneur will undertake her project if and only if $\pi^e(z) \geq \underline{u}$, at location z the measure of entrepreneurs who apply for loans from bank i is

$$D(z) \equiv N \int_0^M \frac{1}{M} 1_{\{\pi^e(z) \geq \underline{u}\}} d\underline{u} = \frac{N}{M} \pi^e(z).$$

Assume that entrepreneurs' signals are independent. Then the mass of loan applicants who can successfully secure loans from bank i is $D(z)k = k\frac{N}{M}\pi^e(z)$ at z. Total entrepreneurial utility at z equals

$$kN\int_0^M \frac{1}{M}\left(\pi^e(z) - \underline{u}\right) 1_{\{\pi^e(z)\geq \underline{u}\}} d\underline{u} = \frac{kN}{M}\frac{\left(\pi^e(z)\right)^2}{2}.$$

If we let $\frac{kN}{M} = 1$, then at location z the total funding demand (after screening) is $\pi^e(z)$, and total entrepreneurial utility is $\frac{(\pi^e(z))^2}{2}$, which is consistent with the bank monitoring model.

Correlation among entrepreneurs' projects. In the screening model, the outcome of a type G entrepreneur's project is driven by an entrepreneur-specific risk factor ψ_j, which is defined as follows:

$$\psi_j \equiv \sqrt{\rho}\theta + \sqrt{1-\rho}\varepsilon_j, \rho \in [0,1]$$

Here both θ and ε_j are random variables that follow standard normal distributions. The random variable θ represents the common risk factor that is the same among all type G entrepreneurs, while ε_j is an idiosyncratic factor that is independent of θ and among entrepreneurs. Obviously, ψ_j also follows a standard normal distribution. We assume that the project of a type G entrepreneur fails if and only if the entrepreneur's risk factor ψ_j is lower than a threshold $\underline{\psi}$. Because a type G entrepreneur succeeds with probability p_G, $\underline{\psi}$ must satisfy the following equation:

$$prob.(\psi_j < \underline{\psi}) = 1 - p_G,$$

which implies

$$\underline{\psi} = \Phi^{-1}\left(1 - p_G\right).$$

Here $\Phi^{-1}(\cdot)$ is the inverse function of the cumulative density function (CDF) of a standard normal distribution.

Discriminatory loan pricing and timeline. As in the monitoring model, banks compete in a localized Bertrand fashion to extend loans. Bank i follows a discriminatory pricing policy in which the loan rate $r_i(z)$ varies with the entrepreneurial location z.

The timing of the lending game is as follows. First, banks post loan rate schedules simultaneously. Once the loan schedules are chosen and hence observable, entrepreneurs decide on whether to implement their projects and which bank to approach. Given entrepreneurs' decisions and banks' loan rates, bank i chooses its optimal screening intensity (viz., $m_i(z)$) for loan applicants at z. After screening, bank i provides funding to loan applicants with signal $s = H$. Finally, observing $m_i(z)$, depositors put their money into banks and are promised a nominal deposit rate d_i.

Equilibrium loan rates. Defining $c_{ki} \equiv \frac{c_i}{k}$ (and $c_k \equiv \frac{c}{k}$ when $c_1 = c_2 = c$), it is easy to show that bank i's expected profit from screening a loan applicant at z is

$$\pi_i^{\text{screen}}(z) = k\left(r_i(z)\, m_i(z) - f - \frac{c_{ki}}{2(1-q_i s_i)}(m_i(z))^2\right). \tag{11}$$

Note that Equation (11) is quite similar to Equation (1) except that π_i^{screen} is multiplied by k. Because the coefficient k of $\pi_i^{\text{screen}}(z)$ does not affect the optimization problem when the objective function is $\pi_i^{\text{screen}}(z)$, Propositions 1 to 4 hold in the screening-based model, with the only difference that c_i (or c) in those propositions are replaced by c_{ki} (or c_k).

Bank i's expected profit by serving location z is

$$\frac{Nk}{M}\pi^e(z)\left(r_i(z)\, m_i(z) - f - \frac{c_{ki}}{2(1-q_i s_i)}(m_i(z))^2\right).$$

Because the coefficient $\frac{Nk}{M}$ does not affect bank i's profit-maximization problem at z, the monopoly loan rate of bank i at z is still characterized by Lemma 3 with c_i replaced by c_{ki}. As a result, Propositions 5 and 6 hold in the screening model (with c_i replaced by c_{ki}).

Social Welfare. If location z is served by bank i and if locations $\{z : z \in \Omega\}$ are served, then social welfare (with $q_1 = q_2 = q$ and $c_1 = c_2 = c$) in the screening model is given by

$$\underbrace{\int_\Omega D(z)kRm_i(z)dz}_{\text{Social benefit}} - \underbrace{\left(\begin{array}{c} \int_\Omega D(z)kf\,dz + \int_\Omega \frac{D(z)c}{2(1-qs_i)}\left(m_i(z)\right)^2 dz \\ + \int_\Omega Nk\int_0^M \frac{1}{M}\underline{u}1_{\{\pi^e(z)\geq \underline{u}\}}d\underline{u}dz + (\theta_1^* + \theta_2^*)\,K \end{array}\right)}_{\text{Social costs}}.$$

Here $r_i(z)$ (resp. $m_i(z)$) is bank i's loan rate (resp. screening intensity) for entrepreneurs at z, $D(z)k$ is the total funding demand (after screening) at z, s_i is the distance between bank i and location z , θ_i^* is the probability that bank i goes bankrupt, and K is the deadweight loss (i.e., bankruptcy costs) associated with a bank's failure.

Recall that $D(z) = \frac{N}{M}\pi^e(z)$, so we can rewrite social welfare, which is denoted by

W^{screen}, as follows:

$$W^{\text{screen}} = \frac{kN}{M}\left(\begin{array}{c} \int_{\Omega} \frac{(\pi^e(z))^2}{2} dz + \int_{\Omega} \pi^e(z) \left(r_i\left(z\right) m_i(z) dz - f - \frac{c_k(m_i(z))^2}{2(1-qs_i)} \right) dz \\ -\left(\theta_1^* + \theta_2^*\right) K' \end{array}\right),$$

where $K' \equiv \frac{M}{kN} K$. Note that W^{screen} is consistent with W (Equation 7) except that W^{screen} is multiplied by a coefficient $\frac{kN}{M}$. Because the coefficient $\frac{kN}{M}$ does not affect a social planner's optimization problem, Propositions 8 to 11 hold in the screening model.

Bank stability. For a given common factor θ, the project of a type G entrepreneur fails if and only if

$$\psi_j < \underline{\psi} \Leftrightarrow \varepsilon_j < \frac{\underline{\psi} - \sqrt{\rho}\theta}{\sqrt{1-\rho}},$$

which happens with probability

$$\Phi\left(\frac{\underline{\psi} - \sqrt{\rho}\theta}{\sqrt{1-\rho}}\right).$$

If entrepreneurs located within $[0, \tilde{x}]$ are served by bank 1, if total funding demand (after screening) at $z \in [0, \tilde{x}]$ is $D(z)k$, and if the loan rate (resp. screening intensity) of bank 1 is $r_1\left(z\right)$ (resp. $m_1(z)$) for entrepreneurs at $z \in [0, \tilde{x}]$, then the measure of type G entrepreneurs who successfully secure funding from bank 1 at z is equal to

$$prob.\left(type = G \mid s = H\right) D(z)k = D(z)k\frac{m_1(z)}{p_G}.$$

As a result, the loan repayment bank 1 can receive at z is $r_1\left(z\right) D(z)k\frac{m_1(z)}{p_G}\left(1 - \Phi\left(\frac{\underline{\psi} - \sqrt{\rho}\theta}{\sqrt{1-\rho}}\right)\right)$ when the common factor equals θ; the aggregate loan repayment (ALP) from location 0 to $\tilde{x}$ is

$$ALP\left(\theta\right) = \int_0^{\tilde{x}} r_1\left(z\right) D(z)k\frac{m_1(z)}{p_G}\left(1 - \Phi\left(\frac{\underline{\psi} - \sqrt{\rho}\theta}{\sqrt{1-\rho}}\right)\right) dz.$$

It is clear that $ALP\left(\theta\right)$ is increasing in θ and that $\lim_{\theta\to-\infty} ALP\left(\theta\right) = 0$. So bank 1 defaults if and only if θ is lower than a threshold θ^*.

The threshold θ^* is determined by two conditions. First, if $\theta = \theta^*$, then $ALP\left(\theta\right)$ exactly covers bank 1's promised payment to depositors:

$$ALP\left(\theta^*\right) = d_1 \int_0^{\tilde{x}} D(z)kdz. \tag{12}$$

Second, bank 1's expected payment to depositors equals the minimum total expected payoff required by depositors:

$$\int_{-\infty}^{\theta^*} \phi(\theta) ALP(\theta) d\theta + (1 - \Phi(\theta^*)) d_1 \int_0^{\tilde{x}} D(z) kdz = f \int_0^{\tilde{x}} D(z) kdz. \tag{13}$$

Here $\phi(\theta) = \frac{1}{\sqrt{2\pi}} e^{-\frac{\theta^2}{2}}$ is the probability density function (PDF) of a standard normal distribution, and $(1 - \Phi(\theta^*))$ is the probability that bank 1 can fully repay depositors (i.e., $prob.(\theta \geq \theta^*)$). Combining (12) and (13), we can remove d_1 and get the following equation that determines θ^*:

$$\int_{-\infty}^{\theta^*} \phi(\theta) ALP(\theta) d\theta + (1 - \Phi(\theta^*)) ALP(\theta^*) - f \int_0^{\tilde{x}} D(z) kdz = 0. \tag{14}$$

Bank 1 defaults if and only if $\theta < \theta^*$, which happens with probability $\Phi(\theta^*)$. With Equation (14), we can show that θ^* is independent of q_1 in the local monopoly equilibrium (see the proof of Proposition 7 for the method), so Proposition 7 is robust in the screening model.

Numerical study. Now we use numerical methods to analyze how the development and diffusion of information technology affect bank stability and social welfare in the screening-based model. We focus on the interesting case $0 < \rho < 1$ so that bank stability will be affected by information technology. If $\rho = 1$, then all type G entrepreneurs succeed (or fail) together, and so bank i will default with probability $1 - p_G$, which is not affected by information technology. If $\rho = 0$, then the aggregate loan repayment is riskless for bank i, so the bank never goes bankrupt.

Note that Figures 18 to 21 are quite similar to Figures 4 to 7. Therefore, the effects of information technology progress on bank stability does not change qualitatively as we move from the monitoring-based model to the screening-based model. In regard to welfare analysis, we can see that Figures 22 and 23 are quite similar to Figures 10 and 11; this means that the effects of information technology progress on social welfare do not change qualitatively as we move from the monitoring-based model to the screening-based model.

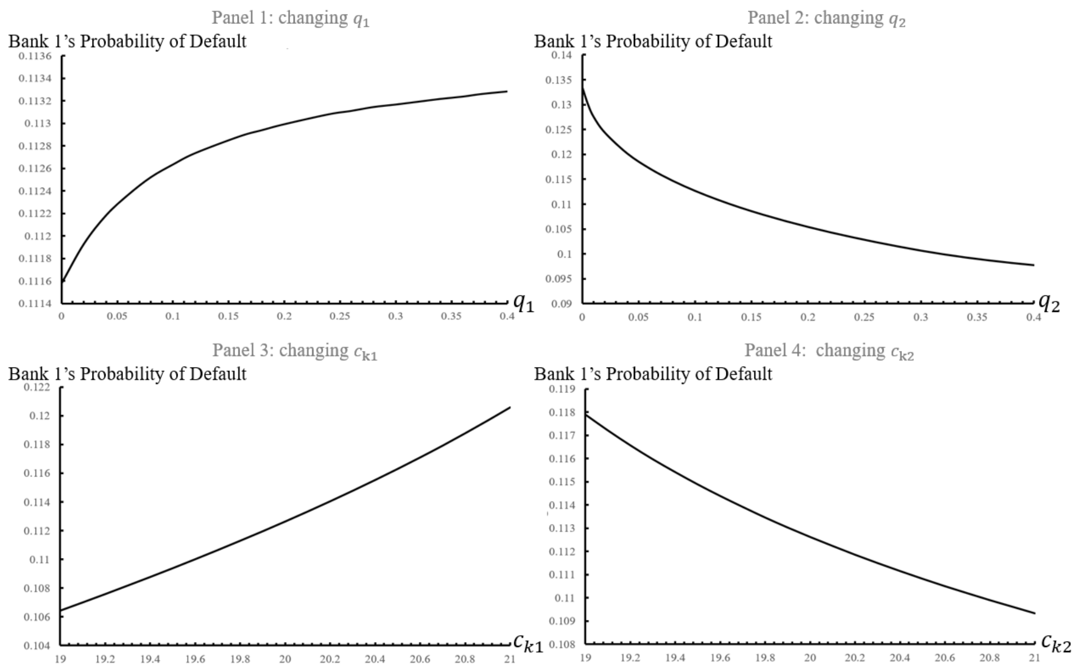

Figure 18: Bank 1's Probability of Default (w.r.t. q_i and c_{ki}). This figure plots bank 1's probability of default against q_i and c_{ki} in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c_{k1} = 20$, $c_{k2} = 20$, $q_1 = 0.1$, $q_2 = 0.1$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$.

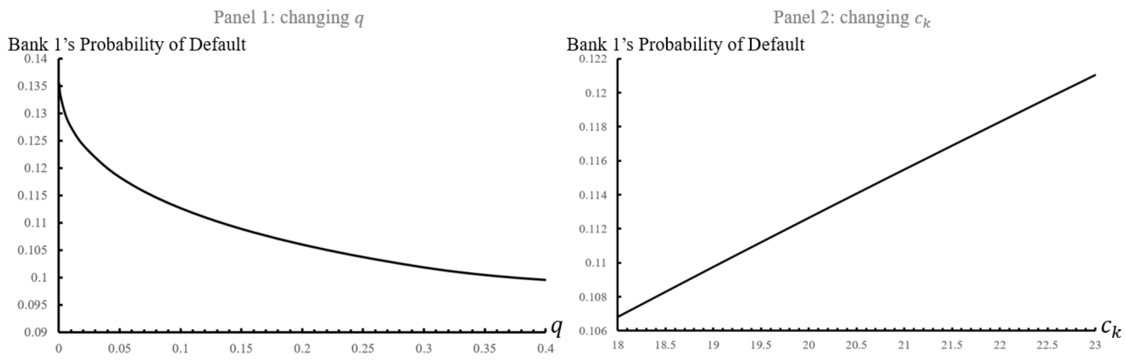

Figure 19: Bank 1's Probability of Default (w.r.t. q and c_k) under Competition. This figure plots bank 1's probability of default against q and c_k with the restriction that $q_1 = q_2 = q$ and $c_{k1} = c_{k2} = c_k$ in the equilibrium under direct bank competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c_k = 20$, $q = 0.1$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$.

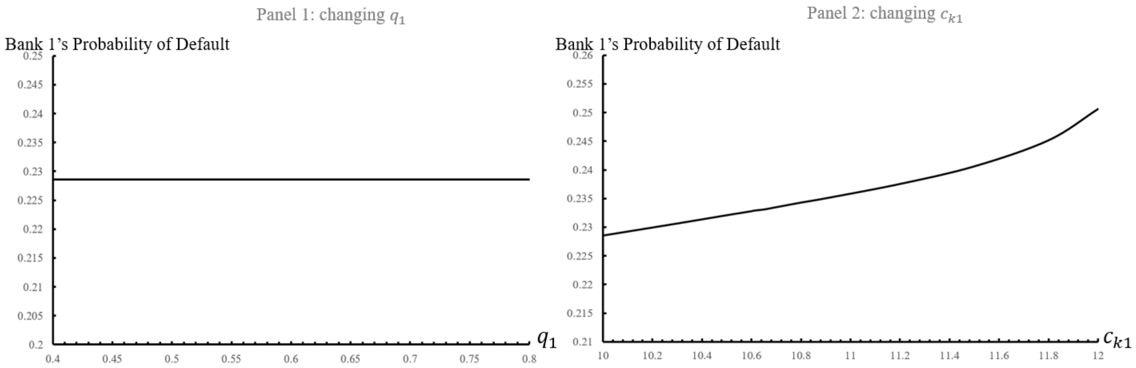

Figure 20: Bank 1's Probability of Default (w.r.t. q_1 and c_{k1}) under Local Monopoly. This figure plots bank 1's probability of default against q_1 and c_{k1} in the local monopoly equilibrium. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c_{k1} = 10$, $q_1 = 0.4$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$.

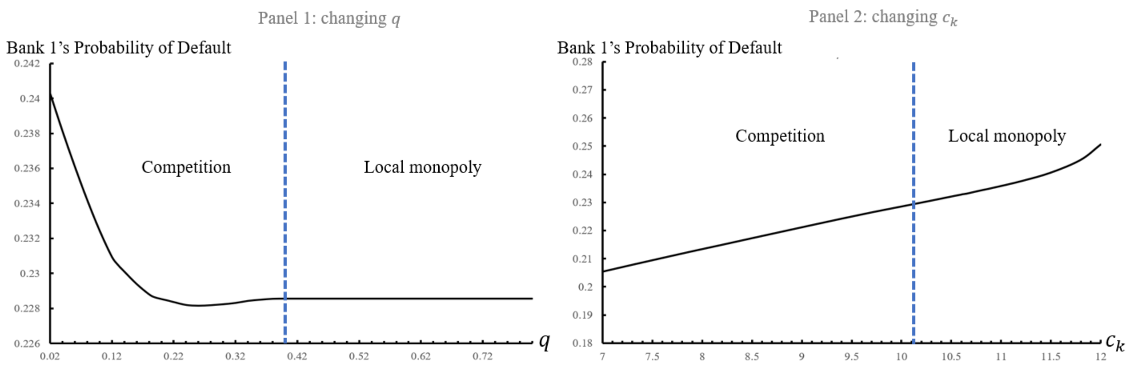

Figure 21: Bank 1's Probability of Default (w.r.t. q and c_k). This figure plots bank 1's probability of default against q and c_k with the restriction that $q_1 = q_2 = q$ and $c_{k1} = c_{k2} = c_k$. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c_k = 10$, $q = 0.4$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$.

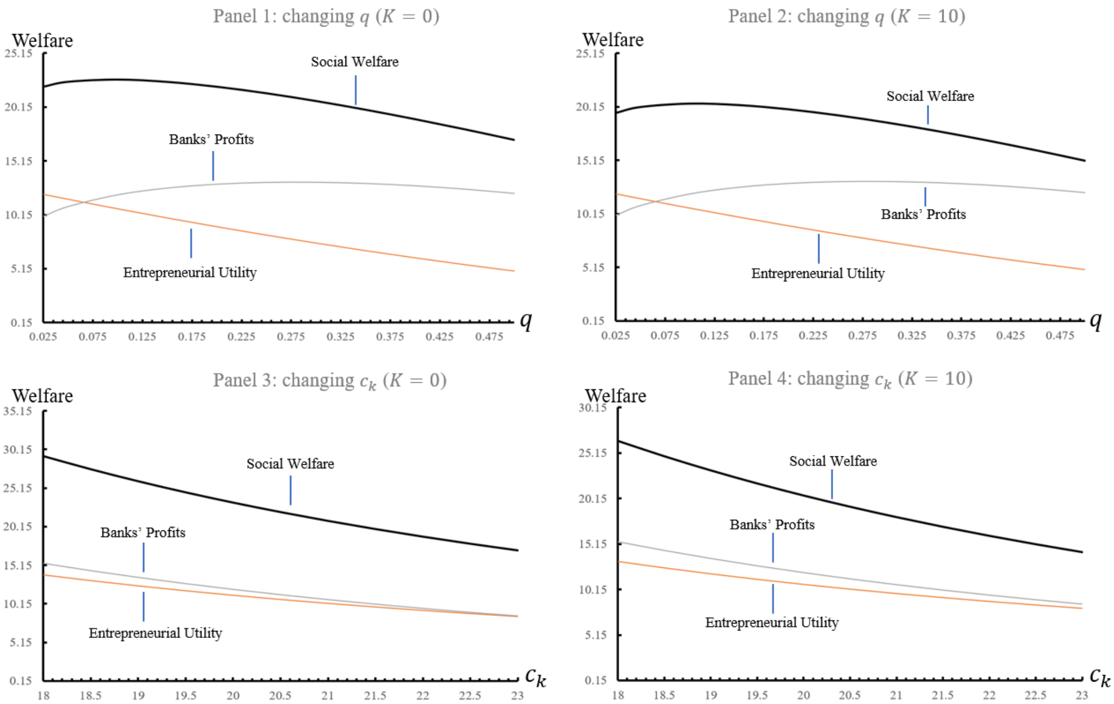

Figure 22: Social Welfare and Banking Sector's Information Technology under Competition. This figure plots social welfare, entrepreneurial utility, and banks' profits against q and c_k in the equilibrium under direct bank competition. The parameter values are: $R = 20$, $f = 1$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$ in all panels; $c_k = 20$ in Panels 1 and 2; $q = 0.1$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 10$ in Panels 2 and 4.

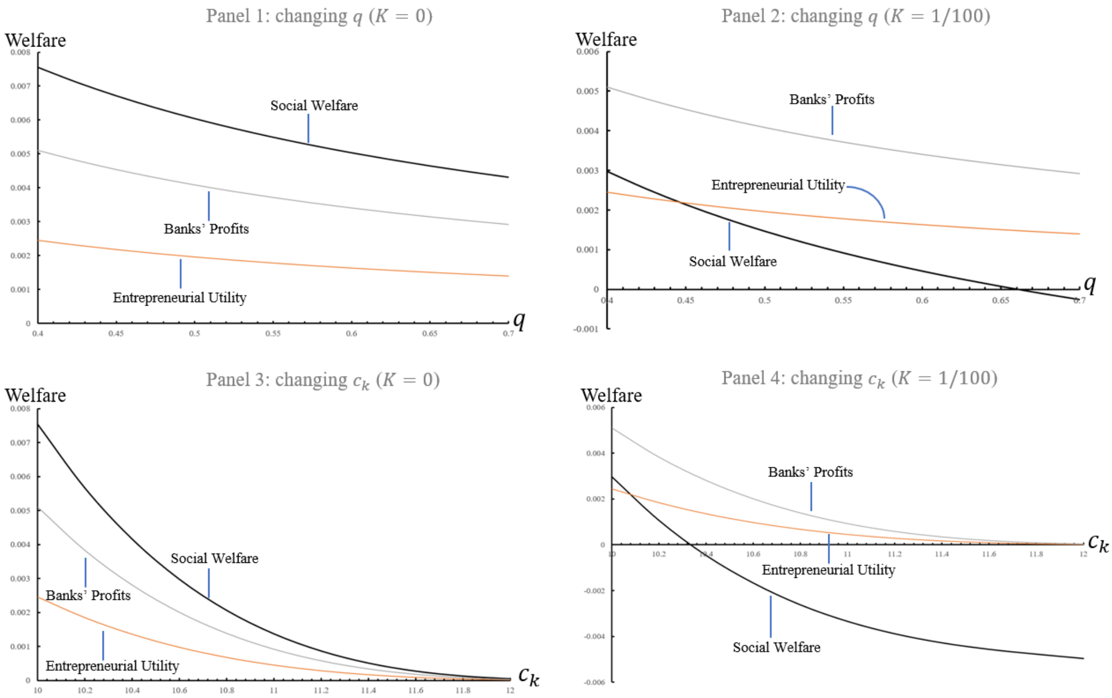

Figure 23: Social Welfare and Banking Sector's Information Technology under Local Monopoly. This figure plots social welfare, entrepreneurial utility, and banks' profits against q and c_k in the local monopoly equilibrium. The parameter values are: $R = 5$, $f = 1$, $p_G = 0.7$, $\rho = 0.8$, and $kN/M = 1$ in all panels; $c_k = 10$ in Panels 1 and 2; $q = 0.4$ in Panels 3 and 4; $K = 0$ in Panels 1 and 3; and $K = 1/100$ in Panels 2 and 4.