Information Technology and Lender Competition*

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Abstract

We study how information technology (IT) affects lender competition, entrepreneurs' investment, and welfare in a spatial model. The effects of an IT improvement depend on whether it weakens the influence of lender–borrower distance on monitoring costs. If it does, it has a hump-shaped effect on entrepreneurs' investment and social welfare. If not, competition intensity does not vary, improving lender profits, entrepreneurs' investment, and social welfare. When entrepreneurs' moral hazard problem is severe, IT-induced competition is more likely to reduce investment and welfare. We also find that lenders' price discrimination is not welfare-optimal. Our results are consistent with received empirical work on lending to SMEs.

JEL Classification: G21, G23, I31

Keywords: credit, monitoring, FinTech, price discrimination, moral hazard, regulation

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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 are engaging in traditional banking businesses using their innovative information and automation technologies.[1] Incumbent 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, allowing 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? What are the welfare implications of IT progress? In particular, does the type of IT matter for competition and welfare? Is there a welfare loss from price discrimination? 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. Our model will help to illuminate the following empirical results:

- Business lending by banks with better IT adoption is less affected by the distance between banks and their borrowers (Ahnert et al., 2024).
- Borrowers with better access to bank financing request loans at lower interest rates on a fintech's 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). Broadband

[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 the volume of FinTech business lending in the United States was greater than 40% from 2016 to 2020 (Berg et al., 2022). See also Vives (2019).

internet implementation intensifies bank competition and reduces banks' loan prices (D'Andrea et al., 2021).

- Banks with superior IT adoption have higher loan growth (Dadoukis et al., 2021 and Branzoli et al., 2024). Entrepreneurship is stronger in US counties that are more exposed to IT-intensive banks (Ahnert et al., 2024).
- The relationship between bank competition and bank credit supply is hump-shaped (Di Patti and Dell'Ariccia, 2004).

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 scalable risky investment projects, which may succeed or fail, and 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 it as given that IT is advanced enough for lenders to price flexibly. An entrepreneur can shirk and derive a private benefit, which is ex-ante random and unobservable, after obtaining loans from the lender; if she shirks, her investment project will fail for sure. A critical lender function is monitoring entrepreneurs to reduce their private benefits of shirking (see, e.g., Holmstrom and Tirole, 1997). Monitoring is more costly for a lender if there is a larger distance between the lender and the monitored entrepreneur. This distance can be physical[2] or in the characteristics space from the lender's expertise in certain sectors or industries.[3] After an entrepreneur has chosen a lender for funding, her private benefit of shirking becomes observable to the lender, which will then adjust credit availability – modeled as the maximum size of the loan available to the entrepreneur – based on the observed private benefit. For simplicity, we assume that lenders can provide loans at a given marginal funding cost and do not model how lenders compete to develop relationships with investors or depositors.[4]

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

[4]We admit that this is a limitation. 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

The model has two important ingredients: First, lender monitoring matters for welfare since it enables entrepreneurs with moral hazard problems to obtain credit and invest. Second, lenders cannot credibly commit to monitoring effort ex ante since they can adjust credit availability later (after observing entrepreneurs' private benefits).

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 in 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 improving the ability to collect more valuable data and process them with better computer hardware or information management software (e.g., desktop applications). In contrast, improving IT-distance reduces the negative effect of lender-borrower distance on monitoring costs. Such an improvement lowers more significantly the costs of monitoring entrepreneurs located farther away. For example, better internet connectivity and communication technology (e.g., video conferencing) reduce the physical distance friction.[5] 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.[6]

Under the set-up 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 provide more loans. This is so because a lender's IT progress increases its competitive advantage over its rival.

When both lenders make 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 reduces the costs of monitoring an entrepreneur without altering lenders' relative cost advantage (i.e., IT-basic improves), lenders' competition intensity will not be affected. In this case, the loan rates that lenders offer to

(2002) study bank competition for deposits within a similar spatial competition framework, but in their models, banks can directly invest in risky assets.

[5] Jiang et al. (2023) finds that 3G mobile networks significantly reduce distance friction for banks, geographically expanding their lending.

[6] 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).

entrepreneurs do not vary; lenders become more profitable and provide more loans because monitoring is now cheaper (i.e., monitoring efficiency is higher). 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 their differentiation becomes smaller. Then, the loan rates offered to entrepreneurs decline for both lenders. Such a differentiation-reducing effect decreases lenders' profits despite the fact that IT progress makes monitoring cheaper.

The effect of IT-distance progress on lenders' credit supply is "hump-shaped". IT-distance progress generates three effects on loan supply: First, it improves lenders' monitoring efficiency, tending to increase their credit supply. Second, lenders' differentiation and loan rates decrease, increasing entrepreneurs' skin in the game and alleviating moral hazard; this effect also tends to increase credit supply. Finally, lenders' skin in the game decreases, reducing their monitoring incentives and willingness to supply credit. The first two effects dominate and increase lenders' credit supply and entrepreneurs' investment when IT-distance is not sufficiently advanced (i.e., when lender differentiation is high), while the last effect – the decrease in lenders' monitoring incentives – dominates and reduces lenders' credit supply and entrepreneurs' investment when IT-distance is sufficiently advanced. Moreover, as entrepreneurs' moral hazard problem becomes more severe, the last effect will be more likely to dominate the first two. The reason is that a more severe moral hazard problem increases the need for monitoring, hence making the provision of monitoring incentives (determined by lenders' skin in the game) more important to credit supply. In contrast, IT-basic progress unambiguously increases lenders' credit supply since it has no differentiation effect.

Our model can shed light on the competition between a traditional bank – which has better access to firm data and hence an advantage in IT-basic – and a fintech lender with better IT-distance and lack of firm data. With its better IT-basic, the bank can ensure a positive market share because it has higher monitoring efficiency than the fintech when serving firms sufficiently close to the bank. 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. Moreover, if the bank has a cheaper funding source (e.g., deposits) than the fintech, then the bank will offer lower loan rates and volumes than the fintech when serving entrepreneurs of similar characteristics.

Next, we analyze the welfare effects of information technology progress. We find that more intense competition does not always favor social welfare. When lender competition is not intense, increasing competition intensity improves welfare because it increases entrepreneurs' skin in the game from excessively low levels and substantially alleviates their moral hazard problem. Yet "too much" competition reduces social welfare because high competition intensity decreases lenders' skin in the game and their monitoring incentives, thereby reducing lenders' willingness to extend credit supply. Hence, an improvement in IT-distance – which decreases lender differentiation – may or may not benefit social welfare owing to the consequent increased lender competition. IT-distance progress will be more likely to reduce social welfare when entrepreneurs' moral hazard problem is more severe because the need for monitoring will increase in this case, making lenders' monitoring incentives more crucial. In contrast, improving lenders' IT-basic has no differentiation effect and hence improves welfare unambiguously.

From the social point of view, the welfare-maximizing loan rate does not depend on lenders' IT. This rate represents the socially optimal way to share the project value between an entrepreneur and her lender. Although a lender's IT determines the value of a project it finances (i.e., the size of the pie), the welfare-maximizing way to share the pie must balance the severity of the entrepreneur's moral hazard and the lender's monitoring incentive, which is a trade-off independent of the lender's IT. The implication is that lenders' price discrimination will generate inefficient equilibrium outcomes: A lender will price aggressively at far-away locations – where the lender's IT advantage is low – to gain as much business as possible while at locations close to the lender's area of specialization it will price very high to exploit its high IT advantage. Such a strategy does not balance the severity of moral hazards well with the lender's monitoring incentive at each location. Regulators can improve welfare by setting a proper reference loan rate for lenders and limiting their ability to price discriminate.

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 model studying how lending competition affects the collateral requirements of bank contracts. Several papers have emphasized the importance of monitoring in lending.[7] Almazan (2002) studies how lender capitalization, interest rates, and regulatory shocks affect monitoring efficiency in a spatial competition model where lenders have no market power over entrepreneurs. 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

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

yields a positive return.[8] Different from the aforementioned papers, our model focuses on how different types of IT progress (IT-basic v.s. IT-distance) generate different effects on lenders' monitoring, market power, entrepreneurs' investment, and welfare.

Our paper also belongs to the literature studying information technology and lending competition. Hauswald and Marquez (2006) extend the adverse selection model in Hauswald and Marquez (2003) and show that the equilibrium loan rates received by borrowers are decreasing in the lender-borrower distance and in the intensity of lender competition (measured by the number of lenders), similar to our model prediction. However, our model builds on a different mechanism – entrepreneurs' moral hazard and lender monitoring (as in Holmstrom and Tirole, 1997) – and we analyze the relationship between the severity of entrepreneurs' moral hazard and the equilibrium effects of IT progress. Furthermore, our results differ from those of Hauswald and Marquez (2006), in which an improvement in the lending sector's IT will soften lender competition, and social welfare increases 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 improvements, depending on the type of improved IT, and that social welfare decreases in the intensity of lender competition if competition is very intense.

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 but that it can soften lending competition and hurt borrowers if the fintech is "over-empowered" by the data sharing mechanism. Our work has a different focus: we distinguish two types of information technology and compare their different equilibrium consequences. In addition, we show that one lender's IT progress and the entire lending sector's IT progress generate quite different equilibrium outcomes.

Our theoretical framework is 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.[9] To start with, there is considerable evidence showing that IT makes

[8] Bouvard et al. (2022) study lending and monitoring in a market where a bigtech and competitive banks can provide loans and monitor entrepreneurs. In addition to providing loans, the bigtech itself is a monopolistic platform charging participation fees from entrepreneurs (i.e., merchants).

[9] 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 the 2008 financial crisis substituted for a bank lending reduction.

non-traditional data useful for assessing the quality of borrowers.[10] Moreover, a wide stream of research documents the lending efficiency increase brought about by information technology.[11] Several papers provide evidence consistent with our results. Branzoli et al. (2024) 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 its lending volume. D'Andrea et al. (2021) find that broadband internet implementation intensifies bank competition and reduces banks' loan prices, which is consistent with the effect of IT-distance progress in our model. Ahnert et al. (2024) 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 aligns with this finding. Ahnert et al. (2024) 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 IT-basic progress in the lending sector spurs credit supply and entrepreneurial investment. However, IT-distance progress intensifies lender competition, so its effect on lenders' credit supply is hump-shaped, which is consistent with Di Patti and Dell'Ariccia (2004).[12]

The rest of our paper proceeds as follows. Section 2 presents the model setup. Section 3 examines the lending market equilibrium, and Section 4 examines the effects of information technology. Section 5 provides a welfare analysis of information technology progress. We conclude in Section 6 with a summary of our findings. Appendix A presents the proofs while other appendices deal with model extensions.

[10]The non-traditional data include 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., 2023; Berg et al., 2020), and cashless payment information (Ghosh et al., 2022; Ouyang, 2023).

[11]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 traditional banks. 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. Fuster et al. (2019) estimate that technology-based lenders process mortgage applications 20% faster than traditional banks without incurring greater default risk. Liu et al. (2024) find that a BigTech lender has superior information about entrepreneurs in its ecosystem, so it can extend loans to borrowers underserved by banks without incurring greater risks.

[12]The literature on the Paycheck Protection Program (PPP) launched by the US Small Business Administration (SBA) also highlights the importance of technology. However, we will refrain from explaining those findings within our framework because PPP loans - when properly used by borrowers - are forgivable and carry a uniform loan rate of 1%, which drastically diminishes the space for lenders' monitoring and strategic pricing.

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. At each location, there is one penniless entrepreneur. A point on the city represents the characteristics of the 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. 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, 2023 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 the entrepreneur at z and lender 2 is $1-z$. Figure 1 gives an illustration of the economy.

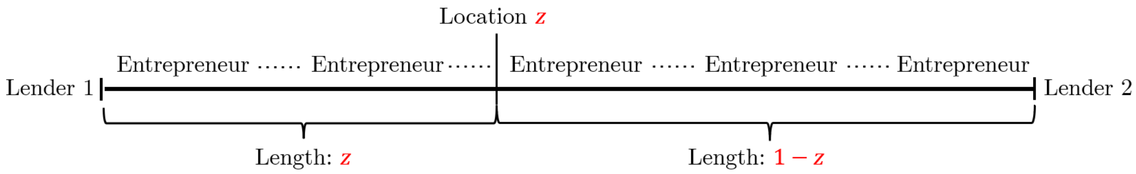

Figure 1: The Economy.

Entrepreneurs and investment projects. Each entrepreneur has no initial capital and is endowed with a scalable risky investment project; hence, entrepreneurs require funding from lenders to undertake projects.

An entrepreneur's project return depends on (a) whether the entrepreneur shirks and (b) the entrepreneur's investment size. If the entrepreneur at z invests $I(z)$ and does not shirk, her project yields the following risky return (where $R > 0$):

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

In the event of success (resp. failure) – which happens with probability p (resp. $1-p$) – the entrepreneur's project yields $I(z)R$ (resp. 0). The success probability $p \in (0,1)$ is a constant.[13] Project returns are independent for entrepreneurs who do not shirk. Lenders

[13] We could also allow the entrepreneur to influence the success probability by exerting effort. Then,

post loan rates and provide credit to entrepreneurs. If the entrepreneur at z borrows $I_i(z)$ units of funds from lender i ($i = \{1, 2\}$) at loan rate $r_i(z)$, the entrepreneur must promise to repay $I_i(z)r_i(z)$.

The funding costs of lenders. We assume lenders can provide loans at a given marginal funding cost, f.[14] Appendix B analyzes the case where the two lenders have different marginal funding costs. We let $pR - f > 0$ hold, meaning that entrepreneurs' projects can generate positive expected returns net of funding cost.

Shirking opportunity and lender monitoring. An entrepreneur can shirk and derive a private benefit from investment. Following Holmstrom and Tirole (1997), we assume that shirking brings the entrepreneur (at z) a total private benefit of $I_i(z)\tilde{B}(z)$ if she invests $I_i(z)$ units of funds without being monitored, where $\tilde{B}(z) > 0$ is the random marginal private benefit derived from a unit of investment. If the entrepreneur shirks, her investment project fails (i.e., returns 0) for sure.

Before the entrepreneur at z determines which lender to borrow from, $\tilde{B}(z)$ is random and unobservable to entrepreneurs and lenders. The random variable $\tilde{B}(z)$ is independent across locations z and follows a binary distribution:

$$Prob.(\tilde{B}(z) = B) = k \text{ and } Prob.(\tilde{B}(z) = b) = 1 - k, \quad (1)$$

with $B > b$ and $k \in [0, 1]$. From lenders' perspective, the shirking opportunity gives rise to the entrepreneurs' moral hazard problem, which is more severe when $\tilde{B}(z) = B$ than when $\tilde{B}(z) = b$. Therefore, a higher k implies a higher ex-ante severity of entrepreneurs' moral hazard problem. We assume $B < f$, implying that shirking is always socially undesirable since it cannot generate a non-negative return net of funding costs.

After the entrepreneur at z builds her lending relationship with lender i, $\tilde{B}(z)$ realizes and becomes observable to both the entrepreneur and the lender. Then, lender i can monitor the entrepreneur and decrease her private benefit of shirking by $m_i(z)$, the lender's *monitoring intensity* at z. As a result, the entrepreneur will not shirk if and only if the following incentive compatibility (IC) condition holds:

$$pI_i(z)(R - r_i(z)) \geq I_i(z)\tilde{B}(z) - m_i(z) \quad \text{[IC]}. \quad (2)$$

an additional effect is introduced, but our results are robust to this extension.

[14] Similar assumptions are adopted in Holmstrom and Tirole (1997), Hauswald and Marquez (2003, 2006), and He et al. (2023). An alternative assumption is that lenders have no capital and attract deposits or debt from competitive risk-neutral investors, who require a break-even expected funding unit's return of f.

If the entrepreneur does not shirk, her expected utility (i.e., profit) is the left-hand side of (2): she receives $I_i(z)(R - r_i(z))$ in the event of success, which happens with probability p. If she shirks, her utility becomes $I_i(z)\tilde{B}(z) - m_i(z)$ since the project returns 0.

Credit limit. After observing $\tilde{B}(z)$, lender i can set a loan size upper-bound $\overline{I}_i(z)$ ("credit limit") for the entrepreneur at z to control moral hazard by capping her investment scale. Since the entrepreneur's funding comes from the lender, the entrepreneur's investment scale cannot exceed $\overline{I}_i(z)$ (i.e., $I_i(z) \in [0, \overline{I}_i(z)]$).

In our model, lender i manages its borrowers' moral hazard through two channels: (a) monitoring (represented by $m_i(z)$), and (b) controlling credit availability (represented by $\overline{I}_i(z)$). Our setup is consistent with the theory and evidence of Acharya et al. (2014), in which banks discipline borrowers by combining monitoring and the capacity to adjust credit lines based on future information.[15]

Non-trivial moral hazard. Throughout the paper, we assume that the marginal private benefit $\tilde{B}(z)$ is sufficiently large such that the moral hazard problem is not trivial:

$$\tilde{B}(z) \geq 2(pR - f), \tag{3}$$

which is equivalent to $B > b \geq 2(pR - f)$. Inequality (3) implies that, without monitoring, an entrepreneur's per-unit expected pledgeable income cannot make lenders break even.[16] To see this, consider that the entrepreneur at z borrows from lender i with the loan rate $r_i(z)$. Without monitoring, she will not shirk if and only if $p(R - r_i(z)) \geq \tilde{B}(z)$, implying $pr_i(z) \leq pR - \tilde{B}(z)$; that is, the entrepreneur can at most pledge an expected marginal return of $pR - \tilde{B}(z)$ to lender i. However, Inequality (3) implies $pr_i(z) \leq pR - \tilde{B}(z) < f$, so the entrepreneur's expected pledgeable income cannot cover lender i's funding costs if there is no monitoring. As a result, lenders must monitor borrowers when lending.

Monitoring and information technology. If the entrepreneur at z borrows from lender i and is monitored with intensity $m_i(z)$, the lender incurs the monitoring cost:

$$C_i(m_i(z), z) = \frac{c_i}{2(1 - q_i s_i)}(m_i(z))^2. \tag{4}$$

[15] Sufi (2009) finds that firms do not treat banks' credit lines as a cash-like liquidity commitment because credit lines are adjustable. Chodorow-Reich and Falato (2022) show that banks can reduce loan commitment following borrowers' covenant violations.

[16] In addition, Inequality (3) implies that an entrepreneur's ex-ante expected utility (to be specified later by Equation 10) is a concave function of the loan rate she borrows with, which ensures that all equilibrium outcomes are continuous functions of parameters and simplifies our analysis.

Here $c_i > 0$, $q_i \in [0, 1)$, and s_i is the distance between lender i and location z; hence, 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.[17] The cost function (4) 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.[18]

Remark: The cost function (4) 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

$$\frac{\partial^2 \left(\frac{C_1(m_1,z)}{C_2(m_2,z)}\right)}{\partial z \partial q} = \frac{2(1 - q(1 - z))}{(1 - qz)^3} \left(\frac{m_1}{m_2}\right)^2 > 0, \tag{5}$$

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 analysis (Minnis and Sutherland, 2017; Gustafson et al., 2021; Branzoli and Fringuellotti, 2022). Specifically, lenders can collect entrepreneurs' data (e.g., by onsite visits or frequently requesting information) and assess whether funds are diverted towards private benefits. If borrowers are not acting appropriately, lenders

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

[18] This is consistent with Giometti and Pietrosanti (2023) who document that lenders specialize in lending to specific industries because of their information advantages in monitoring those industries.

can provide warnings and threats, disciplining borrowers and potentially improving their behavior.[19] Equation (4) captures the fact that a lender's efficiency of information acquisition and processing depends on not only its basic capability but also the distance friction.

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 convey to distant loan officers, incurring informativeness loss in the process of remote information transmission (see Liberti and Petersen, 2019). The second way is to view s_i as the "expertise distance" between an entrepreneur's characteristics and lender i's s specialization. The effectiveness of an information analysis framework will be lower when it is used to deal with firms beyond the framework's intended scope of application (e.g., a framework for a food company or a real estate company).

Distance friction can be weakened by some technologies. The diffusion of the internet and the development of communication technology (like smartphones, mobile apps, social media, or video conferencing) facilitate remote information collection and exchange, reducing the friction caused by physical distance. The friction of the expertise distance can be weakened if an IT improvement facilitates human capital's expansion of specialized areas. For example, improvements in remote learning, search engines, and AI (like GPT) make it easier for loan officers to process the information of firms they do not specialize in, thereby decreasing q_i.

Technologies that decrease c_i are related to improvements in lenders' basic efficiency of information acquisition and/or processing, such as advances in chip technology and cloud computing/storage, adopting better software (e.g., desktop applications, see He et al., 2022), and exploiting new sources of information (like transaction data and digital footprints) with machine learning (ML) techniques.[20]

[19] If the collected information shows a breach of covenants, lenders can obtain control rights and directly intervene to fix borrowers' behavior. Such intervention is easier for BigTech lenders since they have advantages in information collection and contract enforcement in their ecosystems (Liu et al., 2024); in addition, they can threaten to exclude misbehaving borrowers from future use of their platforms (Frost et al., 2019 and Li and Pegoraro, 2023). 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 on a real-time basis (Chen et al., 2022).

[20] 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. (2023) 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'

One consequence of technological progress is the increased availability of cheap but imprecise data (see Dugast and Foucault, 2018). In this case, information *acquisition* becomes easier but the decrease in data quality increases the difficulty of information *processing*. The net change of c_i depends on which effect dominates.

Some technologies 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 also helps 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.

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, smartphone, mobile apps, social media
Decreasing q_i (expertise distance friction) (extending competence of human capital/ hardening soft information)	ML with big/unconventional data, remote learning and AI

Competition with discriminatory loan pricing. Lenders compete in a localized Bertrand fashion to attract entrepreneurs. Lender i follows a discriminatory pricing policy in which the loan rate $r_i(z)$ varies as a function of the entrepreneurial location z.[21]

The timing of the duopoly lending game is shown in Figure 2. First, lenders (without observing $\tilde{B}(z)$) post loan rate schedules simultaneously. Once the loan rate schedules are chosen and posted, entrepreneurs (without observing $\tilde{B}(z)$) decide which lender to approach for credit. Then, lender-borrower relationships are established, and $\tilde{B}(z)$ realizes and becomes observable to both the entrepreneur at z and her lender. Next, lender i determines its optimal monitoring intensity $m_i(z)$ and credit limit $\overline{I_i}(z)$ depending on its entrepreneurs' locations. Entrepreneurs choose their investment based on available credit limits, that is, $I_i(z) \in [0, \overline{I_i}(z)]$. Finally, entrepreneurs determine whether to shirk.

Key ingredients. Compared with a traditional Hotelling (1929) model (where sellers

social networks and physical locations, thereby increasing lenders' ability to intervene and enforce the repayment of borrowers.

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

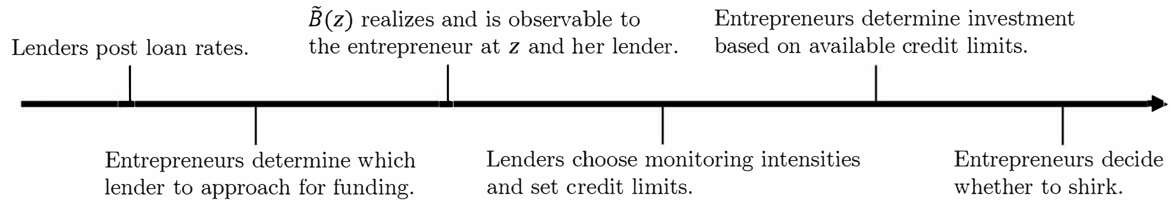

Figure 2: Timeline.

with heterogeneous production costs compete for consumers), our model has two additional ingredients. The first ingredient is that lenders' effort (monitoring) matters for welfare since it enables entrepreneurs to invest.[22] The second ingredient is that lenders cannot commit to effort ex ante (lenders can set their monitoring intensities and credit limits based on the new information $\tilde{B}(z)$ after entrepreneurs have chosen lenders).

3 Equilibrium

In this section, we first derive some optimal decisions of lenders and entrepreneurs and then solve for the equilibrium loan rates. 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 the entrepreneur at z.

3.1 Optimal monitoring intensity, credit limit, and entrepreneurs' decisions

It is easy to see that the entrepreneur at z always uses up her credit limit for investment (i.e., $I_i(z) = \overline{I}_i(z)$ holds when she is served by lender i). After $r_i(z)$, $m_i(z)$, and $\overline{I}_i(z)$ have been determined, the entrepreneur's *ex-post* expected utility is as follows:

$$\max_{I_i(z)\in[0,\overline{I}_i(z)]} \left\{ I_i(z)p\left(R - r_i(z)\right), I_i(z)\tilde{B}(z) - m_i(z) \right\}, \tag{6}$$

so $I_i(z) = \overline{I}_i(z)$ is obviously her optimal choice.

Optimal monitoring intensity. Lender i can anticipate $I_i(z) = \overline{I}_i(z)$ when determining its monitoring intensity $m_i(z)$ at z. Since an entrepreneur's shirking implies the failure

[22]Without monitoring, entrepreneurs cannot implement their projects because of the moral hazard problem. Then, both entrepreneurs and lenders make a zero profit.

of her project and a zero return to the lender, lenders must prevent their entrepreneurs from shirking when providing loans, yielding the following lemma.

Lemma 1. *If lender i provides loans to the entrepreneur at z with loan rate $r_i(z)$ and observes $\tilde{B}(z)$, its optimal monitoring intensity is:*

$$m_i(z) = \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z))), \tag{7}$$

where $\overline{I}_i(z)$ is the lender's credit limit at z.

With $I_i(z) = \overline{I}_i(z)$, Lemma 1 means Condition (2) holds with equality. For lenders, the only benefit of costly monitoring is to prevent entrepreneurs' shirking. Hence, lender i will choose $m_i(z)$ as low as possible, subject to Condition (2), which ensures that the entrepreneur will not shirk.

According to Equation (7), a higher monitoring intensity is needed as the credit limit (which equals investment) increases. The reason is that a larger credit size implies private benefits must be reduced more (by monitoring) to ensure Condition (2). Consistent with the result, Heitz et al. (2023) document that a bank will monitor a borrower more frequently if the loan amount is larger.

In addition, note that $m_i(z)$ is increasing in $\tilde{B}(z) - p(R - r_i(z))$, which reflects the severity of the entrepreneur's moral hazard. To see this, recall that $p(R - r_i(z))$ is the marginal expected return (i.e., skin in the game) to the entrepreneur at z if she does not shirk. Thus, $\tilde{B}(z) - p(R - r_i(z))$ measures the potential net benefit she can derive from a unit of investment by shirking. As $\tilde{B}(z) - p(R - r_i(z))$ increases, shirking becomes more attractive, so a higher monitoring intensity is needed to prevent shirking. Obviously, increasing $r_i(z)$ will reduce the entrepreneur's skin in the game $p(R - r_i(z))$, thereby increasing $\tilde{B}(z) - p(R - r_i(z)))$ and the need for monitoring.

Optimal credit limit. According to the timeline, an entrepreneur has decided which lender to borrow from *before* lenders determine credit limits. If the entrepreneur at z approaches lender i, then the lender's expected profit from financing the entrepreneur can be written as

$$\pi_i(z) = \overline{I}_i(z)(pr_i(z) - f) - \frac{c_i}{2(1 - q_i s_i)} (m_i(z))^2. \tag{8}$$

The first term of $\pi_i(z)$ is the entrepreneur's expected loan repayment minus the funding costs. Specifically, if monitoring prevents shirking, lender i will receive the entrepreneur's full loan repayment $\overline{I}_i(z)r_i(z)$ with probability p (i.e., in the event of project success). The funding costs are $\overline{I}_i(z)f$. The second term of $\pi_i(z)$ represents lender i's monitoring costs.

Lender i chooses its optimal credit limit $\overline{I}_i(z)$ to maximize its expected profit $\pi_i(z)$, taking $r_i(z)$ as given; the result is presented in Lemma 2.

Lemma 2. *If lender i provides loans to the entrepreneur at z with loan rate $r_i(z)$ and observes $\tilde{B}(z)$, its optimal credit limit is:*

$$\overline{I}_i(z) = \frac{1 - q_i s_i}{c_i} \frac{pr_i(z) - f}{(\tilde{B}(z) - p(R - r_i(z)))^2}$$

The entrepreneur's investment size $I_i(z)$ equals $\overline{I}_i(z)$.

Recall that a larger credit limit or more severe moral hazard needs a higher monitoring intensity (Lemma 1). Hence, $\overline{I}_i(z)$ is determined by how much moral hazard lender i's monitoring can alleviate. There are three factors affecting $\overline{I}_i(z)$: (a) lender i's information technology at z, which is represented by $(1 - q_i s_i)/c_i$, (b) the lender's skin in the game $pr_i(z) - f$, and (c) the entrepreneur's potential net benefit of shirking, which is $\tilde{B}(z)$ minus the entrepreneur's skin in the game $p(R - r_i(z))$. First, $\overline{I}_i(z)$ is increasing in $(1 - q_i s_i)/c_i$ because better IT implies a higher monitoring efficiency (i.e., monitoring becomes cheaper). Second, $\overline{I}_i(z)$ is increasing in $pr_i(z) - f$ because a higher lender i's skin in the game increases its willingness to provide credit and monitoring. Finally, $\overline{I}_i(z)$ is increasing in $p(R - r_i(z))$ because a higher entrepreneur's skin in the game makes the moral hazard problem less severe (i.e., $\tilde{B}(z) - p(R - r_i(z))$ becomes smaller), reducing the need for monitoring. Note that increasing $r_i(z)$ increases lender i's skin in the game but decreases the entrepreneur's, so the net effect of changing $r_i(z)$ on $\overline{I}_i(z)$ is ambiguous (to be analyzed later in detail).

Entrepreneurs' decisions. After observing the loan rates posted by lenders, an entrepreneur will approach the lender that can provide higher *ex-ante* expected entrepreneurial utility. If lender i offers loan rate $r_i(z)$ at z, then its expected credit limit $E[\overline{I}_i(z)]$ (based on Lemma 2 and the distribution of $\tilde{B}(z)$) is as follows:

$$E[\overline{I}_i(z)] = \frac{1 - q_i s_i}{c_i} \left(k \frac{(pr_i(z) - f)}{(B - p(R - r_i(z)))^2} + (1 - k) \frac{(pr_i(z) - f)}{(b - p(R - r_i(z)))^2} \right). \quad (9)$$

As a result, the entrepreneur's ex-ante expected utility is:

$$U(q_i, c_i, s_i, r_i(z)) \equiv \underbrace{E[\overline{I}_i(z)]}_{\text{given in Equation (9)}} \times p\,(R - r_i(z))\,, \tag{10}$$

which takes into consideration that lender monitoring will prevent shirking. Inequality (3) ensures that $U(q_i, c_i, s_i, r_i(z))$ is a concave function of $r_i(z)$. Note that the entrepreneur's expected utility depends not only on her skin in the game $p(R - r_i(z))$ but also on the expected credit limit $E[\overline{I}_i(z)]$, which is her expected investment. The latter is affected by lender i's IT and skin in the game. Therefore, the entrepreneur does not simply choose the lender with a lower loan rate. If $U(q_1, c_1, z, r_1(z)) > U(q_2, c_2, 1 - z, r_2(z))$, obviously the entrepreneur will approach lender 1 for loans.

3.2 Equilibrium loan rates

In this section, we study how lenders determine their loan rates.

Best loan rate and monopoly loan rate. Before proceeding, we define two notable loan rates of lender i.

Definition 1. *Lender i's best loan rate at z is the loan rate that maximizes the ex-ante expected utility of the entrepreneur at z. Lender i's monopoly loan rate at z is the loan rate lender i would choose if it faced no competition at z.*

The best loan rate determines how much utility a lender can provide in the Bertrand competition, while the monopoly loan rate determines the maximum profit a lender can earn. The following lemma characterizes the two loan rates.

Lemma 3. *At any location, a lender's best loan rate, denoted by $\underline{r}$, is increasing in k and independent of q_i, c_i, and s_i, and satisfies $f/p < \underline{r} < R$. Hence, the maximum expected utility lender i can provide to the entrepreneur at z is $U(q_i, c_i, s_i, \underline{r})$. A lender's monopoly loan rate is R. Lenders will offer loan rates within the interval $[\underline{r}, R]$.*

If lender i faces no competition at z, it always prefers a higher loan rate. Hence, its profit-maximizing strategy is to offer the highest possible loan rate R and monitor the entrepreneur at z to prevent shirking. Under this strategy, the lender extracts the entire project value, leaving zero surplus to the entrepreneur.

When $r_i(z) = \underline{r}$, the utility $U(q_i, c_i, s_i, r_i(z))$ reaches its maximum. The best loan rate $\underline{r}$ is higher than f/p, implying that lowering $r_i(z)$ may not always increase a lender's attractiveness to entrepreneurs. The reason is that entrepreneurs care about not only the loan rate but also the expected credit limit (see Equation 9). If $r_i(z)$ is lower than $\underline{r}$, lender i's skin in the game and the monitoring incentive will be very small. In this case, further reducing $r_i(z)$ will decrease $E[\overline{I_i}(z)]$ rapidly, thereby hurting the entrepreneur at z. As $r_i(z)$ approaches f/p, the lender's skin in the game $pr_i(z) - f$ will decrease to 0, implying $E[\overline{I_i}(z)] \to 0$ (see Lemma 2). Hence, $\underline{r} > f/p$ must hold.

Note that $\underline{r}$ is unaffected by lender i's monitoring efficiency (i.e., is independent of q_i, c_i, or s_i). The reason is that $\underline{r}$ represents the entrepreneurial utility-maximizing way to allocate the project net value between an entrepreneur and her lender. Although parameters q_i, c_i, and s_i affect the project net value (i.e., the size of the pie), the utility-maximizing allocation rule (i.e., the sharing of the pie) is independent of them.

When k is higher, the potential marginal private benefit $\tilde{B}(z)$ is more likely to be high. In this case, entrepreneurs' moral hazard problem is expected to be more severe, generating a higher need for lenders' monitoring to alleviate the problem. This means that a lender's expected credit limit will be very low if its skin in the game – which determines the lender's monitoring incentive – is small. As a result, allocating a higher share of the pie to lenders (i.e., raising their monitoring incentives) is aligned with entrepreneurs' interests, leading to a higher best loan rate $\underline{r}$.

In a competition of the Bertrand type, lender i's loan rate is always within the interval $[\underline{r}, R]$. If $r_i(z) < \underline{r}$, decreasing $r_i(z)$ hurts the lender without increasing its attractiveness, so neither lender will offer a loan rate below $\underline{r}$. In the interval $[\underline{r}, R]$, increasing $r_i(z)$ implies a higher lender i's profit at z, but it implies lower entrepreneurial utility, thereby reducing the lender's attractiveness in the competition.

Equilibrium loan rates. We posit some standard assumptions in our Bertrand competition model. (i) When $U(q_1, c_1, z, r_1(z)) = U(q_2, c_2, 1-z, r_2(z))$ holds, we assume that the entrepreneur at z will approach the lender that can potentially provide a higher maximum expected entrepreneurial utility (i.e., will approach lender 1 if $U(q_1, c_1, z, \underline{r}) > U(q_2, c_2, 1-z, \underline{r})$).[23] (ii) If both $U(q_1, c_1, z, r_1(z)) = U(q_2, c_2, 1-z, r_2(z))$ and $U(q_1, c_1, z, \underline{r}) = U(q_2, c_2, 1-z, \underline{r})$ hold, then we assume the entrepreneur will randomly approach a lender with probability 1/2; different entrepreneurs' random choices are independent.

Using Lemmas 1 to 3, we can solve for lenders' equilibrium loan rates. If lender 1 wants to attract the entrepreneur at z, it must offer a loan rate weakly more attractive than the best loan rate $\underline{r}$ of lender 2 (i.e., ensure $U(q_1, c_1, z, r_1(z)) \geq U(q_2, c_2, 1-z, \underline{r})$). If

[23]If $U(q_1, c_1, z, \underline{r}) > U(q_2, c_2, 1-z, \underline{r})$ holds, lender 1 can provide utility $U(q_2, c_2, 1-z, r_2(z)) + \varepsilon$ (with ε small) no matter how lender 2 sets $r_2(z)$.

lender 1 cannot do so, then the entrepreneur will be served by lender 2 instead. Reasoning in this way yields the equilibrium loan rates in Proposition 1.[24]

Proposition 1. *Let*

$$\tilde{x} \equiv \frac{1 - c_1/c_2 + c_1 q_2/c_2}{c_1 q_2/c_2 + q_1}.$$

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). At $z = \tilde{x}$, the entrepreneur is served by lender $i \in \{1, 2\}$ with probability $1/2$. At $z \in [0, \tilde{x}]$, lender 1's equilibrium loan rate schedule, $r_1^*(z)$, is the unique solution (in interval $[\underline{r}, R]$) of

$$\underbrace{U(q_1, c_1, z, r_1^*(z))}_{\text{entrepreneurial utility provided by } r_1^*(z)} = \underbrace{U(q_2, c_2, 1 - z, \underline{r})}_{\text{maximum utility lender 2 provides}}. \tag{11}$$

At $z \in [\tilde{x}, 1]$, lender 2's equilibrium loan rate schedule $r_2^*(z)$ is determined in a symmetric way.

Proposition 1 shows the existence and uniqueness of the equilibrium. 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 this case, lenders' pricing policy displayed in Proposition 1 is still robust for the dominant lender.[25] 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 farther 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: $(1 - q_1\tilde{x})/c_1 = (1 - q_2(1 - \tilde{x}))/c_2$. The two lenders offer the same maximum utility at this location, and the entrepreneur

[24] In our model, a lender's profit at z is discontinuous in the two lenders' loan rates. A pure-strategy Nash equilibrium still exists because Bertrand lending competition in our model is a *better-reply secure* game. See Dasgupta and Maskin (1986) and Reny (1999).

[25] 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 efficiency and the corresponding expected credit limit of lender 2 are so low that it cannot attract any entrepreneur even if its best loan rate $\underline{r}$ is offered. The equilibrium loan rate of lender 1 at z still equals $r_1^*(z)$ because lender 2's competitive pressure still exists even though it serves no locations.

randomly chooses a lender with a probability of 1/2. 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. This result is consistent with Ahnert et al. (2024) who document that small business lending by banks with higher IT adoption is less affected by bank-borrower distance.

Next, we characterize lenders' pricing strategies.

Corollary 1. *Let $q_i > 0$ for some $i \in \{1, 2\}$ and $z \in [0, \tilde{x}]$. Lender 1's equilibrium loan rate $r_1^*(z)$ is decreasing in z. A symmetric result holds for $r_2^*(z)$ at $z \in [\tilde{x}, 1]$. At the indifference location $z = \tilde{x}$, $r_1^*(z) = r_2^*(z) = \underline{r}$ holds.*

With distance friction (i.e., $q_i > 0$ for some $i \in \{1, 2\}$), the schedule $r_1^*(z)$ displays a "perverse" pattern (see Panel 1 of Figure 3): As lender 1's monitoring efficiency goes down (i.e., as an entrepreneur is farther away), 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 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 equilibrium loan rate $r_1^*(z)$ should exactly match the maximum utility $U(q_2, c_2, 1 - z, \underline{r})$ lender 2 can provide.

As z increases in the region $[0, \tilde{x}]$, lender 1's monitoring efficiency decreases relative to lender 2's. Hence, lender 1 must offer a lower $r_1^*(z)$ to match the maximum utility provided by lender 2, implying the perverse loan rate pattern. The implication of the result is that entrepreneurs in the region $[0, \tilde{x}]$ cannot benefit from lender 1's advantageous monitoring efficiency; instead, lender 1 itself extracts the entire benefit of its IT advantage over lender 2. Corollary 1 is consistent with the findings of Herpfer et al. (2022): 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. Therefore, a lender must offer its best loan rate $\underline{r}$ to match the utility provided by the rival lender. Panel 1 of Figure 3 graphically illustrates lenders' equilibrium rates when $q_i > 0$.

The case with no distance friction ($q_1 = q_2 = 0$). If $c_1 = c_2$ holds, the two lenders have the same monitoring efficiency at all locations, meaning that competition intensity is unboundedly high everywhere. In this case, every location is an indifference location with both lenders offering the best loan rate $\underline{r}$, and, by assumption, every entrepreneur will randomly choose a lender with probability 1/2. Then, each lender can obtain half of the market, which is consistent with the limit by letting $q_1 = q_2$ tend to 0. Note that

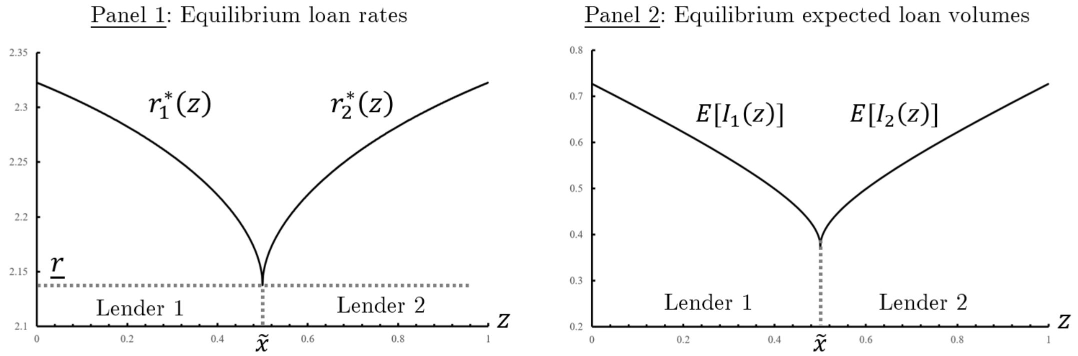

Figure 3: Equilibrium Loan Rates and Expected Loan Volumes for Different Locations. This figure plots the equilibrium loan rate and expected loan volume against the entrepreneurial location. The parameter values are $R = 2.4$, $B = 0.9$, $b = 0.4$, $k = 0.5$, $p = 0.5$, $f = 1$, $c_1 = 1$, $c_2 = 1$, $q_1 = 0.6$, and $q_2 = 0.6$.

in this case, $r_1^*(z) = r_2^*(z) = \underline{r}$ is also consistent with the pricing strategies displayed in Proposition 1.[26]

Investment. The investment $I_i(z)$ of the entrepreneur at z is random and depends on $\tilde{B}(z)$. However, the randomness will disappear if we average the investment of a positive mass of entrepreneurs, in which case the expected investment $E[I_i(z)]$ at z (based on the distribution of $\tilde{B}(z)$) matters. The following corollary characterizes how $E[I_i(z)]$ varies with location.

Corollary 2. *Let $q_i > 0$ for some $i \in \{1, 2\}$ and $z \in [0, \tilde{x}]$. The entrepreneur's expected investment $E[I_1(z)]$ – which equals $E[\overline{I_1}(z)]$ – is decreasing in z when z is sufficiently close to $\tilde{x}$. A symmetric result holds for $E[I_2(z)]$ at $z \in [\tilde{x}, 1]$.*

As z increases in the region $[0, \tilde{x}]$, several competing effects work on lender 1's credit limit and hence expected entrepreneurial investment. First, if $q_1 > 0$, the direct effect of increasing z is to decrease lender 1's monitoring efficiency (because of the longer lending distance), which tends to reduce $E[I_1(z)]$. Second, the indirect effect is that $r_1^*(z)$ decreases (see Corollary 1), which in general has an ambiguous effect on $E[I_1(z)]$. On the one hand, a lower $r_1^*(z)$ increases the entrepreneur's skin in the game, making the moral hazard problem less severe and hence tending to increase $E[I_1(z)]$; on the other hand, it reduces lender 1's skin in the game and monitoring incentive, tending to decrease

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

$E[I_1(z)]$. When z is close to $\tilde{x}$, lender competition is very intense (i.e., $r_1^*(z)$ is very close to $\underline{r}$), so the dominant effect of decreasing $r_1^*(z)$ is to reduce lender 1's monitoring incentive, which, together with the direct effect, leads to a lower $E[I_1(z)]$. Panel 2 of Figure 3 illustrates the result.[27]

4 Information technology and lender competition

In this section, we first derive comparative statics of monitoring parameters on loan rates, lending volumes, and lender profits. Then, we study the competition between a fintech and a bank.

4.1 Comparative statics of monitoring parameters

We analyze the comparative statics of (a) an individual lender's (e.g., lender i's) IT and (b) the lending sector's IT, with a focus on the latter. Table 2 summarizes the results. When looking at the lending sector (instead of an individual lender), we let $c_1 = c_2 = c$ and $q_1 = q_2 = q$ hold and use q and c to represent the sector's IT-distance and IT-basic, respectively.

Table 2: Summary of Comparative Statics

	q_1	c_1	q_2	c_2	q ($q_i = q,\ c_i = c$)	c ($q_i = q,\ c_i = c$)
$r_1^*(z)$ at $z \in [0, \tilde{x})$	↓	↓	↑	↑	↑	- -
L_1	↓	↓	$\uparrow^{num}$	$\uparrow^{num}$	hump-shaped	↓
$\int_0^{\tilde{x}} \pi_1(z)dz$ (Lender 1's aggregate profits)	↓	↓	↑	↑	$\uparrow^{num}$	↓

This table summarizes how endogenous variables (in the first column) is affected by parameters (in the first row). "↑" (resp. "↓") means that an endogenous variable is increasing (resp. decreasing) in the corresponding parameter. "- -" means that an endogenous variable is independent of the corresponding parameter. "$\uparrow^{num}$" (resp. "$\downarrow^{num}$") means that an endogenous variable is increasing (resp. decreasing) in the corresponding parameter based on numerical studies. "Hump-shaped" means the effect of a parameter increase has an "positive-then-negative" effect on the endogenous variable.

[27]When z is not close to $\tilde{x}$, $E[I_1(z)]$ may be increasing in z (i.e., the indirect effect on $E[I_1(z)]$ may be positive and dominant because the moral hazard problem becomes less severe). However, based on our numerical analysis, $E[I_1(z)]$ is increasing in z (for z not close to $\tilde{x}$) only when the two lenders are quite asymmetric. In the symmetric case with $q_1 = q_2$ and $c_1 = c_1$, a numerical study finds that $E[I_1(z)]$ is decreasing in z even when z is not close to $\tilde{x}$. This is in line with the evidence that a bank tends to lend more to firms about which the bank has better expertise (Blickle et al., 2023; Duquerroy et al., 2022; Paravisini et al., 2023).

Information technology and loan rates. The following corollary analyzes how equilibrium loan rates vary with c and q (the lending sector's IT) in the case $c_1 = c_2 = c$ and $q_1 = q_2 = q$.

Corollary 3. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. Lender i's equilibrium loan rate $r_i^*(z)$ is increasing in q (except for $z = 1/2$ where $r_i^*(z) = \underline{r}$) and is not affected by c. If $q = 0$, $r_i^*(z) = \underline{r}$ holds for all locations.*

Corollary 3 highlights a crucial difference between c (IT-basic) and q (IT-distance). As q increases, monitoring costs become more sensitive to distance, which increases lender differentiation. Higher differentiation increases lender 1's market power at $z \in [0, 1/2)$ because lender 2's monitoring efficiency is more severely hurt by a higher q at a location closer to lender 1. A symmetric reasoning applies to lender 2 at $z \in (1/2, 1]$. Hence, both lenders can post higher loan rates for their respective entrepreneurs as q increases. Lender differentiation will disappear when $q = 0$, implying unbounded competition intensity and $r_i^*(z) = \underline{r}$ at all locations.[28] In contrast, although an increase in c makes monitoring more costly, lenders' differentiation is unaffected; hence, equilibrium loan rates are unaffected.

In sum: unlike increasing c, 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 D'Andrea et al. (2021) who find that broadband internet implementation intensifies bank competition and reduces banks' loan price, and Duquerroy et al. (2022) who document that increased branch specialization in SME lending – which can be viewed as an increase in q – substantially curtails the intensity of lending competition.[29] Paravisini et al. (2023) find a similar result in the credit market for export-related loans.

Corollary 3 tells us that, when studying how changes in information technology affect lender competition, we should first specify the *type* of IT change.[30]

[28]Decreasing q is equivalent to shortening the length of the linear city while increasing the density of entrepreneurs at each location. To see this, consider that the IT-distance parameter changes from q to q'. Then, for lender 1, the distance friction at z becomes $q'z = q(q'z/q)$, which can be viewed as a IT-distance parameter q and a lending distance $q'z/q$. That is, after the parameter change, the city can be viewed as one with a length of q'/q and entrepreneurs of mass 1, implying that the density of entrepreneurs at each location becomes q/q'.

[29]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.

[30]The 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

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

The equilibrium consequences of a lender's IT improvement are quite different from those of a general lending sector's IT improvement. Indeed, a lender adopting better IT increases its loan rates (see the effects of q_1 and c_1 on $r_1^*(z)$ in Table 2), while both lenders' loan rates will decrease if the lending sector's IT-distance improves. A lender's IT improvement affects both itself and the other lender's behavior, giving rise to a competitive spillover effect. Our model highlights that caution is necessary when using diff-in-diff methods in empirical research on technological progress.[31]

Information technology and lending volume. Lender 1's (resp. lender 2's) aggregate loan volume equals $L_1 \equiv \int_0^{\tilde{x}} I_1(z)dz$ (resp. $L_2 \equiv \int_{\tilde{x}}^1 I_2(z)dz$). Although $I_i(z)$ is random, the aggregate lending volume L_i depends on $E[I_i(z)]$ and is deterministic (e.g., $\int_0^{\tilde{x}} I_1(z)dz = \int_0^{\tilde{x}} E[I_1(z)]dz$) because $\tilde{B}(z)$ is independent across z. The following proposition shows how the lending sector's IT affects lenders' total lending volume $L_1 + L_2$, which is also entrepreneurs' total investment.

Proposition 2. *Let $c_1 = c_2 = c$ and $q_1 = q_2 = q$. Entrepreneurs' total investment (i.e., $L_1 + L_2$) is decreasing in c while it is increasing in q if q is sufficiently small.*

Proposition 2 states that the two types of IT have different effects on the market's credit supply. IT-basic progress (i.e., decreasing c) increases lenders' lending volume and, hence, total investment because it improves lenders' monitoring efficiency without intensifying their competition. See Panel 2 of Figure 4 for an illustration. This is consistent with Ahnert et al. (2024) 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.

A decrease in q (IT-distance progress) has more complex effects. First, it improves lenders' monitoring efficiency (as IT-basic does), which tends to increase total investment. Second, it reduces lenders' differentiation and intensifies their competition, decreasing lenders' loan rates and generating an ambiguous effect on lenders' expected credit limits. When q is sufficiently small, lenders' loan rates will approach $\underline{r}$; in this case, the dominant effect of lowering lenders' loan rates is to decrease their monitoring incentives and expected credit limits. In addition, the speed of loan rate reduction will be unboundedly high when q is close to 0 because then the intensity of lender competition will tend to infinity (i.e., lender differentiation will disappear). As a result, when q is very small,

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.

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

lenders' total lending volume will decrease as IT-distance improves, although monitoring becomes cheaper.

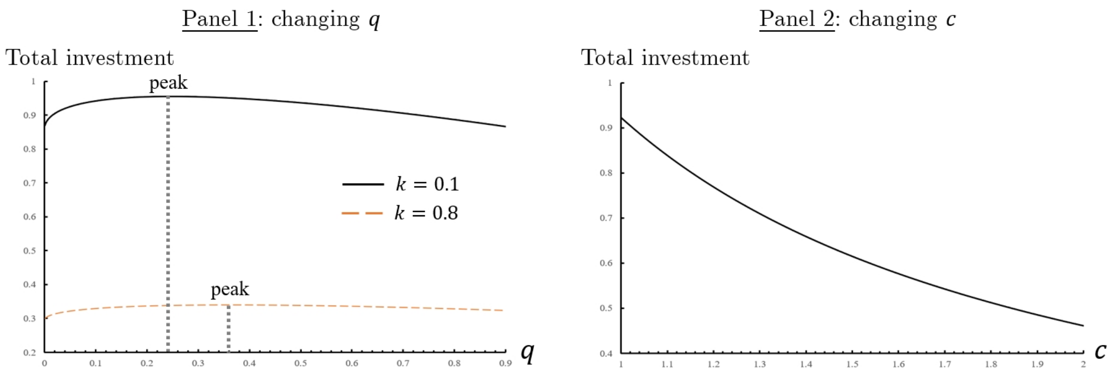

Figure 4: Information Technology and Total Investment. This figure plots entrepreneurs' total investment (i.e., lenders' total loan volume) against c and q. The parameter values are: $R = 2.4$, $B = 0.9$, $b = 0.4$, $p = 0.5$, and $f = 1$ in both panels; $c = 1$ in Panel 1, with $k = 0.1$ for the solid curve and $k = 0.8$ for the dashed curve; $q = 0.6$ and $k = 0.1$ in Panel 2.

Figure 4 illustrates Proposition 2. Decreasing c has no differentiation effect and hence increases total investment unambiguously. Decreasing q, however, has a "hump-shaped" net effect on investment (see Panel 1 of Figure 4). When q is large, the investment-spurring effects of decreasing q are dominant: (a) monitoring becomes cheaper, and (b) lower loan rates increase entrepreneurs' skin in the game, reducing the severity of the moral hazard. However, when q is small, the dominant effect of decreasing q is reducing lenders' monitoring incentives, thereby decreasing total investment. This result is consistent with Di Patti and Dell'Ariccia (2004), who document that the relationship between bank competition – which is affected by q in our model – and banks' credit supply is hump-shaped.

Furthermore, a numerical study finds that increasing k will increase the investment-maximizing level of q. This can be seen from Panel 1 of Figure 4: The solid curve (with a low k) peaks at a lower q than the dashed curve (with a high k). This is so since a higher k implies a higher ex-ante severity of entrepreneurs' moral hazard, which increases the need for monitoring to alleviate the problem and make credit available. Therefore, the provision of monitoring incentives (determined by lenders' skin in the game) becomes more important to credit supply and investment.[32] Hence, the differentiation effect of

[32]Note that entrepreneurs' skin in the game can alleviate the moral hazard problem and reduce the need for monitoring, but alone can solve the moral hazard problem only when it is trivial. Otherwise, credit supply has to rely on lenders' monitoring, and a higher potential private benefit will strengthen the reliance.

decreasing q is more likely to reduce total investment when k is higher.

Information technology and lender profit. Lender 1's aggregate lending profit from all locations is equal to $\int_0^{\tilde{x}} \pi_1(z)dz$; here $\pi_1(z)$ is lender 1's profit from financing the entrepreneur at z (see Equation 8). Symmetrically, we can define lender 2's aggregate profit. The effects of IT on lender profit are given in Table 2. Although a decrease in q $(= q_1 = q_2)$ implies cheaper monitoring, it also reduces lenders' differentiation and intensifies their competition. Our numerical study finds that the differentiation effect dominates and decreases lender profit. In contrast, a decrease in c $(= c_1 = c_2)$ has no differentiation effect and increases lender profit.

The effects of an individual lender's IT. Table 2 also shows the effects of q_i and c_i (without the restriction $q_1 = q_2 = q$ or $c_1 = c_2 = c$). As lender i's IT improves – be it IT-basic (c_i) or IT-distance (q_i) – the lender will have a higher competitive advantage and obtain larger market share, which increases the lender's loan rates, aggregate lending volume, and profit. Meanwhile, higher lender i's competitiveness will force its rival to lower loan rates, lose market share, and make less profit.

4.2 Competition between a bank and a fintech

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.[33]

Suppose that lender 1 is a bank with relatively low c_1 (smaller than c_2) and positive q_1, while lender 2 is a fintech with relatively high c_2 (because of lack of data) and $q_2 = 0$ (uniform capability to monitor different entrepreneurs). Then, according to Corollary 1, the fintech's loan rate is decreasing in its lending distance (i.e., increasing in z when $z \in [\tilde{x}, 1]$, see Panel 1 of Figure 5). The reason is that the maximum utility provided by the bank (i.e., lender 1) is decreasing in z; to match this utility, the fintech will increase its loan rate as z increases in the region $[\tilde{x}, 1]$. This result is consistent with Butler et al. (2017), who document that borrowers with better access to bank financing request loans

[33]Banks' advantage in the access to customer data is the rationale of the Open Banking initiative launched by several governments, including the European Union and the United Kingdom. See Babina et al. (2024) and He et al. (2023).

at lower interest rates on a fintech platform.[34] Moreover, note that $c_1 < c_2$ must imply $\tilde{x} > 0$, no matter how large the bank's q_1 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 0. 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.

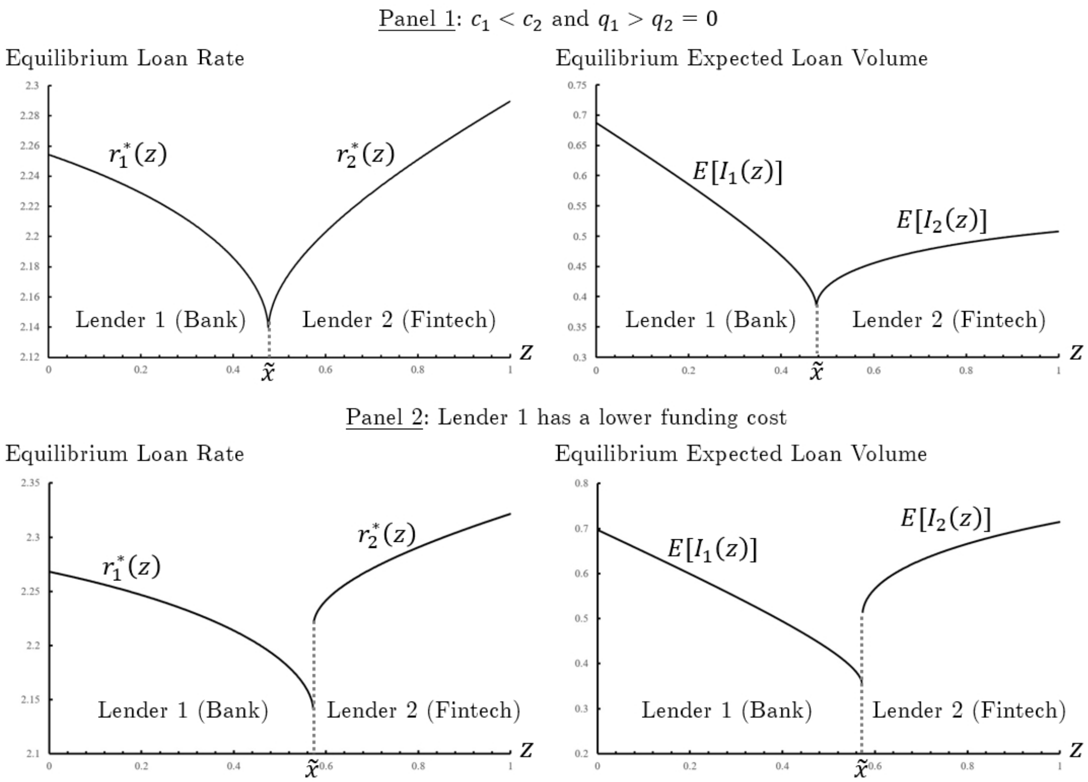

Figure 5: Equilibrium Loan Rates and Volumes under Bank-Fintech Competition. This figure plots the equilibrium loan rate and expected loan volume against the entrepreneurial location. In Panel 1, the parameter values are $R = 2.4$, $B = 0.9$, $b = 0.4$, $k = 0.5$, $p = 0.5$, $f = 1$, $c_1 = 1$, $c_2 = 1.4$, $q_1 = 0.6$, and $q_2 = 0$. In Panel 2, lender i's marginal funding cost is f_i (with $i \in \{1, 2\}$); the parameter values are $R = 2.4$, $B = 0.9$, $b = 0.4$, $k = 0.5$, $p = 0.5$, $f_1 = 1$, $f_2 = 1.05$, $c_1 = 1$, $c_2 = 0.7$, $q_1 = 0.6$, and $q_2 = 0$.

Heterogeneous funding costs. Banks and fintechs have different funding sources and,

[34] Open banking policy can be viewed as a decrease in c_2 because it improves customer data availability for the fintech. Based on our model, the decrease in c_2 (due to open banking) will expand the market area served by lender 2 (fintech). This result is consistent with Babina et al. (2024), who document that open banking policy significantly enlarges venture capital investment in fintechs, which can be viewed as a proxy for fintechs' expansion.

hence, may face heterogeneous funding costs. In Appendix B, we relax the assumption that the two lenders face the same marginal funding cost f. We find that decreasing a lender's funding cost will increase the lender's skin in the game and expected credit limit, improving its competitive advantage. As a result, the lender gains a larger market area (Corollary B.1) and increases loan rates and expected loan volumes (Corollary B.2). However, if both lenders' funding costs decrease, their loan rates will decrease (Corollary B.3). It follows that if a policymaker aims to decrease loan rates by reducing lenders' funding costs, it should reduce the funding costs for *all* lenders. Otherwise, some lenders can exploit larger funding cost advantages and charge higher loan rates.

With heterogeneous funding costs, lenders' best loan rates are no longer the same: The lender with a lower marginal funding cost has a lower best loan rate (Lemma B.1). Suppose that lender 1 is a bank with a lower marginal funding cost than lender 2 (fintech). At the indifference location $z = \tilde{x}$, the two lenders offer the same entrepreneurial utility, but they have different advantages: The bank has an advantage in funding costs, while the fintech has an advantage in IT. As a result, the equilibrium loan rates and expected volumes are discontinuous at the indifference location (Proposition B.2). The bank's funding cost advantage allows it to offer a lower (best) loan rate at $z = \tilde{x}$, while the fintech's IT advantage allows it to provide a higher expected credit limit to compete with the bank (see Panel 2 of Figure 5).

5 Welfare analysis

In this section, we first analyze how the development and diffusion of the lending sector's information technology affect social welfare. Then, we examine the relationship between equilibrium loan rates and socially optimal ones. Throughout the section, we let $q_1 = q_2 = q$ and $c_1 = c_2 = c$, and hence use q and c to represent the lending sector's IT-distance and IT-basic.

If the entrepreneur at location z is financed by lender i (with $i = 1$ or 2), then social welfare is given by

$$W \equiv \underbrace{\int_0^1 I_i\left(z\right) p \left(R - r_i(z)\right)\, dz}_{\text{Entrepreneurs' aggregate utility}} + \underbrace{\int_0^1 \left(I_i\left(z\right) \left(pr_i(z) - f\right) - \frac{c(m_i(z))^2}{2(1-qs_i)} \right) dz}_{\text{Lenders' total profits}}. \tag{12}$$

Here $r_i(z)$, $m_i(z)$, and $I_i(z)$ are lender i's loan rate, monitoring intensity, and credit limit (i.e., loan volume) for the entrepreneur at z respectively. Even if $I_i(z)$ and $m_i(z)$

are functions of $\tilde{B}(z)$, W is deterministic since $\tilde{B}(z)$ is independent across z. According to Expression (12), social welfare consists of entrepreneurs' utility and lenders' profits, incorporating that lenders' monitoring prevents entrepreneurs' shirking.

5.1 Welfare properties of the symmetric equilibrium

In this subsection, we analyze the welfare effects of information technology progress. Figure 6 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 3). Greater lender competition (together with higher monitoring efficiency) translates into lenders providing higher entrepreneurial utility. So, as can be seen in Panels 1 and 3 of Figure 6, 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. Our numerical study finds that the differentiation effect dominates, so lenders' profits decrease as q decreases (see Table 2). Perhaps more surprising is the following result: decreasing q reduces social welfare for q small enough.

Proposition 3. *Social welfare is increasing in q if q is sufficiently small while it is decreasing in c.*

In general, the effect of q on welfare is ambiguous. Whether a reduction in q and the resultant increased competition intensity are welfare-improving depends on whether we start with a low or high level of competition (Panels 1 and 3 of Figure 6). When q is high, reducing q improves welfare for two reasons: First, a lower q implies higher monitoring efficiency in the lending sector (cost-saving effect). Second, when lender differentiation is high, intensifying lender competition will significantly alleviate entrepreneurs' moral hazard and increase their investment (see Panel 1 of Figure 4). A potential welfare-reducing effect also exists: More intense lender competition reduces lenders' skin in the game and monitoring incentives. However, the last effect is dominated when q is high.

The story flips when q is small enough. In this case, high competition intensity leaves lenders with very low skin in the game. Then, further decreasing q reduces social welfare because the reduction in lenders' monitoring incentives – which decreases their willingness to alleviate entrepreneurs' moral hazard and extend credit limits – becomes the dominant effect. Entrepreneurs' investment rapidly decreases as a result. More intense lender competition still improves entrepreneurs' utility (by decreasing the loan

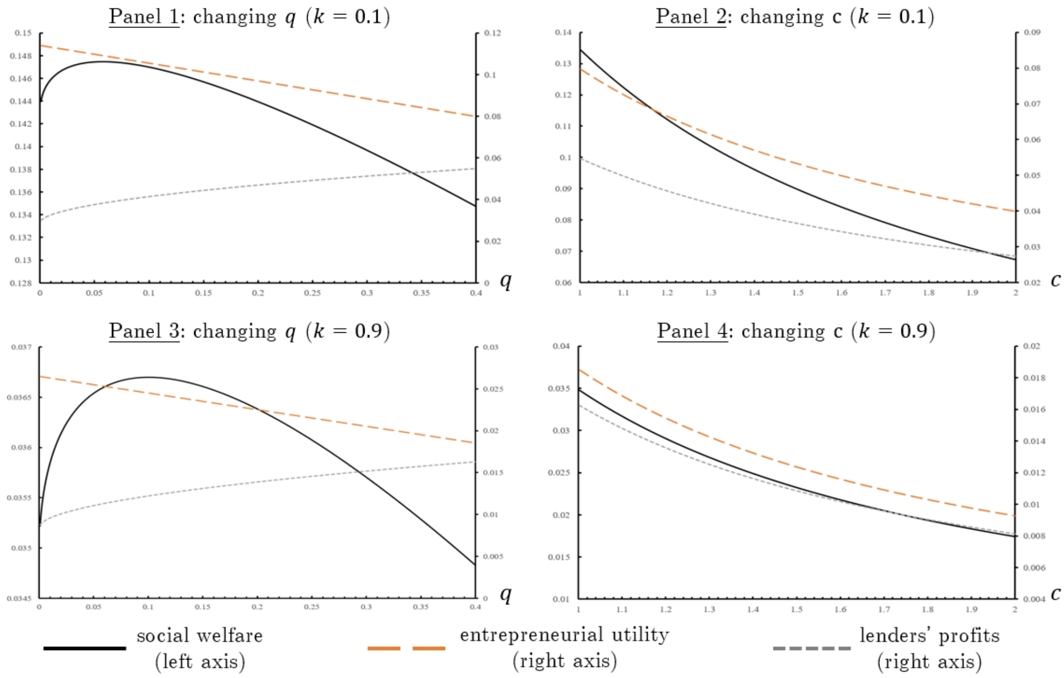

Figure 6: Social Welfare and Lending Sector's Information Technology. This figure plots social welfare, entrepreneurial utility, and lenders' profits against c and q. The parameter values are: $R = 2.4$, $B = 0.9$, $b = 0.4$, $p = 0.5$ and $f = 1$ in all panels; $c = 1$ in Panels 1 and 3; $q = 0.4$ in Panels 2 and 4; $k = 0.1$ in Panels 1 and 2; and $k = 0.9$ in Panels 3 and 4.

rates). In addition, the cost-saving effect is dominated.[35]

In contrast, decreasing c unambiguously improves social welfare since it does not affect lender differentiation (Corollary 3). See Panels 2 and 4 of Figure 6 for an illustration.

Furthermore, a numerical study finds that increasing k, the probability of a high realization of $\tilde{B}(z)$, will increase the welfare-maximizing level of q. This can be seen from Panels 1 and 3 of Figure 6: In Panel 3, where k is higher, social welfare peaks at a higher q than in Panel 1. A higher k (i.e., higher ex-ante severity of moral hazard) raises the need for monitoring, increasing the importance of lenders' monitoring incentives and their skin in the game for welfare. As a result, IT-distance progress is more likely to reduce social welfare when $\tilde{B}(z)$ is more likely to be high.

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. Hence, when discussing IT progress, one must stipulate the type of IT involved.

[35] The existence of the lower bound $\underline{r}$ for lenders' pricing is not an ingredient driving the result. Social welfare would decrease further if lenders decreased their loan rates below $\underline{r}$.

Key model ingredients, competition, and welfare. The result that reducing distance friction may harm welfare is driven by two ingredients: (a) lender monitoring matters for welfare, and (b) lenders cannot commit ex ante to monitoring effort (they set credit limits and monitoring intensities after entrepreneurs have chosen lenders). Note that credit limits determine the need for monitoring (Lemma 1). The second ingredient implies that monitoring is not committed when lenders post loan rates; instead, it is incentivized by lenders' skin in the game determined by loan rate competition. As a result, reducing q (when it is already very low) will excessively intensify competition and reduce lenders' monitoring incentives, which hurts welfare because of ingredient (a).[36]

Endogenous lender locations. In Online Appendix C, we allow lenders to choose their locations before lending competition happens. We find that when $q > 0$, lenders choose different locations, implying the existence of lender differentiation. In addition, we find that lenders move closer to each other as q decreases, further reducing lender differentiation (without bringing a cost-saving effect). This additional differentiation effect (i.e., the diminishing distance between lenders) makes IT-distance progress more likely to cause excessive competition and harm welfare. In contrast, decreasing c does not affect lenders' location choices, so it unambiguously improves welfare.

5.2 Socially optimal loan rates

In this subsection, we examine how IT affects the relationship between equilibrium loan rates and socially optimal ones.

Social planner's problem. We consider the case where the social planner, without observing $\tilde{B}(z)$, can choose the socially optimal loan rate schedule of lender i, denoted by $\{r_i^o(z)\}$, to maximize social welfare W. The other choice variables of lenders and entrepreneurs are determined in equilibrium for given loan rates; that is, each entrepreneur approaches the lender that can provide higher utility, and lenders' monitoring and credit limits are determined as in Lemmas 1 and 2. Note that shirking is never desirable for the social planner since $\tilde{B}(z) < f$. The following proposition characterizes the socially optimal loan rates.

[36]The implications of our model apply more generally than the credit market. Competition among firms (which need not be lenders) can hurt social welfare if (a) firms' efforts matter for welfare and (b) firms determine their efforts after customers have chosen what firm to patronize (i.e., firms cannot credibly commit to effort ex ante).

Proposition 4. *Price discrimination is not efficient. At any location, the socially optimal loan rate for both lenders is* r^o*, which is increasing in* k *and independent of* q*,* c*, and* z*, and satisfies* $\underline{r} < r^o < R$*. The entrepreneur at* $z \in [0, 1/2)$ *(resp.* $z \in (1/2, 1]$*) approaches lender 1 (resp. lender 2); the entrepreneur at* $z = 1/2$ *approaches lender* i *(with* $i \in \{1, 2\}$*) with probability* $1/2$*.*

From the social point of view, lowering r^o decreases lenders' skin in the game (i.e., reducing their monitoring incentives), potentially reducing their credit limits and hurting welfare. Yet as r^o decreases, entrepreneurs' skin in the game will increase, making moral hazard less severe and reducing the need for monitoring (Lemma 1), which tends to improve social welfare. The social planner must balance the social benefits (less severe moral hazard) and costs (lower monitoring incentive) of decreasing r^o, leading to the relation $\underline{r} < r^o < R$: At one extreme, $\underline{r}$ maximizes entrepreneurs' utility but implies an excessively low lenders' monitoring incentives (and also excessively low credit limits). The monopoly loan rate R is the other extreme, which maximizes lenders' profits and the severity of the entrepreneurs' moral hazard.

As k increases, the ex-ante severity of entrepreneurs' moral hazard problem becomes higher, increasing the need for lenders' monitoring to alleviate the problem and make credit available. Therefore, the social planner will increase r^o to give lenders higher monitoring incentives.

Note that r^o is unaffected by information technology (i.e., q or c) or the lending distance s_i. The reason is that r^o controls the efficient relative size of lender profit with respect to entrepreneurial utility (i.e., the sharing of the pie), which is a trade-off between the severity of moral hazard and lenders' monitoring incentives. Although q, c, and s_i determine the absolute project value (i.e., the size of the pie), the welfare-maximizing way to share the pie is independent of those parameters.

Given that lenders offer r^o, the entrepreneur at $z \in [0, 1/2)$ (resp. $z \in (1/2, 1]$) approaches lender 1 (resp. lender 2), while the entrepreneur at $z = 1/2$ randomizes her choice. Such choices of entrepreneurs are efficient for welfare since each location is served by the lender with (weakly) better monitoring efficiency. Note that at $z = 1/2$, lender i's equilibrium loan rate is lower than r^o. This is so since the two lenders have the same monitoring efficiency at $z = 1/2$, implying unbounded competition. As a result, the equilibrium loan rate at $z = 1/2$ always equals the best loan rate $\underline{r}$ (see Corollary 1), which is excessively low compared with the socially optimal level r^o. See Panel 1 of Figure 7 for an illustration.

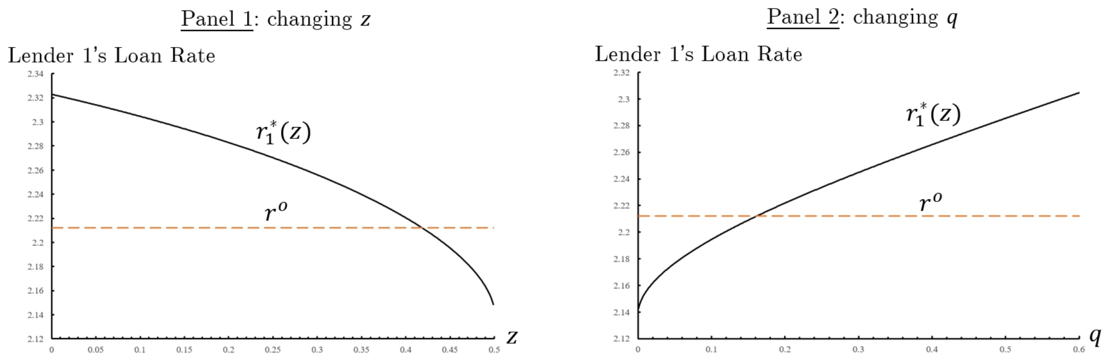

Figure 7: Comparing $r_1^*(z)$ and r^o. This figure plots $r_1^*(z)$ and r^o against z (Panel 1) and q (Panel 2). The parameter values are: $R = 2.4$, $f = 1$, $B = 0.9$, $b = 0.4$, $k = 0.5$, $p = 0.5$ and $c = 1$ in both panels; $q = 0.6$ in Panel 1; $z = 0.1$ in Panel 2.

Equilibrium loan rates v.s. socially optimal rates. Proposition 4 implies that the "perverse" pattern of lender i's equilibrium loan rate $r_i^*(z)$ (displayed in Corollary 1) is not efficient. A lender maximizes profit instead of social welfare, so it will extract more project value when it has more market power. Such a strategy does not balance the severity of moral hazard well with the lender's monitoring incentive. In addition, if lenders offer r^o, it is easy to show that lender i's expected credit limit $E[\overline{I_i}(z)]$ is linearly increasing in $(1-qs_i)/c$. This aligns with the welfare-maximizing consideration because a higher monitoring efficiency corresponds to a higher expected lending volume. In contrast, in equilibrium, decreasing q – which improves both lenders' monitoring efficiency – may reduce their lending volumes (Proposition 2). A straightforward policy implication of Proposition 4 is that regulators can guide lenders' pricing to improve allocation efficiency by setting r^o as the reference loan rate for lenders and limiting their ability to price discriminate based on borrowers' locations.

Remark (asymmetric IT): If the two lenders' IT is asymmetric (i.e., $q_1 \neq q_2$ or/and $c_1 \neq c_2$), the socially optimal loan rate (of both lenders) is still equal to r^o since r^o is independent of lenders' IT. Given that both lenders offer r^o, entrepreneurs' choices are still efficient from the social point of view: The entrepreneur at z will approach the lender with better IT at z, or randomize her choice if the two lenders have the same monitoring efficiency at z.

For the rest of the section, we still focus on the case $q_1 = q_2 = q$ and $c_1 = c_2 = c$. The following corollary shows how the lending sector's IT affects the relationship between the equilibrium loan rates and the socially optimal one.

Corollary 4. *When q is sufficiently small, $r_i^*(z) < r^o$ holds for all locations.*

As q decreases, lender differentiation will be smaller. At any location served by lender i, the corresponding increase in competition intensity will gradually drive the equilibrium loan rate $r_i^*(z)$ to the best loan rate $\underline{r}$, which is lower than the socially optimal level r^o according to Proposition 4. As a result, $r_i^*(z) < r^o$ holds for all locations when q is small enough; in this case, lenders' monitoring incentives are excessively low for all entrepreneurs. See Panel 2 of Figure 7 for an illustration.

Corollary 4 provides an explanation for Proposition 3 from another angle. When q is small enough, equilibrium loan rates deviate below the socially optimal level at all locations. Then, further decreasing q enlarges the deviation, reducing social welfare.

Figure 8 illustrates the relationship between lender 1's equilibrium loan rate and r^o in $z \times q$ space. For all three panels, lender competition is excessively intense (i.e., $r_1^*(z) < r^o$ holds) in Region II (the colored area). Consistent with our results, $r_1^*(z)$ is lower than r^o when q is small or z is close to 1/2.

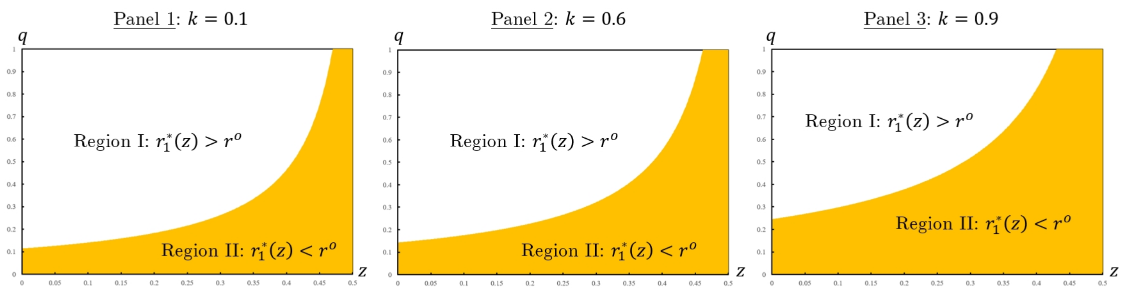

Figure 8: Relations between $r_1^*(z)$ and r^o in $z \times q$ Space. This figure compares $r_1^*(z)$ with r^o in $z \times q$ space. The parameter values are $R = 2.4$, $c = 1$, $f = 1$, $B = 0.9$, $b = 0.4$, and $p = 0.5$.

A numerical study finds that as k increases, Region II will become larger in $z \times q$ space (Comparing the three panels of Figure 8 for an illustration), which means IT-distance progress is more likely to induce excessive lender competition. The intuition is that increasing k will raise the need for monitoring, so lenders' skin in the game (i.e., monitoring incentives) will be more important for welfare. Then, decreasing lender differentiation (through reducing q) can more easily induce $r_i^*(z) < r^o$.

First-best case. In Online Appendix D, we analyze the first-best case, where the social planner determines both loan rates and credit limits. In this case, the social planner will choose the rate $\underline{r}$ – the best loan rate given in Lemma 3 – and set high credit limits. The reason is that the social planner would like to alleviate entrepreneurs' moral hazard using a low loan rate and to increase total project values by setting high credit limits. Like r^o, the first-best loan rate $\underline{r}$ is also independent of q, c, and s_i. However, the first-best credit limit (chosen by the social planner) at z does depend on those parameters. Therefore, implementing the first-best allocation requires the social planner to observe lenders' IT at each location, which is more difficult than just setting loan rate r^o and letting lenders themselves choose credit limits.

6 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 provide more loans. 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. The effect of IT-distance progress on entrepreneurs' total investment is hump-shaped (Proposition 2 and Figure 4). IT-distance progress is more likely to reduce investment when the ex-ante severity of entrepreneurs' moral hazard problem is higher (i.e., k is higher). Therefore, we should be careful to identify the kind of information technology change being considered before gauging its impact.

Consistently with received empirical evidence, we have the testable 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 has a larger aggregate lending volume. We also find that a lender's loan rate will increase after the lender's IT improves relative to other lenders'. See Proposition 1, Corollary 1, and Table 2.

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 alleviate their moral hazard; on the other hand, lower lender differentiation can reduce lenders' profits, monitoring incentives, and willingness to extend credit limits. Whether or not an improvement in lenders' IT-distance benefits social welfare depends on whether the lending market has insufficient or too much competition at the outset. When q is low, there is always excessive competition and insufficient monitoring incentives (Proposition 3). IT-distance progress is more likely to induce excessive competition and harm welfare when the ex-ante severity of entrepreneurs' moral hazard is higher (see Figures 6 and 8). The market may over- or under-shoot the welfare optimal rate. It will tend to under-shoot – implying that the market under-provides monitoring – when lender competition is very intense (Proposition 4 and its corollary). Finally, we find that price discrimination is inefficient and that a regulator could improve welfare by imposing a uniform reference loan rate.

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Appendix A: Proofs

Proof of Lemmas 1 and 2. After observing $\tilde{B}(z)$, if lender i chooses $m_i(z) < \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z)))$, the entrepreneur at z will shirk; in this case, providing loans to the entrepreneur cannot bring a non-negative profit to the lender. Hence, $m_i(z) \geq \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z)))$ must hold. Obviously, choosing $m_i(z) > \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z)))$ is strictly dominated by choosing $m_i(z) = \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z)))$ because the latter is sufficient to prevent shirking.

With $m_i(z) = \overline{I}_i(z)(\tilde{B}(z) - p(R - r_i(z)))$, maximizing $\pi_i(z)$ (Equation 8) yields Lemma 2.

Proof of Lemma 3. In this proof, we take as given that lender i's monitoring intensity and credit limit at z are as given in Lemmas 1 and 2. According to Equations (9) and (10), if the entrepreneur at z borrows from lender i at the loan rate $r_i(z) \in [0, R]$, her expected utility $U(q_i, c_i, s_i, r_i(z))$ equals $((1 - q_i s_i)/c_i) V(r_i(z))$, with

$$V(r_i(z)) \equiv k \frac{(pr_i(z) - f)\, p(R - r_i(z))}{(B - p(R - r_i(z)))^2} + (1 - k) \frac{(pr_i(z) - f)\, p(R - r_i(z))}{(b - p(R - r_i(z)))^2}. \qquad \text{(A.1)}$$

Maximizing $U(q_i, c_i, s_i, r_i(z))$ (by choosing $r_i(z)$) is equivalent to maximizing $V(r_i(z))$. Since $V(r_i(z))$ is not a function of q_i, c_i, or s_i, the best loan rate $\underline{r}$ must be independent of q_i, c_i, and s_i.

Note that $V(r_i(z)) \leq 0$ when $r_i(z) \in [0, f/p]$, while $V(r_i(z)) > 0$ when $r_i(z) \in (f/p, R)$. Hence, we need only consider $r_i(z) \in (f/p, R)$ when determining the utility-maximizing loan rate $\underline{r}$. We can show that

$$\begin{cases} V'(f/p) = k\frac{p(pR-f)}{(B-(pR-f))^2} + (1-k)\frac{p(pR-f)}{(b-(pR-f))^2} > 0 \\ V'(R) = k\frac{p(f-pR)}{B^2} + (1-k)\frac{p(f-pR)}{b^2} < 0 \end{cases},$$

so there exists at least one $r_i(z)$ (in the interval $(f/p, R)$) that solves $V'(r_i(z)) = 0$. Next, we need to check the second-order condition. Note that $V(r_i(z))$ can be written as

$$V(r_i(z)) = E\left[v\left(r_i(z), \tilde{B}(z)\right)\right] = kv(r_i(z), B) + (1-k)v(r_i(z), b),$$

with the function $v\left(r_i(z), \tilde{B}(z)\right)$ defined as follows:

$$v\left(r_i(z), \tilde{B}(z)\right) \equiv \frac{\left(pr_i(z) - f\right) p\left(R - r_i(z)\right)}{\left(\tilde{B}(z) - p\left(R - r_i(z)\right)\right)^2}, \ \tilde{B}(z) \in \{B, b\}.$$

If $v\left(r_i(z), \tilde{B}(z)\right)$ is a concave function of $r_i(z)$ (in the interval $(f/p, R)$) for a given $\tilde{B}(z)$, then $V\left(r_i(z)\right)$ must be concave in the interval $(f/p, R)$.

We can show that

$$v_{11}\left(r_i(z), \tilde{B}(z)\right) \equiv \frac{\partial^2 v\left(r_i(z), \tilde{B}(z)\right)}{\partial r_i(z)^2} = \frac{\psi\left(r_i(z), \tilde{B}(z)\right)}{\left(\tilde{B}(z) - p\left(R - r_i(z)\right)\right)^4},$$

with the function $\psi\left(r_i(z), \tilde{B}(z)\right)$ defined as follows:

$$\psi\left(r_i(z), \tilde{B}(z)\right) \equiv -2p^2\left(\left(\tilde{B}(z)\right)^2 + 2\tilde{B}(z)\left(f - pr_i(z)\right) + p\left(r_i(z) - R\right)\left(pR - f\right)\right).$$

Note that the sign of $v_{11}\left(r_i(z), \tilde{B}(z)\right)$ is determined by that of $\psi\left(r_i(z), \tilde{B}(z)\right)$. With Inequality (3), we can show that

$$\begin{cases} \frac{\partial \psi\left(r_i(z), \tilde{B}(z)\right)}{\partial r_i(z)} = 2p^3\left(2\tilde{B}(z) + f - pR\right) > 0 \\ \psi\left(f/p, \tilde{B}(z)\right) = -2p^2\left(\left(\tilde{B}(z)\right)^2 - \left(f - pR\right)^2\right) < 0 \\ \psi\left(R, \tilde{B}(z)\right) = -2\tilde{B}(z)p^2\left(\tilde{B}(z) - 2\left(pR - f\right)\right) < 0 \end{cases}.$$

Therefore, for a given $\tilde{B}(z)$, $\psi\left(r_i(z), \tilde{B}(z)\right) < 0$ must hold in the interval $(f/p, R)$, which means $v_{11}\left(r_i(z), \tilde{B}(z)\right) < 0$ also holds in this interval. As a result, $v\left(r_i(z), \tilde{B}(z)\right)$ is a concave function of $r_i(z)$ (in the interval $(f/p, R)$) for a given $\tilde{B}(z)$, so $V\left(r_i(z)\right)$ must be concave in the interval $(f/p, R)$. Then, the solution to $V'\left(r_i(z)\right) = 0$ must be unique in this interval. This unique solution (denoted by $\underline{r}$) is the best loan rate.

Let $\underline{r}^B \in (f/p, R)$ denote the solution to $\partial v\left(r_i(z), B\right)/\partial r_i(z) = 0$, and $\underline{r}^b \in (f/p, R)$ denote the solution to $\partial v\left(r_i(z), b\right)/\partial r_i(z) = 0$. It is easy to check that

$$\underline{r}^b = R - \frac{b\left(pR - f\right)}{p\left(2b + f - pR\right)} < R - \frac{B\left(pR - f\right)}{p\left(2B + f - pR\right)} = \underline{r}^B.$$

Since $\underline{r}$ satisfies

$$V'(\underline{r}) = k \left.\frac{\partial v(r_i(z), B)}{\partial r_i(z)}\right|_{r_i(z)=\underline{r}} + (1-k) \left.\frac{\partial v(r_i(z), b)}{\partial r_i(z)}\right|_{r_i(z)=\underline{r}} = 0,$$

it must hold that

$$\underline{r}^b < \underline{r} < \underline{r}^B, \quad \left.\frac{\partial v(r_i(z), B)}{\partial r_i(z)}\right|_{r_i(z)=\underline{r}} > 0 \text{ and } \left.\frac{\partial v(r_i(z), b)}{\partial r_i(z)}\right|_{r_i(z)=\underline{r}} < 0.$$

Then, according to the concavity of $v\left(r_i(z), \tilde{B}(z)\right)$, as k increases, $\underline{r}$ must increase to keep $V'(\underline{r}) = 0$ holding.

Next, we look at the monopoly loan rate. Before $\tilde{B}(z)$ becomes observable, lender i's ex-ante expected profit from serving the entrepreneur at z is $E[\pi_i(z)]$. It can be shown that

$$\frac{\partial E[\pi_i(z)]}{\partial r_i(z)} = \frac{1-q_i s_i}{c_i} E\left[\frac{p(pr_i(z)-f)\left(\tilde{B}(z)+f-pR\right)}{(\tilde{B}(z)-p(R-r_i(z)))^3}\right], \tag{A.2}$$

which is positive for $r_i(z) \in (f/p, R]$ because $\tilde{B}(z) + f - pR > 0$ (see Inequality 3). The lender will never choose $r_i(z) \leq f/p$; otherwise, its profit from serving the entrepreneur at z is negative. Hence, the monopoly loan rate is R, which maximizes $E[\pi_i(z)]$.

Proof of Proposition 1 and Corollary 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 rate $\underline{r}$ at the indifference location; meanwhile, the entrepreneur at the location feels indifferent. So we have the following equation for the indifference location $\tilde{x}$:

$$\frac{1-q_1\tilde{x}}{c_1} V(\underline{r}) = \frac{1-q_2(1-\tilde{x})}{c_2} V(\underline{r}),$$

where the function $V(\cdot)$ is defined by Equation (A.1) in the proof of Lemma 3. Solving the equation yields 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 an advantage in the competition with its rival. Hence, if $0 < \tilde{x} < 1$, entrepreneurs in $[0, \tilde{x})$ are served by lender 1, while those in $(\tilde{x}, 1]$ are served by lender 2.

At location $z \in [0, \tilde{x})$, lender 1 must offer a loan rate $r_1(z)$ to maximize its own profit from this location, subject to the constraint that the entrepreneur at z's utility is no less than $U(q_2, c_2, 1-z, \underline{r})$. Recall that lender 1's monopoly loan rate is R, which leaves 0 profit to the entrepreneur. Lender 1's optimal choice is to set $r_1(z)$ as high as possible, implying Equation (11). Similarly, lender 2's equilibrium loan rate $r_2^*(z)$ at $z \in (\tilde{x}, 1]$ is determined by:

$$U(q_2, c_2, 1-z, r_2^*(z)) = U(q_1, c_1, z, \underline{r}).$$

At the indifference location $z = \tilde{x}$, $U(q_2, c_2, 1-z, \underline{r}) = U(q_1, c_1, z, \underline{r})$ holds, so the two lenders both offer $\underline{r}$ and provide the same entrepreneurial utility. As a result, the entrepreneur at $z = \tilde{x}$ will randomly choose a lender with probability 1/2.

When $r_1^*(z) \in [\underline{r}, R]$, the left-hand side of Equation (11) is decreasing in $r_1^*(z)$ since $V'(r_1^*(z)) < 0$ for $r_1^*(z) \in (\underline{r}, R]$. If z increases in the region $[0, \tilde{x}]$, the left-hand side of Equation (11) will decrease for a given $r_1^*(z)$, while the right-hand side will increase; hence, $r_1^*(z)$ must decrease to keep Equation (11) holding.

Proof of Corollary 2. In equilibrium, we can write $E[\overline{I_1}(z)]$ (with $z \in [0, \tilde{x}]$) as follows:

$$E[\overline{I_1}(z)] = \frac{1-q_1 z}{c_1} \frac{V(r_1^*(z))}{p(R - r_1^*(z))}, \tag{A.3}$$

where the function $V(\cdot)$ is defined by Equation (A.1) in the proof of Lemma 3.

It can be shown that

$$\begin{cases} \frac{\partial E[\overline{I_1}(z)]}{\partial z} = \frac{-q_1}{c_1} \frac{V\left(r_1^*(z)\right)}{p\left(R - r_1^*(z)\right)} + \underbrace{\frac{1-q_1 z}{c_1} \frac{V'(r_1^*(z))\, p(R - r_1^*(z)) + pV(r_1^*(z))}{(p(R - r_1^*(z)))^2}}_{\text{positive when } r_1^*(z) \text{ is close to } \underline{r} \text{ since } V'(\underline{r})=0} \frac{\partial r_1^*(z)}{\partial z} \\ \frac{\partial r_1^*(z)}{\partial z} = \frac{c_1}{1-q_1 z} \frac{\frac{q_2}{c_2} V(\underline{r}) + \frac{q_1}{c_1} V\left(r_1^*(z)\right)}{V'\left(r_1^*(z)\right)} \end{cases} \tag{A.4}$$

As z approaches $\tilde{x}$, $r_1^*(z)$ – which is higher than $\underline{r}$ – will approach $\underline{r}$. Meanwhile, because of the concavity of $V(r_1^*(z))$, $V'(r_1^*(z)) < 0$ holds when $r_1^*(z) > \underline{r}$. Hence, $V'(r_1^*(z))$ will approach 0 from the negative side as z approaches $\tilde{x}$. Then, according to the second equation of (A.4), $\lim_{z \to \tilde{x}^-} \partial r_1^*(z)/\partial z = -\infty$ holds when $q_i > 0$ holds for some $i \in \{1, 2\}$. As a result, $\lim_{z \to \tilde{x}^-} \partial E[\overline{I_1}(z)]/\partial z = -\infty$ according to the first equation of (A.4).

Proof of Corollary 3. At $z \in [0, \tilde{x}]$, Equation (11) can be written as:

$$V(r_1^*(z)) = \frac{c_1}{c_2} \frac{1 - q_2(1-z)}{1 - q_1 z} V(\underline{r}) \tag{A.5}$$

The left-hand side of Equation (A.5) is decreasing in $r_1^*(z)$ when $r_1^*(z) \in [\underline{r}, R]$. If c_1/c_2 or $(1 - q_2(1-z))/(1 - q_1 z)$ marginally decreases, the right-hand side of Equation (A.5) will decrease; hence, $r_1^*(z)$ must increase to keep Equation (A.5) holding.

If $q_1 = q_2 = q$ and $c_1 = c_2 = c$, obviously the right-hand side of Equation (A.5) is independent of c, so is $r_1^*(z)$. At $z \in [0, 1/2)$, $(1-q(1-z))/(1-qz)$ is decreasing in q. Hence, $r_1^*(z)$ is increasing in q at $z \in [0,1/2)$. At $z = 1/2$, $r_1^*(z) = \underline{r}$ according to Corollary 1.

Proof of Proposition 2. We make the convention that the SLLN holds for a continuum of independent random variables with uniformly bounded variances (see Vives, 2010). Since $\tilde{B}(z)$ is independent across z, L_1 is equal to $\int_0^{\tilde{x}} E[I_1(z)]dz$ almost surely. With $c_1 = c_2 = c$ and $q_1 = q_2 = q$, it holds that $\tilde{x} = 1/2$ and $L_1 = L_2$, so we focus on L_1 in the proof. It can be shown that $\partial L_1/\partial c = \int_0^{1/2} \partial E[I_1(z)]/\partial c dz$. Since $r_1^*(z)$ is independent of c, $E[I_1(z)]$ must be decreasing in c according to Lemma 2. Hence, L_1 is decreasing in c.

As for the effect of q, we also have $\partial L_1/\partial q = \int_0^{1/2} \partial E[I_1(z)]/\partial q dz$. According to Equations (11) and (A.3), we can show

$$\begin{cases} \frac{\partial E[\overline{I_1}(z)]}{\partial q} = \frac{-z}{c}\frac{V\left(r_1^*(z)\right)}{p\left(R-r_1^*(z)\right)} + \underbrace{\frac{1-qz}{c}\frac{V'\left(r_1^*(z)\right)p\left(R-r_1^*(z)\right)+pV\left(r_1^*(z)\right)}{\left(p\left(R-r_1^*(z)\right)\right)^2}}_{\text{positive when } r_1^*(z) \text{ is close to } \underline{r} \text{ since } V'(\underline{r})=0}\frac{\partial r_1^*(z)}{\partial q} \\ \frac{\partial r_1^*(z)}{\partial q} = \frac{zV\left(r_1^*(z)\right)-(1-z)V(\underline{r})}{(1-qz)V'\left(r_1^*(z)\right)} \text{ for } z\in[0,1/2)\,;\ \frac{\partial r_1^*(z)}{\partial q} = 0 \text{ for } z = \frac{1}{2} \end{cases}. \tag{A.6}$$

When q is sufficiently close to 0, $r_1^*(z)$ will be very close to $\underline{r}$, implying that $\lim_{q\to 0} zV\left(r_1^*(z)\right) - (1-z)V(\underline{r}) < 0$ at $z \in [0,1/2)$. Therefore, $\lim_{q\to 0}\partial r_1^*(z)/\partial q = +\infty$ must hold when $z \in [0,1/2)$ since $V'\left(r_1^*(z)\right)$ will approach 0 from the negative side as q approaches 0. As a result, $\lim_{q\to 0}\partial E[\overline{I_1}(z)]/\partial q = +\infty$ must hold when $z \in [0,1/2)$. When $z = 1/2$, $\partial r_1^*(z)/\partial q = 0$ holds, so $\partial E[\overline{I_1}(1/2)]/\partial q$ is finite according to the first equation of (A.6). Therefore, $\lim_{q\to 0}\int_0^{1/2} \partial E[I_1(z)]/\partial q dz = +\infty$. That is, L_1 is increasing in q if q is sufficiently small.

Proof of Proposition 3. We make the convention that the SLLN holds for a continuum of independent random variables with uniformly bounded variances. Since the two lenders are symmetric and $\tilde{B}(z)$ is independent across z, we can use function $V(\cdot)$ – which is defined by Equation (A.1) in the proof of Lemma 3 – to rewrite the equilibrium social welfare W as follows:

$$2\int_0^{1/2}\frac{1-qz}{c}V\left(r_1^*(z)\right)dz + \underbrace{2\int_0^{1/2}\frac{1-qz}{2c}\frac{\left(pr_1^*(z)-f\right)}{p\left(R-r_1^*(z)\right)}V\left(r_1^*(z)\right)dz}_{=\int_0^{1/2}E[\pi_1(z)]dz}.$$

Since c does not affect $r_1^*(z)$, obviously W is decreasing in c.

As for effect of q, it can be shown that

$$\frac{\partial W}{\partial q}=\int_0^{1/2}\left(\begin{array}{c}\frac{-2z}{c}\left(1+\frac{1}{2}\frac{\left(pr_1^*(z)-f\right)}{p\left(R-r_1^*(z)\right)}\right)V\left(r_1^*(z)\right)\\ +\underbrace{\frac{1-qz}{c}\left(\frac{\left(pR-f\right)V\left(r_1^*(z)\right)}{p\left(R-r_1^*(z)\right)^2}+\frac{\left(2pR-pr_1^*(z)-f\right)V'\left(r_1^*(z)\right)}{p\left(R-r_1^*(z)\right)}\right)\frac{\partial r_1^*(z)}{\partial q}}_{\text{positive when } r_1^*(z) \text{ is close to } \underline{r} \text{ since } V'(\underline{r})=0}\end{array}\right)dz$$

As q approaches 0, $r_1^*(z)$ will approach $\underline{r}$, so $V'\left(r_1^*(z)\right)$ will approach 0. Meanwhile, recall that $\lim_{q\to 0}\partial r_1^*(z)/\partial q=+\infty$ for $z<1/2$ (see the Proof of Proposition 2), so $\lim_{q\to 0}\partial W/\partial q=+\infty$ must hold. Hence, social welfare is increasing in q if q is sufficiently small.

Proof of Proposition 4. Note that controlling lenders' loan rates allows the social planner to determine which lender serves a certain location. For example, if the social planner does not want lender 1 to serve location z, it can simply let $r_1(z)=R$; then the entrepreneur at z will approach lender 2 for any $r_2(z)\in[\underline{r},R)$.

Assume that lender i serves location z. Since $\tilde{B}(z)$ is independent across z, maximizing social welfare W (by choosing $r_i(z)$) is equivalent to maximizing the sum of the ex-ante expected entrepreneurial utility and expected lender profit at z, which equals:

$$W_z\equiv\underbrace{\frac{1-qs_i}{c}V\left(r_i(z)\right)}_{\text{expected entrepreneur utility at } z}+\underbrace{E[\pi_i\left(z\right)]}_{\text{expected lender } i\text{'s profit at } z}.$$

In the proof of Lemma 3, we have shown that $\partial E[\pi_i\left(z\right)]/\partial r_i(z)>0$ for $r_i(z)\in(f/p,R]$. Meanwhile, it is easy to check that $W_z\leq 0$ holds when $r_i(z)\in[0,f/p]$ and $W_z>0$ holds when $r_i(z)\in(f/p,R]$, meaning that the social planner will only consider the interval $(f/p,R]$ when determining the socially optimal loan rate $r_i^o(z)$.

Note that W_z can be written as:

$$W_z=\frac{1-qs_i}{c}\underbrace{\left(V\left(r_i(z)\right)+\frac{1}{2}\frac{\left(pr_i(z)-f\right)}{p\left(R-r_i(z)\right)}V\left(r_i(z)\right)\right)}_{\text{independent of } q,\ c, \text{ and } s_i},$$

so the loan rate maximizing W_z is independent of q, c, and s_i, implying $r_i^o(z)=r^o$ (which does not depend on i or z).

Since $V'\left(\underline{r}\right)=0$ and $V'\left(r_i(z)\right)>0$ for $r_i(z)\in(f/p,\underline{r})$, it must hold that

$$\frac{\partial W_z}{\partial r_i(z)}=\frac{1-qs_i}{c}V'\left(r_i(z)\right)+\frac{\partial E[\pi_i\left(z\right)]}{\partial r_i(z)}>0 \text{ when } r_i(z)\in\left(f/p,\underline{r}\right].$$

Therefore, $r^o > \underline{r}$ must hold. We can further rewrite W_z as follows:

$$W_z = \frac{1-qs_i}{c} E\left[w\left(r_i(z), \tilde{B}(z)\right)\right] = \frac{1-qs_i}{c}\left(kw\left(r_i(z), B\right) + (1-k)\, w\left(r_i(z), b\right)\right)$$

with the function $w\left(r_i(z), \tilde{B}(z)\right)$ defined as follows:

$$w\left(r_i(z), \tilde{B}(z)\right) \equiv \frac{2\left(pr_i(z)-f\right)p\left(R-r_i(z)\right) + \left(pr_i(z)-f\right)^2}{2(\tilde{B}(z)-p(R-r_i(z)))^2}, \ \ \tilde{B}(z) \in \{B, b\}\,.$$

Following proof of Lemma 3 (see how we show that $v\left(r_i(z), \tilde{B}(z)\right)$ is a concave function of $r_i(z)$), we can show that $w\left(r_i(z), \tilde{B}(z)\right)$ is a concave function of $r_i(z)$ in the interval $(f/p, R]$ for a given $\tilde{B}(z)$. Hence, W_z is a concave function of $r_i(z)$ in the interval $(f/p, R]$. Let r_B^o denote the solution to $\partial w\left(r_i(z), B\right)/\partial r_i(z) = 0$, and r_b^o denote the solution to $\partial w\left(r_i(z), b\right)/\partial r_i(z) = 0$. It is easy to check that

$$\underline{r} < r_b^o = R - \frac{(pR-f)^2}{bp} < R - \frac{(pR-f)^2}{Bp} = r_B^o < R.$$

Then, according to the concavity of $w\left(r_i(z), \tilde{B}(z)\right)$, we must have

$$\left.\frac{\partial W_z}{\partial r_i(z)}\right|_{r_i(z)=r_b^o} > 0 \text{ and } \left.\frac{\partial W_z}{\partial r_i(z)}\right|_{r_i(z)=r_B^o} < 0,$$

implying that r^o is unique solution to $\partial W_z/\partial r_i(z) = 0$ in the interval (r_b^o, r_B^o). When $r_i(z) = r^o$, the following inequalities must hold:

$$\left.\frac{\partial w\left(r_i(z), B\right)}{\partial r_i(z)}\right|_{r_i(z)=r^o} > 0 \text{ and } \left.\frac{\partial w\left(r_i(z), b\right)}{\partial r_i(z)}\right|_{r_i(z)=r^o} < 0.$$

Then, as k increases, $\partial W_z/\partial r_i(z)$ will shift upward, so r^o must increase to keep $\partial W_z/\partial r_i(z) = 0$ holding.

When the two lenders post the same loan rate r^o, obviously the entrepreneur at $z \in [0, 1/2)$ (resp. $z \in (1/2, 1]$) approaches lender 1 (resp. lender 2); the entrepreneur at $z = 1/2$ approaches lender i (with $i \in \{1, 2\}$) with probability $1/2$.

Proof of Corollary 4. Since $\lim_{q\to 0} r_i^*(z) = \underline{r}$ holds for any value of z, $r_i^*(z) < r^o$ holds for all locations when q is sufficiently small.

Appendix B: Heterogeneous funding costs

Summary. In this appendix, we let the two lenders face different marginal funding costs. Then, lenders' best loan rates are no longer the same; the lender with a lower marginal funding cost has a lower best loan rate. Reducing a lender's marginal funding cost will increase its competitive advantage, extending its market share and raising its loan rates and expected lending volumes. In contrast, reducing both lenders' marginal funding costs will decrease their loan rates. At the indifference location, both lenders offer their best loan rates and provide the same entrepreneurial utility. However, the curve of equilibrium loan rates is discontinuous at the indifference location when lenders face heterogeneous funding costs (see Panel 2 of Figure 5): The lender with a lower marginal funding cost – which can be viewed as a bank with access to cheap funding (e.g., deposits) – offers a lower (best) loan rate because of its advantage in funding costs. In contrast, its rival (which can be viewed as a fintech lender with a more expensive funding source) has an advantage in IT and provides a larger expected loan volume at the indifference location.

Model setup. In the main text, we assume that the two lenders face the same marginal funding cost f when providing loans, which does not consider the possibility that different types of lenders may face different funding costs (e.g., banks v.s. fintechs). In this appendix, we consider this possibility by assuming that lender i's (with $i \in \{1, 2\}$) marginal funding cost is f_i. Now, we modify Inequality (3) of the main text to

$$\tilde{B}(z) \geq 2(pR - f_i), \ i \in \{1, 2\} \tag{B.1}$$

to ensure that the moral hazard problem is non-trivial. All the other assumptions of the main text still apply.

Now, lender i faces a marginal funding cost of f_i (instead of f), so Lemma 3 of the main text should be modified as follows.

Lemma B.1. *At any location, lender i's best loan rate, denoted by $\underline{r_i}$, is increasing in k and f_i, independent of q_i, c_i, and s_i, and within the interval $(f_i/p, R)$. Lender i's monopoly loan rate is R. Lender i will offer loan rates within the interval $[\underline{r_i}, R]$.*

Generally speaking, Lemma B.1 is consistent with Lemma 3. Lemma B.1 further shows that a lender's best loan rate is increasing in its marginal funding cost. Everything else being equal, a higher f_i will decrease lender i's skin in the game $pr_i(z) - f_i$, weakening its monitoring incentive. Hence, the best loan rate must increase to alleviate the decrease in lender i's skin in the game, ensuring that its monitoring incentive will not decrease by too much. According to Lemma B.1, lenders' best loan rates need not be the same in this appendix. Therefore, lender i's best loan rate, $\underline{r_i}$, has a subscript "i".

Equilibrium loan rates. If an entrepreneur at z borrows from lender i at the loan rate $r_i(z)$, her expected utility is equal to

$$U(q_i, c_i, s_i, f_i, r_i(z)) \equiv E[\overline{I_i}(z)]p\left(R - r_i(z)\right), \tag{B.2}$$

where $E[\overline{I_i}(z)]$ is equal to

$$E[\overline{I_i}(z)] = \frac{1 - q_i s_i}{c_i}\left(k\frac{(pr_i(z) - f_i)}{\left(B - p\left(R - r_i(z)\right)\right)^2} + (1 - k)\frac{(pr_i(z) - f_i)}{\left(b - p\left(R - r_i(z)\right)\right)^2}\right). \tag{B.3}$$

Obviously, the maximum utility lender i can provide at z is $U(q_i, c_i, s_i, f_i, \underline{r_i})$. If lender 1 wants to attract the entrepreneur at z, it must offer a loan rate weakly more attractive than the best loan rate $\underline{r_2}$ of lender 2 (that is, providing expected utility no less than $U(q_2, c_2, 1 - z, f_2, \underline{r_2})$). If lender 1 cannot do so, then the entrepreneur will be served by lender 2 instead. Reasoning in this way yields the following result.

Proposition B.1. *Let*

$$U(q_1, c_1, 0, f_1, \underline{r_1}) > U(q_2, c_2, 1, f_2, \underline{r_2}) \text{ and } U(q_1, c_1, 1, f_1, \underline{r_1}) < U(q_2, c_2, 0, f_2, \underline{r_2}). \tag{B.4}$$

There exists a unique $\tilde{x} \in (0, 1)$ such that entrepreneurs located in $[0, \tilde{x})$ (resp. $(\tilde{x}, 1]$) are served by lender 1 (resp. lender 2). At $z = \tilde{x}$, the entrepreneur is served by lender i (with $i \in \{1, 2\}$) with probability $1/2$. At $z \in [0, \tilde{x}]$, lender 1's equilibrium loan rate schedule, $r_1^*(z)$, is the unique solution (in interval $[\underline{r_1}, R]$) of

$$U(q_1, c_1, z, f_1, r_1^*(z)) = U(q_2, c_2, 1 - z, f_2, \underline{r_2}) \tag{B.5}$$

At $z \in [\tilde{x}, 1]$, lender 2's equilibrium loan rate schedule, $r_2^*(z)$, is determined in a symmetric way in the interval $[\underline{r_2}, R]$.

Condition (B.4) means that lender 1 (resp. lender 2) can provide strictly higher utility than the rival at location $z = 0$ (resp. $z = 1$), so each lender will have a positive market share in equilibrium. If Condition (B.4) does not hold, one lender will dominate the entire market and drive out the other lender. Throughout the appendix, we focus on the case with $\tilde{x} \in (0, 1)$.

Proposition B.1 is consistent with Proposition 1. At $z \in [0, \tilde{x}]$, lender 1's pricing strategy is maximizing its own profit (i.e., choosing $r_1^*(z)$ as high as possible) while ensuring that entrepreneurial utility is no less than the maximum utility lender 2 can provide. Based on this strategy, at $z \in [0, \tilde{x}]$ the entrepreneurial utility implied by lender 1's equilibrium loan rate $r_1^*(z)$ should exactly match $U(q_2, c_2, 1 - z, f_2, \underline{r_2})$.

The effects of heterogeneous funding costs. The following proposition characterizes lenders' loan rates at different locations.

Proposition B.2. *Let $q_i > 0$ for some $i \in \{1, 2\}$ and $f_1 < f_2$. Lender i's equilibrium loan rate $r_i^*(z)$ is decreasing in its lending distance s_i.*

At the indifference location $z = \tilde{x}$, the following relations hold:

$$\begin{cases} r_1^*(\tilde{x}) = \underline{r_1} < \underline{r_2} = r_2^*(\tilde{x}) \\ \frac{1-q_1\tilde{x}}{c_1} < \frac{1-q_2(1-\tilde{x})}{c_2} \\ E[\overline{I_1}(\tilde{x})] < E[\overline{I_2}(\tilde{x})] \end{cases}.$$

The first part of the result is consistent with Corollary 1. The second part of Proposition B.2 shows the effects of heterogeneous funding costs. With heterogeneous funding costs, the two lenders behave differently at the indifference location $z = \tilde{x}$. At $z = \tilde{x}$, both lenders must offer their best loan rates to attract the entrepreneur. With $f_1 < f_2$, lender 1 has a lower best loan rate (i.e., $\underline{r_1} < \underline{r_2}$; see Lemma B.1), so its loan rate is lower than lender 2's at the indifference location. Panel 2 of Figure 5 illustrates the result.

At $z = \tilde{x}$, the entrepreneur is indifferent between the two lenders' offers. Although a lower marginal funding cost allows lender 1 to offer a lower loan rate, lender 2 has better monitoring efficiency (i.e., $(1 - q_1\tilde{x})/c_1 < (1 - q_2(1 - \tilde{x}))/c_2$) and provides a larger expected loan volume (i.e., $E[\overline{I_1}(\tilde{x})] < E[\overline{I_2}(\tilde{x})]$), making the entrepreneur at $z = \tilde{x}$ indifferent (Panel 2 of Figure 5).

We can view lender 1 as a bank with access to cheap funding (e.g., deposits), while lender 2 as a fintech with a more expensive funding source. Then, Proposition B.2 implies that, when serving entrepreneurs of similar characteristics (i.e., entrepreneurs around the indifference location), fintech lenders will offer higher loan rates and larger loan volumes than traditional banks.

The following corollary shows how f_i affects lenders' market shares.

Corollary B.1. *Lender 1's market share (measured by $\tilde{x}$) is decreasing in f_1 and increasing in f_2.*

Given lender 1's loan rate $r_1(z)$, a decrease in f_1 will increase lender 1's skin in the game without reducing the entrepreneur's skin in the game (as a result, $E[\overline{I_1}(z)]$ will increase; see Equation B.3). Hence, everything else being equal, a decrease in f_1 will increase the utility lender 1 provides, improving its competitive advantage. A higher competitive advantage enables lender 1 to obtain a larger market share, thereby reducing the rival's market share.

The following corollary shows how f_i affects a lender's pricing and expected loan volume.

Corollary B.2. *Let $z \in [0, \tilde{x}]$. Lender 1's equilibrium loan rate $r_1^*(z)$ and expected loan volume $E[\overline{I_1}(z)]$ are decreasing in f_1.*

As f_1 decreases, lender 1's competitive advantage becomes higher, allowing the lender to increase $r_1^*(z)$. An increase in $r_1^*(z)$ reduces the entrepreneur's skin in the game, so lender 1 must provide a higher expected credit limit (i.e., increase $E[\overline{I_1}(z)]$) to match the maximum utility lender 2 provides.

The implication of Corollary B.2 is that reducing a lender's funding costs does not translate into the lender's lower loan rates; instead, the lender will fully exploit its market power and extract the entire benefit of its funding cost advantage.

Finally, we look at the symmetric case with $q_i = q$, $c_i = c$, and $f_i = f$ and study the effect of f.

Corollary B.3. *Let $c_1 = c_2 = c$, $q_1 = q_2 = q$, and $f_1 = f_2 = f$. Lender i's equilibrium loan rate $r_i^*(z)$ is increasing in f.*

As both lenders' marginal funding cost f decreases, lender i must decrease its loan rates to protect its market share. The reason is that a lower f allows the rival to offer a lower best loan rate, increasing its threat to lender i. As a result, both lenders charge lower loan rates from their entrepreneurs.

Comparing Corollaries B.2 and B.3 yields the following implication: If a policymaker aims to decrease loan rates by reducing lenders' funding costs, it should reduce the funding costs for all lenders. Otherwise, some lenders can enjoy a larger funding cost advantage and charge higher loan rates.

Online Appendices

Appendix C: Endogenous lender locations

Summary: In this appendix, we allow lenders to choose their locations before the lending competition happens. We find that when $q > 0$, lenders choose different locations, implying the existence of lender differentiation. Therefore, as in the main text, decreasing q will reduce lender differentiation and intensify the competition. When q is small enough, the differentiation effect of decreasing q will dominate its cost-saving effect and harm welfare. In addition, we find that lenders move closer to each other as q decreases, further reducing lender differentiation (without bringing a cost-saving effect). This additional differentiation effect (i.e., the diminishing distance between lenders) makes IT-distance progress more likely to cause excessive competition and harm welfare.

Model extension. In this appendix, we analyze lenders' endogenous location choices. We refer to the left extreme of the linear city as location 0, and the right extreme as location 1. Location z of the city refers to the point whose distance from location 0 is z; hence, the distance between locations z and 1 is $1 - z$. Let z_i ($i \in \{1, 2\}$) denote the location of lender i. Figure C.1 gives an illustration of the economy.

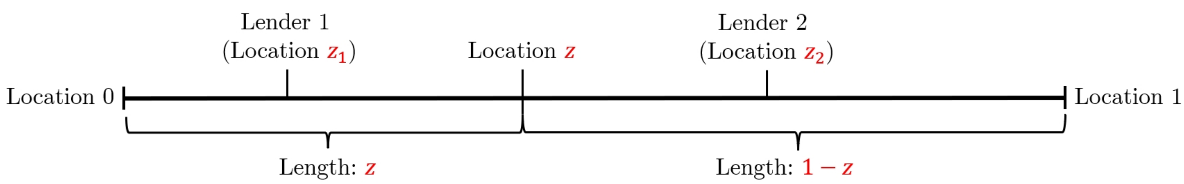

Figure C.1: The Economy.

The timeline of this appendix is as follows (see Figure C.2): First, the two lenders simultaneously choose their locations (i.e., lender i determine z_i). Then, lenders compete by posting loan rates, as in the main text. All the other assumptions of the main text still apply here.

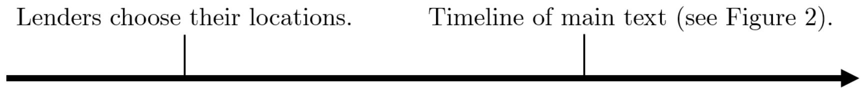

Figure C.2: Timeline.

In this appendix, the distance between locations z and z_i is

$$s_i = \max\{z_i - z, z - z_i\}, \tag{C.1}$$

which is the lending distance when lender i serves location z. If the entrepreneur at z borrows from lender i and is monitored with intensity $m_i(z)$, the lender incurs the monitoring cost

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

with s_i given by Equation (C.1) now. It is easy to check that Lemmas 1 to 3 still hold. After lenders have determined their locations, their competition still takes the localized Bertrand fashion. Therefore, we have the following proposition, which is a more general version of Proposition 1.

Proposition C.1. *Let*

$$IT_i(z) \equiv \frac{1 - q_i s_i}{c_i},$$

with s_i given by Equation (C.1). If $IT_1(z) > IT_2(z)$ (resp. $IT_1(z) < IT_2(z)$), location z is served by lender 1 (resp. lender 2). If $IT_1(z) = IT_2(z)$, location z is served by lender $i \in \{1, 2\}$ with probability $1/2$. When $IT_1(z) \geq IT_2(z)$, lender 1's equilibrium loan rate schedule, $r_1^*(z)$, is the unique solution (in interval $[\underline{r}, R]$) of

$$\underbrace{U(q_1, c_1, s_1, r_1^*(z))}_{\text{entrepreneurial utility provided by } r_1^*(z)} = \underbrace{U(q_2, c_2, s_2, \underline{r})}_{\text{maximum utility lender 2 provides}}. \tag{C.2}$$

When $IT_1(z) \leq IT_2(z)$, lender 2's equilibrium loan rate schedule $r_2^*(z)$ is determined in a symmetric way.

In our model, lender i's monitoring efficiency at z can be measured by $IT_i(z)$ (the inverse of the monitoring cost coefficient). Proposition C.1 states that in equilibrium, location z will be served by a lender with (weakly) better IT at this location, which is consistent with Proposition 1. Lender i's pricing strategy at a location it serves is the same as that in the main text: maximizing its own profit while matching the maximum utility provided by the rival, leading to Equation (C.2). If the two lenders have the same monitoring efficiency at z, they will both offer the best loan rate $\underline{r}$, and the entrepreneur there will randomly choose a lender. Note that if we let $z_1 = 0$, $z_2 = 1$, $IT_1(0) > IT_2(0)$, and $IT_1(1) < IT_2(1)$ hold, Proposition C.1 reduces to Proposition 1.

Lenders' best responses in location choices. We focus on the symmetric case

$q_1 = q_2 = q$ and $c_1 = c_2 = c$ and use numerical methods to analyze lender 1's optimal location choice, given lender 2's location z_2. We find that when $q > 0$, lender 1's optimal location is different from lender 2's location z_2. Figure C.3 illustrates the result.

According to Panel 1 of Figure C.3, lender 1's location z_1 indeed matters to its total profit. Lender 1's profit peaks at around $z_1 = 0.35$, which is different from lender 2's location $z_2 = 0.6$. Note that lender 1's profit discontinuously drops at the point $z_1 = z_2$. The reason is that $z_2 > 0.5$ in this panel. When $z_1 = z_2 - \varepsilon$ (with ε infinitesimal), lender 1 can serve the market area $[0, z_2 - \varepsilon]$, which is more than half of the total market when $z_2 > 0.5$. However, if z_1 increases to $z_2 + \varepsilon$ (with ε infinitesimal), lender 1 will suddenly lose the market area $[0, z_2]$, causing a discontinuous profit drop.[C1]

Panel 2 of Figure C.3 shows that as lender 2's location z_2 changes, lender 1's optimal location will also change (see the solid curve). However, no matter how z_2 changes, the optimal z_1 always differs from z_2 (see the dashed curve), implying that lenders would like to have some extent of differentiation when they can endogenously choose their locations.

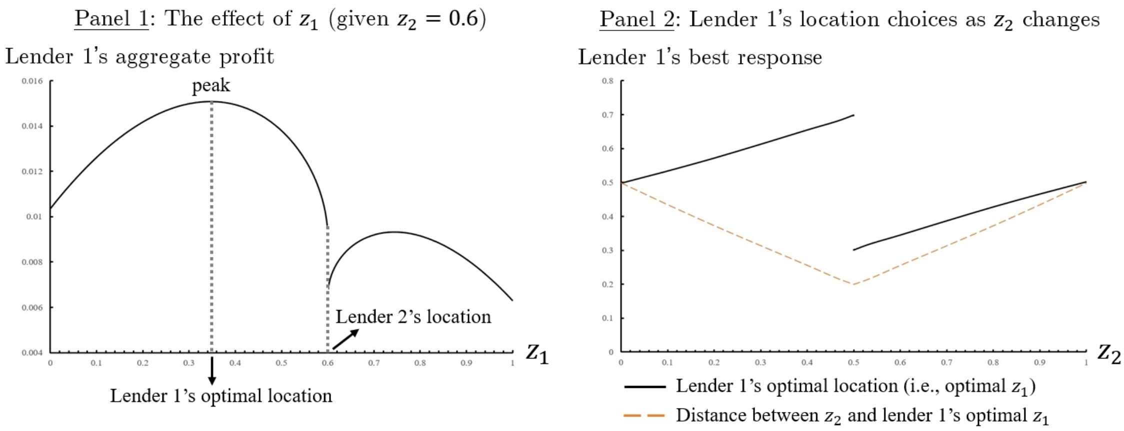

Figure C.3: Lender 1's Optimal Location Choice ($q > 0$). Panel 1 plots how lender 1's aggregate profit changes as its location z_1 varies. Panel 2 plots lender 1's best response as lender 2's location z_2 varies: The solid curve plots lender 1's optimal location (i.e., optimal z_1), while the dashed curve plots the distance between z_2 and lender 1's optimal z_1. The parameter values are: $R = 2.4$, $B = 0.9$, $b = 0.4$, $p = 0.5$, $q = 0.6$, $c = 1$, and $f = 1$ in both panels; $z_2 = 0.6$ in Panel 1.

A special case is $q = 0$, which means there is no lender differentiation no matter how lenders choose their locations. In this case, lenders are indifferent about their locations.

Symmetric equilibrium and welfare effect of IT. When determining lenders' endogenous locations, we focus on the symmetric equilibrium where the distance from

[C1] Reasoning similarly, if $z_2 < 0.5$, lender 1's profit will discontinuously increase at the point $z_1 = z_2$. If $z_2 = 0.5$, lender 1's profit is continuous at $z_1 = z_2$.

lender 1's location z_1 to location 0 is the same as the distance from lender 2's location z_2 to location 1 (i.e., $z_1 = 1 - z_2$). We consider two cases when analyzing the welfare effect of IT. First, we consider that lenders endogenously determine their locations based on the initial IT and no longer change their locations as IT improves. Then, we analyze the case in which lenders adjust locations as IT changes. Our numerical study finds that in both cases, lowering q will hurt social welfare when q is small. See Panel 1 of Figure C.4 for an illustration.

The first case – where lenders determine their locations based on the initial IT and do not adjust locations as IT improves – has no qualitative difference from the baseline model we adopt in the main text. According to the previous analysis (see Figure C.3), lenders will choose different locations when $q > 0$, implying that lender differentiation exists initially. Then, decreasing q will reduce lender differentiation (i.e., intensifying lender competition) and bring a cost-saving effect. When q is small, lender competition will be excessively intense, so further reducing q will harm social welfare despite the cost-saving effect. Panel 1 (the dashed curve) of Figure C.4 illustrates the result. Compared with the main text, the only difference is that lenders now are not located at the two extremes (i.e., locations 0 and 1) of the city. In fact, the baseline model's assumption that lenders are located at the two extremes is not a key ingredient. Once the two lenders are located differently, we can show in theory (following the proof of Proposition 3) that lowering q will hurt social welfare when q is small enough.

Next, we look at the second case – lenders adjust locations as IT changes. Our numerical study finds that as q decreases, lenders will move closer to each other (i.e., $|z_1 - z_2|$ will be smaller). Panel 2 of Figure C.4 illustrates the result. Moving closer to the rival will bring two competing effects to a lender: (a) First, the lender can gain a larger market share by eroding the rival's; (b) second, the lender will face more intense competition at each location it serves since moving closer to the rival implies lower differentiation. As q decreases, effect (b) will be weakened since the distance between lenders' locations will be less important for their market power.[C2] Therefore, effect (a) will induce lenders to move closer. As q approaches zero, the distance between lenders also approaches zero. When $q = 0$, lender profit and social welfare are independent of lenders' locations; we let $|z_1 - z_2| = 0$ hold in this special case.[C3]

Allowing lenders to adjust locations does not qualitatively change the welfare effect

[C2]This can be better understood by considering the limit case $q \to 0$. In this case, "staying away from the rival" almost brings no market power to a lender since there is almost no distance friction.

[C3]In this case, lenders post their best loan rate $\underline{r}$ for all locations, and every entrepreneur randomly choose a lender with probability 1/2, no matter how lenders choose their locations.

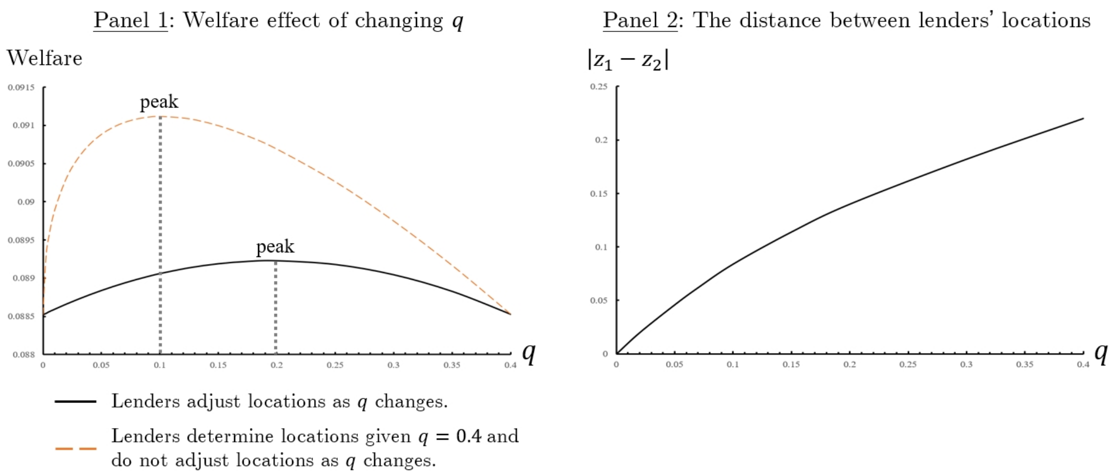

Figure C.4: Welfare Effect of q with Endogenous Lender Location. Panel 1 plots how social welfare changes as q varies: The solid curve corresponds to the case in which lenders adjust locations as IT changes, while the dashed curve corresponds to the case in which lenders determine their locations based on the initial IT ($q = 0.4$) and no longer change their locations as IT improves. Panel 2 plots the distance $|z_1 - z_2|$ between lenders' endogenous locations as q varies. The parameter values are: $R = 2.4$, $B = 0.9$, $b = 0.4$, $p = 0.5$, $q = 0.6$, $c = 1$, and $f = 1$.

of IT-distance: Lowering q harms social welfare when q is small enough. Panel 1 (solid curve) of Figure C.4 illustrates the result. In addition, we find that lowering q is more likely to harm welfare when lenders can adjust locations than when they cannot. This can be seen by comparing the two curves in Panel 1 of Figure C.4: The solid curve peaks at a higher q than the dashed one. The reason is that as q decreases, lenders move closer to each other, further reducing lender differentiation (without bringing a cost-saving effect). This additional differentiation effect (i.e., the diminishing distance between lenders) makes IT-distance progress more likely to cause excessive competition and harm welfare.

In contrast, we find that changing c will not affect lenders' location choices, even if they are allowed to adjust locations. The reason is that changing c does not affect the relative importance of a location over other locations. Hence, as in the main text, decreasing c unambiguously increases social welfare since it improves the lending sector's IT without bringing any differentiation effect.

Appendix D: First-best allocation

Summary. In this appendix, we analyze the first-best case, in which the social planner chooses both loan rates and credit limits. In this case, the social planner will choose the rate $\underline{r}$ – the best loan rate given in Lemma 3 – and set high credit limits. The reason is that the social planner would like to alleviate entrepreneurs' moral hazard using a low loan rate and to increase total project values by setting high credit limits. Like r^o (the socially optimal loan rate given in Proposition 4), the first-best loan rate $\underline{r}$ is also independent of q, c, and s_i. However, the first-best credit limit (chosen by the social planner) at z does depend on those parameters. Therefore, implementing the first-best allocation requires the social planner to observe lenders' IT at each location, which is more difficult than just setting loan rate r^o and letting lenders themselves choose credit limits.

The first-best allocation. In this appendix, we consider the social planner's optimization problem in the first-best case, in which the social planner can choose (a) the loan rate schedule of lender i, denoted by $\{r_i^{FB}(z)\}$, and (b) the lender's credit limit schedule, denoted by $\{\overline{I_i^{FB}}(z)\}$ to maximize social welfare W. Consistent with the timeline of the main text, the social planner first determines $r_i^{FB}(z)$ without observing $\tilde{B}(z)$. Then, each entrepreneur determines which lender to borrow from. Next, $\tilde{B}(z)$ realizes, and the social planner determines $\overline{I_i^{FB}}(z)$ based on $\tilde{B}(z)$. Although entrepreneurs do not observe $\overline{I_i^{FB}}(z)$ or $\tilde{B}(z)$ when determining which lender to approach, they can correctly anticipate how the social planner will determine $\overline{I_i^{FB}}(z)$ based on $\tilde{B}(z)$. Note that shirking is never desirable for the social planner since $\tilde{B}(z) < f$.

Suppose we allow lenders to make negative profits. In that case, there exists an allocation: $r_i^{FB}(z) = 0$ and $\overline{I_i^{FB}}(z) = +\infty$, which brings unboundedly high social welfare. This allocation simply lets each entrepreneur extract the entire expected return pR of each unit of investment, which eliminates her shirking incentive since $pR > f > \tilde{B}(z)$. As a result, no matter how high $\overline{I_i^{FB}}(z)$ is, the entrepreneur will not shirk, and lender monitoring is not needed. Under this allocation, lenders make infinitely negative profits since they provide loans at the marginal cost f and ask for a zero rate.

For the rest of this appendix, we focus on the more interesting and realistic case: After observing $r_i^{FB}(z)$, $\overline{I_i^{FB}}(z)$, and $\tilde{B}(z)$, lender i can choose not to serve location z if providing loans imply a negative lending profit at z. Given $\overline{I_i^{FB}}(z)$ and $r_i^{FB}(z)$ and observing $\tilde{B}(z)$, lender i's optimal monitoring intensity (if it is willing to serve location

z) is still given by Lemma 1:

$$m_i^{FB}(z) = \overline{I_i^{FB}}(z)(\tilde{B}(z) - p(R - r_i^{FB}(z))),$$

which minimizes the monitoring costs while preventing shirking. Then, lender i's expected lending profit at z (when $\overline{I_i^{FB}}(z)$ and $\tilde{B}(z)$ become observable to the lender) is

$$\pi_i^{FB}(z) = \overline{I_i^{FB}}(z)(pr_i^{FB}(z) - f) - \frac{c_i}{2(1 - q_i s_i)} \left(m_i^{FB}(z)\right)^2. \tag{D.1}$$

If $\pi_i^{FB}(z) < 0$, obviously the lender will choose not to serve location z. If no lender serves location z, the investment and net project value at z will be zero, which is strictly dominated by the equilibrium allocation of the main text. Therefore, the social planner must ensure $\pi_i^{FB}(z) \geq 0$ if it lets lender i serve location z.

When lender i serves location z, we can write social welfare W (under first-best allocation) as follows:

$$W = \int_0^1 \left(\overline{I_i^{FB}}(z) (pR - f) - \frac{c(m_i^{FB}(z))^2}{2(1 - qs_i)} \right) dz. \tag{D.2}$$

If the constraint $\pi_i^{FB}(z) \geq 0$ is not binding, maximizing W by choosing $\overline{I_i^{FB}}(z)$ yields:

$$\overline{I_i^{FB}}(z) = I_i^{Nbind} = \frac{1 - qs_i}{c} \frac{pR - f}{(\tilde{B}(z) - p(R - r_i^{FB}(z)))^2}.$$

If $\pi_i^{FB}(z) \geq 0$ is binding, then we can show that $\pi_i^{FB}(z) = 0$ is equivalent to

$$\overline{I_i^{FB}}(z) = I_i^{bind} = \frac{1 - qs_i}{c} \frac{2(pr_i^{FB}(z) - f)}{(\tilde{B}(z) - p(R - r_i^{FB}(z)))^2}. \tag{D.3}$$

Whether $\pi_i^{FB}(z) \geq 0$ is binding depends on whether $I_i^{Nbind} \geq I_i^{bind}$ (which is equivalent to $pR - f \geq 2(pr_i^{FB}(z) - f)$).

We can show that $pR - f \geq 2(pr_i^{FB}(z) - f)$ must hold (i.e., $\overline{I_i^{FB}}(z) = I_i^{bind}$). If not (i.e., if $pR - f < 2(pr_i^{FB}(z) - f)$ holds), then $\overline{I_i^{FB}}(z) = I_i^{Nbind}$ will hold, and the ex-ante expected social welfare at location z (denoted by W_z) will be

$$W_z = E\left[\frac{1 - qs_i}{2c} \frac{(pR - f)^2}{(\tilde{B}(z) - p(R - r_i^{FB}(z)))^2} \right], \tag{D.4}$$

which is decreasing in $r_i^{FB}(z)$. Therefore, the social planner will choose $r_i^{FB}(z)$ as low as possible to maximize W_z. However, as the social planner reduces $r_i^{FB}(z)$ to some extent, the relation $pR - f < 2(pr_i^{FB}(z) - f)$ cannot hold. As a result, $pR - f \geq 2(pr_i^{FB}(z) - f)$ must hold, implying $\overline{I_i^{FB}}(z) = I_i^{bind}$.

With $\overline{I_i^{FB}}(z) = I_i^{bind}$, the ex-ante expected social welfare at location z is

$$W_z^{bind} = E\left[I_i^{bind} p\left(R - r_i^{FB}(z)\right)\right], \tag{D.5}$$

which is exactly the expected entrepreneurial utility at z. The intuition is simple: Given that lender i makes a zero profit at z (since $\pi_i^{FB}(z) \geq 0$ is binding), maximizing social welfare is equivalent to maximizing the expected entrepreneurial utility. With Equation (D.3), maximizing W_z^{bind} by choosing $r_i^{FB}(z)$ yields:

$$r_i^{FB}(z) = \underline{r},$$

which is lenders' best loan rate in the main text (see Lemma 3). One can check that $pR - f > 2(p\underline{r} - f)$ always holds, so $\overline{I_i^{FB}}(z) = I_i^{bind}$ indeed holds under the loan rate $\underline{r}$.

With $r_i^{FB}(z) = \underline{r}$ and $\overline{I_i^{FB}}(z) = I_i^{bind}$, obviously entrepreneurs in $[0, 1/2)$ (resp. $(1/2, 1]$) will approach lender 1 (resp. lender 2); the entrepreneur at $z = 1/2$ will randomly approach a lender with probability $1/2$. Such choices of entrepreneurs are socially desirable since each entrepreneur is served by the lender with (weakly) better IT. We summarize the analysis above with the following proposition.

Proposition D.1. *At any location, the first-best loan rate for both lenders is* $\underline{r}$ *(see Lemma 3 for its properties). The first-best credit limit at* z *(served by lender* i*) is*

$$\overline{I_i^{FB}}(z) = \frac{1 - qs_i}{c} \frac{2(p\underline{r} - f)}{\left(\tilde{B}(z) - p(R - \underline{r})\right)^2}.$$

The entrepreneur at $z \in [0, 1/2)$ *(resp.* $z \in (1/2, 1]$*) approaches lender 1 (resp. lender 2); the entrepreneur at* $z = 1/2$ *approaches lender* i *(with* $i \in \{1, 2\}$*) with probability* $1/2$.

According to Proposition D.1, the first-best loan rate $r_i^{FB}(z)$ (which equals $\underline{r}$) is lower than the socially optimal loan rate r^o of the main text. The reason is that r^o must be high enough to incentivize lenders' monitoring and credit supply. In contrast, under the first-best allocation, the social planner can directly determine lenders' credit limits, so the loan rate $r_i^{FB}(z)$ need not be as high as r^o to generate monitoring incentives and credit supply. From the social point of view, lowering $r_i^{FB}(z)$ will alleviate the entrepreneur's moral hazard (since it decreases $\tilde{B}(z)-p(R-r_i^{FB}(z))$) and reduce the need for monitoring, which improves welfare by saving monitoring costs. Therefore, the social planner would like to choose $r_i^{FB}(z) < r^o$. However, the social planner cannot unboundedly reduce $r_i^{FB}(z)$ since lender i requires a non-negative profit to work at z. As a result, the first-best loan rate is set to $\underline{r}$ (which maximizes entrepreneurial utility while ensuring zero lender profit).

Note that $\overline{I_i^{FB}}(z)$ is higher than what lender i would choose by its own under the loan rate $\underline{r}$. If we let lender i set its own credit limit (at the loan rate $\underline{r}$), according to Lemma 2, the credit limit would be

$$\frac{1-q_i s_i}{c_i}\frac{p\underline{r}-f}{(\tilde{B}(z)-p(R-\underline{r}))^2},$$

which is only $\overline{I_i^{FB}}(z)/2$. In addition, a numerical study finds that $E\left[\overline{I_i^{FB}}(z)\right]$ is higher than lender i's expected credit limit at z in equilibrium (where both loan rates and credit limits are chosen by lenders themselves, rather than by the social planner). The social planner prefers a high $\overline{I_i^{FB}}(z)$ since it implies a high total value of the project at z. A high $\overline{I_i^{FB}}(z)$ implies a large burden on lender i since it must choose a high $m_i^{FB}(z)$ to prevent shirking; however, the social planner does not aim to maximize lenders' profits. Therefore, $\overline{I_i^{FB}}(z)$ is higher than what lender i would choose by itself.

Similar to r^o, the first-best loan rate $\underline{r}$ does not depend on q, c, or s_i. However, the first-best credit limit (i.e., loan volume) depends on $(1-qs_i)/c$. This intuition is simple: If lender i's IT improves (i.e., $(1-qs_i)/c$ improves), the social planner would like it to provide more loans.

To implement this first-best allocation (represented by $r_i^{FB}(z)$ and $\overline{I_i^{FB}}(z)$), the social planner must be able to observe $(1-qs_i)/c$ at each location. In contrast, implementing the socially optimal loan rate r^o of the main text does not require the social planner to observe q, c, or s_i since (a) r^o is independent of them, and (b) credit limits are chosen by lenders themselves. Therefore, the first-best allocation is more difficult to implement than the (constrained) socially optimal allocation of the main text.