Information Technology and Lender Competition*

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Abstract

We study how information technology (IT) affects competition and stability of lenders, investment, and welfare in a spatial model. While an IT improvement spurs entrepreneurs' investment, other effects depend on whether the IT weakens the influence of lender–borrower distance on monitoring costs. If so, lending competition intensifies, which can reduce the profitability and stability of lenders and social welfare. Otherwise, competition intensity does not vary, bringing positive effects for lenders and welfare. IT investments of a bank and a fintech tend to be strategic complements. Lenders will invest excessively in IT, eliminating differentiation, if it is cheap enough. If not, the different types of IT investment co-move in response to shocks. Our results are consistent with received empirical work on lending to SMEs.

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1 Introduction

The banking industry is undergoing a digital revolution. A growing number of financial technology (FinTech) companies and BigTech platforms engage in traditional banking businesses using their innovative information and automation technologies.[1] Traditional banks are also moving from reliance on physical branches to adopting information technology (IT) and Big Data in response to the availability of technology and to changes in consumer expectations of service, which are two main drivers of digital disruption (FSB, 2019). Such a transformation spurs the banking sector's increasing investment in IT, which allows financial intermediaries to offer personalized services and to price discriminate. The COVID-19 pandemic has accelerated this digitalization process and fostered remote loan operations and the development and diffusion of IT in the credit market (Carletti et al., 2020).

How do the development and diffusion of information technology affect lending competition? How do lenders determine their IT investment? Are they more or rather less stable as IT develops? What are the welfare implications of IT progress? To answer those questions, we build a model of spatial competition in which lenders compete to provide entrepreneurs with loans. Lenders in our model refer to institutions that can provide loans in the credit market, including commercial banks, shadow banks, fintechs or bigtech platforms. In particular, our model will help to illuminate the following empirical results:

- Small business lending by banks with better IT adoption is less affected by the distance between the banks and their borrowers (Ahnert et al., 2022).
- Borrowers with better access to bank financing request loans at lower interest rates on a fintech platform (Butler et al., 2017). A bank will charge its borrowers higher loan rates if the borrowers get geographically closer to the bank or/and farther away from competing banks (Herpfer et al., 2022).
- Increased bank/branch industry specialization (e.g., in export/SME) lending curtails bank competition (Paravisini et al., 2023; Duquerroy et al., 2022).

[1] 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, almost one third of small and medium firms that sought financing applied with a FinTech firm or online lender, up from 19% in 2016 (US Federal Reserve's Small Business Credit Survey 2019). The annual growth rate of FinTech business lending volume in the US was over 40% from 2016 to 2020 (Berg et al., 2022). See also Vives (2019).

- Banks with superior IT adoption have higher loan growth (Dadoukis et al., 2021 and Branzoli et al., 2021). Entrepreneurship (proxied by job creation by young enterprises) is stronger in US counties that are more exposed to IT-intensive banks (Ahnert et al., 2022). Development of fintech lending can improve financial inclusion by helping unbanked customers gain access to finance (Jagtiani and Lemieux, 2018).

- Banks with higher pre-crisis IT adoption had fewer non-performing loans during the crisis (Pierri and Timmer, 2022).

The lending market is modeled as a linear city à la Hotelling (1929) where two lenders, located at the two extremes of the city, compete for entrepreneurs who are distributed along the segment. Entrepreneurs can undertake risky investment projects, which may either succeed or fail, but have no initial capital; hence they require funding from lenders. Lenders have no direct access to investment projects and compete in a Bertrand fashion by simultaneously posting their discriminatory loan rate schedules. We take as given that IT is advanced enough so that lenders can price flexibly. In addition to financing entrepreneurs, another critical lender function is monitoring entrepreneurs in order to increase the probability of their projects' success (see e.g. Martinez-Miera and Repullo, 2019). Monitoring is more costly for a lender if there is more distance between the lender and the monitored entrepreneur. This distance can be physical[2] or in characteristics space from the expertise of the lender on certain sectors or industries.[3]

In the model we distinguish two types of information technology: (a) information collection/processing technology (IT-basic for short) and (b) distance friction-reducing technology (IT-distance for short). Improvements of the two types of IT generate different outcomes. Specifically, an improvement in IT-basic lowers *evenly* the costs of monitoring entrepreneurs in different locations. Such an improvement in the lending sector does not affect lenders' relative cost advantage in different locations – for example, by making improvements in the ability to collect more valuable data and process them with better computer hardware or information management software (e.g. desktop applications). In contrast, an improvement in IT-distance reduces the negative effect of lender–borrower distance on monitoring costs. Such an improvement lowers more significantly the costs of

[2]There is evidence that firm–lender *physical* distance matters for lending. See Degryse and Ongena (2005), Petersen and Rajan (2002) and Brevoort and Wolken (2009).

[3]Blickle et al. (2021) find that a bank "specializes" by concentrating its lending disproportionately on one industry about which the bank has better knowledge. Paravisini et al. (2023) document that exporters to a given country are more likely to be financed by a bank that has better expertise in the country. Duquerroy et al. (2022) find that in local markets there exist specialized bank branches that concentrate their SME lending on certain industries.

monitoring entrepreneurs located farther. For example, better internet connectivity and communication technology (e.g. video conferencing) reduce the physical distance friction. The improvement in remote learning devices, search engines and artificial intelligence (AI) makes it easier to extend expertise, thereby reducing the expertise distance friction. Big Data and machine learning techniques may improve both IT-basic and IT-distance.[4]

We assume that lenders (say banks or fintechs) have no own capital to finance loans, so they must attract funds (say deposits or short-term debt) from risk-neutral investors. For simplicity, we do not model how lenders compete to develop relationships with investors or depositors, which we admit as a limitation.[5]

Under the set-up just described, we study how information technology affects lender competition and obtain results consistent with the available empirical evidence. The equilibrium consequences of improvements in the two types of technology (IT-basic v.s. IT-distance) are compared. We find that by adopting more advanced IT, whatever its type, a lender can charge higher loan rates and have a lower probability of being insolvent. This is so since a lender's IT progress increases its competitive advantage over the rival.

When two competing lenders each makes technological progress, that progress will not increase the overall competitive advantage of either lender. In this case, different types of IT progress can yield different results. If IT progress involves a reduction in the costs of monitoring an entrepreneur without altering lenders' relative cost advantage (i.e., IT-basic improves), then lenders' competition intensity will not be affected. In this case, the loan rates that lenders offer to entrepreneurs do not vary; lenders become more profitable and have higher monitoring incentives because monitoring is now cheaper. However, if IT progress involves a weakening in the influence of lender–borrower distance on monitoring costs (i.e., IT-distance improves), lenders' competition intensity will increase because it will reduce lenders' differentiation. Then the loan rates offered to entrepreneurs decline for both lenders. Such a differentiation-reducing effect, when strong enough, will decrease lenders' profits despite the fact that IT progress makes monitoring cheaper. Moreover, the decrease in lenders' loan rates lowers their skin in the lending game and hence can reduce their monitoring incentives. Both types of IT progress make entrepreneurs better

[4]There are many companies (e.g., Zestfinance, Scienaptic systems, Datarobot, Underwrite.ai) that help the financial industry improve information processing via Big Data and machine learning techniques, thus transforming soft data into hard data. See also Boot et al. (2021).

[5]Drechsler et al. (2021) emphasize the importance of the deposit franchise for banks to increase their market power over retail deposits, allowing them to borrow at rates that are low and insensitive to market interest rates. Matutes and Vives (1996) and Cordella and Yeyati (2002) study bank competition for deposits within a similar spatial competition framework but in their models banks can directly invest in risky assets.

off and hence spur more entrepreneurs to undertake investment projects.

The two types of IT have different effects on lender stability, which in our paper is measured by a lender's probability of being solvent. The progress of IT-basic increases lender stability because it makes monitoring cheaper without reducing lenders' differentiation and monitoring incentives. In contrast, the progress of IT-distance will decrease lender stability when the differentiation-reducing effect is strong enough because of three reasons. First, the differentiation-reducing effect decreases lenders' loan rates, so an entrepreneur repays less to its lender in the event of project success. Second, lenders' lower monitoring effort (induced by the decrease in their skin in the game) makes entrepreneurs more likely to fail. Finally, the funding providers of lenders, knowing that entrepreneurs' expected repayment becomes lower, will require lenders to promise a higher nominal return, which further increases the difficulty for lenders to stay solvent.

When lenders endogenously determine their levels of IT, the equilibrium results depend on the cost of acquiring IT. If IT is cheap enough, then both lenders will acquire the best possible IT (i.e., improve both IT-basic and IT-distance to the highest level) in their quest to compete for the market, which eliminates lender differentiation and hence induces extremely intense lender competition. If IT is not so cheap, then the two types of IT co-move in an interior symmetric equilibrium in response to IT cost shocks; that is, a decrease in the cost of acquiring one type of IT will increase lenders' investment in both types of IT. Furthermore, we find that a fintech's IT investment tends to be a strategic complement of the IT investment of a bank with superior IT-basic (e.g., with better access to firm data).

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 and hence spurs their investment. Yet "too much" competition can reduce social welfare because high competition intensity will decrease lenders' incentive to monitor entrepreneurs, which in turn will render those projects less likely to succeed. So an improvement in lenders' IT-distance may or may not benefit social welfare owing to the consequent increased lender competition (caused by the decrease in lender differentiation). In fact, if information technology is cheap, lenders are trapped in a prisoner's dilemma and choose a very low level of differentiation, excessive from the social point of view. In contrast, an improvement in lenders' IT-basic brings no differentiation effect and hence improves welfare. The welfare-improving outcome arises also if, in equilibrium, lenders do not compete with each other; in that case the only effect of IT progress (whatever its type) is to make monitoring cheaper, which allows lenders to extend the market and hence improves financial inclusion.

Our baseline model assumes that funding providers of a lender can observe the lender's monitoring effort (which determines its risk position). Our results hold also if those funding providers (e.g., depositors) are protected by a fairly priced insurance scheme (e.g., deposit insurance) and do *not* observe the lender's monitoring levels. The reason is that lender risk is priced fairly in both cases and so lenders' payoff functions are the same.

Related literature. Our work builds on the spatial competition models of Hotelling (1929) and Thisse and Vives (1988), but focuses on lenders' competition to finance entrepreneurs' projects. Villas-Boas and Schmidt-Mohr (1999) build a spatial lending competition model in which banks offer menus of contracts with different collateral levels to sort borrowers of different qualities. Their focus is on how competition affects the collateral requirements of contracts, while ours is on how IT affects lender competition. Almazan (2002) studies how lender capitalization, interest rates, and regulatory shocks can affect lender competition and monitoring efficiency in a spatial competition model where a lender's monitoring expertise decreases with lender–borrower distance. In Almazan's model, the only difference between lenders is the levels of their capital; lenders cannot strategically choose loan rates because loan contracts are offered by entrepreneurs, who have all bargaining power vis-a-vis lenders. In our work, lenders differ in their IT, and the strategic pricing of lenders is based on their competitive advantage – which is affected by information technology. Several papers have emphasized the importance of monitoring in lending.[6] Martinez-Miera and Repullo (2019) examine the effectiveness of monetary and macroprudential policies in addressing a financial system's risks within a framework where lender monitoring can increase the probability that investing in an entrepreneur yields a positive return; this is similar to our set-up. However, our focus is on how information technology affects lender monitoring, which in turn affects lender competition, stability, and social welfare. Our work is also related to the extensive literature that explores the connection between lender competition and lender stability (for a survey, see Vives, 2016).

Our study also belongs to the literature that studies information technology and lending competition. Hauswald and Marquez (2003) in an adverse selection model find that

[6]See, e.g., Diamond (1984) and Holmstrom and Tirole (1997) for pioneering work.

improving an informed lender's ability to process information strengthens the "winner's curse" faced by an uninformed lender, decreases the intensity of lender competition, and increases the loan rate that borrowers are expected to pay. Hauswald and Marquez (2006) extend that model by allowing (a) endogenous investment by lenders in information processing technology and (b) lender–borrower distance to have a negative effect on the precision of lenders' information. Similarly to our work, these authors find that the equilibrium loan rates received by borrowers are decreasing in lender-borrower distance and in the intensity of lender competition (measured by the number of lenders). However, the mechanism behind our results differs since there is no scope for a winners' curse in our model.

Our results differ from the models of Hauswald and Marquez where an improvement in the entire lending sector's IT will soften lender competition; lenders' IT investment is decreasing in the intensity of lender competition; and social welfare is increasing in the intensity of lender competition if competition is already very intense. In contrast, we find that lender competition is either intensified or unaffected by the lending sector's IT improvement, depending on the type of the improved IT; lenders may have extremely strong incentive to invest in IT even if lender competition is highly intense, in which case lenders are trapped in a prisoner's dilemma; and social welfare is decreasing in the intensity of lender competition if competition is very intense. In addition, our work analyzes the interplay of different types of IT and the strategic relation between different lenders' IT investment.

In a model where a traditional bank and a fintech lender compete to extend loans, He et al. (2023) analyze the effects of "open banking" – an information sharing mechanism that enables borrowers to share their customer data stored in a bank with a fintech that has advanced information processing technology but less access to customer data. They find that open banking increases the fintech's screening ability and competitiveness, but that it can soften lending competition and hurt borrowers if the fintech is "overempowered" by the data sharing mechanism. Our work has a different focus: we distinguish two types of information technology and compare their different equilibrium consequences. Moreover, in He et al. (2023) the improvement of the fintech's screening efficiency – which potentially brings adverse welfare effects – is driven by the presence of an exogenous open banking policy, while in our model socially undesirable IT improvement can arise from lenders' endogenous technology investment.

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.[7] 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., 2023; Netzer et al., 2019), contract terms (Kawai et al., 2022; Hertzberg et al., 2018), mobile phone call records (Björkegren and Grissen, 2020), digital footprints (Agarwal et al., 2021; Berg et al., 2020), and cashless payment information (Ghosh et al., 2022; Ouyang, 2022) – 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 assessment based on Big Data (e.g., platform transactions and the reputation of sellers) and processed with machine learning techniques has outperformed credit bureau ratings in terms of predicting the loss rates of small businesses.[8]

Several papers provide evidence consistent with our results. Branzoli et al. (2021) and Dadoukis et al. (2021) find that banks with higher IT adoption have larger loan growth; this is consistent with our finding that an improvement of a lender's IT increases the loan volume the lender can extend. Jagtiani and Lemieux (2018) find that fintech lenders, with better IT and no reliance on branches, can extend loans to remote unbanked areas, thereby improving financial inclusion. Ahnert et al. (2022) document that small business lending by banks with higher IT adoption is less affected by the distance between the bank headquarters and their borrowers. Our model is in line with the findings since we show that a lender's geographic reach will be extended if the lender adopts better information technology. Ahnert et al. (2022) also find that job creation by young enterprises, a proxy for entrepreneurship, is stronger in US counties that are more exposed to IT-intensive banks; consistent with this finding, our model shows that an improvement in the lending sector's IT will encourage more entrepreneurs to undertake investment projects. Pierri and Timmer (2022) 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 lender will become more stable as its IT progresses.

[7]Philippon (2016) claims that the existing financial system's inefficiency can explain the emergence of new entrants that bring novel technology to the sector. Gopal and Schnabl (2022) show that most of the increase in fintech lending to SMEs after 2008 financial crisis substituted for a reduction in lending by banks.

[8]Furthermore, Fuster et al. (2019) estimate that technology-based lenders process mortgage applications 20% faster than do traditional banks yet without incurring greater default risk. Buchak et al. (2018) find that lenders with advanced technology can offer more convenient services to borrowers and hence charge higher loan rates in the US mortgage market than do traditional banks.

The Paycheck Protection Program (PPP) launched by the US Small Business Administration (SBA) also highlights the importance of technology. Erel and Liebersohn (2021) find that fintech lenders extend PPP loans to small businesses that are poorly served by the banking system (e.g., ZIP codes with fewer bank branches and lower incomes or industries with little ex ante small business lending).[9] Kwan et al. (2022) show that banks with better IT originate more PPP loans – especially in areas with more severe COVID-19 outbreaks, higher levels of Internet use, and more intense bank competition. Griffin et al. (2023) find that PPP loans distributed by fintechs have a substantially higher incidence of suspicious features than loans from traditional banks, suggesting that fintechs facilitate fraudulent credit. However, we will refrain from explaining those results within our framework, because PPP loans - when properly used by borrowers - are forgivable and carry a uniform loan rate of 1%, which diminishes drastically the space for lenders' monitoring and strategic pricing.[10]

The rest of our paper proceeds as follows. Section 2 presents the model set-up. In Section 3, we examine the lending market equilibrium with given information technology. Section 4 studies how lenders endogenously determine their IT investment. In Section 5, we analyze how information technology affects lender stability, and Section 6 provides a welfare analysis of information technology progress. We conclude in Section 7 with a summary of our findings. Appendix A presents all the proofs, and other appendices deal with extensions and robustness checks.

2 The model

The economy and players. The economy is represented by a linear "city", of length 1, that is inhabited by entrepreneurs and lenders. A point on the city represents the characteristics of an entrepreneur (type of project, technology, geographical position, industry, . . .) at this location, and two close points mean that the entrepreneurs in those locations are similar.

There are two lenders, labeled by $i = \{1, 2\}$, located at the two extremes of the city.

[9] Similarly, Howell et al. (2021), Atkins et al. (2022) and Fei (2022) document that fintech lenders were more likely to provide PPP loans to black-owned (or minority-owned) businesses, which are poorly served by traditional banks.

[10] The aim of PPP loans is to help small businesses pay their employees and additional fixed expenses during the COVID-19 pandemic. Under SBA's interpretation of the initial bill, PPP loans can be forgiven if two conditions are satisfied: (a) loans are used to cover payroll costs, mortgage interest, rent and utility costs; (b) employee counts and compensation levels are maintained. See Granja et al. (2022) for a detailed introduction and an evaluation of the program.

Hence a lender is closer to some entrepreneurs than to others. This means, for example, that lenders are specialized in different sectors of the economy (see Paravisini et al., 2023 for export-related lending, Duquerroy et al., 2022 for SME lending and Giometti and Pietrosanti, 2022 for syndicated corporate loans). If the distance between an entrepreneur and lender 1 is z, we say that the entrepreneur is located at (location) z. As a result, the distance between an entrepreneur at z and lender 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.

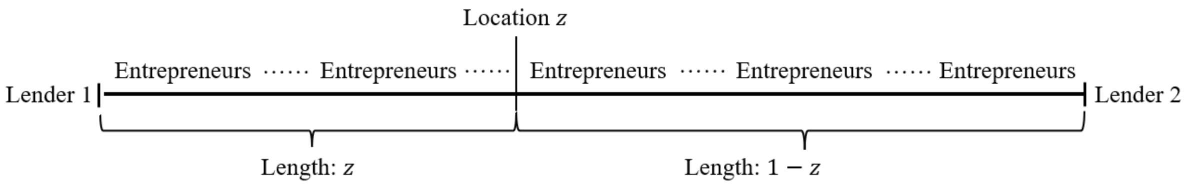

Figure 1: The Economy.

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 lenders 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 lender. More specifically, the project of an entrepreneur (monitored with intensity $m(z)$) succeeds if and only if

$$\theta \geq 1 - m(z),$$

where θ is a random variable (or say, risk factor) that is uniformly distributed over the interval $[0, 1]$; hence the event $\theta \geq 1 - m(z)$ happens exactly with probability $m(z)$. The random variable θ is the same across all entrepreneurs; in other words, it is a common risk factor that can be viewed as a measure of economic conditions. An entrepreneur at z who borrows from lender 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).

Funding source. We assume that lenders have no capital to finance their loans, so they must attract deposits or short-term debt from competitive risk-neutral investors. Investors' funding supply to lender i is perfectly elastic when the expected return to investors is no less than their break-even return f. The promised nominal return of lender i to its investors is denoted by d_i, which must be set so as to make investors break even. We assume that, before d_i is determined, lender i's monitoring intensities have already been observed by investors. Hence d_i can be adjusted to reflect the lender's risk, which ensures that the lender's expected payment to a unit of investors' funding is no less than f regardless of how intensely the lender chooses to monitor.[11]

Remark (funding by insured depositors): The results of our model hold if lenders are funded by insured depositors who cannot observe lenders' monitoring but are protected by a fairly priced deposit insurance scheme; the deposit insurance fund (DIF) can observe lender monitoring and make a zero expected profit by offering a fair risk-adjusted insurance premium rate.[12] Online Appendix F shows that all results in the paper hold under this alternative assumption.

Entrepreneurs' utility and investment decisions. An entrepreneur 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 $m(z)$, her expected monetary return from the project's payoff is $(R - r(z))m(z)$. The entrepreneur incurs a private disutility cost, $\varepsilon m(z)$ (with $R > \varepsilon$), when monitored with intensity $m(z)$.[13] Therefore, the entrepreneur's expected gross utility from the investment is:

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

[11]There is empirical evidence that investors do care about and have access to information on lenders' risk. Iyer et al. (2013) find that uninsured depositors do monitor lenders' financial health, because they are more likely to run than insured depositors, and such runs can be driven by their private information. Chen et al. (2022a) find that uninsured deposit interest rates are sensitive to lender performance, and the sensitivity is higher for lenders with better transparency.

[12]Risk-adjusted deposit insurance is adopted in a growing number of countries. In the US, the Federal Deposit Insurance Corporation (FDIC) implemented variable risk-based premiums in 1994 for banks and in 1998 for savings institutions. Garnett et al. (2020) provide the history and rules of risk-based premiums in the US. This practice was soon followed by many other countries. Demirgüç-Kunt et al. (2015) list the countries that adopt risk-based deposit insurance premium (as of 2013); among the countries that have deposit insurance schemes, 31% adopt risk-adjusted insurance. China switched to it in 2016 and then increased its flexibility in the following years.

[13]Lender monitoring eliminates private benefits of control and forces borrowers to give up shirking. The relation $R > \varepsilon$ means that monitoring is value-enhancing considering the private cost.

We assume that the entrepreneur derives net utility $\pi^e(z) - \underline{u}$ by implementing the risky project, so she seeks funding if and only if $\pi^e(z) \geq \underline{u}$. Here $\underline{u}$ is the reservation utility (i.e., opportunity cost) of the entrepreneur's alternative activities. For each entrepreneur, $\underline{u}$ is independently and uniformly distributed on $[0, M]$. The funding demand (which is also the mass of entrepreneurs undertaking investment projects) at location z is therefore

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

where $1_{\{\cdot\}}$ is an indicator function that equals 1 if the condition in $\{\cdot\}$ holds and equals 0 otherwise. Total entrepreneurial utility at location z can be written as

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

Note that the effect of the entrepreneurial private cost $\varepsilon m(z)$ is simply reducing the expected project return from $Rm(z)$ to $(R - \varepsilon)m(z)$. Without loss of generality, in the rest of the paper we let $\varepsilon = 0$.

Monitoring and information technology. The two lenders can use monitoring to increase entrepreneurs' probability of success. If an entrepreneur at z borrows from lender i and is monitored with intensity $m_i(z)$, then the lender incurs the non-pecuniary monitoring cost

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

Here $c_i \geq \underline{c} > R$, $R \geq \sqrt{2c_i f}$, $q_i \in [0, 1)$, and s_i is the distance between lender i and location 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 lender i's information technology. Parameter c_i is the slope of marginal monitoring costs when lender-borrower distance is zero, and hence represents lender i's basic monitoring efficiency (*IT-basic*). Parameter q_i (*IT-distance* of lender i) measures the negative effect of lender-borrower "distance friction" on the lender's information collection and data analysis.[14] The cost function (1) captures the idea that a lender has a greater capacity to discipline nearby borrowers and must expend more effort to monitor entrepreneurs who are more distant from the lender's expertise or geographic location.[15]

[14]A similar classification of technology can be found in Boot et al. (2021).

[15]This is consistent with Giometti and Pietrosanti (2022) who document that lenders specialize in lending to specific industries because of their information advantages in monitoring those industries.

The constraint $R \geq \sqrt{2c_i f}$ must hold to guarantee that lender i is willing to provide loans to at least some entrepreneur(s) in the market. The lower bound $\underline{c}$ of c_i is assumed to be higher than R to ensure that lender i's monitoring intensity - which is equal to the success probability of monitored entrepreneurs - is always smaller than 1.

Remark: The cost function (1) has two crucial properties when $q_1 = q_2 = q$ and $c_1 = c_2 = c$. First, the ratio of the two lenders' 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:

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

This property implies that increasing c does not affect a lender's relative cost advantage, although it makes monitoring more costly for both lenders. The second property is

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

which means that the sensitivity of the relative cost advantage to z is increasing in q. Note that $C_1(m_1, z)/C_2(m_2, z)$ is increasing in z. Therefore, a higher q not only makes monitoring more costly but also magnifies the importance of lender specialization by increasing the importance of distance in determining the relative cost advantage of a lender's monitoring.

Interpretation of monitoring. Lenders typically monitor their borrowers through information collection and covenant restrictions (Wang and Xia, 2014; Minnis and Sutherland, 2017; Gustafson et al., 2021). Specifically, lenders can collect entrepreneurs' data (e.g., by onsite visit or frequently requesting information) and assess how the business is doing and whether there is a diversion of funds towards private benefits. If borrowers are not acting appropriately, lenders can provide warnings and advice, which discipline borrowers and potentially improve their behavior. If the collected information shows the breach of covenants, lenders can obtain control rights and directly intervene to fix borrowers' behavior. Such intervention is easier for BigTech lenders since they can threaten to exclude misbehaving borrowers from future use of their platforms (Frost et al., 2019). With advanced information technology (such as the abundance of comprehensive transactional and locational data on borrowers' online activities and machine learning techniques), this kind of monitoring process can be conducted almost in real time (Chen et al., 2022b).

Monitoring creates value for both lenders and entrepreneurs; we can view it as lenders' expertise-based advising, mentoring or/and information production that is helpful for entrepreneurs. There is evidence that borrowers do value the expertise of lenders. Paravisini et al. (2023) find that an exporter prefers borrowing from a bank with better expertise in the target market. Duquerroy et al. (2022) document that an SME borrows less if its account is reallocated from a branch with expertise in the SME's industry to one without such expertise. There is also direct evidence showing that monitoring improves borrowers' firm values. Lee and Sharpe (2009) find that more intense lender monitoring leads to higher stock returns of borrowers; similarly, Dass and Massa (2011) show that lender monitoring can improve corporate governance of borrowers, thereby increasing their firm values.

To give a more specific interpretation to parameters q_i and c_i of the monitoring cost function (1), we assume that lender i's monitoring intensity at z (denoted by $m_i(z)$) is determined by two factors: data analysis and distance friction, that is

$$m_i(z) \equiv \underbrace{\alpha_i I_i(z)}_{\text{data analysis}} \overbrace{\sqrt{1 - q_i s_i}}^{\text{distance friction}},$$

where α_i measures lender i's efficiency of information processing and $I_i(z)$ is the amount of information (data) acquired by the lender about the monitored entrepreneur at z. The data analysis factor, $\alpha_i I_i(z)$, reflects the idea that monitoring relies on collecting and processing information about the firm; monitoring is more effective if the lender has more information about the firm (i.e., if $I_i(z)$ is higher) or if the lender has a better model to process the data (i.e., if α_i is larger). However, the effectiveness of a lender's data analysis must be discounted by a distance friction factor $\sqrt{1 - q_i s_i}$ because a lender may not have a uniform capability to collect and analyze the information of entrepreneurs of different characteristics.

The distance friction can be interpreted in two ways. First, we can view s_i as the "physical distance" between location z and lender i. Physical distance matters because first-hand borrower information often contains soft information that is hard to perfectly convey to distant loan officers (see Liberti and Petersen, 2019); in this case the distance friction factor reflects the informativeness loss in the process of remote information transmission. In contrast, if an entrepreneur is physically close to the lender, loan officers can closely communicate with the borrower, avoiding the loss of soft information. The second way is to view s_i as the "expertise gap" between an entrepreneur's characteristics and lender i's s specialized area. The expertise gap matters because the effectiveness of an information processing model will be lower when it is used to deal with firms that the model is not designed for. For example, the framework for analyzing a food company's information cannot maintain high effectiveness if it is applied to a real-estate company.

We further assume that acquiring information amount $I_i(z)$ will incur a cost of $\gamma_i(I_i(z))^2/2$ for lender i, where γ_i measures the lender's cost of information acquisition. If the lender chooses monitoring intensity $m_i(z)$ for an entrepreneur at z, then the amount of information (i.e., $I_i(z)$) needed is equal to $m_i(z)/(\alpha_i\sqrt{1-q_i s_i})$, which will cost the lender

$$\frac{\gamma_i}{2\alpha_i^2(1-q_i s_i)}(m_i(z))^2. \tag{3}$$

Letting $c_i \equiv \gamma_i/\alpha_i^2$, the cost of monitoring an entrepreneur at location z with intensity $m_i(z)$ is exactly given by the cost function (1). Therefore, c_i can be interpreted as the *cost of acquiring an efficiency unit of information* at zero distance, which inversely measures a lender's basic efficiency of information acquisition and processing (i.e., IT-basic).

Technologies that decrease c_i are related to improvements in information acquisition (i.e., a lower γ_i) and processing (i.e., a higher α_i), as shown in the following examples. Advances in chip technology and cloud computing/storage increase α_i. Adopting better software (e.g. desktop applications) improves the efficiency of document assembly and information classification and processing, which facilitates both information acquisition and data analyzing (i.e., decreases γ_i and increases α_i, see He et al., 2022). Exploiting new sources of information (like transaction data and digital footprints) with machine learning (ML) techniques also decreases c_i because it extends the pool of valuable information (i.e., decreases γ_i) and upgrades information processing methods (i.e., increases α_i).[16]

One consequence of technological progress is the increased availability of cheap but imprecise data (see Dugast and Foucault, 2018). In our model, the abundance of such data can be represented by a decrease in both γ_i and α_i. As information availability increases, γ_i will decrease because information acquisition becomes easier. However, the decrease in data quality increases the difficulty of information processing, thereby reducing α_i. A lender's basic monitoring efficiency will decrease (i.e., c_i increases) if the lower α_i (caused

[16] ML can process real-time borrower data quickly at large volumes and low operating costs (Huang et al., 2020). Mester et al. (2007) find that transaction information in borrowers' accounts - which provides ongoing data on borrowers' activities - is useful for lenders' monitoring. Dai et al. (2022) show that monitoring borrowers' digital footprints can increase the repayment likelihood on delinquent loans by 26.5%, because digital footprints (e.g., cell phone, email or/and apps footprints) reveal borrowers' social networks and physical locations, thereby increasing lenders' ability to intervene and enforce the repayment of borrowers.

by low-quality data) dominates.

Technologies that decrease q_i can diminish the physical distance friction (e.g., improvements in communication) or the expertise friction (such as extending the competence of human capital or hardening soft information). The diffusion of internet and the development of communication technology (like smart phones, mobile apps, social media, or video conferencing) facilitate remote information collection and exchange, and hence reduce the friction caused by the lender-borrower physical distance. The friction of the expertise gap can be weakened if an IT improvement facilitates lenders to extend their specialized areas. For example, improvements in human capital, facilitated by remote learning, better search engines and AI such as ChatGPT, make it easier for loan officers to process the information of firms they do not specialize in, thereby decreasing q_i. The development of code sharing platforms (like Github) is another example that can facilitate lenders' expertise extension.

Table 1: Technology Improvements and Monitoring Efficiency

Improvement of efficiency	Related technology
Decreasing c_i (improvement in collecting or/and processing information)	ML with big/unconventional data advances in cloud storage and computing, information management software
Decreasing q_i (physical distance friction) (improvement in communication)	Diffusion of internet, video conferencing, smart phone, mobile apps, social media
Decreasing q_i (expertise friction) (extending competence of human capital/ hardening soft information)	ML with big/unconventional data, remote learning and AI

There are also technologies that decrease both c_i and q_i: ML with big data decreases c_i by improving lender i's ability to acquire and process information. It makes also possible to harden soft information (e.g., digital footprints) and hence reduces the reliance on lenders' expertise in certain areas, which lowers q_i. Table 1 summarizes the technology improvements and the corresponding effects on monitoring efficiency.

The difference between a traditional bank and a fintech lender can be reflected in parameters q_i and c_i. Compared with banks, fintechs tend to have better IT-distance (i.e., lower q_i) since they connect digitally with entrepreneurs and process information with automatic algorithms. In contrast, banks may have higher basic monitoring efficiency (i.e., lower c_i) because they usually have better access to firm information.[17] Banks and

[17]Banks' advantage in the access to firm data is the rationale of Open Banking initiative launched by several governments including the European Union and the United Kingdom. See Babina et al. (2022)

fintechs have different abilities to acquire information (measured by γ_i) and to process it (measured by α_i). Better access to firm information by banks shows in a lower γ_i than fintech lenders. Fintechs' more capable IT infrastructure shows in a higher α_i. Therefore, a bank will have better basic monitoring efficiency than a fintech if the bank's advantage in information acquisition dominates the disadvantage in the capability of information processing.

Competition with discriminatory loan pricing. When extending loans, lenders compete in a localized Bertrand fashion. Lender i follows a discriminatory pricing policy in which the loan rate $r_i(z)$ varies as a function of the entrepreneurial location z.[18]

The timing of the two-stage duopoly lending game is shown in Figure 2 and consists of an IT investment stage and a lending competition stage. At the IT investment stage, lenders simultaneously choose their information technology (i.e., lender i determines q_i and c_i). Then at the lending competition stage, lenders compete taking as given q_i and c_i.

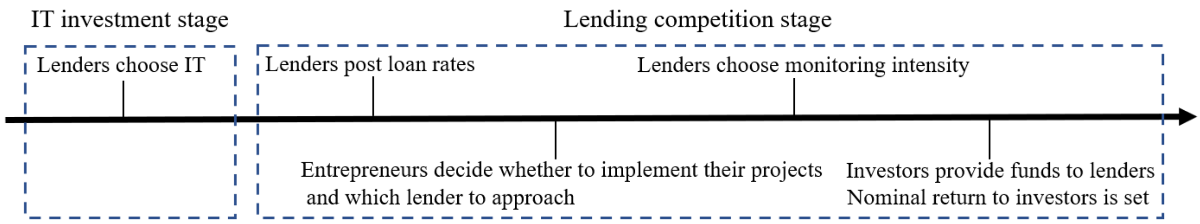

Figure 2: Timeline.

Within the lending competition stage, the following events take place in sequence: First, lenders post loan rate schedules simultaneously. Once the loan rate schedules are chosen and posted, entrepreneurs decide whether to implement their projects and which lender to approach for funding. Given entrepreneurs' decisions and the loan rates of each lender, lender i chooses its optimal monitoring intensity $m_i(z)$ depending on the location of entrepreneurs. Finally, investors – after observing $m_i(z)$ – put their money into lenders and are promised a nominal return d_i.

and He et al. (2023).

[18]Degryse and Ongena (2005) document spatial discrimination in loan pricing. See also Agarwal and Hauswald (2010) and Herpfer et al. (2022).

3 Equilibrium at the lending competition stage

In this section we analyze the equilibrium at the lending competition stage. Two types of equilibria may arise. The first type is the equilibrium with direct competition, in which case all locations are served by the two lenders. The second type is the local monopoly equilibrium, where the two lenders do not compete with each other and some locations are not served by either lender. Throughout the paper we focus mostly on the equilibrium with direct competition but we also characterize the local monopoly equilibrium in Appendix C.

Since lenders' loan rates can vary with entrepreneurial locations, there is localized Bertrand competition between lenders at each location. Without loss of generality, we concentrate on location z and analyze how lenders set loan rates to compete for entrepreneurs at z.

3.1 Optimal monitoring intensity

We solve the equilibrium by backward induction and so first examine how lenders choose their monitoring intensities. Lender i's loan rate and monitoring intensity for entrepreneurs at z are denoted by $r_i(z)$ and $m_i(z)$, respectively.

According to the timeline, an entrepreneur at z has decided whether to implement her project and which lender to borrow from *before* lenders choose their monitoring intensities. If an entrepreneur at z approaches lender 1, then lender 1's expected profit from financing the entrepreneur can be written as

$$\pi_1(z) \equiv r_1(z)m_1(z) - f - \frac{c_1}{2(1-q_1 z)}(m_1(z))^2. \tag{4}$$

The first term of $\pi_1(z)$ is the expected loan repayment from the entrepreneur at z, because the entrepreneur repays lender 1 the amount $r_1(z)$ with probability $m_1(z)$. The second term measures lender 1's expected funding costs by borrowing from investors, which is determined by investors' break-even expected return f, not the lender's promised nominal return d_1. The reason is that d_1 is determined after investors have observed lender 1's monitoring intensity schedule and hence is adjusted to reflect the lender's ultimate risk. When lender 1 makes its decisions, it knows that investors can undo lender risk by adjusting d_1, so its expected return to investors will be f. Finally, the third term represents lender 1's non-pecuniary monitoring costs.

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

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

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

A symmetric result holds for lender 2.

Note first that $m_1(z)$ is decreasing in c_1 since lender 1 has a lower monitoring incentive as monitoring becomes more costly. Second, $m_1(z)$ is decreasing in z (when $q_1 > 0$) because monitoring an entrepreneur is more costly when the entrepreneur is located farther away. Finally, $m_1(z)$ is increasing in $r_1(z)$. This follows because $r_1(z)$ represents lender 1's skin in the game, which determines the marginal benefit of monitoring an entrepreneur at z.[19]

3.2 Equilibrium loan rates

In this section we study how lenders determine their loan rates. We look first at how entrepreneurs decide which lender to approach after observing lenders' loan rates.

Entrepreneurs' decisions. After observing the loan rates posted by lenders, an entrepreneur will approach the lender that can provide higher expected utility. If lender i offers loan rate $r_i(z)$ at z, then entrepreneurs can expect that the lender's monitoring intensity $m_i(z)$ equals $r_i(z)(1 - q_i s_i)/c_i$ at this location. Hence entrepreneurs at z will consider lender 1 for loans if and only if they derive higher (gross) expected utility by approaching lender 1 instead of lender 2: $(R - r_1(z))m_1(z) \geq (R - r_2(z))m_2(z)$.

[19] According to Lemma 1, lender 1's promised nominal payment d_1 to investors does not affect $m_1(z)$. This result differs from Martinez-Miera and Repullo (2017, 2019), who assume that investors cannot observe a lender's monitoring intensity and show that such intensity is determined by the lender's intermediation margin (loan income *minus* its promised payment to investors), generating a debt overhang problem. In our paper, d_i is adjusted to lender i's risk because its monitoring intensity is observable to investors. We make this assumption for tractability. In the Martinez-Meira and Repullo model, each lender serves only one entrepreneur (or a group of identical entrepreneurs), so a project's failure is equivalent to lender failure and default on the promised payment to investors. Our model extends theirs by letting each lender serve non-identical entrepreneurs. As a result, a project's failure in our model is not equivalent to a lender's default, which would make a lender's optimization problem intractable. The advantage of the observable monitoring assumption is that a lender's optimization problem at each location is independent, giving rise to tractable localized Bertrand competition. In Online Appendix G we consider the case of unobservable monitoring with debt overhang where entrepreneurs are at a unique location and show that our results are robust and, in fact, that debt overhang plays a reinforcement role in some of them.

When the inequality holds, an entrepreneur at z will approach lender 1 if the gross utility $\pi^e(z) = (R - r_1(z))m_1(z)$ is no smaller than her reservation utility $\underline{u}$.

Note that increasing lender i's loan rate has two competing effects on entrepreneurial utility at z: First, the residual payoff $R - r_i(z)$ will decrease, which tends to reduce entrepreneurs' utility. However, lender i will increase its monitoring intensity $m_i(z)$, which increases the success probability of entrepreneurs who approach the lender. Therefore, entrepreneurs do not simply choose the lender whose loan rate is lower.

Best loan rate. The competitiveness of a lender is determined by its best loan rate, which is defined as follows:

Definition 1. *The best loan rate that lender i can offer to an entrepreneur at z is the loan rate that maximizes the entrepreneur's expected utility and ensures the lender a non-negative profit.*

In a competition of the Bertrand type, a lender 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 lender's best loan rate. The best loan rate is characterized by the next lemma.

Lemma 2. *If $R \geq \sqrt{8c_i f/(1-q_i)}$, then lender i's best loan rate is $R/2$ for any entrepreneur. Hence, the maximum gross utility lender i can provide to an entrepreneur at z is $R^2(1-q_i s_i)/(4c_i)$. Neither lender will offer a loan rate that is lower than $R/2$.*

We can best explain Lemma 2 by proving it here. When an entrepreneur at z borrows from lender 1, her expected utility is

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

with $m_1(z) = r_1(z)(1 - q_1 z)/c_1$ (Lemma 1). The best loan rate should maximize U (or $\pi^e(z)$), and the result is $r_1(z) = R/2$. The corresponding maximum $\pi^e(z)$ follows.

Lender 1's expected profit from financing an entrepreneur at z (i.e., $\pi_1(z)$) is given in (4). By Lemma 1, $\pi_1(z)$ is equal to $(r_1(z))^2(1-q_1 z)/(2c_1) - f$, which is positive when both $r_1(z) = R/2$ and $R \geq \sqrt{8c_1 f/(1-q_1)}$ hold. Therefore, the best loan rate $R/2$ is acceptable to lender 1. In a symmetric way, we can show the result for lender 2.

Lemma 2 shows that (a) lowering the loan rate may not increase a lender's attractiveness and (b) the lower bound for a lender's loan rate should be $R/2$. A lower loan rate to an entrepreneur implies a lower monitoring intensity and hence a higher probability of failure, although it leaves a higher payoff in the event of success. When lender i's loan rate is as low as $R/2$, the effect of the loan rate on monitoring intensity becomes dominant, so lender i cannot increase its attractiveness by further reducing its loan rate. Since better IT implies a higher ability to increase entrepreneurs' success probabilities, the maximum utility lender i can provide is increasing in its monitoring efficiency, $(1 - q_i s_i)/c_i$.

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 lenders a non-negative profit at some locations. In this case, a lender's best loan rate is not always $R/2$ (see the analysis in Appendix B; in Appendix C we show that this assumption eliminates the possibility of local monopoly equilibria). We maintain throughout the section the assumption that $R \geq \sqrt{8c_i f/(1 - q_i)}$.

Monopoly loan rates. We use $r_i^m(z)$ to denote lender i's monopoly loan rate at z, which is defined as follows:

Definition 2. *The monopoly loan rate $r_i^m(z)$ of lender i at location z is the loan rate the lender would choose if it faced no competition at the location.*

At location z, lender i would never offer a loan rate that is higher than $r_i^m(z)$. While the best loan rate is the *lower* bound of a lender's loan rate, the monopoly loan rate (with $r_i^m(z) > R/2$, see Lemma A.1 in Appendix A) is the *upper* bound.

Equilibrium loan rates. Given Lemmas 1 and 2, we can solve for lenders' equilibrium loan rates. If lender 1 wants to attract an entrepreneur (at z), it must offer a loan rate more attractive than the best loan rate $R/2$ of lender 2 (that is, providing expected utility no less than the maximum utility lender 2 can provide). If lender 1 cannot do so, then the entrepreneur will instead be served by lender 2. Reasoning in this way yields the equilibrium loan rates in Proposition 1.

Proposition 1. *Assume that $R \geq \sqrt{8c_i f/(1 - q_i)}, i = \{1, 2\}$. Let*

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

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

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

Proposition 1 describes the equilibrium with direct lender competition. The restriction $0 < \tilde{x} < 1$ guarantees that both lenders can attract a positive mass of entrepreneurs in equilibrium. If this restriction does not hold (which occurs when the difference between the two lenders' IT is sufficiently large), then one lender will drive the other lender out in equilibrium; in this case, lenders' pricing policy displayed in Proposition 1 is still robust for the dominant lender.[20] For convenience, we focus on the case $0 < \tilde{x} < 1$ for the rest of the paper.

Proposition 1 implies that lender-borrower distance matters for lending if $q_i > 0$ holds for some i (i.e., if distance friction exists in the market). Attracting an entrepreneur will be harder for a lender if the entrepreneur is located father away, because then the lender's relative cost advantage in monitoring is smaller. As a result, lender 1 (resp. lender 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. The location $z = \tilde{x}$ is the *indifference location* where neither lender has a cost advantage in monitoring, that is: $(1 - q_1\tilde{x})/c_1 = (1 - q_2(1 - \tilde{x}))/c_2$. Note that $\tilde{x}$ is decreasing in q_1 and c_1; this means lender 1 can reach farther locations if its information technology develops (i.e., if q_1 and/or c_1 decrease). This result is consistent with Ahnert et al. (2022) who document that small business lending by banks with higher IT adoption is less affected by bank-borrower distance.

Next we look at lenders' pricing strategies. Proposition 1 states that two cases may arise when lender 1 chooses its loan rate for entrepreneurs at $z \in [0, \tilde{x}]$. In the first case, which occurs when lender 1's competitive advantage is high (i.e., when $(1 - q_2(1 - z))/c_2$ is sufficiently lower than $(1 - q_1 z)/c_1$), lender 2 does not put competitive pressure on lender 1, so the latter offers the monopoly loan rate $r_1^m(z)$, which can provide higher entrepreneurial utility than lender 2's best loan rate. Then there is no effective lender competition at z. In the second case, which occurs when lender 1's competitive advantage at z is not so high, lender 2 can exert sufficient competitive pressure, so lender 1 can no longer maintain its monopoly loan rate at z, charging instead $r_1^{\text{comp}}(z) < r_1^m(z)$ (the

[20] For example, if c_2 is much larger than c_1, then $\tilde{x} \geq 1$ will hold; in this case, lender 1 is the dominant lender; the monitoring intensity of lender 2 is so low that it cannot attract any entrepreneur even if its best loan rate $R/2$ is offered. The equilibrium loan rate of lender 1 at z still equals $r_1^*(z)$, because lender 2's competitive pressure still exists despite that it serves no locations.

superscript "comp" indicates that the lender faces effective competition). Lender 2's pricing strategy follows the same logic.

Because our focus here is on competition, we are primarily interested in $r_i^{\text{comp}}(z)$. The following corollary gives a property of $r_1^{\text{comp}}(z)$; a symmetric result holds for $r_2^{\text{comp}}(z)$.[21]

Corollary 1. *Let $q_i > 0$ for some $i \in \{1, 2\}$ and $z \in [0, \tilde{x}]$. With effective lender competition at z (i.e., if $r_1^{\text{comp}}(z) < r_1^m(z)$), lender 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is decreasing in z. At the indifference location $z = \tilde{x}$, $r_1^{\text{comp}}(z) = R/2$ holds.*

With distance friction (i.e., $q_i > 0$ for some $i \in \{1, 2\}$), the curve of $r_1^{\text{comp}}(z)$ displays a "perverse" pattern (see Figure 3): As lender 1's monitoring efficiency goes down (i.e., an entrepreneur is located farther away, so is more costly to monitor), the loan rate offered to that entrepreneur decreases. Such a pattern results from the optimal pricing strategy of lender 1 at $z \in [0, \tilde{x}]$: maximizing the lender's lending profit, while ensuring that entrepreneurial utility is no less than the maximum utility the rival can provide. Based on this strategy, at $z \in [0, \tilde{x}]$ the entrepreneurial utility implied by lender 1's competitive loan rate $r_1^{\text{comp}}(z)$ should exactly match the maximum utility lender 2 can provide (i.e., the utility implied by lender 2's best loan rate $R/2$). As z increases in the region $[0, \tilde{x}]$, lender 1's (resp. lender 2's) monitoring efficiency becomes lower (resp. higher). Then lender 1 must offer a lower competitive loan rate $r_1^{\text{comp}}(z)$ to match the maximum utility provided by lender 2, implying the loan rate pattern. The implication of the result is that, under effective lender competition, entrepreneurs at $z \in [0, \tilde{x}]$ cannot benefit from lender 1's advantageous monitoring efficiency; instead, lender 1 itself extracts all the benefit of its IT advantage over lender 2. Corollary 1 is consistent with Herpfer et al. (2022) who find that a bank will charge its borrowers higher loan rates if the borrowers geographically get closer to the bank or/and farther away from competing banks.

At the indifference location $z = \tilde{x}$, neither lender has a cost advantage in monitoring, so the intensity of lender competition is maximal there; lender 1 must offer its the best loan rate $R/2$ to attract entrepreneurs there. Figure 3 graphically illustrates lenders' equilibrium rates when $q_i > 0$.

Competition between a bank and a fintech. Suppose that lender 1 is a fintech with relatively high c_1 (because of lack of data) and $q_1 = 0$, while lender 2 is a bank with relatively low c_2 (smaller than c_1) and positive q_2. Then according to Corollary 1, the fintech's loan rate (under effective competition) is still decreasing in $z \in [0, \tilde{x}]$, even if the fintech itself has no distance friction. The reason is that the maximum utility provided by

[21]See Appendix C for details about $r_i^m(z)$.

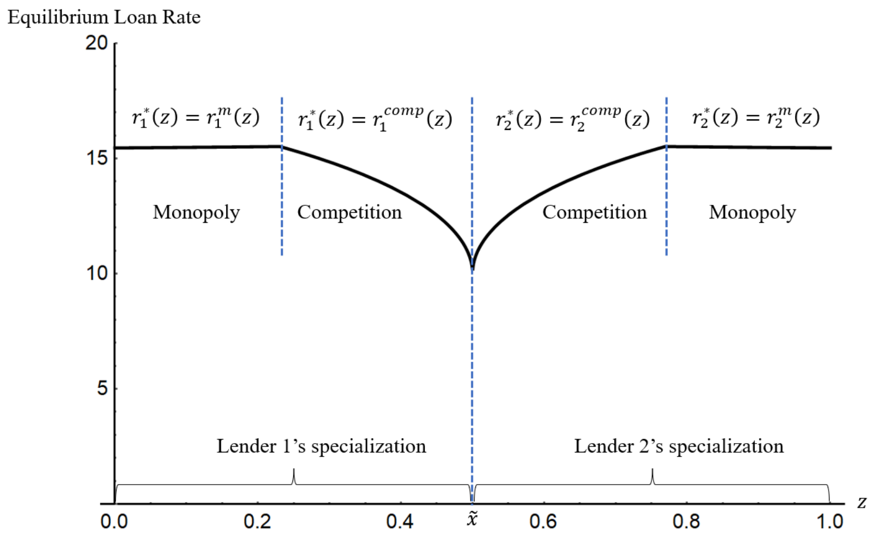

Figure 3: Equilibrium Loan Rates for Different Locations. This figure plots the equilibrium loan rate against the entrepreneurial location in the equilibrium under direct lender competition. The parameter values are $R = 20$, $f = 1$, $c_1 = 1.01R$, $c_2 = 1.01R$, $q_1 = 0.5$, and $q_2 = 0.5$.

the bank (i.e., lender 2) is increasing in z; to match this utility the fintech must decrease its loan rate as z increases in the region $[0, \tilde{x}]$. This result is consistent with Butler et al. (2017) who document that borrowers with better access to bank financing request loans at lower interest rates on a fintech platform. Moreover, note that $c_1 > c_2$ must imply $\tilde{x} < 1$, no matter how large the bank's q_2 is; the reason is that the bank, with its better access to firm information (which leads to $c_1 > c_2$), can ensure that it has higher monitoring efficiency than the fintech when z is sufficiently close to 1. The implication is that although fintechs, with their advantage in IT-distance, can bring competitive pressure to banks, the latter will not be completely replaced because of their superior capability of serving certain types of firms.

The case with no distance friction ($q_1 = q_2 = 0$). If $c_1 = c_2$ holds, then the two lenders have the same monitoring efficiency at all locations, which means competition intensity is infinitely high everywhere. In this case, every location is an indifference location with both lenders offering the best loan rate $R/2$; we let $\tilde{x} = 1/2$ still hold (since this is the natural limit by letting $q_1 = q_2$ tend to 0). Then the pricing strategies displayed in Proposition 1 hold: Lender 1's (resp. lender 2's) equilibrium loan rate is $r_1^{\text{comp}}(z) = R/2$ at $z \in [0, 1/2]$ (resp. $r_2^{\text{comp}}(z) = R/2$ at $z \in (1/2, 1]$).[22]

[22]If $q_1 = q_2 = 0$ and $c_1 \neq c_2$ hold, then the lender with better IT-basic (i.e., higher monitoring efficiency) will drive out the other lender. In this case, the equilibrium loan rate of the dominant lender

Locations with no effective competition. At such a location served by lender i, the equilibrium loan rate is $r_i^m(z)$ (Proposition 1). In Appendix C we show that $r_i^m(z)$ is increasing in the corresponding lender-borrower distance if $q_i > 0$ (e.g., $r_1^m(z)$ is increasing in z if $q_1 > 0$). The reason is that $r_i^m(z)$ only reflects lender i's costs of serving entrepreneurs when competition is absent. As the lender's lending distance increases, monitoring will be more costly if $q_i > 0$, so the monopolistic loan rate $r_i^m(z)$ will increase in response to the rising costs. Figure 3 illustrates how $r_i^m(z)$ varies with z when $q_i > 0$. More properties of $r_i^m(z)$ are displayed in Appendix C.

Corollary 2. ***Entrepreneurs' funding demand.*** *Let $q_2 > 0$ and $z \in [0, \tilde{x}]$. With effective lender competition at z, the funding demand $D(z)$ of entrepreneurs (i.e., lender 1's lending volume) is increasing in z.*

Corollary 2 states that the allocation of loans runs counter cost considerations: With effective competition and $q_2 > 0$, lender 1's lending volume (i.e., the funding demand met by the lender) is greatest at the farthest point ($z = \tilde{x}$) served by the lender. This loan allocation is consistent with the "perverse" loan rate pattern displayed in Corollary 1. The reason is that, based on the pricing strategy of lender 1, the entrepreneurial utility implied by its competitive loan rate $r_1^{\text{comp}}(z)$ should exactly match the maximum utility lender 2 can provide. Let $z \in [0, \tilde{x}]$ be a location with effective competition. As z decreases, the location becomes farther away from lender 2, so the maximum utility lender 2 can provide becomes lower. To match such utility, lender 1 need only provide a lower entrepreneurial utility, which corresponds to a smaller funding demand. Although a smaller z implies higher lender 1's monitoring efficiency, such an efficiency improvement only translates into a higher lender 1's lending profit at z, rather than higher entrepreneurial utility. As is stated below Corollary 1, with effective competition lender 1 will extract all the benefit of its IT advantage after matching the maximum utility lender 2 can provide.[23] A symmetric result holds for lender 2's region $(\tilde{x}, 1]$.

still follows the pricing policy in Proposition 1 and is invariant to z because locations will not affect a lender's competitive advantage when distance friction is absent.

[23]If $q_2 = 0$, however, there is no distance friction for lender 2. In this case, the maximum utility lender 2 can provide is invariant to z. As a result, lender 1 need not provide higher expected utility to entrepreneurs as z increases, which implies that entrepreneurs' funding demand does not vary with z in the region $[0, \tilde{x}]$.

3.3 Information technology and lender competition

The following corollary shows how lender 1's loan rate schedule (under effective competition) is affected by lenders' IT. A symmetric result holds for lender 2.

Corollary 3. *Let $z \in [0, \tilde{x})$. With effective lender competition at z, lender 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is increasing in the lender's competitive advantage, be it due to better basic monitoring technology (i.e., lower c_1/c_2) or to higher local expertise (i.e., lower $(1-q_2(1-z))/(1-q_1 z)$).*

Corollary 3 states that lender 1's equilibrium loan rate is decreasing in c_1 and q_1 (except for location $z = 0$ where q_1 has no effect) and is increasing in c_2 and q_2. As c_1 or q_1 increases, monitoring becomes more costly for lender 1; this outcome reduces lender 1's competitive advantage and induces it to decrease its loan rate in an attempt to match the maximum utility provided by lender 2. Yet as c_2 or q_2 increases, lender 2's competitive advantage will decrease, which allows lender 1 to increase its loan rate. Corollary 3 is reminiscent of the loan rate pattern displayed in Corollary 1: With effective lender competition at $z \in [0, \tilde{x})$, an increase in lender 1's monitoring efficiency does not translate into a lower loan rate, because lender 1 itself extracts all the benefit of its IT improvement.

We have witnessed the development and diffusion of information technology throughout the entire lending sector. We check now the implications for lender competition. We let $c_1 = c_2 = c$ and $q_1 = q_2 = q$ hold and then analyze how equilibrium loan rates vary with c and q, which determine the lending sector's information technology.

Corollary 4. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. With effective lender competition at z (served by lender i), the equilibrium loan rate $r_i^{\text{comp}}(z)$ is increasing in q (except for $z = 1/2$ where $r_i^{\text{comp}}(z) = R/2$) but is not affected by c.*

Corollary 4 highlights a crucial difference between c (IT-basic) and q (IT-distance). As q increases, monitoring costs become more sensitive to distance; this reduces lenders' incentives to monitor far-away entrepreneurs. Then entrepreneurs are more willing to choose nearby lenders because the monitoring intensity to which they are subject decreases more rapidly with distance as q increases. The result is that both lenders can post higher loan rates for their respective entrepreneurs, so $r_i^{\text{comp}}(z)$ is increasing in q. In contrast, if c increases then lenders' monitoring costs increase but their differentiation is unaffected; hence equilibrium loan rates are not affected. In sum: increasing q not only makes monitoring more costly but also increases lenders' differentiation, and the latter effect renders lender competition less intense. This result is consistent with Duquerroy et al. (2022) who find that increased branch specialization in SME lending – which can be viewed as an increase in q – substantially curtails the intensity of lending competition.[24] Paravisini et al. (2023) find a similar result in the credit market for export-related loans.

Corollary 4 tells us that, when studying how changes in information technology affect lender competition, we should first specify the *type* of IT change. Finally, note that this corollary holds for a more general cost function $C_i(m_i, z) = g(c_i, q_i, s_i)m_i^2$ that satisfies

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

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

The differentiation effect of improving lenders' IT-distance (i.e., decreasing q) can reduce lenders' monitoring incentives, which is established in the following corollary.

Corollary 5. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. With effective lender competition at z (served by lender i), the monitoring intensity $m_i(z)$ is decreasing in c while it is increasing in q (except for $z = 1/2$) if q is sufficiently small.*

As q decreases, there is a cost-saving effect, meaning that monitoring becomes cheaper; this effect tends to increase lender i's monitoring incentive. However, the differentiation effect of lowering q intensifies lender competition and hence reduces $r_i^{\text{comp}}(z)$ (except for $z = 1/2$), which tends to reduce its monitoring incentive. When q is sufficiently small, the differentiation effect dominates the cost-saving effect, so lender i's monitoring intensity decreases (except for $z = 1/2$).[25] In contrast, a decrease in c brings no differentiation effect, so lenders' monitoring intensities increase because of the cost-saving effect.

Information technology and local monopoly equilibrium. When lender competition is absent, lender i's equilibrium loan rate $r_i^m(z)$ depends only on its own IT. In Appendix C we show that $r_i^m(z)$ is increasing in $q_i s_i$ and c_i. The reason is that in the local monopoly case an improvement of IT, be it IT-basic or IT-distance, has no competition effect; instead, it only makes monitoring cheaper, which is reflected in lender i's lower loan rates. Moreover, an IT improvement allows lender i to serve farther entrepreneurs. In particular, if lender i is a fintech with zero distance friction (i.e., $q_i = 0$), then the local monopoly equilibrium cannot arise because the fintech is willing to serve

[24] As q increases, a lender's knowledge specializes more in nearby locations and is discounted faster with distance, implying a higher lender specialization. The loan rate and volume disparity at different locations will increase as a consequence.

[25] At the mid location $z = 1/2$, the equilibrium loan rate has already reached the lower bound $R/2$, so a decrease in q always increases the monitoring intensity there.

all locations. Hence, the development of fintech lending can improve financial inclusion by helping some unbanked locations gain access to fintech finance (Jagtiani and Lemieux, 2018). See Proposition C.2 and Corollary C.2 in Appendix C for more details.

Next we look at the relation between the lending sector's IT and a lender's aggregate lending profit. At the lending competition stage, lender 1's aggregate lending profit from all locations is equal to $\int_0^{\tilde{x}} D(z)\pi_1(z)dz$; here $D(z)$ is the funding demand at location z, and $\pi_1(z)$ is lender 1's profit from financing an entrepreneur at z. Symmetrically we can define lender 2's aggregate lending profit. The following proposition shows how a lender's aggregate lending profit is affected by the lending sector's information technology.

Proposition 2. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. Lender i's aggregate lending profit from all locations is decreasing in c while it is increasing in q if q is sufficiently small.*

Decreasing c makes monitoring cheaper without reducing lender differentiation. In contrast, the net effect of q is more complex. Decreasing q has two competing effects on lender i's aggregate lending profit. First, there is a cost-saving effect: a smaller q makes monitoring less costly for lender i, which should increase the lender's lending profit. Second, there is a differentiation effect: a smaller q decreases lender differentiation and so increases the intensity of lender competition, which should reduce lenders' profits. The differentiation effect will dominate the cost-saving effect when q is small enough. The reason is that the intensity of lender competition will go to infinity as q approaches 0 (i.e., as lender differentiation disappears); in contrast, for a given monitoring intensity $m_i(z)$, a marginal decrease in q can reduce the costs of monitoring an entrepreneur at z by only

$$\frac{\partial C_i(m_i(z), z)}{\partial q} = \frac{2s_i c}{4(1 - qs_i)^2}(m_i(z))^2,$$

which is finite even if q approaches 0.

Information technology and lending volume. Does the progress of information technology spur entrepreneurship? To shed light on this question, first we study how the IT progress of a lender affects the mass of entrepreneurs it serves. The mass of entrepreneurs financed by lender 1 (resp. lender 2) – which is also the lender's aggregate loan volume – equals $L_1 \equiv \int_0^{\tilde{x}} D(z)dz$ (resp. $L_2 \equiv \int_{\tilde{x}}^1 D(z)dz$).

Proposition 3. *Lender i's aggregate loan volume L_i is decreasing in q_i and c_i.*

Proposition 3 states that the progress of a lender's IT, whatever its type, will induce the lender to serve more entrepreneurs (i.e., to provide more loans). We explain the result by looking at the IT progress of lender 1 (i.e., a decrease in q_1 or c_1): First, lender 1 will extend its market area (i.e., $\tilde{x}$ will increase) since its competitiveness is increased by the IT progress. Second, at a location served by lender 1, entrepreneurs' funding demand will not be affected by the lender's IT progress; the reason is that an entrepreneur's utility at that location is determined by the maximum utility lender 2 can provide, which is not affected by lender 1's IT. As a result, lender 1's aggregate loan volume will increase as the lender's IT improves. This result is consistent with Dadoukis et al. (2021) and Branzoli et al. (2021) who find that banks with higher IT adoption have larger loan growth.

We also show in Proposition D.1 of Online Appendix D that the progress of a lender's IT-basic (i.e. a lower c_i) will bring more loan volume to the lender when the intensity of lender competition is higher (i.e., when q is smaller).

Next we analyze how the total mass of entrepreneurs undertaking investment projects (i.e., $L_1 + L_2$) is affected by the lending sector's IT.

Proposition 4. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. The total mass of entrepreneurs undertaking investment projects (i.e., $L_1 + L_2$) is decreasing in q and c.*

Proposition 4 states that the progress of the lending sector's IT, whatever its type, will promote entrepreneurs' investment. A decrease in q has two effects that spur entrepreneurship. First, there is a (competition) differentiation effect: Decreasing q diminishes lender differentiation and hence increases the intensity of lender competition. A more intense competition forces lenders to provide higher expected utility to entrepreneurs, which induces more entrepreneurs to undertake their projects. Second, there is a cost-saving effect: A decrease in q makes monitoring less costly, so lenders will choose higher monitoring intensities for given loan rates, which benefits entrepreneurs and hence promotes their investment. Decreasing c does not have the differentiation effect, but the cost-saving effect still works. Proposition 4 is consistent with Ahnert et al. (2022) who find that job creation by young enterprises, which is an indirect measure of entrepreneurial investment, is higher in US counties that are more exposed to IT-intensive banks.

What happens when R is not large enough? In Appendix B we consider the case when R is not large enough and so at some locations lender i cannot make a non-negative profit by posting the loan rate $R/2$. For such a location, the best loan rate lender i can offer to entrepreneurs equals the loan rate that exactly brings lender i zero profit. Appendix B shows that lender i's best loan rate (which is also its lowest acceptable loan rate) is higher than $R/2$ and is increasing in q_i and c_i if $R/2$ is too low to ensure lender i a non-negative profit at z. Most results in this section are robust when R is not large, because the essential difference between c and q still exists – that is, c does not control lender differentiation as q does. However, the result that $r_i^{\text{comp}}(z)$ is unaffected by c (Corollary 4) does not hold when $R/2$ is not lender i's best loan rate (see Corollary B.4 in Appendix B.)

The effects of funding costs. From Proposition 1 we have that $\tilde{x}$ and $r_i^{\text{comp}}(z)$ do not depend on the funding cost f. The reason is that with a large R the funding cost f does not affect a lender's best loan rate $R/2$, thereby having no effect on the maximum utility lenders can provide and competition between them. When R is not large, however, funding costs will affect lender competition. This is analyzed in Appendix B, where we allow the two lenders to have different marginal funding costs (which can be viewed as a measure of the investor-lender relationship). There we find that with small R a decrease in a lender's funding cost (say an improvement in the investor relationship) will increase the maximum utility provided by the lender, because then the lender's best loan rate becomes lower. As a result, the lender gains a larger market area (Proposition B.2) and forces its rival to price lower (Corollary B.3). If both lenders' funding costs decrease, then both lenders will price lower when R is not large (Corollary B.4), implying lower monitoring intensities. However, since the decrease in funding costs does not reduce lender differentiation as q does, the cost-saving effect of cheaper funding dominates and thereby increases lenders' profits (Proposition B.3). Finally, as lowering funding costs decreases lenders' best loan rates, entrepreneurs will benefit from the increase in the maximum utility lenders can provide, implying an increase in total investment (Proposition B.5).

4 Technology investment choice

In this section we analyze how lenders determine their information technology – represented by q_i and c_i – at the IT investment stage. To develop an IT infrastructure that is characterized by q_i and c_i, lender i must incur a cost $T(q_i, c_i) \geq 0$. We assume that $T(q_i, c_i)$ is differentiable with $\partial T(q_i, c_i)/\partial q_i \leq 0$ and $\partial T(q_i, c_i)/\partial c_i \leq 0$, which means that adopting better information technology needs more investment and so is (weakly) more costly. Lender 1's ex ante profit at the IT investment stage is equal to

$$\Pi_1(q_1, q_2, c_1, c_2) \equiv \int_0^{\tilde{x}} D(z)\pi_1(z)dz - T(q_1, c_1),$$

where $\int_0^{\tilde{x}} D(z)\pi_1(z)dz$ is lender 1's aggregate lending profit at the second stage. Sometimes $\Pi_1(q_1, q_2, c_1, c_2)$ is also written as Π_1 for short. In a symmetric way we can define lender 2's first-stage profit Π_2.

We assume that there exist $\overline{q} > 0$ and $\overline{c} > \underline{c}$ such that $\partial T(q_i, c_i) / \partial q_i = 0$ for $q_i \geq \overline{q}$ and $\partial T(q_i, c_i) / \partial c_i = 0$ for $c_i \geq \overline{c}$. Then lender i need only consider information technology that satisfies $q_i \times c_i \in [0, \overline{q}] \times [\underline{c}, \overline{c}]$. We let $R \geq \sqrt{8\overline{c}f/(1-\overline{q})}$, implying that lenders' best loan rate equals $R/2$ at the lending competition stage (characterized in Section 3).

4.1 Lender IT investment: substitutes or complements?

Are the two types of lender i's own IT investment, IT-basic and IT-distance, substitutes or complements? What is the strategic relation between lender 1's IT investment and lender 2's IT investment?

Lender's own IT investment: substitutes or complements? Let's focus on lender 1. Lender 1's own IT-basic and IT-distance (i.e., c_1 and q_1) are complements (resp. substitutes) if $\partial^2\Pi_1/(\partial q_1 \partial c_1) > 0$ (resp. $\partial^2\Pi_1/(\partial q_1 \partial c_1) < 0$). The complexity of the integral $\int_0^{\tilde{x}} D(z)\pi_1(z)dz$ makes it very difficult to determine the sign of $\partial^2\Pi_1/(\partial q_1 \partial c_1)$ in an analytical way. However, we can obtain the following numerical result.

Numerical Result 1. [26] *With effective lender competition at all locations, c_1 and q_1 are complements for lender 1 – that is, $\partial^2\Pi_1/(\partial q_1 \partial c_1) > 0$ – if $T(q_1, c_1)$ is submodular (i.e., if $\partial^2 T(q_1, c_1) / (\partial q_1 \partial c_1) \leq 0$).*

Numerical Result 1 states that if investing in one type of IT does not increase the marginal cost of developing the other type, then the two types of IT are complements for the lender. A smaller c_1 (resp. q_1) increases lender 1's marginal benefit of decreasing q_1 (resp. c_1) for three reasons. First, lender 1's monitoring efficiency at location z is determined by $(1 - q_1 z)/c_1$, so a marginal decrease in q_1 (resp. c_1) has a larger effect on improving the lender's monitoring efficiency if c_1 (resp. q_1) is smaller. Second, it is easy to show that $\partial^2\tilde{x}/(\partial q_1 \partial c_1) > 0$, which means that a marginal decrease in q_1 (resp. c_1) will extend a larger market area for lender 1 if c_1 (resp. q_1) is smaller. Finally, we can show that $\partial(D(\tilde{x})\pi_1(\tilde{x}))/\partial c_1 < 0$ and $\partial(D(\tilde{x})\pi_1(\tilde{x}))/\partial q_1 < 0$; this means a smaller c_1 (resp. q_1) will increase lender 1's expected lending profit at the indifference location

[26]The grid of parameters is as follows: R ranges from 15 to 100; $\underline{c} = 1.01R$; q_i ranges from 0 to 0.3; f ranges from 0.8 to 1.2; c_1 ranges from $\underline{c}$ to $1.3R$; c_2 ranges from $max\{c_1 - c_1 q_2, \underline{c}\}$ to $c_1/(1-q_1)$, which ensures that $0 < \tilde{x} < 1$.

$z = \tilde{x}$, implying a larger marginal benefit of extending market area by reducing q_1 (resp. c_1).[27] As a consequence, q_1 and c_1 are complements if $T(q_1, c_1)$ is submodular.

Lenders' IT investment: strategic substitutes or strategic complements? We obtain the following.

Numerical Result 2. [28] *With effective lender competition at all locations, q_1 and c_2 are strategic substitutes for lender 1: $\partial^2\Pi_1/(\partial q_1 \partial c_2) < 0$, while the signs of $\partial^2\Pi_1/(\partial c_1 \partial c_2)$, $\partial^2\Pi_1/(\partial c_1 \partial q_2)$ and $\partial^2\Pi_1/(\partial q_1 \partial q_2)$ are ambiguous.*

Let IT_i, which equals either q_i or c_i, denote lender i's IT. Then

$$\frac{\partial^2\Pi_1}{\partial IT_1 \partial IT_2} = \underbrace{\frac{\partial \int_0^{\tilde{x}} \frac{\partial D(z)\pi_1(z)}{\partial IT_1} dz}{\partial IT_2}}_{\text{share squeezing effect } -} + \underbrace{\frac{\partial \left(D(\tilde{x})\pi_1(\tilde{x})\right)}{\partial IT_2} \frac{\partial \tilde{x}}{\partial IT_1}}_{\text{boundary profit effect } +} + \underbrace{D(\tilde{x})\pi_1(\tilde{x}) \frac{\partial^2 \tilde{x}}{\partial IT_1 \partial IT_2}}_{\text{share sensitivity effect } +/-}. \quad (5)$$

Equation (5) shows that lender 2's IT progress (i.e., decreasing q_2 or/and c_2) affects lender 1's marginal benefit of developing IT through three channels. First, there is a "share squeezing effect"(first term of Equation 5) we find negative, implying strategic substitutability: a decrease in q_2 or/and c_2 erodes the market area served by lender 1 and its marginal benefit of improving IT decreases. Second, there is a "boundary profit effect" (second term of Equation 5), which is positive and implies strategic complementarity because: (a) $\partial\tilde{x}/\partial IT_1 < 0$, a decrease in IT_1, be it q_1 or c_1, increases lender 1's market area; (b) $\partial\left(D(\tilde{x})\pi_1(\tilde{x})\right)/\partial IT_2 < 0$, lender 1's expected profit (i.e., $D(\tilde{x})\pi_1(\tilde{x})$) at the indifference location $z = \tilde{x}$ will increase as IT_2 (i.e., q_2 or c_2) decreases and forces the lender to specialize in a smaller area.[29] A higher profit at location $z = \tilde{x}$ implies a larger marginal benefit of increasing $\tilde{x}$, so this is a force for strategic complementarity with lender 1 having a greater incentive to reduce q_1 or/and c_1. Finally, there is a "share sensitivity effect" (third term of Equation 5) with an ambiguous sign since $\partial^2\tilde{x}/(\partial IT_1 \partial IT_2)$ may be positive or negative. If it is positive (resp. negative), then $\partial\tilde{x}/\partial IT_1$ - which is negative - will decrease (resp. increase) as c_2 or q_2 decreases, implying a force for strategic complementarity (resp. substitutability) since $\tilde{x}$ becomes more (resp. less) sensitive to

[27]It can be shown that $D(\tilde{x})\pi_1(\tilde{x}) = \frac{(1-q_2(1-\tilde{x})R^2)}{4c_2}\left(\frac{R^2}{8}\frac{1-q_2(1-\tilde{x})}{c_2} - f\right)$, which is decreasing in q_1 and c_1 because $\tilde{x}$ is decreasing in q_1 and c_1.

[28]The grid of parameters is as follows: R ranges from 15 to 100; $\underline{c} = 1.01R$; q_i ranges from 0 to 0.3; f ranges from 0.8 to 1.2; c_1 ranges from $\underline{c}$ to $1.3R$; c_2 ranges from $max\{c_1 - c_1 q_2, \underline{c}\}$ to $c_1/(1-q_1)$, which ensures that $0 < \tilde{x} < 1$.

[29]It can be shown that $D(\tilde{x})\pi_1(\tilde{x}) = \frac{(1-q_1\tilde{x})R^2}{4c_1}\left(\frac{R^2}{8}\frac{1-q_1\tilde{x}}{c_1} - f\right)$, which is decreasing in q_2 and c_2 because $\tilde{x}$ is increasing in q_2 and c_2.

lender 1's IT investment. The net strategic relation between the two lenders' IT depends on which effect dominates. Numerical Result 2 shows that q_1 and c_2 are strategic substitutes, which means the share squeezing effect is dominant in this case. However, for the pairs $\{c_1, c_2\}$, $\{c_1, q_2\}$ and $\{q_1, q_2\}$, the strategic relation is ambiguous.

Strategic complementarity between bank and fintech. Suppose that lender 1 is a bank with high q_1 and low c_1, while lender 2 is a fintech with low q_2 and high c_2 (because of lack of firm data). A numerical study finds that if c_2 is sufficiently higher than c_1, the IT-distance investment of lender 2 is a strategic complement of lender 1's both types of IT (because $\partial^2\Pi_1/\left(\partial q_1\partial q_2\right) > 0$ and $\partial^2\Pi_1/\left(\partial c_1\partial q_2\right) > 0$ in this case). Then the fintech's improvement in the ability to serve distant customers (i.e., reducing q_2) will encourage the bank to improve both types of IT. If the fintech invests to improve its basic IT (i.e., reduce c_2), the bank may invest more in IT-basic because again of strategic complementarity, $\partial^2\Pi_1/\left(\partial c_1\partial c_2\right) > 0$, which holds when c_2 is sufficiently higher than c_1.[30]

4.2 Equilibrium technology investment

We restrict our attention to subgame perfect equilibria (SPE) of the two stage game. The equilibrium at the IT investment stage relies on the properties of function $T(q_i, c_i)$. The following proposition characterizes lenders' IT investment when IT is cheap to acquire.

Proposition 5. *If*

$$\Pi_i\left(0,0,\underline{c},\underline{c}\right) = \frac{R^2}{8\underline{c}}\left(\frac{R^2}{8\underline{c}} - f\right) - T\left(0,\underline{c}\right) > 0, \tag{6}$$

then at the unique SPE we have that $q_1 = q_2 = 0$ and $c_1 = c_2 = \underline{c}$.

Condition (6) means that each lender can still make a positive ex ante profit when both lenders acquire the best possible information technology. If Condition (6) is satisfied, we say IT is "cheap" to acquire. Proposition 5 states that both lenders will choose the best possible IT (i.e., decrease both q_i and c_i to their lower bounds) if it is cheap. In this equilibrium, competition at the second stage is extremely intense because there is no lender differentiation when $q_1 = q_2 = 0$. Lender 1 (resp. lender 2) serves entrepreneurs in $[0, 1/2]$ (resp. $(1/2, 1]$) and offers the best loan rate $R/2$; each lender's aggregate lending profit at the second stage equals $R^2\left(R^2/(8\underline{c}) - f\right)/(8\underline{c})$.

[30]However, the bank may invest less in its both types of IT when c_2 gets close to c_1 because then $\partial^2\Pi_1/\left(\partial q_1\partial c_2\right) < 0$ and $\partial^2\Pi_1/\left(\partial c_1\partial c_2\right) < 0$.

We prove here that $\{q_i = 0, c_i = \underline{c}\}$ is indeed an equilibrium under Condition (6). Given that $q_2 = 0$ and $c_2 = \underline{c}$, lender 1 can make a positive expected profit by setting $q_1 = 0$ and $c_1 = \underline{c}$ according to Condition (6). If lender 1 deviates (from $q_1 = 0$ and/or $c_1 = \underline{c}$), it will lose all its market share and so make a non-positive ex ante profit. Hence lender 1 has no incentive to deviate. The same reasoning applies to lender 2. The uniqueness of the equilibrium is relegated to Appendix A. Both lenders would be better-off if q $(= q_1 = q_2)$ were moderately increased from 0 (see Proposition 2). However, lender i is not willing to increase q_i because the marginal cost of deviating is infinite, implying a *prisoner's dilemma*.[31]

When IT is not cheap. Now we look at lenders' IT investment when Condition (6) is not satisfied. In this case we focus on the interplay between IT-basic and IT-distance in a symmetric interior equilibrium. To do so, we assume

$$T(q_i, c_i) \equiv \beta_q Q(q_i) + \beta_c H(c_i), \tag{7}$$

where $Q(\cdot) \geq 0$, $H(\cdot) \geq 0$, are differentiable with $Q'(\cdot) \leq 0$ and $H'(\cdot) \leq 0$. The cost function (7) implies that the costs of the two types of IT are independent, so $T(q_i, c_i)$ itself cannot induce any interaction between IT-basic and IT-distance. Parameter $\beta_q > 0$ (resp. $\beta_c > 0$) affects lender i's total and marginal costs of reducing q_i (resp. c_i).

We impose some conditions on the IT cost function to ensure the existence of a symmetric interior equilibrium. First, we assume that $\partial T(q_i, c_i)/\partial q_i$ and $\partial T(q_i, c_i)/\partial c_i$ are continuous functions. Second, $\overline{q}$ and $\overline{c}$ are sufficiently small such that the a lender cannot have much better IT than its rival, which ensures effective lender competition for all locations. Finally, we assume that $\lim_{q_i \to 0} -q_i \partial T(q_i, c_i)/\partial q_i$ (resp. $-c_i \partial T(q_i, c_i)/\partial c_i|_{c_i = \underline{c}}$) is large enough for any $c_i \in [\underline{c}, \overline{c})$ (resp. for any $q_i \in [0, \overline{q})$), and that $-q_i \frac{\partial^2 T(q_i,c_i)/\partial q_i^2}{\partial T(q_i,c_i)/\partial q_i}$ and $-c_i \frac{\partial^2 T(q_i,c_i)/\partial c_i^2}{\partial T(q_i,c_i)/\partial c_i}$ are large enough for $q_i \times c_i \in (0, \overline{q}) \times [\underline{c}, \overline{c})$.

With those assumptions, a unique symmetric interior IT investment equilibrium exists (see Lemma A.2). The following proposition characterizes how lenders' equilibrium IT

[31] Lender i is not willing to deviate from $q_i = 0$ and $c_i = \underline{c}$ despite a potentially large marginal benefit of deviation because the extent of strategic complementarity between lender i's IT and q_j $(j \neq i)$ is infinitely high in this boundary equilibrium (see Numerical Result D.1 in Online Appendix D). As a consequence, both lenders are trapped in a prisoner's dilemma if IT is cheap. Under Condition (6) a lender will have the ability to dominate the entire market and exclude the rival unless the rival chooses the best technology; but since they both have access to the same IT choice set, they end up acquiring the best technology and sharing the market. In such an equilibrium without lender differentiation, a slight deviation at the IT investment stage will cause a discontinuous profit fall at the lending competition stage, so the marginal cost of deviation is infinite.

investment will be affected by a cost shock on one type of IT.

Proposition 6. *There exists a unique symmetric interior equilibrium:* $q_i = q^* \in (0, \overline{q})$ *and* $c_i = c^* \in (\underline{c}, \overline{c})$*. At this equilibrium we have:*

$$\frac{\partial q^*}{\partial \beta_q} > 0, \frac{\partial c^*}{\partial \beta_q} > 0, \frac{\partial q^*}{\partial \beta_c} > 0 \text{ and } \frac{\partial c^*}{\partial \beta_c} > 0.$$

Proposition 6 implies that the two types of IT (of the entire lending sector) will co-move in response to a cost shock in the symmetric interior equilibrium. Yet this result hides subtle interactions between lenders' technological choices. Where does the co-movement come from? Numerical Result 3 provides the strategic relation between the two lenders' IT in the symmetric case where $q_1 = q_2 > 0$ and $c_1 = c_2$ hold; the interior equilibrium displayed in Lemma A.2 and Proposition 6 belongs to this symmetric case.

Numerical Result 3. [32] *With effective lender competition at all locations, we have:*

$$\frac{\partial^2 \Pi_1}{\partial c_1 \partial q_2} > 0, \frac{\partial^2 \Pi_1}{\partial q_1 \partial c_2} < 0, \frac{\partial^2 \Pi_1}{\partial q_1 \partial q_2} < 0 \text{ and } \frac{\partial^2 \Pi_1}{\partial c_1 \partial c_2} < 0$$

if $q_1 = q_2 > 0$ *and* $c_1 = c_2$ *hold.*

When $q_1 = q_2 > 0$ and $c_1 = c_2$ hold, c_1 and q_2 are strategic complements for lender 1, while the strategic relation is substitutive for IT pairs $\{q_1, c_2\}$, $\{q_1, q_2\}$ and $\{c_1, c_2\}$. The results are explained by the interplay of effects displayed in Table 2. In Online Appendix D there is a more detailed explanation.

Table 2: The Strategic Relation between Lenders' IT in the Symmetric Case.

	Share squeezing effect	Boundary profit effect	Share sensitivity effect	Net effect
c_1 and q_2	substitutive	complementary	complementary	complementary
q_1 and c_2	substitutive	complementary	substitutive	substitutive
q_1 and q_2	substitutive	complementary	complementary	substitutive
c_1 and c_2	substitutive	complementary	null	substitutive

As β_q decreases, lender 1 reduces q_1 because the direct effect of reducing β_q dominates the strategic substitutability effects of lower q_2 and c_2 (and is reinforced by the complementary effect of the decrease in c_1); lender 1 reduces c_1 because the complementary effects of lower q_1 and q_2 dominate the strategic substitutability effect of a lower c_2.

[32]The grid of parameters is as follows: R ranges from 15 to 100; $\underline{c} = 1.01R$; q_1 $(= q_2)$ ranges from 0.01 to 0.3; f ranges from 0.8 to 1.2; c_1 $(= c_2)$ ranges from $\underline{c}$ to $1.3R$.

As β_c decreases, lender 1 reduces c_1 because the direct effect of reducing β_c dominates the strategic substitutability effect of a lower c_2 (and is reinforced by the complementary effects of the decrease in q_1 and q_2); lender 1 reduces q_1 because the complementary effect of a lower c_1 dominates the strategic substitutability effects of lower q_2 and c_2.

Summary: When lenders endogenously determine their IT, the equilibrium results depend on whether IT is cheap to acquire. With cheap IT (i.e., Condition 6), both lenders will acquire the best possible IT in their quest to compete for the market. As a result, lender differentiation disappears and lender competition becomes extremely intense, trapping both lenders in a prisoner's dilemma. If IT is not so cheap, then the two types of IT co-move in an interior symmetric equilibrium in response to cost shocks; that is, a decrease in the cost of acquiring one type of IT will increase lenders' investment in both types of IT. Furthermore, we find also that the IT investments of a bank and a fintech (which are asymmetric) will tend to be strategic complements.

5 Lender stability

In this section we study how the progress of information technology affects lender stability (measured by the inverse of the probability of lender default). Lender i will default if and only if the aggregate loan repayment it receives cannot satisfy its promised return d_i to investors.[33] The probability of lender i's default is denoted by θ_i^*, which is determined as described in Lemma A.3 in Appendix A.

Lender stability when R is large. We do not have a closed-form solution for a lender's default probability, so we use numerical methods to analyze how IT change – as represented by changes in c_i or q_i – affects this probability.

We find that lender 1 becomes less stable as q_1 or/and c_1 increases (i.e., as the lender's IT becomes worse. See Panels 1 and 3 of Figure 4). As stated in Section 1, this result is consistent with the empirical findings of Pierri and Timmer (2022). An increase in q_1 or/and c_1 reduces lender 1's stability by way of three channels. First, a higher q_1 or/and c_1 increases lender 1's monitoring cost, which decreases the lender's monitoring incentive and reduces the projects' likelihood of success. Second, Corollary 3 establishes that an increase in q_1 or/and c_1 decreases lender 1's competitiveness and thus forces the lender to set lower loan rates, which reduces not only its monitoring intensity but also

[33]This happens when the risk factor θ is sufficiently low. Recall that an entrepreneur (monitored with intensity $m(z)$) succeeds if and only if $\theta \geq 1 - m(z)$, so a lender receives less repayment from entrepreneurs when θ is lower. If $\theta = 0$, all entrepreneurs will fail, so lenders default for sure.

an entrepreneur's loan repayment in the event of success. The two channels together reduce entrepreneurs' expected repayment to lender 1. Third, investors, knowing that a higher q_1 or/and c_1 reduces entrepreneurs' expected repayment, will require a higher promised return d_1 to break even, which further increases the difficulty for lender 1 to stay solvent. The three channels together reduce the lender's stability. Yet we must point out that increasing q_1 or/and c_1 also has a pro-stability *market area effect*. Namely: as q_1 or/and c_1 increases, the region lender 1 serves will shrink (i.e., $\tilde{x}$ will decrease); hence lender 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 stability-reducing effects mentioned previously.

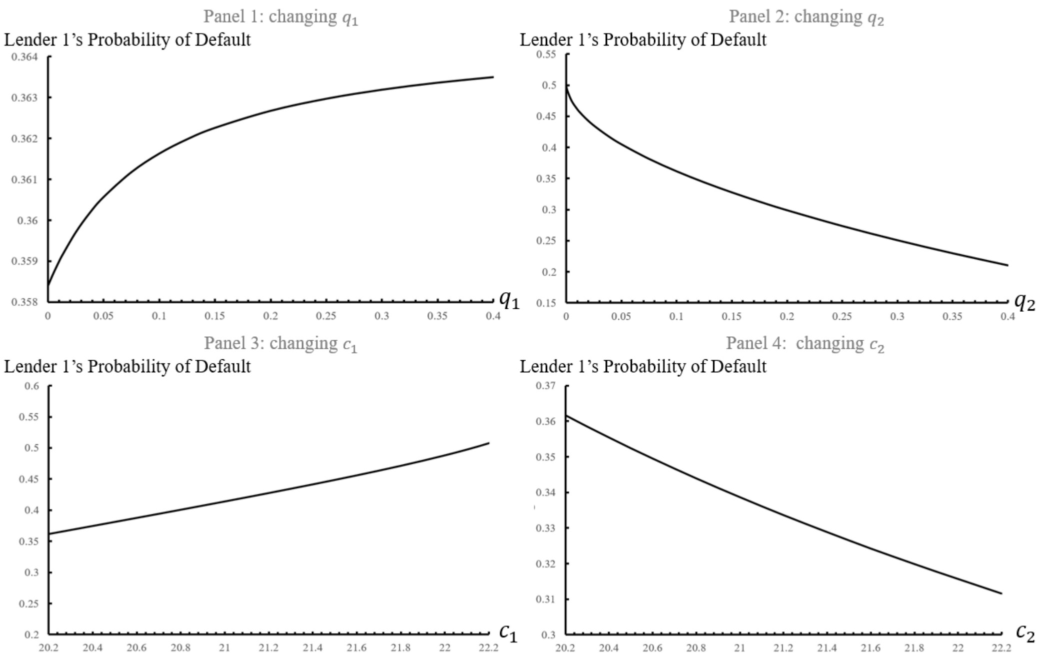

Figure 4: Lender 1's Probability of Default (w.r.t. q_i and c_i). This figure plots lender 1's probability of default against q_i and c_i in the equilibrium under direct lender competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c_1 = 1.01R$, $c_2 = 1.01R$, $q_1 = 0.1$, and $q_2 = 0.1$.

As q_2 or/and c_2 increases, lender 1 becomes more stable (Panels 2 and 4 of Figure 4). This occurs because a higher q_2 or/and c_2 decreases lender 2's competitive advantage (Corollary 3) and enables lender 1 to set higher loan rates, which increases lender 1's monitoring intensity and an entrepreneur's loan repayment in the event of success, and decreases the promised return d_1 required by investors. However, increasing q_2 or/and c_2 has a negative market area effect on lender 1's stability because the region that lender 1 serves will expand (i.e., $\tilde{x}$ will increase). That being said, this market area effect is dominated by those stability-improving effects.

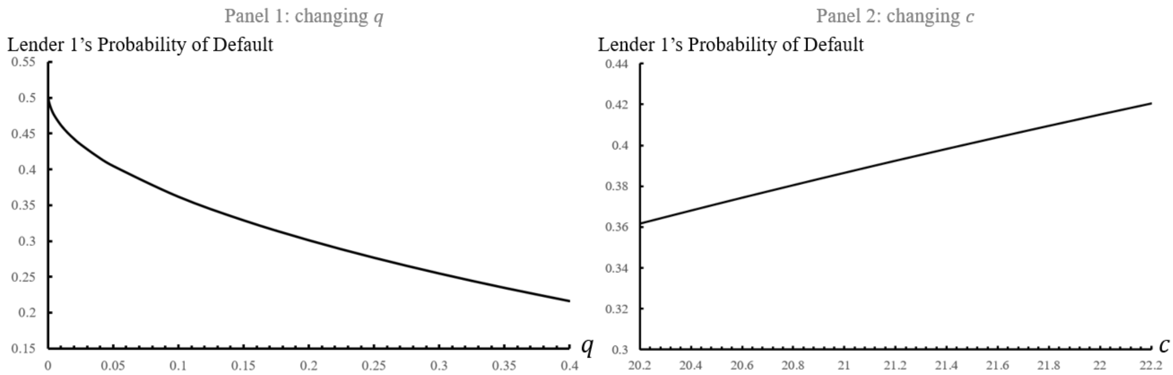

Figure 5: Lender 1's Probability of Default (w.r.t. q and c). This figure plots lender 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$ in the equilibrium under direct lender competition. Except when used as a panel's independent variable, the parameter values are $R = 20$, $f = 1$, $c = 1.01R$, and $q = 0.1$.

Letting $q_1 = q_2 = q$ and $c_1 = c_2 = c$ allows us to analyze how the development and diffusion of information technology in the entire lending sector affect lenders' stability. Although both q and c can be seen as inverse measures of IT in the lending sector, their effects on lender stability are different. Numerical studies show that lender 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 lenders; this effect tends to reduce lenders' monitoring and hence stability. Yet an increase in q increases lenders' differentiation and so makes competition less intense. As a result, both lenders can post higher loan rates (Corollary 4), which tends to enhance the stability of lenders. Here the differentiation effect of q dominates.[34] In contrast, an increase in c does not have the differentiation effect, so the direct cost effect reduces lender stability.

Lender stability when R is not large. If $R \geq \sqrt{8c_i f/(1-q_i)}$ is not satisfied (i.e., if R is not large), the net effect of IT progress on lender stability is more complex. In Appendix C, we show that a local monopoly equilibrium will arise if R is not large while q_i and c_i are sufficiently high (Proposition C.1). However, 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 lenders begin to compete. The effect of IT progress depends on (a) whether or not lenders

[34]This result is in line with Jiang et al. (2018) who document that an intensification of bank competition materially boosts bank risk by reducing bank profits, charter values, and relationship lending.

enjoy local monopolies and (b) the extent of lender competition. Figure 6 graphically illustrates how lender stability is affected by IT progress when R is not large.

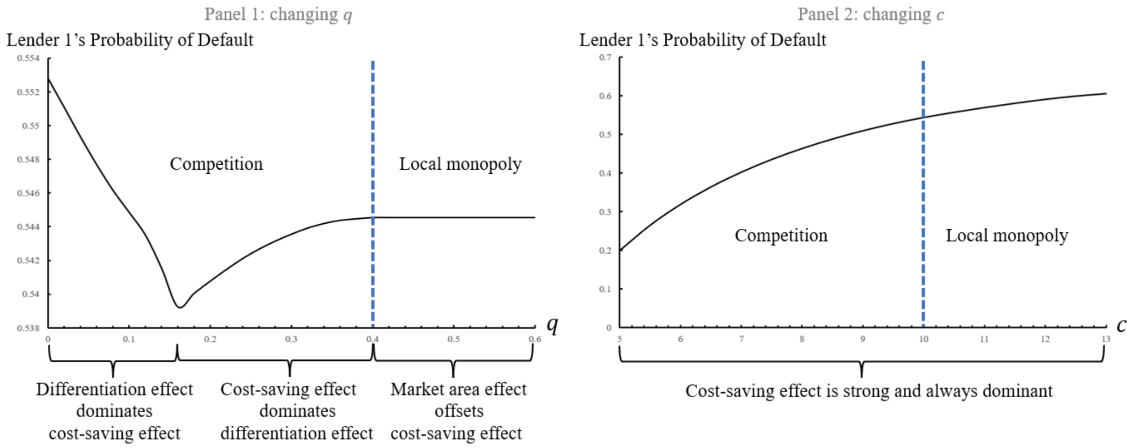

Figure 6: Lender 1's Probability of Default (w.r.t. q and c) when R is not large. This figure plots lender 1's probability of default against q and c with the restriction that $q_1 = q_2 = q$ and $c_1 = c_2 = c$. Except when used as a panel's independent variable, the parameter values are $R = 5$, $f = 1$, $c = 10$, and $q = 0.4$.

A numerical study (see Panel 1 of Figure 6) indicates that, when lenders are initially in a local monopoly equilibrium, lender 1's probability of default is at first independent of q; 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; in this local monopoly equilibrium, lender stability does not vary with q because the cost-saving effect exactly offsets the market area effect (see Proposition C.3 in Appendix C for a detailed explanation). When q declines to a certain level, the equilibrium switches to the one with lender competition (see Inequality C.2 of Appendix C). In this new equilibrium, a further reduction in q brings a differentiation effect, which tends to reduce lender stability. However, decreasing q will improve lender 1's stability when q is not small enough. This happens because then lender 1 has monopoly power over a large part of its entrepreneurs and effective competition occurs only for entrepreneurs who are located near the mid point $z = 1/2$. As a result, the (competition) differentiation effect of q is weak and the cost-saving effect dominates. However, when q is small enough, competition will be so intense that lender 1 has monopoly power over only a small fraction of its entrepreneurs; then the differentiation effect of decreasing q dominates the cost-saving effect. As a result, the net effect of decreasing q on lender stability will flip when q is small enough.[35]

[35]Comparing Panel 1 of Figure 5 and Panel 1 of Figure 6, we find that the "decrease then increase"

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 competition arises for a large group of entrepreneurs. Therefore, lender 1's probability of default is increasing in c (see Panel 2 of Figure 6).

6 Welfare analysis

In this section we analyze the social planner's problem. First we look at the relation between equilibrium loan rates and socially optimal ones. We then analyze how the development and diffusion of the lending sector's information technology affect social welfare in the direct competition equilibrium. In Appendix C, the welfare effect of IT progress in the local monopoly equilibrium is analyzed and the main results are presented in the text. Throughout the section we let $q_1 = q_2 = q$ and $c_1 = c_2 = c$, and hence use q and c to inversely measure the lending sector's IT-distance and IT-basic.

6.1 Socially optimal loan rates

If $\Omega \subseteq [0, 1]$ is the set of locations that are served and if entrepreneurs at location z are financed by lender i,[36] then social welfare is given by

$$W = \underbrace{\int_\Omega \frac{\big((R - r_i(z))m_i(z)\big)^2}{2}\,dz}_{\text{Entrepreneurs' aggregate expected utility}} + \underbrace{\int_\Omega D(z)\left(r_i(z)m_i(z) - f - \frac{c(m_i(z))^2}{2(1 - qs_i)}\right)dz}_{\text{Lenders' expected profits}} - \underbrace{(\theta_1^* + \theta_2^*)K}_{\text{Deadweight loss of lender failure}}. \quad (8)$$

Here $r_i(z)$ (resp. $m_i(z)$) is lender i's loan rate (resp. monitoring intensity) for entrepreneurs at z, $D(z)$ is the funding demand at z, θ_i^* is the probability that lender i is insolvent, and K is the deadweight loss (i.e., bankruptcy costs) associated with a lender's failure. Equation (8) divides social welfare into three components: entrepreneurs' utility,

pattern of lender 1's probability of default (as illustrated in Panel 1 of Figure 6) does not arise when R is large. The reason is that a large R ensures effective lender competition for a significant range of (or even for all) locations.

[36] We will show below that it is socially optimal that a location in Ω is served by the lender with (weakly) smaller lending distance.

lenders' profits, and the expected deadweight loss due to lenders' failure. Bankruptcy costs can be interpreted as the costs of systemic lending sector failure given that both lenders stay solvent or default together when $q_1 = q_2 = q$ and $c_1 = c_2 = c$ hold.

Second-best allocation. We consider the second-best case where the social planner can (a) determine the locations each lender serves and (b) choose the second-best socially optimal loan rate schedule of lender i, denoted by $\{r_i^{\mathrm{SB}}(z)\}$, to maximize social welfare under the constraint that lender i's monitoring intensity at z is equal to $r_i^{\mathrm{SB}}(z)(1-qs_i)/c$. In this case the social planner cannot control lenders' monitoring intensities, which hence must be as described in Lemma 1.

Proposition 7. *Let $K = 0$. At the second-best case lender i serves the same locations as in equilibrium*[37] *and the loan rate $r_i^{\mathrm{SB}}(z)$ at location z (served by lender i) 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 $R/2 < r_i^{\mathrm{SB}}(z) \leq r_i^m(z)$.[38]

Since monitoring incurs social costs, for each location it is always socially more desirable to assign the lender with better monitoring efficiency (i.e., with smaller lending distance). If there exist locations that neither lender is willing to serve in equilibrium (see Appendix C), then it means that projects in those locations cannot generate positive expected values net of monitoring and funding costs; hence the social planner will not let either lender serve such locations. Overall, the social planner will let lender i serve locations that it would serve in equilibrium.

From the perspective of social welfare, lowering $r_i^{\mathrm{SB}}(z)$ decreases lender i's incentive to monitor, which reduces the expected value of projects financed by the lender. Yet as $r_i^{\mathrm{SB}}(z)$ decreases, an entrepreneur's utility will increase (since $r_i^{\mathrm{SB}}(z) \geq R/2$), which will increase the mass of entrepreneurs undertaking investment projects. Hence a social planner must balance the social benefits (i.e., investment-spurring effect) and costs (i.e., monitoring-reducing effect) of decreasing $r_i^{\mathrm{SB}}(z)$ – here $R/2$ is one extreme loan rate, which maximizes entrepreneurs' utility and investment at z; the monopoly loan rate $r_i^m(z)$ is the other extreme, which maximizes lender i's profit and hence incentivizes the lender to choose a high monitoring intensity – leading to the relation $R/2 < r_i^{\mathrm{SB}}(z) \leq r_i^m(z)$.

[37] If there is direct competition in equilibrium, then in the second-best case lender 1 (resp. lender 2) serves the region $[0, 1/2]$ (resp. $(1/2, 1]$); if there is no competition in equilibrium (see Appendix C), then lender 1 (resp. lender 2) serves the region $[0, \frac{R^2-2cf}{qR^2}]$ (resp. $[1-\frac{R^2-2cf}{qR^2}, 1]$).

[38] The equality $r_i^{\mathrm{SB}}(z) = r_i^m(z)$ holds only when lender i's best loan rate at z is R.

In a local monopoly equilibrium, lender i's loan rate at z equals $r_i^m(z)$. Hence Proposition 7 implies that in such an equilibrium lender i's loan rates are higher than the second-best ones (except for the boundary location where $r_i^{\mathrm{SB}}(z) = r_i^m(z)$ holds). See Corollary C.3 in Appendix C for more details.

The following corollary shows how the pattern of $r_i^{\mathrm{SB}}(z)$ differs from that of lender i's competitive equilibrium loan rate.

Corollary 6. *Let $z \in [0, 1/2]$. With distance friction (i.e., $q > 0$), lender 1's second-best socially optimal loan rate $r_1^{\mathrm{SB}}(z)$ is increasing in z, while the corresponding funding demand is decreasing in z.*

This corollary means that the "perverse" pattern of a lender's competitive loan rate and lending volume is not efficient. Instead, it is socially more desirable for a lender to provide higher loan volumes to closer locations, because entrepreneurs there are cheaper to monitor. Specifically, in the region served by lender 1, the social planner would choose a lower $r_1^{\mathrm{SB}}(z)$ to stimulate more funding demand as z decreases (i.e., monitoring becomes cheaper). Under the second-best allocation, entrepreneurs closer to lender 1 benefit from the lender's higher monitoring efficiency and thereby derive higher utility; this is not the case when lender 1 determines its competitive loan rate in equilibrium.

Panel 1 of Figure 7 illustrates $r_1^{\mathrm{SB}}(z)$ and lender 1's equilibrium loan rate as z varies from 0 to 0.5. When z is sufficiently close to 0, lender 1 faces no effective threat from lender 2 and thereby offers $r_1^m(z)$, which is higher than $r_1^{\mathrm{SB}}(z)$ according to Proposition 7. With effective lender competition, lender 1's equilibrium loan rate $r_1^{\mathrm{comp}}(z)$ is decreasing in z, while $r_1^{\mathrm{SB}}(z)$ is increasing in z.

A straightforward policy implication of Corollary 6 is that regulators can guide lenders' pricing to improve allocation efficiency. If regulators have enough information, then the best policy is to set $r_i^{\mathrm{SB}}(z)$ as the reference loan rate schedule for lender i. However, regulators probably do not have precise information to provide a loan rate schedule based on z; in this case, a crude way to improve allocation efficiency is to set a uniform reference loan rate that does not vary with z but is between $r_1^{\mathrm{SB}}(z)$ and lender 1's equilibrium loan rate for any $z \in [0, 1/2]$. Such a uniform reference rate exists because $r_1^{\mathrm{SB}}(z)$ and $r_1^{\mathrm{comp}}(z)$ have different monotonicity with respect to z. Take Panel 1 of Figure 7 as an example, the intersect loan rate $r_1^{\mathrm{SB}}(z_\Delta)$ (at location z_Δ) is between $r_1^{\mathrm{SB}}(z)$ and lender 1's equilibrium loan rate for any $z \in [0, 1/2]$, so social welfare can be improved if regulators force both lenders to price at $r_1^{\mathrm{SB}}(z_\Delta)$.

Moreover, our numerical study finds that an increase in z has much lower an effect on

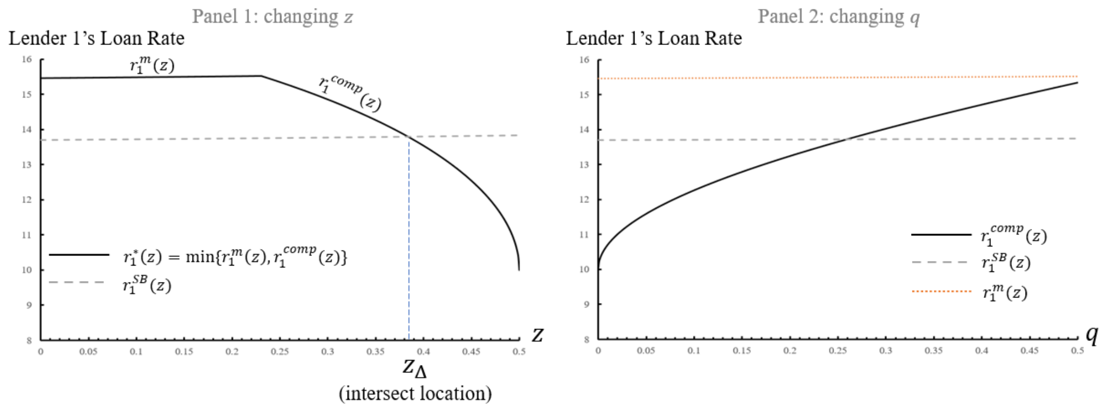

Figure 7: Comparing $r_1^{\text{comp}}(z)$, $r_1^m(z)$, and $r_1^{\text{SB}}(z)$. This figure plots $r_1^{\text{comp}}(z)$, $r_1^m(z)$, and $r_1^{\text{SB}}(z)$ against z (Panel 1) and q (Panel 2). The parameter values are: $R = 20$, $f = 1$ and $c = 1.01R$ in both panels; $q = 0.5$ in Panel 1; $z = 0.25$ in Panel 2.

$r_1^{\text{SB}}(z)$ than on $r_1^{\text{comp}}(z)$.[39] Therefore, the second-best loan rate schedule $r_1^{\text{SB}}(z)$ can be proxied by an arbitrary reference loan rate in $[r_1^{\text{SB}}(0), r_1^{\text{SB}}(1/2)]$, which provides an easier way for regulators to find an efficiency-improving reference rate. We find (see Table 3) that the social planner can improve welfare by regulating rates and forcing both lenders to price at $r_1^{\text{SB}}(0)$.

Table 3: Welfare: Equilibrium v.s. Regulated Rate at $r_1^{\text{SB}}(0)$

	$q = 0$	$q = 0.2$	$q = 0.4$
$c = 20.2$	19.7, 24.7	21.6, 22.1	18.9, 19.7
$c = 40$	3.8, 5.3	4.4, 4.6	3.9, 4.1
$c = 60$	1.4, 1.9	1.56, 1.64	1.3, 1.4

This table compares social welfare in equilibrium with that of the regulated rate at $r_1^{\text{SB}}(0)$. The numbers in a cell are social welfare levels: equilibrium, regulated. The other parameters are $R = 20$ and $f = 1$.

Next we provide an analytical result in relation to Panel 2 of Figure 7.

Proposition 8. *Let $K = 0$. If $R > \sqrt{2cf}$ and if location z is served by lender i, then the inequality $r_i^{\text{comp}}(z) < r_i^{\text{SB}}(z)$ holds for all locations when q is small enough.*[40]

Proposition 8 states that the intensity of lender competition will be too high when q (the differentiation between lenders) is sufficiently low. Entrepreneurs will be better-off as

[39] Because the effect of z on $r_1^{\text{SB}}(z)$ is quite small, the curve of $r_1^{\text{SB}}(z)$ looks like a horizontal line in Panel 1 of Figure 7.

[40] If $R > \sqrt{2cf}$, then there is always effective competition at z when q is small enough. In the boundary case $R = \sqrt{2cf}$, lender i must set its loan rate to R – even when $q = 0$ – in order to ensure itself a non-negative profit; then we always have $r_i^{\text{comp}}(z) = r_i^{\text{SB}}(z) = r_i^m(z) = R$ at locations served by lender i.

the intensity of lender competition increases, which will increase the mass of entrepreneurs undertaking investment projects; but low differentiation can hurt lenders and reduce their monitoring intensities, thereby decreasing the expected value of financed projects.[41] When q is low enough, the monitoring-reducing effect dominates the investment-spurring effect, so the equilibrium loan rate is lower than the socially optimal one. Figure 8 illustrates the relation between $r_1^{\text{comp}}(z)$ and $r_1^{\text{SB}}(z)$ in $z \times q$ space.

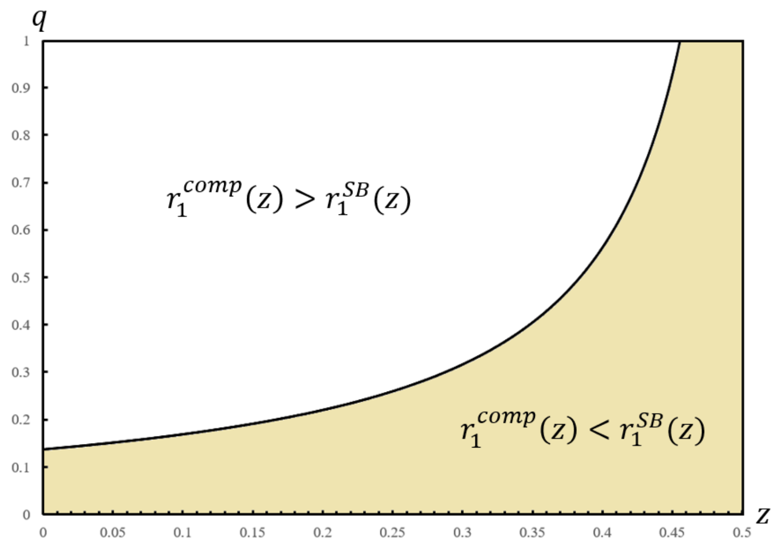

Figure 8: Relations between $r_1^{\text{comp}}(z)$ and $r_1^{\text{SB}}(z)$ in $z \times q$ space. This figure compares $r_1^{\text{comp}}(z)$ with $r_1^{\text{SB}}(z)$ in $z \times q$ space. The parameter values are $R = 20$, $c = 1.01R$, and $f = 1$.

First-best allocation. In Online Appendix D we consider the first-best case where the social planner not only determines lenders' loan rates but also controls their monitoring intensities. Since the social planner need not use loan rates to incentivize lenders' monitoring, the first-best loan rates are lower than the second-best ones (Proposition D.2). When q is sufficiently small, $r_1^{\text{comp}}(z)$ is lower than the first-best loan rate at z because the latter must be high enough to prevent excessive investment (Proposition D.3).

6.2 Welfare properties of the symmetric equilibrium

We analyze the welfare effects of information technology progress for the case of large R (which ensures direct competition).

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

Figure 9 shows how entrepreneurs' utility, lenders' profits, and social welfare vary with q and c. A decrease in q will increase the intensity of lending competition because differentiation will be diminished (Corollary 4). Greater lender competition (together with higher monitoring efficiency) translates into lenders providing higher entrepreneurial utility, which spurs investment. So as can be seen in Panels 1 and 2 of Figure 9, entrepreneurial utility increases if q decreases. From the lenders' perspective, reducing q has two opposing effects: a cost-saving effect since monitoring is cheaper and a differentiation effect which implies more intense competition, with an ambiguous net effect on profits. When q is not small, the cost-saving effect dominates and so decreasing q increases lenders' profits. When q is small enough, however, the differentiation effect dominates and hence reducing q decreases lenders' profits (see Proposition 2). Perhaps more surprising is the following proposition, which shows that decreasing q reduces social welfare for q small enough, even if lender failure incurs no social costs (i.e., if $K = 0$; see Panel 1 of Figure 9).

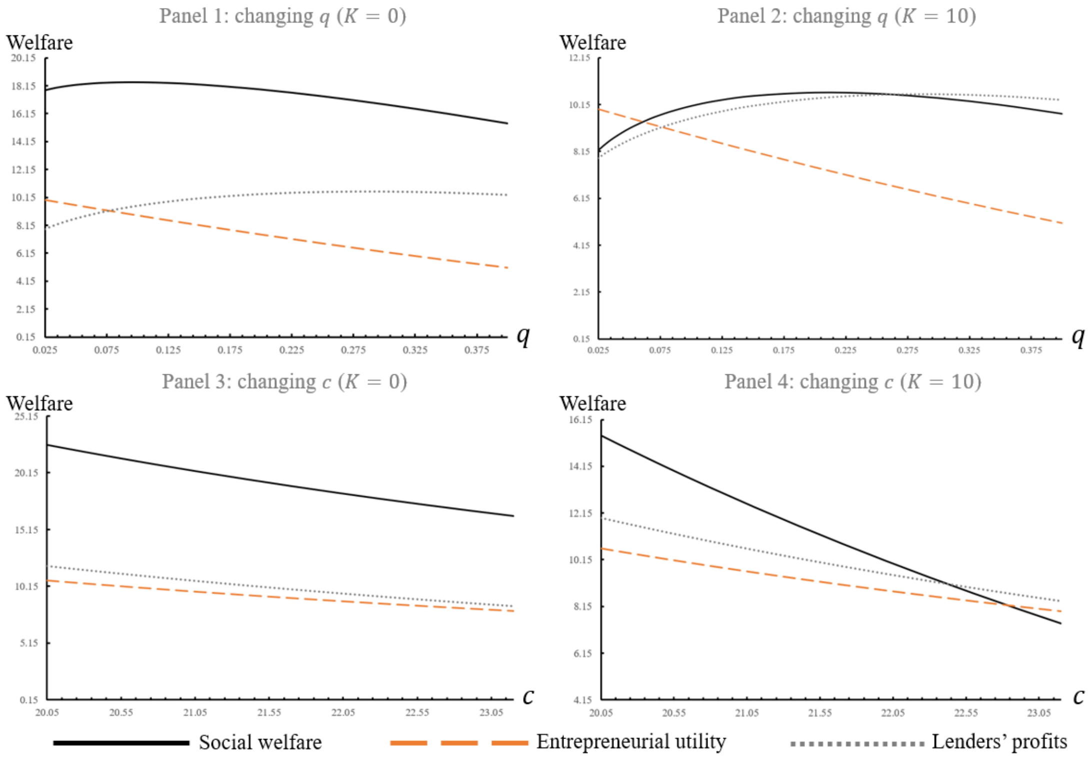

Figure 9: Social Welfare and Lending Sector's Information Technology under Competition. This figure plots social welfare, entrepreneurial utility, and lenders' profits against c and q in the equilibrium under lender competition. The parameter values are: $R = 20$ and $f = 1$ in all panels; $c = 22$ in 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.

Proposition 9. *Let $K = 0$. Social welfare is increasing in q if q is sufficiently small while it is decreasing in c.*

Lenders' loan rates will be excessively low when competition is very intense (i.e., when q is small enough; Proposition 8). Then decreasing q reduces social welfare because a lower lenders' monitoring effort dominates the cost-saving and investment-spurring effects.

Panel 1 of Figure 9 gives a graphic illustration on how q affects social welfare when $K = 0$. 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 lenders' failure. Since a higher intensity of lender competition increases lenders' probability of default, it follows that the socially optimal level of q is higher when K is positive than when $K = 0$ (see Panel 2 of Figure 9).

The second part of Proposition 9 shows that decreasing c improves social welfare when $K = 0$ (see Panel 3 of Figure 9) since it has no effect on lender differentiation (Corollary 4). If $K > 0$, the welfare-improving effect of decreasing c will be strengthened (see Panel 4 of Figure 9) because decreasing c enhances lender stability.

In short: although reducing q (i.e., improving IT-distance) and reducing c (i.e., improving IT-basic) 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 IT involved. However, in a local monopoly equilibrium lenders do not compete with each other, and a decrease in q or/and c brings only a cost-saving effect, thereby improving social welfare (see Proposition C.4 in Appendix C).

The effect of IT investment costs. Finally we take into consideration the IT investment cost $T(q, c)$ when analyzing the welfare effect of changing q and c.

IT is cheap. In this case $q = 0$ and $c = \underline{c}$ arises endogenously (Proposition 5). According to Proposition 9, the monitoring-reducing effect will dominate the cost-saving and investment-spurring effects when q is sufficiently small, so lenders' endogenous IT investment will induce an excessively low level of differentiation (i.e., too low a q) from the social point of view. Taking IT investment costs into consideration strengthens the negative effect of decreasing q (Panel 1 of Figure 10).

As for IT-basic, note that the cheap IT condition (6) does not restrict the marginal cost of decreasing c, so $c = \underline{c}$ (which is lenders' endogenous choice) will be lower than the socially optimal level if $\lim_{c \to \underline{c}} \partial T(q, c)/\partial c \leq 0$ is low enough. The reason is that the marginal benefit (cost-saving effect) of decreasing c is always finite from the social planner's perspective. Panel 2 of Figure 10 gives an example in which $c = \underline{c}$ is excessively low; in this figure $\lim_{c \to \underline{c}} \partial T(q,c)/\partial c = -\infty$.

The cheap-IT scenario can arise for example if information technology is highly advanced in non-financial sectors and then it spills over the lending sector.

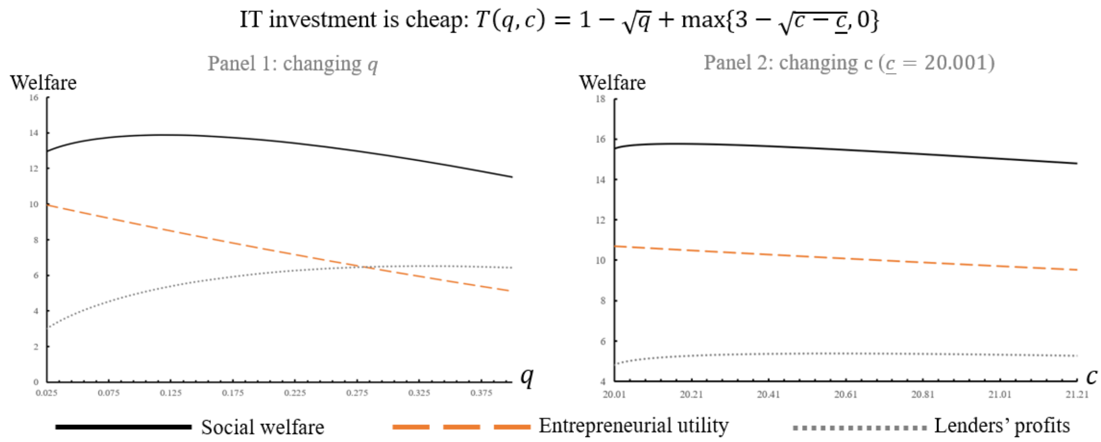

Figure 10: Social Welfare and Lending Sector's Information Technology with Competition and Cheap IT. This figure plots social welfare, entrepreneurial utility, and lenders' profits against c and q in the equilibrium with lender competition and cheap IT. The parameter values are: $R = 20$, $K = 0$ and $f = 1$ in both panels; $c = 22$ in Panel 1; $q = 0.1$ in Panel 2.

IT is not cheap. As in Section 4, we focus on the case that $\partial T(q,c)/\partial q = 0$ (resp. $\partial T(q,c)/\partial c = 0$) for $q \geq \overline{q}$ (resp. $c \geq \overline{c}$), meaning that lender i need only consider information technology that satisfies $q_i \times c_i \in [0, \overline{q}] \times [\underline{c}, \overline{c}]$. Under the assumptions in Lemma A.2, there exists a unique symmetric interior IT investment equilibrium, for which we have the following result.

Proposition 10. *Let $K = 0$, the assumptions of Lemma A.2 hold, and $T(q,c)$ be submodular. If $\overline{q}$ is sufficiently small, then $q_i = q^*$ and $c_i = c^*$ (i.e., lenders' IT-distance and IT-basic choices in the unique symmetric interior equilibrium) are excessively low from the social planner's perspective.*

A lender and the social planner have different marginal benefits of IT investment. A lender cares only about its own profit, so its marginal benefit of IT investment consists of a cost-saving effect on monitoring and a *business stealing effect*. The latter means that by adopting better IT the lender will have a higher competitive advantage and erode the rival lender's profit. In contrast, the social planner cares about entrepreneurial utility and both lenders' profits, so it does not value the business stealing effect.

Because of the cost-saving and business stealing effects, investing in IT always has a positive marginal benefit for a lender, so q^* is always lower than $\overline{q}$ no matter how small $\overline{q}$ is. For the social planner, however, the marginal benefit of decreasing q will turn negative when q is sufficiently small (Proposition 9). Hence q^* must be excessively low from the social planner's perspective when $\overline{q}$ is sufficiently small.

With sufficiently low $\overline{q}$ (and hence low q^*), lenders' endogenous IT investment will induce a very low level of differentiation, giving rise to a very strong business stealing effect: A lender's small improvement in IT-basic will increase the lender's profit by a lot (through eroding the rival's market share).[42] Such a large business stealing effect gives lender i quite a strong incentive to reduce c_i, which leads to an excessively low c^* from the social planner's perspective if $T(q, c)$ is submodular (i.e., if a lower q does not increase the marginal cost of decreasing c).

Remark (local monopoly equilibrium): In this case investing in IT, whatever its type, has a higher marginal benefit for the social planner than for a lender, because a lender does not internalize that higher monitoring efficiency also benefits entrepreneurs. Therefore, lenders' endogenous IT investment will lead to excessively high q and c from the social planner's perspective if $T(q, c)$ is submodular.

7 Conclusion

Our study shows that whether the development of information technology intensifies lender competition depends on its impact on differentiation. If IT progress in the lending sector is of type IT-basic – reducing the costs of monitoring an entrepreneur without altering lenders' relative cost advantage (i.e., lower c) – then neither differentiation nor competition among lenders is affected; hence lenders will be more profitable and more stable. Yet, if the industry's IT progress is of type IT-distance – weakening the influence of lender–entrepreneur distance on monitoring costs (i.e., lower q) – then differentiation among lenders will decrease, competition will become more intense, and lenders may become less profitable and less stable (Proposition 2 and Figure 5). We should 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 have the testable

[42] An extreme example is the case where $\overline{q}$ (and hence q^*) approach 0. In this case lender differentiation almost disappears, so lender 1 can gain a lot of market share if it slightly decreases c_1 (from $c_1 = c_2 = c^*$), which implies that the business stealing effect is nearly infinitely strong for the lender.

implication that a technologically more advanced lender – regardless of how changes in IT affect lender differentiation – lends to more industries/locations, commands greater market power and is more stable (Proposition 1 and Figure 4). We find also that in locations (or industries) with effective lender competition (proxied by low lender concentration), a lender's loan rate will increase after the lender's IT improves relative to other lenders' (Corollaries 1 and 3), while if the lender has monopoly power IT improvements will decrease its loan rate.

In our model, the equilibrium consequences of one lender's IT improvement are quite different from those of the entire lending sector's IT improvement. For example, a lender adopting better IT increases its loan rates, while both lenders' loan rates will decrease if the lending sector's IT-distance improves. The reason of the difference is that an IT improvement of a lender affects not only itself but also the other lender's behavior, a competitive spillover effect. Our model highlights that caution is necessary when using diff-in-diff methods in empirical research on technological progress.[43]

How lenders endogenously choose their IT investment depends on the acquisition cost of IT. If it is cheap enough, then lenders will acquire the best possible IT (i.e., $q_1 = q_2 = 0$ and $c_1 = c_2 = \underline{c}$) in an attempt to obtain all the market, resulting in no lender differentiation and hence extremely intense competition (Proposition 5). If IT is not so cheap, then the two types of IT will co-move in response to a cost shock when a unique interior symmetric equilibrium exists (Proposition 6). The testable implication then is that investment in different types of IT are complements. Furthermore, IT investments of a bank and a fintech tend to be strategic complements.

We find that the welfare effect of information technology progress is ambiguous when it is of type IT-distance. On the one hand, higher competition intensity and better IT always favor entrepreneurs and spur their investment (Proposition 4); on the other hand, lower lender differentiation can reduce lenders' monitoring and profits (and increase expected bankruptcy costs). Whether or not an improvement in lenders' IT-distance 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 (Proposition 9). This is always the case when information technology is cheap because then lenders choose endogenously a very low q. However, if lenders enjoy local monopolies in equilibrium, then IT progress has no (competition) differentiation effect; in this case lenders' IT investment is inefficiently low because they cannot internalize the benefit of IT improvement on entrepreneurs.

[43]Berg et al. (2021) analyze the spillover-induced bias and provide guidance on how to deal with it.

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Appendix A: Proofs

Proof of Equation (4). Let Ω_1 denote the set of locations served by lender 1. When the common risk factor is θ, the aggregate loan repayment lender 1 receives from entrepreneurs is equal to $\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz$, which is (weakly) increasing in θ. Meanwhile the lender must raise $\int_{z\in\Omega_1} D(z)\,dz$ units of funding from investors to finance its loans. Thus the lender must promise to pay back $d_1\int_{z\in\Omega_1} D(z)\,dz$ (here d_1 is endogenous). Then when θ is small enough, the lender cannot fully pay back the promised return to investors.

Let θ_1^* denote the cut-off risk factor such that the lender can fully pay back investors if and only if $\theta\geq\theta_1^*$. Then the lender's expected aggregate lending profit is

$$AP_1=\begin{pmatrix} \int_{\theta_1^*}^1\left(\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz-d_1\int_{z\in\Omega_1} D(z)\,dz\right)\,d\theta \\ -\int_{z\in\Omega_1} D(z)C_1\left(m_1\left(z\right),z\right)\,dz \end{pmatrix}.$$

Since the value of d_1 must ensure that the expected return to investors is f for each unit of funding, we must have the following equation:

$$\int_0^{\theta_1^*}\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz\,d\theta+\int_{\theta_1^*}^1\int_{z\in\Omega_1} d_1D(z)\,dzd\theta=f\int_{z\in\Omega_1} D(z)\,dz. \quad \text{(A.1)}$$

The intuition behind (A.1) is the same as that of the participation condition of Equation (A.6), which explained below Lemma A.3. Inserting (A.1) into AP_1 to cancel d_1, we can show that

$$AP_1=\int_{z\in\Omega_1} D(z)\underbrace{\left(r_1(z)m_1\left(z\right)-f-C_1\left(m_1\left(z\right),z\right)\right)}_{\pi_1(z)}dz$$

because $\int_0^1\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dzd\theta=\int_{z\in\Omega_1} D(z)r_1(z)m_1\left(z\right)\,dz$ holds. Therefore, the lender's profit from financing an entrepreneur at z is given by Equation (4).

Proof of Lemma 1. Taking $r_1(z)$ as given, maximizing $\pi_1(z)\equiv r_1(z)\,m_1(z)-\frac{c_1}{2(1-q_1z)}\left(m_1\left(z\right)\right)^2-f$ by choosing $m_1(z)$ directly yields the following first order condition:

$$r_1\left(z\right)-\frac{c_1}{(1-q_1z)}m_1\left(z\right)=0\Longrightarrow m_1\left(z\right)=\frac{(1-q_1z)r_1\left(z\right)}{c_1}.$$

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

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

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

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

Proof of Lemma A.1. If lender 1 faces no competition, then it will choose $r_1(z)$ to maximize its expected profit from location z; such profit is equal to

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

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 lender 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:

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

It is clear that $h(-\infty) \to +\infty$, $h(0) = -Rf < 0$ and $h\left(\frac{R}{2}\right) = \frac{\left(\frac{R}{2}\right)^2 R(1-q_1 z)}{2c_1} > 0$. Therefore, within $(-\infty, 0)$ and $\left(0, \frac{R}{2}\right)$, there exist two roots for $h(r_1(z)) = 0$. However, those two roots cannot be the profit maximizing loan rate of lender 1 because we have shown that no lender would offer a loan rate that is lower than $R/2$ (see Lemma 2).

We can further show that $h(+\infty) \to -\infty$. So there must exist a third root, denoted by r^{3rd}, within $\left(\frac{R}{2}, +\infty\right)$. If lender 1 finds it profitable to finance entrepreneurs at z, then r^{3rd} must be no larger than R, because total finding demand and lender 1's profit will be negative at location z if the lender offers a loan rate that is higher than R, which is never optimal for the lender. As a consequence, r^{3rd}, which must be within $\left(\frac{R}{2}, R\right]$, is the solution that maximizes lender 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. Because the two lenders compete in a localized Bertrand fashion, both lenders 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 $\tilde{x}$:

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

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

At location $z\in[0,\tilde{x}]$, lender 1 must offer a loan rate $r_1\left(z\right)$ 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 $(R/2)$ of lender 2. If lender 1 has no monopoly power on the entrepreneur, then lender 1's optimal choice is to set $r_1\left(z\right)$ as high as possible; this implies the following equation:

$$\left(R-r_1\left(z\right)\right)\frac{r_1\left(z\right)\left(1-q_1z\right)}{c_1}-\underline{u}=\left(R-\frac{R}{2}\right)\frac{\frac{R}{2}\left(1-q_2(1-z)\right)}{c_2}-\underline{u}.$$

The equation yields $r_1\left(z\right)=r_1^{\text{comp}}(z)$. However, if $r_1^{\text{comp}}(z)$ is higher than lender 1's monopoly loan rate $r_1^m(z)$, then lender 1 has monopoly power on entrepreneurs at z. In this case, lender 1 will simply choose $r_1^m(z)$ as its loan rate. Therefore, lender 1's pricing strategy is $r_1^*\left(z\right)=\min\left\{r_1^{\text{comp}}(z),r_1^m(z)\right\}$ for entrepreneurs located in $[0,\tilde{x}]$. Similarly, we can derive lender 2's equilibrium loan rate $r_2^*\left(z\right)$.

Proof of Corollary 2. If there is effective competition between lenders at z, the loan volume provided by lender 1 to entrepreneurs at $z\in[0,\tilde{x}]$ is $D\left(z\right)=(R-r_1^{\text{comp}}(z))m_1(z)$.We can show that $D\left(z\right)=\frac{(1-q_2(1-z))R^2}{4c_2}$, which is increasing in $z\in[0,\tilde{x}]$ when $q_2>0$. In the same way, we can show that the loan volume provided by lender 2 to entrepreneurs at $z\in(\tilde{x},1]$ is decreasing in z when $q_1>0$.

Proof of Corollary 5. With effective lender competition, obviously $m_i(z)$ is decreasing in c because $r_i^{\text{comp}}(z)$ is independent of c. For the effect of q, we focus on lender 1's monitoring intensity $m_1(z)$ for convenience. In equilibrium, we can show that

$$\frac{\partial m_1(z)}{\partial q}=R\left(\frac{\sqrt{\frac{q(1-2z)}{1-qz}}}{4cq}-\frac{z\left(1+\sqrt{\frac{q(1-2z)}{1-qz}}\right)}{2c}\right).$$

If $z = 1/2$, then $\partial m_1(z)/\partial q = -R/(4c) < 0$. If $z \in [0, 1/2)$, then $\lim_{q \to 0} \partial m_1(z)/\partial q = +\infty$. Therefore, $m_1(z)$ is increasing in q (except for $z = 1/2$) if q is sufficiently small.

Proof of Proposition 2. We need only look at lender 1's aggregate profit because the two lenders are symmetric. If lender 1 has monopoly power in the region $[0, x^m] \subset [0, 1/2]$, then its aggregate profit (denoted by AP_1) is given by

$$AP_1 \equiv \int_0^{x^m} D(z) \left(\frac{(r_1^m(z))^2 (1 - qz)}{2c} - f \right) dz + \int_{x^m}^{1/2} D(z) \left(\frac{(r_1^{\text{comp}}(z))^2 (1 - qz)}{2c} - f \right) dz.$$

We can show that

$$\frac{\partial AP_1}{\partial c} = \left(\begin{array}{c} \int_0^{x^m} \frac{\partial \left(D(z) \left(\frac{(r_1^m(z))^2 (1-qz)}{2c} - f \right) \right)}{\partial c} dz + \int_{x^m}^{1/2} \frac{\partial \left(D(z) \left(\frac{(r_1^{\text{comp}}(z))^2 (1-qz)}{2c} - f \right) \right)}{\partial c} dz \\ + \left(D(x^m) \left(\frac{(r_1^m(x^m))^2 (1-qx^m)}{2c} - f \right) - D(x^m) \left(\frac{(r_1^{\text{comp}}(x^m))^2 (1-qx^m)}{2c} - f \right) \right) \frac{\partial x^m}{\partial c} \end{array} \right).$$

The third term of $\partial AP_1/\partial c$ is equal to 0 because at location $z = x^m$, $r_1^m(x^m)$ is equal to $r_1^{\text{comp}}(x^m)$. Therefore, the sign of $\partial AP_1/\partial c$ depends on the signs of its first two terms. Obviously we have $\partial \left(D(z) \left(\frac{(r_1^m(z))^2 (1-qz)}{2c} - f \right) \right) / \partial c < 0$ because lender 1's monopoly profit at z must be lower when monitoring is more costly. Meanwhile, we can also show that $\partial \left(D(z) \left(\frac{(r_1^{\text{comp}}(z))^2 (1-qz)}{2c} - f \right) \right) / \partial c < 0$ because $D(z) = \frac{(1-q(1-z))R^2}{4c}$ is decreasing in c (see the proof of Corollary 2) while $r_1^{\text{comp}}(z)$ is independent of c when $z \in (x^m, 1/2]$. Therefore, we have $\partial AP_1/\partial c < 0$; lender 1's aggregate profit is decreasing in c.

Next we look at the effect of q. If q is small enough, lender competition is effective at all locations (i.e., $x^m = 0$). In this case, we can show that

$$\frac{\partial AP_1}{\partial q} = \int_0^{1/2} \left(\frac{R^4 \sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} + \mu_b(q, c, z) \right) dz,$$

where $\mu_b(q, c, z)$ is a term that is finite for $q \to 0$. For $z < 1/2$, it is easy to show $\lim_{q \to 0} \frac{R^4 \sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} \to +\infty$. If $z = 1/2$, we have $\frac{R^4 \sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} = 0$. Therefore, we must have $\lim_{q \to 0} \frac{\partial AP_1}{\partial q} \to +\infty$. As a result, lender 1's aggregate profit is increasing in q if q is sufficiently small.

Proof of Proposition 3. First we calculate $\frac{\partial L_1}{\partial q_1}$ and $\frac{\partial L_1}{\partial c_1}$. A symmetric result holds for lender 2. If lender 1 has monopoly power in the region $[0, x^m] \subset [0, \tilde{x}]$, then

$$L_1 = \int_0^{x^m} \frac{(1 - q_1 z) r_1^m(z) (R - r_1^m(z))}{c_1} dz + \int_{x^m}^{\tilde{x}} \frac{(1 - q_2(1 - z)) R^2}{4c_2} dz.$$

If $x^m = 0$, then obviously $\frac{\partial L_1}{\partial q_1} < 0$ and $\frac{\partial L_1}{\partial c_1} < 0$ hold because $\frac{\partial \tilde{x}}{\partial q_1} < 0$ and $\frac{\partial \tilde{x}}{\partial c_1} < 0$ hold. If $\tilde{x} > x^m > 0$, then

$$\frac{\partial L_1}{\partial q_1} = \int_0^{x^m} \frac{\partial \left(\frac{(1-q_1 z) r_1^m(z) \left(R - r_1^m(z)\right)}{c_1} \right)}{\partial q_1} dz + \underbrace{\frac{\left(1 - q_2(1-\tilde{x})\right) R^2}{4c_2} \frac{\partial \tilde{x}}{\partial q_1}}_{<0} \tag{A.3}$$

because $r_1^m(x^m) = r_1^{\text{comp}}(x^m)$. According to Equation (A.2), $r_1^m(z)$ is increasing in q_1 for $z > 0$; an increase in $q_1 z$ will make $h\left(r_1^m(z)\right)$ positive, so $r_1^m(z)$ must increase to keep $h\left(r_1^m(z)\right) = 0$ holding. Hence the first term of Equation (A.3) is negative. Therefore $\frac{\partial L_1}{\partial q_1} < 0$ must hold. In the same way, we can show that $\frac{\partial L_1}{\partial c_1} < 0$ holds.

Proof of Proposition 4. When $q_i = q$ and $c_i = c$, we must have $L_1 = L_2$ and $\tilde{x} = 1/2$, so we need only calculate $\frac{\partial L_1}{\partial q}$ and $\frac{\partial L_1}{\partial c}$. If lender 1 has monopoly power in the region $[0, x^m] \subset [0, \tilde{x}]$, then

$$L_1\big|_{q_i=q, c_i=c} = \int_0^{x^m} \frac{(1-qz)\, r_1^m(z) \left(R - r_1^m(z)\right)}{c} dz + \int_{x^m}^{1/2} \frac{\left(1 - q(1-z)\right) R^2}{4c} dz.$$

If $x^m = 0$, then obviously $\frac{\partial L_1}{\partial q} < 0$ and $\frac{\partial L_1}{\partial c_1} < 0$ hold because $\frac{(1-q(1-z))R^2}{4c}$ is decreasing in q and c. If $\tilde{x} > x^m > 0$, then

$$\frac{\partial L_1}{\partial c} = \int_0^{x^m} \frac{\partial \left(\frac{(1-qz) r_1^m(z) \left(R - r_1^m(z)\right)}{c} \right)}{\partial c} dz + \underbrace{\int_{x^m}^{1/2} \frac{\partial \left(\frac{(1-q(1-z))R^2}{4c} \right)}{\partial c} dz}_{<0} \tag{A.4}$$

because $r_1^m(x^m) = r_1^{\text{comp}}(x^m)$. According to Equation (A.2), $r_1^m(z)$ is increasing in c; an increase in c will make $h\left(r_1^m(z)\right)$ positive, so $r_1^m(z)$ must increase to keep $h\left(r_1^m(z)\right) = 0$ holding. Hence the first term of Equation (A.4) is negative. Therefore $\frac{\partial L_1}{\partial c} < 0$ must hold. In the same way, we can show that $\frac{\partial L_1}{\partial q} < 0$ holds.

Proof of Proposition 5. In the main text we have already shown that $q_1 = q_2 = 0$ and $c_1 = c_2 = \underline{c}$ indeed constitute an equilibrium. Here we show that the equilibrium is unique.

First, we show that $\{q_2 = 0, c_2 = \underline{c}\}$ and $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ cannot be an equilibrium. If lender 2 chooses $\{q_2 = 0, c_2 = \underline{c}\}$, then lender 1's best response must be $\{q_1 = 0, c_1 = \underline{c}\}$, in which case lender 1's ex ante profit is $\Pi_1\left(0, 0, \underline{c}, \underline{c}\right) > 0$. In contrast, if lender 1's IT choice is not $\{q_1 = 0, c_1 = \underline{c}\}$, then lender 1's market share must be 0, which means

$$\Pi_1 (q_1, 0, c_1, \underline{c})|_{q_1>0 \text{ or } c_1>\underline{c}} = -T(q_1, c_1) \leq 0.$$

Therefore, $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ cannot be lender 1's best choice. Overall, $\{q_2 = 0, c_2 = \underline{c}\}$ and $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ cannot be an equilibrium. Reasoning symmetrically, $\{q_1 = 0, c_1 = \underline{c}\}$ and $\{q_2 > 0 \text{ or } c_2 > \underline{c}\}$ cannot be an equilibrium either.

Next, we show that $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ and $\{q_2 > 0 \text{ or } c_2 > \underline{c}\}$ cannot be an equilibrium. In this case, we can show that lender 1 (resp. lender 2) has incentive to deviate if $\tilde{x} \leq 1/2$ (resp. $\tilde{x} \geq 1/2$). If $\tilde{x} \leq 1/2$, then lender 1's market share will increase from $\tilde{x}$ to 1 if the lender deviates from $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ to $\{q_1 = 0, c_1 = \underline{c}\}$; the cost of this deviation is no higher than $T(0, \underline{c})$, while the lender's profit from the incremental market area $(\tilde{x}, 1]$ must satisfy

$$\int_{\tilde{x}}^{1} D(z)\pi_1(z)dz\bigg|_{q_1=0, c_1=\underline{c};\ q_2>0 \text{ or } c_2>\underline{c}} > \int_0^{1/2} D(z)\pi_1(z)dz\bigg|_{q_1=q_2=0, c_1=c_2=\underline{c}}.$$

because $\tilde{x} \leq 1/2$. Meanwhile, lender 1's profit from its initial market area $[0, \tilde{x}]$ will also (weakly) increase as the lender deviates to $\{q_1 = 0, c_1 = \underline{c}\}$. Overall, because of the deviation, lender 1's profit at the lending competition stage will increase by more than $\int_0^{1/2} D(z)\pi_1(z)dz\Big|_{q_1=q_2=0, c_1=c_2=\underline{c}}$, while the IT investment cost will increase by no more than $T(0, \underline{c})$. Then, because we have the condition

$$\Pi_1 (0, 0, \underline{c}, \underline{c}) = \int_0^{1/2} D(z)\pi_1(z)dz\bigg|_{q_1=q_2=0, c_1=c_2=\underline{c}} - T(0, \underline{c}) > 0,$$

lender 1 will become strictly better off if it deviates to $\{q_1 = 0, c_1 = \underline{c}\}$. Therefore, if $\tilde{x} \leq 1/2$, $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ and $\{q_2 > 0 \text{ or } c_2 > \underline{c}\}$ cannot be an equilibrium.

Reasoning symmetrically, $\{q_1 > 0 \text{ or } c_1 > \underline{c}\}$ and $\{q_2 > 0 \text{ or } c_2 > \underline{c}\}$ cannot be an equilibrium if $\tilde{x} \geq 1/2$ because then lender 2 can be strictly better off by deviating to $\{q_2 = 0, c_2 = \underline{c}\}$. Overall, the unique equilibrium is $\{q_1 = 0, c_1 = \underline{c}\}$ and $\{q_2 = 0, c_2 = \underline{c}\}$ if we have the condition $\Pi_1 (0, 0, \underline{c}, \underline{c}) > 0$.

Lemma A.2. *Assume: (a) $\partial T(q_i, c_i)/\partial q_i$ and $\partial T(q_i, c_i)/\partial c_i$ are continuous functions; (b) $\overline{q}$ and $\overline{c}$ are sufficiently small; (c) $\lim_{q_i \to 0} -q_i \partial T(q_i, c_i)/\partial q_i$ (resp. $-c_i \partial T(q_i, c_i)/\partial c_i|_{c_i=\underline{c}}$) is large enough for any $c_i \in [\underline{c}, \overline{c})$ (resp. for any $q_i \in [0, \overline{q})$); (d) $-q_i \frac{\partial^2 T(q_i,c_i)/\partial q_i^2}{\partial T(q_i,c_i)/\partial q_i}$ and*

$-c_i \frac{\partial^2 T(q_i,c_i)/\partial c_i^2}{\partial T(q_i,c_i)/\partial c_i}$ *are large enough for* $q_i \times c_i \in (0,\overline{q}) \times [\underline{c},\overline{c})$*. Then there exists a unique symmetric interior IT investment equilibrium:* $q_i = q^* \in (0,\overline{q})$ *and* $c_i = c^* \in (\underline{c},\overline{c})$*.*

Proof of Lemma A.2. Here we provide a sketch for the proof. See Online Appendix E for a detailed proof of Lemma A.2.

In a symmetric equilibrium, the first order conditions of lender 1 w.r.t q_1 and c_1 are respectively given by:

$$\left.\frac{\partial \Pi_1}{\partial q_1}\right|_{q_i=q,c_i=c} = 0 \text{ and } \left.\frac{\partial \Pi_1}{\partial c_1}\right|_{q_i=q,c_i=c} = 0. \tag{A.5}$$

Since $\partial T(q,c)/\partial q = 0$ when $q \geq \overline{q}$ and $\lim_{q\to 0} -q\partial T(q,c)/\partial q$ is large enough, there must exist a $q^*(c) \in (0,\overline{q})$ that solves $\left.\frac{\partial \Pi_1}{\partial q_1}\right|_{q_i=q,c_i=c} = 0$ for any $c \in [\underline{c},\overline{c}]$. The assumption that $-q\frac{\partial^2 T(q,c)/\partial q^2}{\partial T(q,c)/\partial q}$ is large enough for $q < \overline{q}$ ensures that such $q^*(c)$ is unique. Meanwhile, since $\frac{\partial T(q,c)}{\partial c} = 0$ for $c \geq \overline{c}$ and $-c\partial T(q,c)/\partial c$ is large enough when $c = \underline{c}$, there must exist a $c^* \in (\underline{c},\overline{c})$ that solves $\left.\frac{\partial \Pi_1}{\partial c_1}\right|_{q_i=q^*(c),c_i=c} = 0$. The assumption that $-c\frac{\partial^2 T(q,c)/\partial c^2}{\partial T(q,c)/\partial c}$ is large enough for $c < \overline{c}$ ensures that such c^* is unique. Therefore, the unique solution to (A.5) is $\{q_i = q^*(c^*), c_i = c^*\}$.

In a similar way, we can show that $\{q_1 = q^*(c^*), c_1 = c^*\}$ is the unique solution to lender 1's first order condition given that lender 2 chooses $\{q_2 = q^*(c^*), c_2 = c^*\}$, so $\{q_i = q^*(c^*), c_i = c^*\}$ indeed constitutes an equilibrium.

Proof of Proposition 6. See Lemma A.2 for the existence of a unique symmetric equilibrium. In the symmetric equilibrium q and c solves the following system of equations (which is lender 1's FOC):

$$\underbrace{\left(\begin{array}{c} \int_0^{\frac{1}{2}} \frac{R^4(1-q(1-z))z\left((1-qz)\left(1+2\sqrt{\frac{q(1-2z)}{1-qz}}\right)+q(1-2z)\right)}{32c^2\sqrt{\frac{q(1-2z)}{1-qz}}(1-qz)}dz \\ +\frac{(2-q)R^2\left((2-q)R^2-16cf\right)}{128c^2}\left(\frac{1}{4q}\right) \end{array}\right)}_{\text{denoted by } L_q(q,c)} = -\beta_q Q'(q);$$

$$\underbrace{\left(\begin{array}{c} \int_0^{\frac{1}{2}} \frac{R^4(1-q(1-z))\left((1-qz)\left(1+2\sqrt{\frac{q(1-2z)}{1-qz}}\right)+q(1-2z)\right)}{32c^3\sqrt{\frac{q(1-2z)}{1-qz}}}dz \\ +\frac{(2-q)R^2\left((2-q)R^2-16cf\right)}{128c^2}\left(\frac{2-q}{4cq}\right) \end{array}\right)}_{\text{denoted by } L_c(q,c)} = -\beta_c H'(c).$$

Obviously, $L_q(q,c)$ is decreasing c. Note that $(2-q)R^2 - 16cf \geq 0$ holds because, by assumption, a lender can make non-negative profit at location $z = 1/2$ when it offers the best loan rate $R/2$. Next we show that $L_c(q, c)$ is decreasing in q. Obviously the second term of $L_c(q, c)$ is decreasing in q. The first term of $L_c(q, c)$ can be rewritten as

$$\int_0^{\frac{1}{2}} \frac{R^4 (1 - q(1-z)) \sqrt{1-qz} \left(\left(2\sqrt{1-qz} - \frac{\sqrt{q}z}{\sqrt{1-2z}} \right) + \frac{1}{\sqrt{q(1-2z)}} + \sqrt{q(1-2z)} \right)}{32c^3} dz,$$

which is also decreasing in q because $\frac{1}{\sqrt{q(1-2z)}} + \sqrt{q(1-2z)}$ is decreasing in q for $q \leq 1$. Therefore, $L_c(q, c)$ is decreasing in q.

The equation $L_q(q, c) = -\beta_q Q'(q)$ implies that q is an implicit function of c and β_q, and we denote the implicit function as $q(c, \beta_q)$. For a given c, we have $\partial q(c, \beta_q) / \partial \beta_q > 0$ in the unique symmetric equilibrium because: (a) $-\beta_q Q'(q)$ and $L_q(q, c)$ cross only once as q varies; (b) $-\beta_q Q'(q)$ is higher than $L_q(q, c)$ as q approaches zero, since $-\lim_{q \to 0} q \partial T(q, c) / \partial q$ is sufficiently large while $\lim_{q \to 0} q L_q(q, c)$ is finite. Hence $L_c(q(c, \beta_q), c)$ is decreasing in β_q for a given c. If β_q increases to some $\widehat{\beta}_q > \beta_q$ while c does not change, then we must have $L_c\left(q\left(c, \widehat{\beta}_q\right), c\right) < -\beta_c H'(c)$ because $\beta_c H'(c)$ is not affected by β_q. Since $-c\frac{\partial^2 T(q,c)/\partial c^2}{\partial T(q,c)/\partial c}$ is large (which means $-c\frac{\partial^2 H(c)/\partial c^2}{\partial H(c)/\partial c}$ is large) for $c \in [\underline{c}, \overline{c})$, to regain the symmetric equilibrium c must increases to $\widehat{c} > c$ such that $L_c\left(q\left(\widehat{c}, \widehat{\beta}_q\right), \widehat{c}\right) = -\beta_c H'(\widehat{c})$. Note that $\partial q(c, \beta_q) / \partial c > 0$ holds because $L_q(q, c)$ is decreasing in c. Hence we must have $q\left(\widehat{c}, \widehat{\beta}_q\right) > q(c, \beta_q)$ because $\widehat{c} > c$ and $\widehat{\beta}_q > \beta_q$. Overall, if β_q increases to some $\widehat{\beta}_q > \beta_q$, then c and $q = q(c, \beta_q)$ will respectively increase to $\widehat{c}$ and $q\left(\widehat{c}, \widehat{\beta}_q\right)$, which means $\frac{\partial q^*}{\partial \beta_q} > 0$ and $\frac{\partial c^*}{\partial \beta_q} > 0$. In a symmetric way, we can show that $\frac{\partial q^*}{\partial \beta_c} > 0$ and $\frac{\partial c^*}{\partial \beta_c} > 0$.

Lemma A.3. *Suppose the entrepreneurs located within $[0, \tilde{x}]$ are served by lender 1. Let funding demand at $z \in [0, \tilde{x}]$ be $D(z)$, and let the loan rate and monitoring intensity of lender 1 be respectively $r_1(z)$ and $m_1(z)$ at $z \in [0, \tilde{x}]$. Then lender 1's default probability θ_1^* and the promised nominal return d_1 to investors are jointly determined by the following system of equations:*

$$\begin{cases} [Default] & \underbrace{v_1(\theta_1^*)}_{\text{return to investors conditional on } \theta = \theta_1^*} = d_1; \\ [Participation] & \underbrace{\int_0^{\theta_1^*} v_1(\theta)\, d\theta}_{\theta_1^* E\left[v_1(\theta) | \theta < \theta_1^*\right]} + (1 - \theta_1^*) d_1 = f. \end{cases} \tag{A.6}$$

Function $v_1(\theta)$ is defined as follows:

$$v_1(\theta) \equiv \frac{\int_0^{\tilde{x}} D(z) r_1(z) 1_{\{1-m_1(z)\leq\theta\}}\, dz}{\int_0^{\tilde{x}} D(z)\, dz},$$

which is entrepreneurs' return to a unit of lender 1's loans when the risk factor (i.e., economic condition) is θ; $1_{\{\cdot\}}$ is an indicator function that equals 1 *if the condition in $\{\cdot\}$ holds and equals* 0 *otherwise. Lender 2's default probability θ_2^* and promised nominal return d_2 can be determined in a symmetric way.*

Proof of Lemma A.3. We first show why $v_1(\theta)$ is entrepreneurs' return to a unit of lender 1's loans. When the risk factor is θ, entrepreneurs with $1 - m_1(z) \leq \theta$ (resp. $1 - m_1(z) > \theta$) will succeed (resp. fail) and repay $r_1(z)$ (resp. zero) to lender 1; hence at location $z \in [0, \tilde{x}]$ entrepreneurs' loan repayment is $D(z) r_1(z) 1_{\{1-m_1(z)\leq\theta\}}$. The aggregate loan repayment lender 1 receives from all locations (conditional on risk factor θ) is thus $\int_0^{\tilde{x}} D(z) r_1(z) 1_{\{1-m_1(z)\leq\theta\}}\, dz$. Dividing this aggregate loan repayment by $\int_0^{\tilde{x}} D(z)\, dz$ (i.e., total loan volume of lender 1) yields entrepreneurs' return to a unit of lender 1's loans, which is exactly $v_1(\theta)$.

The equation system (A.6) consists of two conditions: lender 1's default condition and investors' participation condition. Obviously, lender 1 can fully repay the promised return d_1 to investors if and only if $v_1(\theta) \geq d_1$. Meanwhile, $v_1(\theta)$ is increasing in θ because $1_{\{1-m_1(z)\leq\theta\}}$ is more likely to be positive when θ becomes higher. If $\theta = 1$, then $1_{\{1-m_1(z)\leq\theta\}} = 1$ holds for all entrepreneurs served by lender 1; in this case lender 1 must be solvent. If $\theta = 0$, then $1_{\{1-m_1(z)\leq\theta\}} = 0$ holds for all entrepreneurs served by lender 1; in this case the lender must default. Therefore, there exists a unique threshold risk factor $\theta_1^* \in (0, 1)$ that makes $v_1(\theta_1^*) = d_1$ hold, implying that the loan repayment received by lender 1 exactly covers the promised return to investors. When $\theta < \theta_1^*$ holds, $v_1(\theta) < d_1$ will hold, which means that lender 1 defaults on its promised return to investors. Since the risk factor θ is uniformly distributed on $[0, 1]$, lender 1's default probability is exactly equal to θ_1^*.

Next we look at the participation condition in (A.6). If $\theta < \theta_1^*$ (which happens with probability θ_1^*), lender 1 defaults on its promised return, so all the loan repayment received by lender 1 must be used to pay investors; in this case the actual return to investors is $v_1(\theta)$. If $\theta \geq \theta_1^*$ (which happens with probability $1 - \theta_1^*$), lender 1 is solvent and hence fully repays investors the promised return d_1. As a result, the unconditional expected return to investors is $\theta_1^* E[v_1(\theta) | \theta < \theta_1^*] + (1 - \theta_1^*) d_1$, which is exactly the left hand side of the participation condition. To ensure that investors are willing to provide funding, such an unconditional expected return to investors must equal f, implying the participation condition of (A.6). Combining both conditions can pin down lender 1's default probability.

Proof of Proposition 7 and Corollary 6. If an entrepreneur at location $z \in [0, 1/2]$ is served by lender 2 with loan rate $r_2(z)$ and monitoring intensity $\frac{r_2(z)(1-q(1-z))}{c}$, then the entrepreneur can derive expected utility $\frac{r_2(z)(R-r_2(z))(1-q(1-z))}{c} - \underline{u}$, while the lender's expected profit is $\frac{(r_2(z))^2(1-q(1-z))}{2c} - f$. If lender 1 serves the same entrepreneur with loan rate $r_2(z)$, then the entrepreneur's utility and the lender profit from serving her will both (weakly) increase because $z \in [0, 1/2]$. Therefore, the social planner will let lender 1 (resp. lender 2) serve the region $[0, 1/2]$ (resp. $(1/2, 1]$) if lenders are willing to serve all locations.

If lender i serves an entrepreneur at z, then the total surplus generated (the entrepreneur's utility plus the lender's profit) is

$$\frac{r_i(z)(R - r_i(z))(1 - qs_i)}{c} - \underline{u} + \frac{(r_i(z))^2(1 - qs_i)}{2c} - f,$$

which is maximized when $r_i(z) = R$; the resulting maximum surplus is $\frac{(R)^2(1-qs_i)}{2c} - \underline{u} - f$. If neither lender is willing to serve location z, then it means $\frac{(R)^2(1-qs_i)}{2c} - f$ (lender profit from serving an entrepreneur at z with loan rate R) is negative for $i = 1, 2$; in this case, the social planner will not let either lender to serve location z because $\frac{(R)^2(1-qs_i)}{2c} - \underline{u} - f$ must be negative for any $\underline{u} \geq 0$.

The second-best socially optimal loan rate of lender 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

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

which has two solutions.

It must hold that $1 - qs_i > 0$ because the farthest location lender 1 (or lender 2) finances is $z = \frac{1}{2}$ in the symmetric case. Therefore, it is clear that $h^{\mathrm{SB}}(-\infty) \to -\infty$, $h^{\mathrm{SB}}\left(\frac{R}{2}\right) > 0$ and $h^{\mathrm{SB}}(+\infty) \to -\infty$; 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

$\frac{R\left(2R-6r_i^{\text{SB}}(z)\right)(1-qs_i)}{2c}+2f<0$, is satisfied by the larger solution of the FOC:

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

Given that $r_i^{\text{SB}}(z)>R/2$, obviously $h^{\text{SB}}\left(r_i^{\text{SB}}(z)\right)$ is increasing in s_i when $q>0$. Thus an increase in s_i (with $q>0$) will increase $r_i^{\text{SB}}(z)$ to keep $h^{\text{SB}}\left(r_i^{\text{SB}}(z)\right)$ holding. Therefore Corollary 6 is proved.

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

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

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

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

Proof of Proposition 8. We consider the limiting case $q=0$. In this case, lender i must offer its best loan rate in equilibrium because there is no lender differentiation. That is, $r_i^{\text{comp}}(z)=\frac{R}{2}$ if $R\geq2\sqrt{2cf}$ and $r_i^{\text{comp}}(z)=\sqrt{2cf}$ if $\sqrt{2cf}<R<2\sqrt{2cf}$ (see Appendix B for lender i's best loan rates when R is not large). In the case $R\geq2\sqrt{2cf}$, it is easy to see $r_i^{\text{comp}}(z)=\frac{R}{2}<r_i^{\text{SB}}(z)$ because $h^{\text{SB}}\left(\frac{R}{2}\right)>0$. 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

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

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

Proof of Proposition 9. In a symmetric competitive equilibrium with $K=0$, social welfare W can be simplified to

$$W = 2\int_0^{1/2} \left(\frac{1}{2}(D(z))^2 + D(z)\left(\frac{(r_1(z))^2(1-qz)}{2c} - f\right)\right) dz.$$

If lender 1 has monopoly power in the region $[0, x^m] \subset [0, 1/2]$, then following the proof of Proposition 2 we can show that

$$\frac{\partial W}{\partial c} = \begin{pmatrix} 2\int_0^{x^m} \frac{\partial\left(\left(\frac{1}{2}(D(z))^2 + D(z)\left(\frac{(r_1^m(z))^2(1-qz)}{2c} - f\right)\right)\right)}{\partial c} dz \\ +2\int_{x^m}^{1/2} \frac{\partial\left(\left(\frac{1}{2}(D(z))^2 + D(z)\left(\frac{(r_1^{com}(z))^2(1-qz)}{2c} - f\right)\right)\right)}{\partial c} dz \end{pmatrix}. \tag{A.7}$$

For $z \in [0, x^m]$, $D(z) = \frac{r_1^m(z)(1-qz)}{c}(R - r_1^m(z))$ is decreasing in c because $r_1^m(z)$ is increasing in c (Proposition C.2); meanwhile, $D(z)\left(\frac{(r_1^m(z))^2(1-qz)}{2c} - f\right)$ is also decreasing in c according to the proof of Proposition 2. Therefore, the first term of $\frac{\partial W}{\partial c}$ is negative. For $z \in (x^m, 1/2]$, $D(z) = \frac{(1-q(1-z))R^2}{4c}$ is obviously decreasing in c; meanwhile, $D(z)\left(\frac{(r_1^{com}(z))^2(1-qz)}{2c} - f\right)$ is also decreasing in c according to the proof of Proposition 2. Therefore, the second term of $\frac{\partial W}{\partial c}$ is also negative. Overall, we have $\frac{\partial W}{\partial c} < 0$, which means social welfare is decreasing in c.

Next we look at the effect of q. If q is small enough, lender competition is effective at all locations (i.e., $x^m = 0$). In this case, we can show that

$$\frac{\partial W}{\partial q} = 2\int_0^{1/2} \left(\frac{R^4\sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} + \mu_W(q, c, z)\right) dz,$$

where $\mu_W(q, c, z)$ is a term that is finite for $q \to 0$. For $z < 1/2$, we have $\lim\limits_{q\to 0} \frac{R^4\sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} \to +\infty$. For $z = 1/2$, we have $\frac{R^4\sqrt{\frac{q(1-2z)}{1-qz}}}{32c^2 q} = 0$. Therefore, $\lim\limits_{q\to 0} \frac{\partial W}{\partial q} \to +\infty$ must hold. As a consequence, social welfare is increasing in q if q is sufficiently small.

Proof of Proposition 10. Since $q^* \in (0, \overline{q})$, obviously q^* is excessively low if $\overline{q}$ is sufficiently close to zero (Proposition 9). When lenders endogenously choose their IT, lender i's marginal benefit of decreasing c_i at the symmetric equilibrium is $L_c(q^*, c^*)$ (see the proof of Proposition 6). c^* is determined by

$$L_c(q^*, c^*) = -\left.\frac{\partial T(q^*, c)}{\partial c}\right|_{c=c^*}.$$

From the perspective of the social planner, the marginal benefit of decreasing c is $-\frac{\partial W}{\partial c}$ (see Equation A.7 in the proof of Proposition 9). Let q^o denote the social planner's choice of q, then the social planner's choice about c (denoted by c^o) is determined by

$$-\left.\frac{\partial W}{\partial c}\right|_{q=q^o,c=c^o} = -\left.\frac{\partial T(q^o,c)}{\partial c}\right|_{c=c^o}.$$

Note that $-\left.\frac{\partial W}{\partial c}\right|_{q=q^o}$ is finite for any $q^o \geq 0$ and $c \geq \underline{c} > R$. However, it is clear that $\lim_{q^* \to 0} L_c(q^*, c^*) = +\infty$. When $\overline{q}$ is sufficiently small, both $L_c(q^*, c^*) > -\left.\frac{\partial W}{\partial c}\right|_{q=q^o}$ and $q^* < q^o$ will hold; in this case, the following inequality must hold

$$\left.\frac{\partial T(q^*,c)}{\partial c}\right|_{c=c^*} < \left.\frac{\partial T(q^o,c)}{\partial c}\right|_{c=c^o} < 0,$$

which implies $c^* < c^o$ if $\frac{\partial^2 T(q,c)}{\partial q \partial c} \leq 0$ (i.e., if $T(q,c)$ is submodular).

Appendix B: Insufficiently large R

In this part we consider lender competition under a general R that need not be large. In addition, we relax the assumption that investors require the same break-even expected return f for both lenders; instead, investors' required expected return is f_i for lender i. All the other set-ups in the main text still hold.

Following the proof of Equation (4) in Appendix A, we can find that Equation (4) still holds when f is replaced by the corresponding lender's marginal funding cost (i.e., f_i for lender i). Hence, Lemma 1 also holds. Following the way we prove Lemma 2, it is easy to show that $R/2$ is still lender i's best loan rate at z if it can guarantee a non-negative profit for the lender at this location. However, $R/2$ may not guarantee lenders a non-negative profit at z when R is not large enough. Specifically, lender 1's expected profit from financing an entrepreneur at z is given by:

$$\pi_1(z) = \frac{(r_1(z))^2 (1 - q_1 z)}{2c_1} - f_1$$

when lender 1 posts loan rate $r_1(z)$ for the entrepreneur. If $\pi_1(z)$ is positive given $r_1(z) = R/2$, then lender 1's best loan rate at location z is still $R/2$. However, if $\pi_1(z)$ is negative given $r_1(z) = R/2$, then $R/2$ is no longer lender 1's best loan rate. A symmetric result holds for lender 2. When $R/2$ is too low to be lender 1's best loan rate, the lowest acceptable loan rate for lender 1 is determined by $\pi_1(z) = 0$, which yields:

$$r_1(z) = \overline{r}_1(z) \equiv \sqrt{\frac{2c_1 f_1}{1 - q_1 z}}.$$

Similarly, the lowest acceptable loan rate for lender 2 equals $\overline{r}_2(z) \equiv \sqrt{2c_2 f_2/(1 - q_2(1 - z))}$ if $R/2$ is too low to be the best loan rate. As a result, lender i 's best loan loan rate at location z is given by

$$r_i^b(z) = \max\left\{\frac{R}{2}, \overline{r}_i(z)\right\}. \tag{B.1}$$

Because the two lenders are symmetric, we need only look at how lender 1 chooses its loan rates. If at z lender 1 does not face enough competition pressure from lender 2, then lender 1 will maintain its monopoly loan rate $r_1^m(z)$. If lender 1 faces effective competition at z, and wants to attract entrepreneurs 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 lender 2. If lender 1 cannot do so, then location z will be served by lender 2. If lender 1 can do so, then its strategy is to maximize its own profit, subject to the constraint that an entrepreneur's expected utility is no less than what she would derive from accepting $r_2^b(z)$ offered by lender 2 (i.e., the maximum utility lender 2 can provide). Following this reasoning, the equilibrium loan rate offered by lender 1, if there is effective competition between lenders, 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

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

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

$$r_2^{\text{comp}}(z) = \frac{R}{2} + \frac{1}{2}\sqrt{R^2 - 4\frac{c_2}{c_1}\frac{1-q_1 z}{1-q_2(1-z)}\left(R - r_1^b(z)\right) r_1^b(z)}. \tag{B.3}$$

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

$$\left(R - r_1^b(\tilde{x})\right)\frac{r_1^b(\tilde{x})(1-q_1\tilde{x})}{c_1} - \underline{u} = \left(R - r_2^b(\tilde{x})\right)\frac{r_2^b(\tilde{x})(1-q_2(1-\tilde{x}))}{c_2} - \underline{u}. \tag{B.4}$$

Equation (B.4) does not yield a closed-form solution. However, at locations where both lenders are willing to serve, $R/2 \le r_i^b(z) \le R$ must hold, so the left hand side of Equation (B.4) is weakly decreasing in $\tilde{x}$, and the right hand side is weakly increasing in $\tilde{x}$. If $q_i > 0$ for some i, then whenever there exists a solution $\tilde{x} \in [0,1]$ that solves Equation (B.4), such a solution must be unique (in the special case with $q_1 = q_2 = 0$, $c_1 = c_2$ and $f_1 = f_2$, we let $\tilde{x} = 1/2$).

It is possible that Equation (B.4) yields no solution in the region $[0,1]$. If this occurs, then it means one lender dominates the entire lending market. We focus on the interesting case that both lenders can serve a positive measure of locations in equilibrium, and so summarize our foregoing analysis with the following proposition:

Proposition B.1. *Assume that there exists an $\tilde{x} \in (0,1)$ solving Equation (B.4). Then* *there exists an equilibrium where entrepreneurs located in $[0, \tilde{x}]$ are served by lender 1, while the other locations are served by lender 2. Lender 1 and lender 2's equilibrium loan rates, $r_1^*(z)$ and $r_2^*(z)$, are respectively given by the following two equations:*

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

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

where $r_i^{\text{comp}}(z)$ is defined by Equations (B.2) and (B.3).

We need only focus on lender 1 because the two lenders are symmetric. Note that if $r_2^b(z) = R/2$, 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 and does not depend on f_i.

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 B.1. *Let $q_i > 0$ for some i, $z \in [0, \tilde{x}]$ and $r_2^b(z) = \overline{r}_2(z)$. With effective lender competition at z, lender 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is decreasing in z. At the indifference 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 lender 1 at $z = \tilde{x}$ is $r_1^b(z)$, which may or may not be $R/2$.

Corollary B.2. *Let $q_2 > 0$, $z \in [0, \tilde{x}]$ and $r_2^b(z) = \overline{r}_2(z)$ hold. With effective lender competition at z, the funding demand $D(z)$ of entrepreneurs (i.e., lender 1's lending volume) is increasing in z.*

The intuition underlying Corollary 2 directly applies here.

Comparative statics. Next we analyze how the foregoing equilibrium is affected by parameters. The following proposition characterizes the role of f_i.

Proposition B.2. *If* $r_1^b(\tilde{x}) = \overline{r}_1(\tilde{x}) > R/2$ *(resp.* $r_2^b(\tilde{x}) = \overline{r}_2(\tilde{x}) > R/2$*), then* $\tilde{x}$ *is decreasing (resp. increasing) in* f_1 *(resp.* f_2*).*

This proposition states that if lender i's best loan rate $r_i^b(\tilde{x})$ at the indifference location $\tilde{x}$ is the zero-profit loan rate $\overline{r}_i(\tilde{x})$, then decreasing the lender's funding cost f_i can increase the market area served by the lender. The reason is that a lower f_i will decrease $\overline{r}_i(z)$ for a given z, which increases the maximum utility lender i can provide. Therefore, lender i becomes more competitive and can serve a larger market area. Note that this result does not hold in the main text (see the formula of $\tilde{x}$ in Proposition 1); the reason is that with a sufficiently large R lender i's funding cost has no effect on the lender's best loan rate, thereby the maximum utility (which represents the lender's competitiveness) provided by lender i does not depend on the lender's funding cost.

Corollary B.3. *Let* $z \in (0, \tilde{x})$ *and* $r_2^b(z) = \overline{r}_2(z)$ *hold. With effective lender competition at* z*, lender 1's equilibrium loan rate* $r_1^{\text{comp}}(z)$ *is decreasing in* c_1 *and* q_1*, is independent of* f_1*, and is increasing in* c_2*,* q_2 *and* f_2*.*

The effects of c_i and q_i are consistent and share the same intuition with those in Corollary 3, so we focus on explaining the effects of f_i here. An increase in f_1 has no effect on $r_1^{\text{comp}}(z)$ because lender 1 must choose $r_1^{\text{comp}}(z)$ to match the maximum utility provided by lender 2, which is not affected by f_1. Therefore, lender 1 need not adjust $r_1^{\text{comp}}(z)$ as f_1 varies. As f_2 increases, lender 2's best loan rate (which equals $\overline{r}_2(z)$ here) will increase; hence the maximum utility lender 2 can provide will decrease, allowing lender 1 to match that utility with a higher $r_1^{\text{comp}}(z)$.

Letting $c_1 = c_2 = c$, $q_1 = q_2 = q$, and $f_1 = f_2 = f$, we can study the effects of the lending sector's information technology in the symmetric case. The following corollary gives the result:

Corollary B.4. *Let* $c_i = c$*,* $q_i = q$*,* $f_i = f$ *and* $z \in [0, 1/2]$*. With effective lender competition at* z*, lender 1's equilibrium loan rate* $r_1^{\text{comp}}(z)$ *is increasing in* c*,* q *and* f *when* $r_2^b(z) = \overline{r}_2(z)$*. A symmetric result holds for lender 2.*

Different from Corollary 4, if $r_2^b(z) = \overline{r}_2(z)$ (i.e., if R is not large enough to make $R/2$ the best loan rate of lender 2 at z), $r_1^{\text{comp}}(z)$ is increasing in c. The reason is that now the best loan rate lender 2 can offer is $\overline{r}_2(z)$, rather than $R/2$. If c increases, then $\overline{r}_2(z)$ will also increase, which decreases the competition pressure lender 2 puts on lender 1. As a consequence, lender 1 can choose a higher $r_1^{\text{comp}}(z)$ to match the maximum utility provided by lender 2. Symmetrically, lender 2 also faces less competition from lender 1 if c increases, so $r_2^{\text{comp}}(z)$ is increasing in c at $z \in (1/2, 1]$.

Reasoning similarly, as f increases, lender 2's best loan rate $\overline{r}_2(z)$ will increase, which reduces the maxiumum utility lender 2 can provide; to match this utility lender 1 can increase $r_1^{\text{comp}}(z)$.

Proposition B.3. *Let $c_i = c$, $q_i = q$, $f_i = f$ and $r_i^b(z) = \overline{r}_i(z)$ hold. Lender i's aggregate lending profit from all locations is increasing in q if q is sufficiently small; a numerical study finds that lender i's aggregate lending profit is decreasing in c and f.*

This result confirms the robustness of Proposition 2. As parameter q approaches 0, lender differentiation will disappear, which will dominate the cost-saving effect and thereby reduce lender profit. Decreasing c or f will intensify lender competition by decreasing the value of $\overline{r}_i(z)$, but it will not reduce lender differentiation, so the cost-saving effect of decreasing c or f dominates according to the numerical study.

Proposition B.4. *Let $r_i^b(z) = \overline{r}_i(z)$ hold. Lender i's aggregate loan volume L_i is decreasing in q_i, c_i and f_i.*

The intuition of Proposition 3 directly applies here.

Proposition B.5. *Let $c_i = c$, $q_i = q$, $f_i = f$ and $r_i^b(z) = \overline{r}_i(z)$ hold. The total mass of entrepreneurs undertaking investment projects (i.e., $L_1 + L_2$) is decreasing in q, c and f.*

This result means Proposition 4 is robust for the case without large R. The intuition is that a higher competition intensity and better monitoring efficiency are beneficial for entrepreneurs. In addition, a decrease in f also benefits entrepreneurs because both lenders must offer lower loan rates according to Corollary B.4; this does not happen in the main text because there f has no effect on $r_i^{\text{comp}}(z)$.

Appendix C: Local monopoly equilibrium

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

Since the two lenders are symmetric, we focus on lender 1's decisions. If entrepreneurs at z are target clients of lender 1 and if there is no lender competition, then lender 1 must guarantee that the expected profit of an entrepreneur at z who borrows from the lender is non-negative; otherwise, no entrepreneur at z would want to be served by the lender. If lender 1's loan rate for entrepreneurs at z is $r_1(z) \in [0, R]$, then an entrepreneur's expected net utility from investment at z is

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

which is non-negative for $\underline{u} = 0$. In other words, lender 1 can serve all locations by offering a loan rate $r_1(z) \in [0, R]$. Even if $r_1(z) = R$, an entrepreneur with $\underline{u} = 0$ is willing to accept the offer of lender 1.

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

$$z > \frac{R^2 - 2c_1 f}{q_1 R^2}. \tag{C.1}$$

Inequality (C.1) implies that lender 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, lender 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 lenders are willing to serve. Hence the local monopoly equilibrium exists if

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

In such an equilibrium, there is no competition between lenders and so lender 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 C.1. *Let* $\frac{R^2-2c_i f}{q_i R^2} \geq 0$ *for* $i = \{1, 2\}$*, 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 lender i's loan rate at z equals* $r_i^m(z)$*. Lender 1 serves entrepreneurs in* $\left[0, \frac{R^2-2c_1 f}{q_1 R^2}\right]$ *while lender 2 serves entrepreneurs in* $\left[1 - \frac{R^2-2c_2 f}{q_2 R^2}, 1\right]$*.*

According to Proposition C.1, a local monopoly equilibrium will arise when R is not large yet q_i and c_i are sufficiently large. Note that $q_i > 0, i = \{1, 2\}$ must hold in such an equilibrium; otherwise Condition (C.2) will be violated.

Corollary C.1 shows how $r_1^m(z)$ varies with entrepreneurial location z; a symmetric result holds for $r_2^m(z)$.

Corollary C.1. *In the local monopoly equilibrium (which ensures* $q_i > 0$*), lender 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* $r_1^m(z) = R$*.*

Note that the pattern of lender 1's loan rate with respect to z in the local monopoly equilibrium is different from that in the case with lender 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 lenders compete for entrepreneurs at z, what determines the equilibrium loan rate is the intensity of lender 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, lenders no longer compete with each other and so the equilibrium loan rate reflects lenders' costs of providing loans (monitoring and funding costs) instead of competition intensity.

Information technology and local monopoly equilibrium. The following proposition shows how information technology affects loan rates in the local monopoly equilibrium.

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

In the local monopoly equilibrium information technology progress (i.e., reducing c_1 or q_1) simply makes monitoring cheaper for lender 1 (except for the special location $z = 0$ where reducing q_1 has no effect on lender 1's monitoring efficiency), which increases lender 1's profit per unit of loans and hence induces the lender to be more concerned about total funding demand. As a result, lender 1 decreases its loan rates in order to increase the funding demand and maximize its monopoly profit.

The following corollary shows how information technology affects the market area a lender can serve.

Corollary C.2. *In the local monopoly equilibrium, the market area served by lender 1 (i.e.,* $[0, \frac{R^2-2c_1 f}{q_1 R^2}]$*) will shrink as* q_1 *or/and* c_1 *increases.*

The local monopoly equilibrium arises only when both lenders find it too costly to serve sufficiently distant entrepreneurs. As lender 1's IT improves (i.e., q_1 or/and c_1 decreases), the lender will reach farther locations because monitoring becomes less costly. Corollary C.2 implies that in the local monopoly equilibrium IT progress of lenders will improve financial inclusion by enabling lenders to cover more locations.

Lender stability under local monopoly. In a local monopoly equilibrium, lender 1 is not affected by q_2 or c_2; therefore, we need only look at the effects of q_1 and c_1 on lender 1's stability. Proposition C.3 gives a relevant result.

Proposition C.3. *In the local monopoly equilibrium, lender 1's probability of default is independent of* q_1*.*

A higher q_1 has two competing effects on lender 1's stability. The first one is a direct cost effect: increasing q_1 makes monitoring more costly, which reduces the intensity of lender 1's monitoring and thus reduces lender stability. The second effect is an indirect market area effect: the region that lender 1 serves will shrink as q_1 increases, which promotes the lender's stability because it can then concentrate more on nearby entrepreneurs (who are easier to monitor). Proposition C.3 means that the market area effect exactly offsets the cost effect.[44]

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, the cost effect of c_1 is stronger than that of q_1.[45] A numerical study establishes that the cost effect dominates as c_1 increases.

[44] 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.

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

Welfare analysis in the local monopoly equilibrium. In Proposition 7, we have shown that $R/2 < r_i^{\mathrm{SB}}(z) \leq r_i^m(z)$ holds. According to Proposition C.1, lender i's equilibrium loan rate in the local monopoly equilibrium exactly equals $r_i^m(z)$, so we have the following corollary.

Corollary C.3. *Let $K = 0$. Then, in a local monopoly equilibrium where lender 1 serves the region $\left[0, \frac{R^2-2cf}{qR^2}\right]$, lender 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 lender 2.*

Next we analyze how the development and diffusion of information technology affect social welfare in the local monopoly equilibrium. The following proposition shows how social welfare is affected by q and c when there is no social cost of lender failure.

Proposition C.4. *Let $K = 0$. Social welfare is decreasing in q and c in the local monopoly equilibrium.*

In a local monopoly equilibrium, the welfare effects of q and c are not qualitatively different. A marginal decrease in q or c brings only a cost-saving effect in this equilibrium, which promotes entrepreneurial utility, lenders' profits, and social welfare (Panels 1 and 3 of Figure C.1). Taking bankruptcy cost K into consideration strengthens (resp. does not change) the welfare-improving effect of decreasing c (resp. q) because, when there is no lender competition, a smaller c (resp. q) enhances (resp. does not affect) lender stability; see Panels 2 and 4 of Figure C.1.

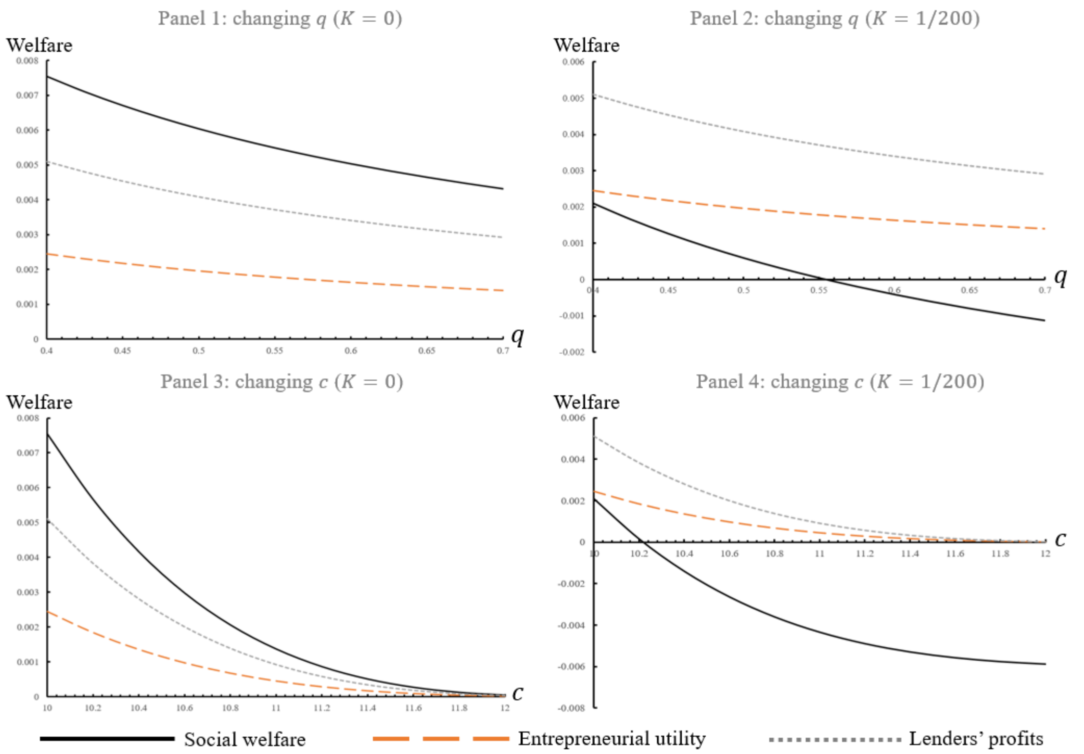


Figure C.1: Social Welfare and Lending Sector's Information Technology under Local Monopoly. This figure plots social welfare, entrepreneurial utility, and lenders' profits against c and q in the local monopoly equilibrium. The parameter values are: $R = 5$ and $f = 1$ in all panels; $c = 10$ in Panels 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.

Online Appendix

Appendix D: Supplementary findings

In this appendix, we provide supplementary results and explanations for the paper.

Supplementary findings for Section 3

Proposition D.1. ***IT and lending volume sensitivity.*** *If $q_1 = q_2 = q$ and if there is effective lender competition at all locations (i.e., if $r_i^{\text{comp}}(z) < r_i^m(z)$ for all $z \in [0,1]$), then the sensitivity of lender i's aggregate loan volume to c_i is decreasing in q (i.e., $\left.\frac{\partial^2 L_i}{\partial c_i \partial q}\right|_{q_i=q} > 0$).*

This proposition states that the progress of a lender's IT-basic (i.e. a lower c_i) will bring more loan volume to the lender when the intensity of lender competition is higher (i.e., when q is smaller). Two factors contribute to the result. First, a lender's marginal expansion of market area (which is caused by the progress of the lender's IT-basic) will bring more loans to the lender if q is smaller because entrepreneurs are better off and hence demand more funding at each location when lenders compete more intensely. Second, a lender's marginal progress of IT-basic will lead to a larger market area 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-basic progress can affect more (distant) entrepreneurs' decisions when lender differentiation is smaller.

Endogenous lender differentiation. In our model lenders are by assumption located at the two extremes of the linear city; that is, the differentiation of lenders' expertise is maximal. We find from a numerical study that such maximal lender differentiation will arise endogenously in equilibrium if lenders 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 lender to stay as distant as possible from its rival. However, if a lender's IT is sufficiently better than that of the other lender (e.g., if q_1 and/or c_1 are sufficiently lower than q_2 and/or c_2), then the lender 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 lender out of the market; in contrast, the lender 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.

Supplementary findings for Section 4

Complementary explanation for Proposition 5. If we restrict our attention to the case $c_1 = c_2$, which will hold in a symmetric equilibrium, then we have the following limiting result.

Numerical Result D.1. [46] *If lender competition is effective at all locations and if $c_1 = c_2$, then for $q_2 > 0$ we have:*

$$\lim_{q_1 \to 0} \frac{\partial^2 \Pi_1}{\partial q_1 \partial q_2} > 0 \text{ and } \lim_{q_2 \to 0} \left(\lim_{q_1 \to 0} \frac{\partial^2 \Pi_1}{\partial q_1 \partial q_2} \right) \to +\infty;$$

$$\lim_{q_1 \to 0} \frac{\partial^2 \Pi_1}{\partial c_1 \partial q_2} > 0 \text{ and } \lim_{q_2 \to 0} \left(\lim_{q_1 \to 0} \frac{\partial^2 \Pi_1}{\partial c_1 \partial q_2} \right) \to +\infty.$$

The restriction $c_1 = c_2$ ensures $0 < \tilde{x} < 1$ no matter how q_1 and q_2 vary.[47] Numerical Result D.1 states that if there is no gap between the two lenders' IT-basic (i.e., if $c_1 = c_2$) and if $q_1 \to 0$, then q_2 and the IT of lender 1 are strategic complements. The reason is that the share sensitivity effect of decreasing q_2 becomes strategically complementary if $q_1 \to 0$.[48] The share sensitivity effect, together with the boundary profit effect, dominate the share squeezing effect in this limiting case. Furthermore, the strategically complementary share sensitivity effect is infinitely large if q_2 also approaches 0, because then lender differentiation almost disappears. Then lender 1's market share is infinitely sensitive to its IT investment. Numerical Result D.1 is relevant to understand Proposition 5 where the two lenders are trapped in a limiting (boundary) equilibrium.

Complementary explanation for Numerical Result 3. First, note that Numerical Result 2 has already shown that $\partial^2 \Pi_1 / (\partial q_1 \partial c_2) > 0$ holds in more general cases because the share squeezing effect is dominant; hence it is natural that $\partial^2 \Pi_1 / (\partial q_1 \partial c_2) > 0$ holds in the interior symmetric case. Meanwhile, it is easy to show that $\partial^2 \tilde{x} / (\partial q_1 \partial c_2) < 0$ when $q_1 = q_2 > 0$ and $c_1 = c_2$ hold; this means the share sensitivity effect of c_2 on q_1 is strategically substitutive, which strengthens the share squeezing effect. The strategically complementary boundary profit effect is dominated.

[46] The grid of parameters is as follows: R ranges from 15 to 100; $\underline{c} = 1.01R$; q_2 ranges from 0 to 0.3; f ranges from 0.8 to 1.2; c_1 $(= c_2)$ ranges from $\underline{c}$ to $1.3R$.

[47] Without the restriction $c_1 = c_2$, as q_1 and q_2 approach 0, lender 1 will drive out (resp. be driven out by) lender 1 if $c_1 < c_2$ (resp. $c_1 > c_2$).

[48] We can show that $\lim_{q_1 \to 0} \partial^2 \tilde{x} / (\partial q_1 \partial q_2) > 0$, $\lim_{q_1 \to 0} \partial^2 \tilde{x} / (\partial c_1 \partial q_2) > 0$, $\lim_{q_2 \to 0} \left(\lim_{q_1 \to 0} \partial^2 \tilde{x} / (\partial q_1 \partial q_2) \right) \to +\infty$ and $\lim_{q_2 \to 0} \left(\lim_{q_1 \to 0} \partial^2 \tilde{x} / (\partial c_1 \partial q_2) \right) \to +\infty$ if $c_1 = c_2$.

For the strategic relation between c_1 and q_2, we can show that $\partial^2\tilde{x}/(\partial c_1 \partial q_2) > 0$ when $q_1 = q_2 > 0$ and $c_1 = c_2$ hold; this means the share sensitivity effect of q_2 on c_1 is strategically complementary. The share sensitivity effect, together with the boundary profit effect, dominates the strategically substitutive share squeezing effect, so c_1 and q_2 are strategic complements for lender 1 in the interior symmetric case.

For q_1 and q_2, the share squeezing effect is dominant in the interior symmetric case, so q_1 and q_2 are strategic substitutes for lender 1. We can show that $\partial^2\tilde{x}/(\partial q_1 \partial q_2) > 0$ when $q_1 = q_2 > 0$ and $c_1 = c_2$ hold; this means the share sensitivity effect of q_2 on q_1 is strategically complementary. However, the share sensitivity effect, together with the boundary profit effect, is not strong enough to dominate the share squeezing effect.

Finally, we look at the strategic relation between c_1 and c_2. We can show that $\partial^2\tilde{x}/(\partial c_1 \partial c_2) = 0$ when $q_1 = q_2 > 0$ and $c_1 = c_2$ hold; this means the share sensitivity effect of c_2 on c_1 is null. c_1 and c_2 are strategic substitutes for lender 1 in the interior symmetric case because the share squeezing effect dominates the boundary profit effect.

Complementary discussion on the strategic relation between q_1 and q_2. Note that Numerical Result 3 shows that q_1 and q_2 are strategic substitutes when $q_1 = q_2 > 0$ and $c_1 = c_2$ (the interior symmetric equilibrium belongs to this case); however, Numerical Result D.1 shows that q_1 and q_2 are strategic complements in the limiting case $q_1 \to 0$. Those are not contradictory results. The complementarity displayed in Numerical Result D.1 highly relies on the condition $q_1 \to 0$; therefore, it is useful only when describing lender 1's marginal benefit of IT investment in boundary case $q_1 = 0$. Proposition 5 exactly provides an equilibrium that belongs to the boundary case.

In contrast, Proposition 6 describes a symmetric interior equilibrium, which is beyond the scope of Numerical Result D.1. In a symmetric interior equilibrium, $q_1 = q_2 > 0$ and $c_1 = c_2$ hold, so we can use Numerical Result 3 to understand the strategic relation between q_1 and q_2. Figure D.1 reconciles Numerical Result D.1 with Numerical Result 3. Panel 6 of Figure D.1 shows that $\partial^2\Pi_1/(\partial q_1 \partial q_2)$ is always negative when $q_1 = q_2 = q > 0$ and $c_1 = c_2$. However, if we remove the restriction $q_1 = q_2$ and gradually let q_1 approach 0 (from Panel 1 to Panel 5), we can find that the sign of $\partial^2\Pi_1/(\partial q_1 \partial q_2)$ gradually evolves from being ambiguous to being positive.

Supplementary findings for Section 6

First-best allocation. Now we consider the first-best socially optimal case, where the social planner can (a) determine the locations each lender serves, (b) choose the first-

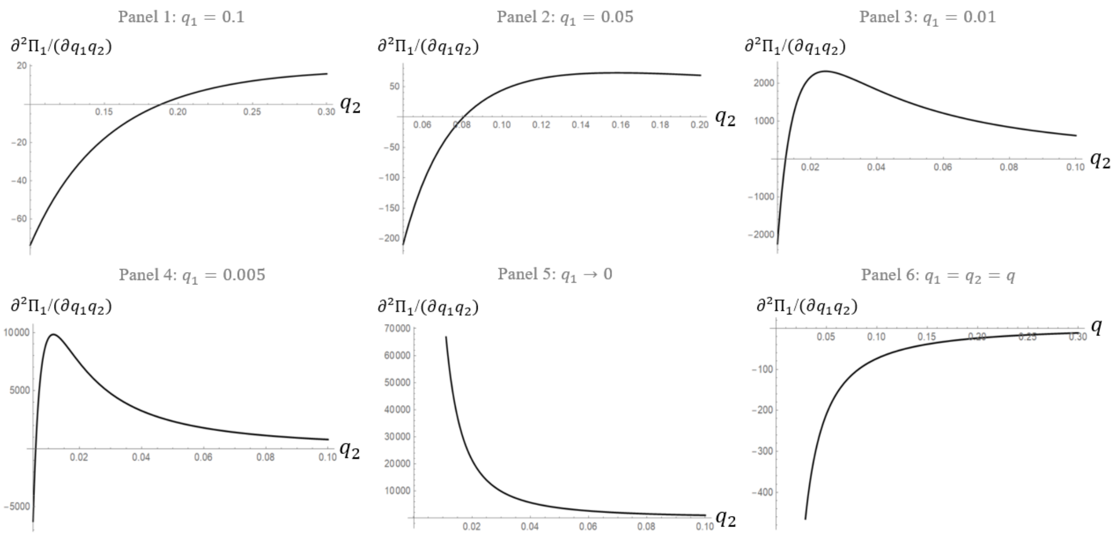


Figure D.1: The Effects of q_2 on Lender 1's Marginal Benefit of reducing q_1. This figure shows how the sign of $\partial^2\Pi_1/(\partial q_1 \partial q_2)$ varies with parameters when lender competition is effective at all locations and $0 < \tilde{x} < 1$. The parameter values are $R = 20$, $f = 1$, $c_1 = 1.01R$, $c_2 = 1.01R$.

best socially optimal loan rate schedule (denoted by $\{r_i^{\mathrm{FB}}(z)\}$) of lender i, and (c) set lenders' monitoring intensities. The monitoring intensities chosen by the social planner are observable for entrepreneurs, so they can have a correct expectation about investment returns and make decisions accordingly. In the first best case, lenders' monitoring intensities are no longer constrained by Lemma 1. The following proposition characterizes the first-best case.

Proposition D.2. *Let $K = 0$. At the first-best case lender i serves the same locations as in equilibrium. At location z (served by lender i), the first-best socially optimal loan rate $r_i^{\mathrm{FB}}(z)$ and monitoring intensity $m_i^{\mathrm{FB}}(z)$ are given by*

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

here $r_i^{\mathrm{FB}}(z) \leq r_i^{\mathrm{SB}}(z)$.[49]

In the first-best case, a social planner can directly choose monitoring intensities and so need not rely on loan rates to incentivize lenders' 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

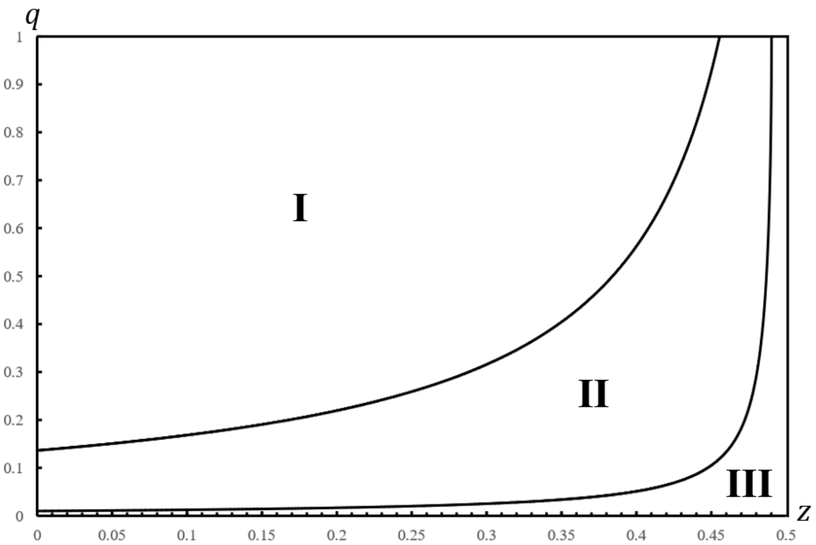
[49] We have that $r_i^{\mathrm{FB}}(z) = r_i^{\mathrm{SB}}(z)$ holds only when lender i's best loan rate at z is R.

$(1 - qs_i)R/c$, which is the monitoring intensity lender i would choose in equilibrium if and only if its loan rate were equal to the upper bound R.

The relation between $r_i^{\text{comp}}(z)$ and the first-best socially optimal loan rate $r_i^{\text{FB}}(z)$ is given by Proposition D.3.

Proposition D.3. *Let $K = 0$. If $R > \sqrt{2cf}$ and if location z is served by lender i, then $r_i^{\text{comp}}(z) < r_i^{\text{FB}}(z)$ holds for all locations when q is small enough.*

In the first-best case, the monitoring intensity $m_i^{\text{FB}}(z)$ is higher than what lender i would choose in equilibrium (unless the lender's equilibrium loan rate is R). Since a higher monitoring intensity benefits entrepreneurs, the social planner must control $r_i^{\text{FB}}(z)$ in order to avoid inefficiently excessive funding demand (i.e., excessive investment) at location z – which means that $r_i^{\text{FB}}(z)$ cannot be too low. So when lender competition is intense enough (i.e., when q is small enough), the equilibrium loan rate $r_i^{\text{comp}}(z)$ will be lower than $r_i^{\text{FB}}(z)$. Figure D.2 illustrates the relations involving $r_1^{\text{comp}}(z)$, $r_1^{\text{SB}}(z)$, and $r_1^{\text{FB}}(z)$ in $z \times q$ space.



I: $r_1^{comp}(z) > r_1^{SB}(z)$ **II**: $r_1^{SB}(z) > r_1^{comp}(z) > r_1^{FB}(z)$ **III**: $r_1^{comp}(z) < r_1^{FB}(z)$

Figure D.2: Relations among $r_1^{\text{comp}}(z)$, $r_1^{\text{SB}}(z)$, and $r_1^{\text{FB}}(z)$ in $z \times q$ space. This figure compares $r_1^{comp}(z)$ with $r_1^{\text{SB}}(z)$ and $r_1^{\text{FB}}(z)$ in $z \times q$ space. The parameter values are $R = 20$, $c = 1.01R$, and $f = 1$.

Appendix E: Detailed proof of Lemma A.2

In this appendix, we provide a detailed proof for Lemma A.2. The first order conditions of lender 1 w.r.t q_1 and c_1 are respectively:

$$\frac{\partial \Pi_1\left(q_1,q_2,c_1,c_2\right)}{\partial q_1}=0 \text{ and } \frac{\partial \Pi_1\left(q_1,q_2,c_1,c_2\right)}{\partial c_1}=0.$$

In a symmetric equilibrium, the two equations above must hold with $q_1=q_2=q$ and $c_1=c_2=c$, which implies

$$\underbrace{\left.\frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\right|_{q_i=q,c_i=c}-\frac{\partial T\left(q,c\right)}{\partial q}}_{=\left.\frac{\partial \Pi_1(q_1,q_2,c_1,c_2)}{\partial q_1}\right|_{q_i=q,c_i=c}}=0;\ \underbrace{\left.\frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial c_1}\right|_{q_i=q,c_i=c}-\frac{\partial T\left(q,c\right)}{\partial c}}_{=\left.\frac{\partial \Pi_1(q_1,q_2,c_1,c_2)}{\partial c_1}\right|_{q_i=q,c_i=c}}=0 \tag{E.1}$$

where

$$\left.\frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\right|_{q_i=q,c_i=c}=\left(\begin{array}{c}\int_0^{\frac{1}{2}}-\frac{R^4(1-q(1-z))z\left((1-qz)\left(1+2\sqrt{\frac{q(1-2z)}{1-qz}}\right)+q(1-2z)\right)}{32c^2\sqrt{\frac{q(1-2z)}{1-qz}}(1-qz)}dz\\+\frac{(2-q)R^2\left((2-q)R^2-16cf\right)}{128c^2}\left(-\frac{1}{4q}\right)\end{array}\right);$$

$$\left.\frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial c_1}\right|_{q_i=q,c_i=c}=\left(\begin{array}{c}\int_0^{\frac{1}{2}}-\frac{R^4(1-q(1-z))\left((1-qz)\left(1+2\sqrt{\frac{q(1-2z)}{1-qz}}\right)+q(1-2z)\right)}{32c^3\sqrt{\frac{q(1-2z)}{1-qz}}}dz\\+\frac{(2-q)R^2\left((2-q)R^2-16cf\right)}{128c^2}\left(-\frac{2-q}{4cq}\right)\end{array}\right).$$

We prove the lemma with two steps: first, we show that the system of equations (E.1) has a unique solution; second, we prove that the solution is indeed an equilibrium.

Step 1. Now we show that the system of equations (E.1) indeed has a unique solution. First, we show there exist a unique q that solves

$$-\left.\frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\right|_{q_i=q,c_i=c}=-\frac{\partial T\left(q,c\right)}{\partial q} \tag{E.2}$$

for a given $c\in[\underline{c},\overline{c}]$. The left hand side (LHS) of Equation (E.2) is lender 1's marginal benefit of decreasing q_1 (under the restriction $q_i=q$ and $c_i=c$), while the right hand side (RHS) is marginal cost of doing so. Obviously, both sides of Equation (E.2) are positive.

Equation (E.2) is equivalent to

$$-q\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q,c_i=c}=-q\frac{\partial T\left(q,c\right)}{\partial q} \tag{E.3}$$

if $q>0$. Obviously, we have that

$$-q\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q>0,c_i=c}>0 \text{ and}$$

$$\lim_{q\to 0}\left(-q\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q>0,c_i=c}\right)=\frac{R^2\left(R^2-8cf\right)}{128c^2}<+\infty$$

for all $c\in[\underline{c},\overline{c}]$. Since $\partial T\left(q,c\right)/\partial q=0$ when $q\geq\overline{q}$ and $\lim\limits_{q\to 0}-q\partial T\left(q,c\right)/\partial q$ is large enough, there must exist a $q\in(0,\overline{q})$ that solves Equation (E.3) for any $c\in[\underline{c},\overline{c}]$. We denote the largest solution as $q\left(c\right)$ and let $q_{\max}\equiv\max\limits_{c\in[\underline{c},\overline{c}]}q\left(c\right)$. The assumption $\lim\limits_{q\to 0}-q\partial T\left(q,c\right)/\partial q$ is large ensures that $q_{\max}$ must belong to the open interval $(0,\overline{q})$.

Next we need to show that $q\left(c\right)$ is the unique solution to Equation (E.3) when $-q\frac{\partial^2 T(q,c)/\partial q^2}{\partial T(q,c)/\partial q}$ is large enough for $q<\overline{q}$. Note that $q\left(c\right)$ must be the unique solution if $-q\partial T\left(q,c\right)/\partial q$ increases faster than $-q\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz/\partial q_1\big|_{q_i=q,c_i=c}$ as q decreases in the interval $(0,q\left(c\right)]$, which means:

$$\frac{\partial T\left(q,c\right)}{\partial q}+q\frac{\partial^2 T\left(q,c\right)}{\partial q^2}>\partial\left(q\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q,c_i=c}\right)/\partial q$$

holds for $q\in(0,q\left(c\right)]$. The inequality above can be written as

$$-1-q\frac{\partial^2 T\left(q,c\right)/\partial q^2}{\partial T\left(q,c\right)/\partial q}>\frac{\partial\left(q\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\Big|_{q_i=q,c_i=c}\right)/\partial q}{-\partial T\left(q,c\right)/\partial q} \tag{E.4}$$

for $q\in(0,q\left(c\right)]$. The assumption that $-q\frac{\partial^2 T(q,c)/\partial q^2}{\partial T(q,c)/\partial q}$ is large enough for $q<\overline{q}$ means the LHS of Inequality (E.4) is large enough for $q\in(0,q\left(c\right)]$. This means Inequality (E.4) will hold if the RHS of (E.4) is smaller than $+\infty$ for $q\in(0,q\left(c\right)]$. Since $-\partial T\left(q,c\right)/\partial q>0$

must hold for $q \leq q_{\max} < \overline{q}$, we need only show that

$$\partial\left(q\frac{\partial\int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q,c_i=c}\right)/\partial q < +\infty \tag{E.5}$$

holds for for $q \in (0, q(c)]$. Note that

$$\begin{aligned} & q\frac{\partial\int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_i=q,c_i=c} \\ = & \left(\begin{array}{c} \underbrace{-\int_0^{\frac{1}{2}} q\frac{R^4(1-q(1-z))z\left((1-qz)\left(1+2\sqrt{\frac{q(1-2z)}{1-qz}}\right)+q(1-2z)\right)}{32c^2\sqrt{\frac{q(1-2z)}{1-qz}}(1-qz)}dz}_{\text{denoted by } RHS_1^q} \\ \underbrace{-\frac{1}{4}\frac{(2-q)R^2((2-q)R^2-16cf)}{128c^2}}_{\text{denoted by } RHS_2^q} \end{array} \right). \end{aligned}$$

It is clear that $\partial RHS_2^q/\partial q < +\infty$. Since it holds that

$$RHS_1^q < 0 \text{ and } \lim_{q\to 0} RHS_1^q = 0,$$

we must have $\lim_{q\to 0}\frac{\partial RHS_1^q}{\partial q} < 0 < +\infty$. Therefore, Inequality (E.5) indeed holds. As a consequence, $q(c)$ is the unique solution to Equation (E.3) when $-q\frac{\partial^2 T(q,c)/\partial q^2}{\partial T(q,c)/\partial q}$ is large enough for $q < \overline{q}$. Meanwhile, by implicit function theorem and Inequality (E.4), we can show that $\max_{c\in[\underline{c},\overline{c}]}\partial q(c)/\partial c$ is finite.

To show that the system of equations (E.1) has a solution, next we need to show that there exists a unique $c \in (\underline{c}, \overline{c})$ that solves

$$-c\frac{\partial\int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial c_1}\bigg|_{q_i=q(c),c_i=c} = -c\frac{\partial T(q,c)}{\partial c}\bigg|_{q=q(c)} \tag{E.6}$$

given that q is equal to $q(c)$. The LHS of Equation (E.6) must be positive and finite on the close interval $[\underline{c}, \overline{c}]$. Since $\frac{\partial T(q,c)}{\partial c} = 0$ for $c \geq \overline{c}$ and $-c\partial T(q,c)/\partial c$ is large enough when $c = \underline{c}$, there must at least exist a $c \in (\underline{c}, \overline{c})$ that solves Equation (E.6). We denote the largest solution to (E.6) as $c^* \in (\underline{c}, \overline{c})$. Meanwhile, c^* must be the unique solution if $-c\partial T(q,c)/\partial c$ increases faster than $-c\partial\int_0^{\tilde{x}} D(z)\pi_1(z)dz/\partial c_1\Big|_{q_i=q(c),c_i=c}$ as c decreases in the interval $[\underline{c}, c^*]$, which means:

$$\frac{\partial T\left(q\left(c\right),c\right)}{\partial c}+c\frac{\partial^2 T\left(q\left(c\right),c\right)}{\partial c^2}+\frac{\partial^2 T\left(q\left(c\right),c\right)}{\partial q\partial c}\frac{\partial q\left(c\right)}{\partial c}>\frac{\partial\left(c\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial c_1}\Big|_{q_i=q(c),c_i=c}\right)}{\partial c}$$

holds for $c\in[\underline{c}, c^*]$. The inequality above can be written as

$$-1-c\frac{\partial^2 T\left(q\left(c\right),c\right)/\partial c^2}{\partial T\left(q\left(c\right),c\right)/\partial c}-c\frac{\frac{\partial^2 T(q(c),c)}{\partial q\partial c}\frac{\partial q(c)}{\partial c}}{\partial T\left(q\left(c\right),c\right)/\partial c}>\frac{\partial\left(c\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial c_1}\Big|_{q_i=q(c),c_i=c}\right)/\partial c}{-\partial T\left(q\left(c\right),c\right)/\partial c} \tag{E.7}$$

Since $\max\limits_{c\in[\underline{c},\overline{c}]}\partial q\left(c\right)/\partial c$ is finite, $\partial\left(c\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial c_1}\Big|_{q_i=q(c),c_i=c}\right)/\partial c$ must be finite for all $c\in[\underline{c},\overline{c}]$ because it is a continuous function of c in the close interval $[\underline{c},\overline{c}]$. Meanwhile, the assumption that $-c\frac{\partial^2 T(q,c)/\partial c^2}{\partial T(q,c)/\partial c}$ is large enough for $c\in[\underline{c},\overline{c}]$ ensures that the LHS of Inequality (E.7) is large enough for $\underline{c}\leq c\leq c^*$; this means Inequality (E.7) indeed holds. Therefore, c^* is the unique solution to Equation (E.6). Overall, there exists a unique solution $\{c^*, q^*\equiv q\left(c^*\right)\}\in(\underline{c},\overline{c})\times(0,\overline{q})$ that solves the system of equations (E.1). This means in a symmetric equilibrium we must have $q_i=q^*\in(0,\overline{q})$ and $c_i=c^*\in(\underline{c},\overline{c})$.

Step 2. Next, we need to show that $q_i=q^*$ and $c_i=c^*$ indeed constitute an equilibrium. To do this, we need to show that lender 1's optimal IT investment is $c_1=c^*$ and $q_1=q^*$ if lender 2's investment is represented by $c_2=c^*$ and $q_2=q^*$. Given that $c_2=c^*$ and $q_2=q^*$, the first order conditions of lender 1 are

$$\underbrace{-\,q_1\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial q_1}\Bigg|_{q_2=q^*,\;c_2=c^*}}_{\text{denoted by }MBq_1}=-q_1\frac{\partial T\left(q_1,c_1\right)}{\partial q_1}\text{ and} \tag{E.8}$$

$$\underbrace{-\,c_1\frac{\partial\int_0^{\tilde{x}}D(z)\pi_1(z)dz}{\partial c_1}\Bigg|_{q_2=q^*,\;c_2=c^*}}_{\text{denoted by }MBc_1}=-c_1\frac{\partial T\left(q_1,c_1\right)}{\partial c_1} \tag{E.9}$$

where

$$MBq_1 = -q_1 \left(\begin{array}{c} \int_0^{\tilde{x}} \frac{R^4(1-q_2(1-z))z\left(c_1+c_1q_2(-1+z)+2c_2(-1+q_1z)\left(1+\sqrt{1-\frac{c_1(1-q_2(1-z))}{c_2(1-q_1z)}}\right)\right)}{32c_1(c_2)^2(1-q_1z)\sqrt{1-\frac{c_1(1-q_2(1-z))}{c_2(1-q_1z)}}}dz \\ +\frac{(q_1(-1+q_2)-q_2)R^2\left(8c_2q_1f+8c_1q_2f+(-q_1+(-1+q_1)q_2)R^2\right)}{32(c_2q_1+c_1q_2)^2}\frac{-c_2(c_2+c_1(-1+q_2))}{(c_2q_1+c_1q_2)^2} \end{array} \right);$$

$$MBc_1 = -c_1 \left(\begin{array}{c} \int_0^{\tilde{x}} \frac{R^4(1-q_2(1-z))\left(c_1+c_1q_2(-1+z)+2c_2(-1+q_1z)\left(1+\sqrt{1-\frac{c_1(1-q_2(1-z))}{c_2(1-q_1z)}}\right)\right)}{32(c_1)^2(c_2)^2\sqrt{1-\frac{c_1(1-q_2(1-z))}{c_2(1-q_1z)}}}dz \\ +\frac{(q_1(-1+q_2)-q_2)R^2\left(8c_2q_1f+8c_1q_2f+(-q_1+(-1+q_1)q_2)R^2\right)}{32(c_2q_1+c_1q_2)^2}\frac{-c_2(q_2-q_1(-1+q_2))}{(c_2q_1+c_1q_2)^2} \end{array} \right).$$

We can show that $MBq_1 > 0$ and $\lim_{q_1 \to 0} MBq_1 = 0$ hold, which implies

$$-\partial MBq_1/\partial q_1 = \partial \left(q_1 \frac{\partial \int_0^{\tilde{x}} D(z)\pi_1(z)dz}{\partial q_1}\bigg|_{q_2=q^*,\ c_2=c^*} \right) /\partial q_1 < +\infty$$

for $q_1 \in (0, \overline{q}]$. Therefore, following the way in which we show the existence and uniqueness of the solution to (E.1), we can also show that the solution to equations (E.8) and (E.9) exists and is unique if $\lim_{q\to 0} -q\partial T(q,c)/\partial q$ and $-c\partial T(q,c)/\partial c|_{c=\underline{c}}$ are large enough and if $-q\frac{\partial^2 T(q,c)/\partial q^2}{\partial T(q,c)/\partial q}$ (resp. $-c\frac{\partial^2 T(q,c)/\partial c^2}{\partial T(q,c)/\partial c}$) is large enough for $q \in (0, \overline{q})$ (resp. $c \in [\underline{c}, \overline{c})$); in this case, the solution must be $q_1 = q^*$ and $c_1 = c^*$. Therefore, given that $c_2 = c^*$ and $q_2 = q^*$, lender 1's best response is to choose $c_1 = c^*$ and $q_1 = q^*$; this means $q_i = q^*$ and $c_i = c^*$ indeed constitute an equilibrium.

Appendix F: Fair deposit insurance

In this supplementary material, we consider the case that lenders are funded by depositors who are fully insured. Whenever lender i cannot fully repay its promised return to depositors, a deposit insurance fund (DIF) would intervene and ensure that depositors are fully paid. In exchange for the insurance fund's service, lender i must pay a fraction β_i of its deposits to the DIF as the premium (for a similar deposit insurance set-up, see Matutes and Vives, 1996, 2000). β_i is called the "insurance premium rate". We assume β_i is fairly determined and so based on lender i's risk (i.e., monitoring); this means the DIF makes a zero expected profit.

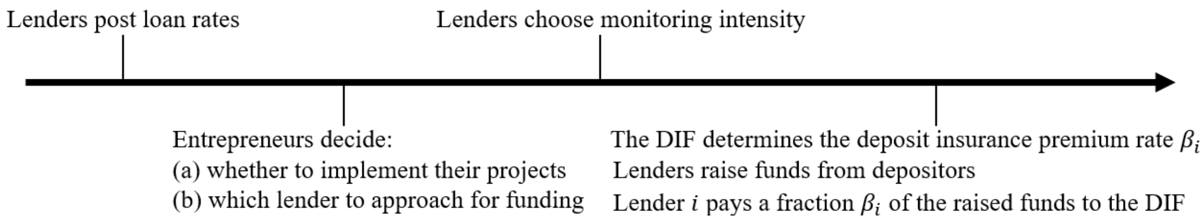


Figure F.1: Timeline (at Lending Competition Stage) with Deposit Insurance.

With the deposit insurance (DI), the timeline of the lending competition stage is as follows (see Figure F.1): First, lenders post loan rate schedules simultaneously. Once the loan rate schedules are chosen and posted, entrepreneurs decide whether to implement their projects and which lender to approach for funding. Given entrepreneurs' decisions and the loan rates of each lender, lender i chooses its optimal monitoring intensity depending on the location of entrepreneurs (i.e., $m_i(z)$). The DIF – after observing $m_i(z)$ – fairly determines the insurance premium rate β_i for lender i. To provide loans, lender i raises funds from depositors, and pays a fraction β_i of the deposits to the DIF as the premium.

Lender profit with the deposit insurance. Because the two lenders are symmetric, we need only focus on lender 1 and analyze how the presence of the fair DI affects the lender's profit function, which determines its optimization problem. We denote lender 1's loan rate and monitoring intensity for entrepreneurs at z by $r_1(z)$ and $m_1(z)$ respectively. If lender 1 finances entrepreneurs located in $\Omega_1 \subseteq [0,1]$, then the total funding demand the lender must meet is $\int_{z\in\Omega_1} D(z)\,dz$ (with $D(z)$ being the funding demand at z). To meet the funding demand, the lender must raise $1/(1-\beta_1)\int_{z\in\Omega_1} D(z)\,dz$ units of funds from depositors and pay $\beta_1/(1-\beta_1)\int_{z\in\Omega_1} D(z)\,dz$ to the DIF because the insurance premium rate is β_1. Since insured deposits are riskless from the perspective of depositors, the lender must promise to repay depositors $f/(1-\beta_1)\int_{z\in\Omega_1} D(z)\,dz$ to make them break even.

When the common risk factor is θ, the aggregate loan repayment lender 1 receives from entrepreneurs is equal to $\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz$, where $1_{\{\cdot\}}$ is an indicator function that equals 1 (resp. 0) if the condition in $\{\cdot\}$ holds (resp. does not hold). If $1_{\{1-m_1(z)\leq\theta\}}=1$, it means projects at z succeed, so the $D(z)$ entrepreneurs (who implement their projects at z) can repay $D(z)r_1(z)$ to lender 1. Such aggregate loan repayment is increasing in θ. Let θ_1^* denote the cut-off risk factor such that lender 1 can fully repay depositors if and only if $\theta\geq\theta_1^*$. Then the lender's expected aggregate lending profit is

$$AP_1 \equiv \left(\begin{array}{c} \int_{\theta_1^*}^{1} \underbrace{\left(\int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz - \frac{f}{1-\beta_1}\int_{z\in\Omega_1} D(z)\,dz\right)}_{\text{lender 1's monetary profit for a given }\theta(\geq\theta_1^*)} d\theta \\ \underbrace{-\int_{z\in\Omega_1} D(z)C_1\left(m_1(z),z\right)\,dz}_{\text{non-pecuniary monitoring costs}} \end{array}\right). \tag{F.1}$$

For a given β_1, the expected profit of the DIF is

$$\pi_{DIF} \equiv \left(\begin{array}{c} \underbrace{f\frac{\beta_1}{1-\beta_1}\int_{z\in\Omega_1} D(z)\,dz}_{\text{value of the insurance premium}} \\ -\int_0^{\theta_1^*} \underbrace{\left(\frac{f}{1-\beta_1}\int_{z\in\Omega_1} D(z)\,dz - \int_{z\in\Omega_1} D(z)r_1(z)1_{\{1-m_1(z)\leq\theta\}}\,dz\right)}_{\text{The DIF's payment to depositors for a given }\theta(<\theta_1^*)} d\theta \end{array}\right).$$

The sum of lender 1's and the DIF's expected profits is

$$AP_1+\pi_{DIF} = \int_{z\in\Omega_1} D(z)\left(r_1(z)m_1(z) - f - C_1\left(m_1(z),z\right)\right)dz > 0,$$

which is positive and independent of β_1. Meanwhile, note that $\pi_{DIF}<0$ if $\beta_1=0$; $AP_1=0$ (which means $\pi_{DIF}>0$) if $\beta_1\to 1$. Therefore, there exists a positive fair $\beta_1\in(0,1)$ such that $\pi_{DIF}=0$, which means the deposit insurance is fairly priced. For such a fair β_1, lender 1's expected profit is

$$AP_1 = AP_1 + \pi_{DIF} = \int_{z\in\Omega_1} D(z)\underbrace{\left(r_1(z)m_1(z) - f - C_1(m_1(z), z)\right)}_{\text{denoted by } \pi_1^{DI}(z)} dz.$$

Hence, the lender's profit from financing an individual entrepreneur at $z \in \Omega_1$ is

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

The first term of $\pi_1^{DI}(z)$ is the expected loan repayment lender 1 receives from an entrepreneur at z, because the entrepreneur repays $r_1(z)$ with probability $m_1(z)$. The second term measures the expected marginal funding cost of providing loans. The intuition is that lender 1 effectively bears all the funding costs of providing loans when the DIF makes a zero expected profit (i.e., when β_1 is fairly determined). The third term represents lender 1's non-pecuniary monitoring costs.

Note that $\pi_1^{DI}(z)$ is the same as $\pi_1(z)$ (see Equation 4), which means the presence of the fair DI does not affect lenders' objective functions in the lending competition. Therefore, all propositions in Sections 3, 4 and 6 still hold here because they are based on the objective function $\pi_i(z)$, which is not affected by the deposit insurance.

Default probability. Since the risk factor θ is uniformly distributed on $[0, 1]$, lender 1 would default when $\theta < \theta_1^*$ if the lender's default probability is equal to θ_1^*. When $\theta = \theta_1^*$ and $\Omega_1 = [0, \tilde{x}]$, the aggregate loan repayment received by lender 1 should exactly equal the lender's promised payment to depositors, implying

$$\underbrace{\int_0^{\tilde{x}} D(z)r_1(z)1_{\{1-m_1(z)\le\theta_1^*\}}\,dz}_{\text{aggregate loan repayment to lender 1 conditional on } \theta=\theta_1^*} = \underbrace{\frac{f}{1-\beta_1}\int_0^{\tilde{x}} D(z)\,dz}_{\text{promised repayment to depositors}}. \tag{F.2}$$

Meanwhile, a fair β_1 implies $\pi_{DIF} = 0$, so we have

$$\underbrace{\frac{\beta_1 f}{1-\beta_1}\int_0^{\tilde{x}} D(z)\,dz}_{\text{value of the insurance premium}} = \int_0^{\theta_1^*} \underbrace{\left(\frac{f}{1-\beta_1}\int_0^{\tilde{x}} D(z)\,dz - \int_0^{\tilde{x}} D(z)r_1(z)1_{\{1-m_1(z)\le\theta\}}\,dz\right)}_{\text{The DIF's payment to depositors for a given } \theta(<\theta_1^*)} d\theta,$$

which can be simplified to:

$$f\int_0^{\tilde{x}} D(z)\,dz = \int_0^{\theta_1^*}\int_0^{\tilde{x}} D(z)r_1(z)1_{\{1-m_1(z)\le\theta\}}\,dz d\theta + (1-\theta_1^*)\frac{f}{1-\beta_1}\int_0^{\tilde{x}} D(z)\,dz. \tag{F.3}$$

Inserting Equation (F.2) into Equation (F.3) and dividing both sides by $\int_0^{\tilde{x}} D(z)$ yield

$$f = \int_0^{\theta_1^*} v_1(\theta)\, d\theta + (1 - \theta_1^*)\, v_1(\theta_1^*) \,. \tag{F.4}$$

Note that in Lemma A.3 – which pins down a lender's default probability in the baseline model – if we insert the default condition of (A.6) into the participation condition, we can exactly get Equation (F.4). Therefore, the presence of the fair deposit insurance does not affect a lender's default probability. All properties on a lender's (or the lending sector's) stability displayed in Section 5 are robust.

The intuition for the result is as follows. Without deposit insurance, lender 1 must promise a nominal return of d_1 to investors for each unit of loan funding. With fair DI, although the nominal promised return is reduced to f (because DI makes deposits riskless), the lender must raise $1/(1-\beta_1)$ units of funds for each unit of loans, where β_1 is the DI premium rate. The reason is that, for each unit of funds raised from depositors, lender 1 must first pay β_1 units to the DIF, so only $1-\beta_1$ units can be used for lending. As a result, a unit of loans corresponds to a promised payment of $f/(1-\beta_1)$ to depositors. When β_1 is fairly determined, the presence of DI neither increases nor decreases the funding cost borne by the lender, so the equation $d_1 = f/(1-\beta_1)$ must hold. This means that in the presence of the fairly priced DI, $f/(1-\beta_1)$ substitutes the role of the nominal promised return d_1. Therefore, allowing for such deposit insurance does not affect any result in the paper.

Appendix G: Unobservable monitoring intensity

Summary. Our baseline model lets investors observe lenders' monitoring, so in Lemma 1 lender i's monitoring intensity is not affected by d_i, which avoids lenders' debt overhang problem. To take debt overhang into account, we build a simplified model in this appendix by assuming that: (a) there exists only one *unique* location (still called location z) with entrepreneurs (that is, all the other locations are vacant and have no entrepreneurs living there); (b) investors *cannot* observe lender monitoring. The rest of the set-up in Section 2 still applies. In this simplified model, the debt overhang problem arises because d_i cannot be contingent on lender i's monitoring intensity. Suppose that the unique location z is served by lender 1. With unobservable monitoring the lender's skin in the game becomes $r_1(z) - d_1$, so the corresponding monitoring intensity is $(1 - q_1 z)(r_1(z) - d_1)/c_1$. The essential difference between c and q in our baseline model is robust with unobservable monitoring. We find that lender 1's skin in the game $r_1(z) - d_1$ is increasing in q while it is unaffected by c, which is consistent with Corollary 4 where a lender's loan rate is increasing in q but not affected by c. When q is sufficiently small, the differentiation effect of decreasing q reduces lender 1's monitoring and profit; the monitoring-reducing effect (with small q) dominates the cost-saving and investment-spurring effects and hence decreases social welfare. The debt overhang problem plays a role of reinforcement: As a lower q reduces lender 1's monitoring and social welfare, investors will require a higher d_1 to break even, which further decreases the lender's skin in the game and hence reinforces the decrease in monitoring and welfare. In contrast, the cost-saving and investment-spurring effects of decreasing c are always dominant, so lender 1's monitoring and profit increase and social welfare improves.

Model set-up with debt overhang. We consider the case that investors cannot observe lenders' monitoring intensities. To do this, we simplify the baseline model by assuming that on the linear city there exists only one *unique* location with entrepreneurs of mass M (that is, all the other locations are vacant and have no entrepreneurs living there). We denote this unique location with entrepreneurs by location z, which means its distance from lender 1 (resp. lender 2) is z (resp. $1 - z$). The rest of the set-up in the paper (Section 2) still applies here. Now the two lenders compete (in Bertrand fashion) for entrepreneurs of the unique location in the city.

The following lemma characterizes lenders' monitoring intensities when investors cannot observe lenders' monitoring.

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

$$m_1(z) = \frac{(r_1(z) - d_1)(1 - q_1 z)}{c_1} = \frac{1 - q_1 z}{2c_1}\left(r_1(z) + \sqrt{(r_1(z))^2 - \frac{4c_1 f}{1 - q_1 z}}\right).$$

A symmetric result holds for lender 2.

When investors cannot observe lenders' monitoring, a debt overhang problem will arise because the promised nominal return d_1 cannot be contingent on $m_1(z)$. In this case, lender 1's skin in the game is determined by the margin $r_1(z) - d_1$. As in the paper, lender 1 has a higher monitoring incentive when $r_1(z)$ and/or $(1 - q_1 z)/c_1$ are higher. Different from the paper, $m_1(z)$ is decreasing in d_1 because a higher promised return will reduce the lender's skin in the game. The nominal promised return d_1 is an endogenous variable. Since there is only a unique location with entrepreneurs in the city, $m_1(z)$ is also lender 1's probability of being solvent if the lender serves the location. As a result, we have

$$d_1 = \frac{f}{m_1(z)} = \frac{f}{\frac{1-q_1 z}{2c_1}\left(r_1(z) + \sqrt{(r_1(z))^2 - \frac{4c_1 f}{1-q_1 z}}\right)},$$

which is increasing in q_1, c_1 and f, while is decreasing in $r_1(z)$. The reason is that a higher $r_1(z)$ or $(1 - q_1 z)/c_1$ implies a higher lender 1's monitoring intensity, thereby decreasing the nominal return required by investors.

In sum, increasing $r_1(z)$ or $(1 - q_1 z)/c_1$ can increase lender 1's monitoring intensity, which is consistent with the result in the main text. Moreover, a higher $r_1(z)$ or $(1 - q_1 z)/c_1$ reduces d_1, which further widens the margin $r_1(z) - d_1$ and hence reinforces the increase in lender 1's monitoring intensity.

The following lemma characterizes lenders' best loan rates and the maximum utility they can provide.

Lemma G.2. *With sufficiently large R, lender i's best loan rate (i.e., the lower bound of its loan rate) for the unique location z is*

$$r_i^o \equiv \frac{R}{2} + \frac{2c_i f}{R(1 - q_i s_i)},$$

where s_i is the distance between the location and lender i.

The maximum gross utility provided by lender i is $U_i\left(r_i^o\right)$, where

$$U_i\left(r\right) \equiv \underbrace{\frac{1-q_i s_i}{2c_i}\left(r+\sqrt{r^2-\frac{4c_i f}{1-q_i s_i}}\right)}_{\text{monitoring intensity with loan rate } r}\left(R-r\right).$$

Note that $U_i\left(r\right)$ represents the gross utility provided by lender i when the loan rate is r; an entrepreneur with opportunity costs $\underline{u}$ derives net utility $U_i\left(r\right)-\underline{u}$ if she borrowers from the lender. As in the main text, entrepreneurial utility depends on not only the residual return (i.e., $R-r$) to entrepreneurs in the event of success, but also the success probability $m_i\left(z\right)$, which is characterized by Lemma G.1. Lender i's loan rate cannot be too low; otherwise the negative effect on its monitoring becomes dominant. As a result, lender i's loan rate must be no less than its best loan rate r_i^o. When the best loan rate r_i^o is offered, the utility provided by lender i will reach the maximum level $U_i\left(r_i^o\right)$; increasing the lender's loan rate (above r_i^o) will decrease the utility provided by the lender.

Equilibrium loan rate. Without loss of generality, we assume

$$U_1\left(r_1^o\right) > U_2\left(r_2^o\right), \tag{G.1}$$

which is equivalent to $(1-q_1 z)/c_1 > (1-q_2(1-z))/c_2$. Inequality (G.1) means that at location z lender 1 has better monitoring efficiency and hence can provide higher utility than lender 2. As a result, in equilibrium the unique location z will be served by lender 1, so we need only look at how lender 1 chooses its loan rate for entrepreneurs at z. In the symmetric case with $q_i = q$ and $c_i = c$, the relation $U_1\left(r_1^o\right) > U_2\left(r_2^o\right)$ can be reduced to $z \in [0, 1/2)$, which means the unique location is closer to lender 1 than to lender 2.

Lender 1's pricing strategy for location z is exactly the same as in the main text. If lender 1 wants to attract an entrepreneur (at z) who decides to undertake a project, it must offer the entrepreneur a loan rate that is more attractive than the best loan rate r_2^o of lender 2. The best strategy is to maximize lender 1's own profit – subject to the constraint that the entrepreneur's expected utility is no less than the maximum utility $U_2\left(r_2^o\right)$ lender 2 can provide.

We focus on the case with effective lending competition; then lender 1's equilibrium competitive loan rate, denoted by $r_1^{\text{comp}}(z)$, is determined by the following equation:

$$U_1\left(r_1^{\text{comp}}(z)\right) = U_2\left(r_2^o\right), \tag{G.2}$$

which has a unique solution for $r_1^{\text{comp}}(z)$ in the interval $[r_1^o, R]$. By offering $r_1^{\text{comp}}(z)$, the utility provided by lender 1 exactly matches the maximum utility provided by lender 2, thereby ensuring that entrepreneurs at location z will not approach lender 2. The following proposition characterizes $r_1^{\text{comp}}(z)$.

Proposition G.1. *With effective lender competition, lender 1's equilibrium loan rate $r_1^{\text{comp}}(z)$ is decreasing in z when $q_2 > 0$. In addition, $r_1^{\text{comp}}(z)$ is decreasing in c_1 and $q_1 z$, while increasing in c_2 and $q_2(1-z)$.*

This proposition is consistent with Corollaries 1 and 3 of the main text. Note that the curve of $r_1^{\text{comp}}(z)$ displays a "perverse" pattern as in Corollary 1. As z increases, lender 1's (resp. lender 2's) monitoring efficiency becomes lower (resp. higher). Therefore, lender 1 must offer a lower competitive loan rate $r_1^{\text{comp}}(z)$ to match the maximum utility $U_2(r_2^o)$ provided by lender 2. As c_1 or $q_1 z$ increases, monitoring becomes more costly for lender 1; this outcome reduces lender 1's competitive advantage and induces it to decrease its loan rate in an attempt to match the maximum utility provided by lender 2. Yet as c_2 or $q_2(1-z)$ increases, the maximum utility provided by lender 2 will decrease, which allows lender 1 to increase its loan rate.

The following corollary analyzes how lender 1's monitoring intensity is affected by its IT. Since lender 1 serves only the unique location z, its insolvency is equivalent to entrepreneurs' failure at z. Therefore, lender 1's monitoring intensity $m_1(z)$ is a measure of the lender's stability.

Corollary G.1. *With effective lender competition, lender 1's stability (measured by $m_1(z)$) is decreasing in c_1 and $q_1 z$, while increasing in c_2 and $q_2(1-z)$.*

An increase in c_1 and $q_1 z$ decreases $m_1(z)$ for three reasons. First, $r_1^{\text{comp}}(z)$ decreases according to Proposition G.1, which reduces lender 1's skin in the game and its monitoring incentive. Second, worse IT itself has a direct negative effect on lender 1's monitoring (Lemma G.1). Finally, there is a *reinforcement effect* through d_1: knowing that lender 1's lower $r_1^{\text{comp}}(z)$ and worse IT will reduce lender 1's stability, investors will require a higher d_1 to break even, which further decreases lender 1's skin in the game (i.e., $r_1^{\text{comp}}(z) - d_1$) and hence monitoring intensity. Reasoning in a similar way, an increase in c_2 and $q_2(1-z)$ increases $m_1(z)$ because (a) $r_1^{\text{comp}}(z)$ increases and (b) a decrease in d_1 reinforces the increase in lender 1's skin in the game.

Corollary G.2. *Let $q_2 > 0$ hold. With effective lender competition, the funding demand of entrepreneurs (at the unique location served by lender 1) is increasing in z.*

This result is consistent with Corollary 2 of the main text. If $q_2 > 0$, the maximum utility $U_2(r_2^o)$ provided by lender 2 will become higher as z increases. To match $U_2(r_2^o)$, the utility provided by lender 1 must also increase, which increases the funding demand of entrepreneurs at the unique location.

IT improvement in the lending sector. Next we focus on the symmetric case with $q_i = q$ and $c_i = c$. The following proposition shows that IT improvement in the lending sector always spurs investment.

Proposition G.2. *Let $q_i = q$ and $c_i = c$ hold. The funding demand of entrepreneurs (at the unique location served by lender 1) is decreasing in q and c.*

This result is consistent with Proposition 4. As q or c decreases, the maximum utility $U_2(r_2^o)$ provided by lender 2 will become higher, so the utility provided by lender 1 must also increase, which increases the funding demand of entrepreneurs at the unique location.

Next we analyze the effects of q and c on $r_1^{\text{comp}}(z)$.

Proposition G.3. *Let $q_i = q$ and $c_i = c$ hold. Then $r_1^{\text{comp}}(z)$ is increasing in q and c while $r_1^{\text{comp}}(z) - d_1$ is increasing in q but it is not affected by c.*

Different from Corollary 4 of the main text where $r_1^{\text{comp}}(z)$ is not affected by c, here $r_1^{\text{comp}}(z)$ will decrease as c decreases. The reason is that a lower c not only improves both lenders' basic technology but also lowers the best loan rate r_i^o (Lemma G.2). However, the essential difference between q and c is robust: c does not control lender differentiation as q does.

Since c has no differentiation effect, lowering c reduces $r_1^{\text{comp}}(z)$ quite slowly and approximately linearly (Panel 4 of Figure G.1). Therefore, the direct cost-saving effect of decreasing c is dominant; investors will require a lower d_1, expecting that lender 1 will increase $m_1(z)$ due to the cost-saving effect. The decrease in d_1 offsets the decrease in $r_1^{\text{comp}}(z)$, leaving lender 1's skin in the game unaffected. In contrast, q determines lender differentiation, so its decrease will reduce $r_1^{\text{comp}}(z)$ quite rapidly; in particular, a numerical study finds that $\partial r_1^{\text{comp}}(z)/\partial q$ will approach $+\infty$ as q approaches 0 (Panel 1 of Figure G.1). As a result, the change of d_1 cannot offset the decrease in $r_1^{\text{comp}}(z)$, implying a lower $r_1^{\text{comp}}(z) - d_1$. In fact, later we will show that for q small enough the differentiation effect of reducing q will increase d_1, thereby reinforcing the decrease in lender 1's skin in the game.

The following proposition characterizes the effects of IT on lender 1's monitoring intensity $m_1(z)$ and profit.

Proposition G.4. *Let $q_i = q$ and $c_i = c$ hold. Lender 1's monitoring intensity $m_1(z)$ (which measures the lender's stability) and profit are decreasing in c. A numerical study finds that they are increasing in q if q is sufficiently small.*[50]

Decreasing q brings a differentiation-reducing effect, which is strong enough to dominate the cost-saving effect for q small enough. Thus lender 1's monitoring intensity and profit are increasing in q if q is sufficiently small. Note that the promised nominal return d_1 plays a role of reinforcement: When q is small, its decrease will induce investors to require a higher d_1 to break even, which reinforces the decrease in lender 1's skin in the game, monitoring intensity and profit. See Panels 2 and 3 of Figure G.1 for an illustration.

In contrast, a decrease in c does not affect lender 1's skin in the game $r_1^{\text{comp}}(z) - d_1$, so its monitoring intensity and lending profit will increase because monitoring becomes cheaper (See Panels 5 and 6 of Figure G.1).

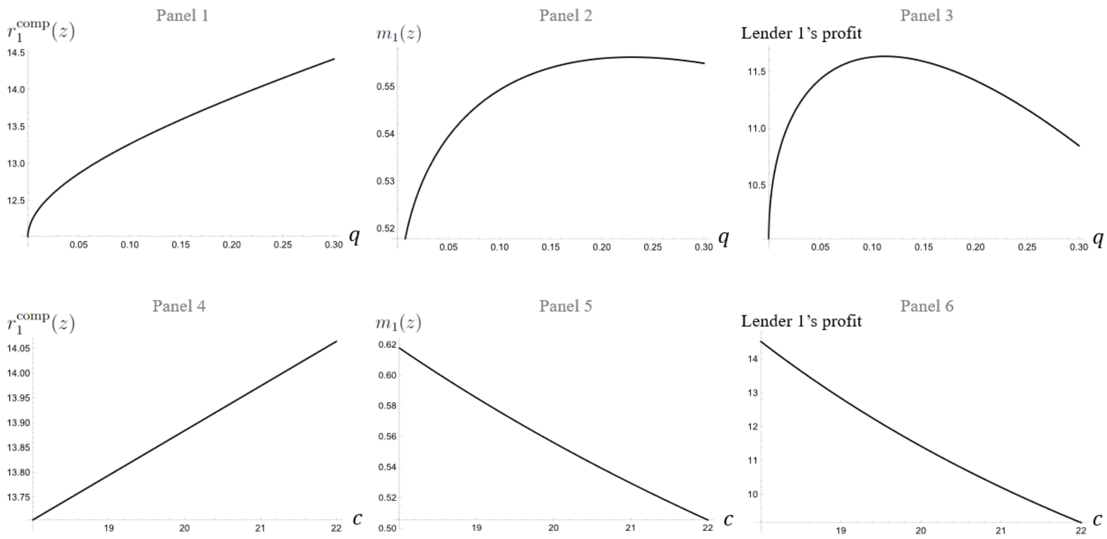


Figure G.1: The Effects of q and c on Lender 1's Loan Rate, Monitoring Intensity and Profit. This figure plots lender 1's loan rate, monitoring intensity and lending profit against q (Panels 1 to 3) and c (Panels 4 to 6) in the equilibrium under lender competition. The parameter values are: $R = 20$, $f = 1$ and $z = 0.4$ in all panels; $c = 20$ in Panels 1 to 3; $q = 0.2$ in Panels 4 to 6.

Social welfare. Finally, we consider how the change of q and c affects social welfare, which is measured by the sum of lender 1's profit and total entrepreneurial utility.

[50] The grid of parameters is as follows: R ranges from 15 to 100; c ranges from $0.8R$ to $1.2R$; q ranges from 0 to 0.3; f ranges from 0.8 to 1.2; z ranges from 0 to 0.49.

Proposition G.5. *Social welfare is decreasing in c. A numerical study finds that it is increasing in q if q is sufficiently small.*[51]

This result is consistent and shares the same intuition with Proposition 9. A decrease in q will decrease lender differentiation and reduce lender 1's loan rate $r_1^{\text{comp}}(z)$ substantially when q is sufficiently small. A very low $r_1^{\text{comp}}(z)$ implies too little monitoring incentive of lender 1 from the social point of view; such a monitoring-reducing effect of decreasing q will dominate the cost-saving and investment-spurring effects when q is sufficiently small, thereby reducing social welfare (Panel 1 of Figure G.2). Moreover, d_1 will increase as the differentiation effect of decreasing q is sufficiently strong, which further reinforces the monitoring-reducing effect and the decrease in social welfare.

In contrast, decreasing c brings no differentiation effect and does not affect lender 1's skin in the game $r_1^{\text{comp}}(z) - d_1$, so the lender's monitoring intensity and profit increase (Panels 5 and 6 of Figure G.1). Meanwhile, a lower c will increase entrepreneurial utility according to Proposition G.2. As a result, social welfare is decreasing in c (Panel 2 of Figure G.2).

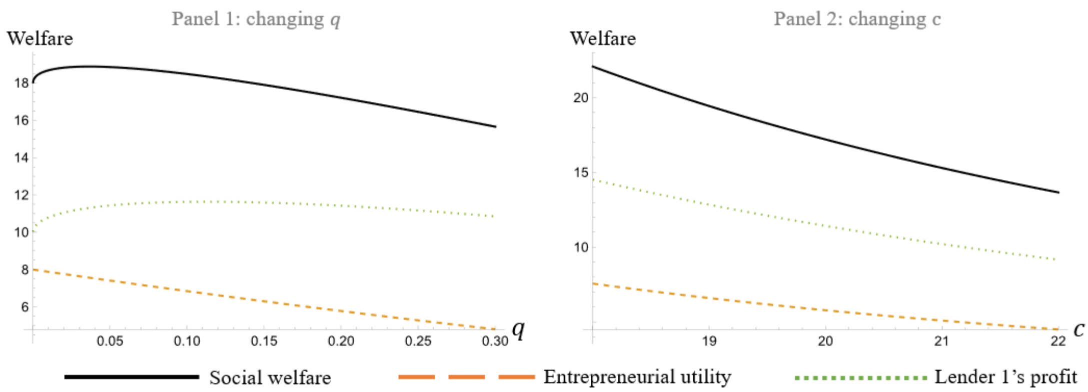


Figure G.2: Social Welfare and Lending Sector's Information Technology under Competition. This figure plots social welfare, entrepreneurial utility, and lenders' profits against q (Panel 1) and c (Panel 2) in the equilibrium under lender competition. The parameter values are: $R = 20$, $f = 1$ and $z = 0.4$ in both panels; $c = 20$ in Panel 1; $q = 0.2$ in Panel 2.

[51]The grid of parameters is as follows: R ranges from 15 to 100; c ranges from $0.8R$ to $1.2R$; q ranges from 0 to 0.3; f ranges from 0.8 to 1.2; z ranges from 0 to 0.49.

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