Bank Competition, Firm Ownership, and Margins of Innovation*

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Abstract

This paper investigates the effect of bank competition on innovation and how the effect is dependent on the ownership structure of the firms. Combining the data of Chinese manufacturing firms with bank branching information in 2006 and 2007, we find that: first, intensified bank competition has a positive impact on the probability of investing in R&D of State-Owned Firms (SOFs), but not Private Firms (PFs); second, increased banking competition only enhances the level of investment in R&D of PFs. These results are stable to a series of robustness checks. Then we build a model to explain the empirical results. The model relies on the assumptions that: SOFs are less likely to default; asymmetric information on the riskiness of R&D exists between firms and banks; banks compete with each other in a Bertrand-Edgeworth game in the loan market. Under these assumptions, in equilibrium only PFs face credit rationing. We numerically solve the model and obtain results that are consistent with our empirical findings. The counterfactual experiments show that the welfare gains are much more sensitive to banking deregulation when the loan guarantee provided to SOFs are removed.

Keywords: bank competition; firm ownership; innovation

1 Introduction

Financial development has been recognized as an important factor in facilitating economic development, while innovation has been recognized as a fundamental determinant of sustainable economic growth since Schumpeter (1934). Banking finance is an important external financing in many developing countries where the banks are dominant financial intermediaries.[1] The degree of bank competition can affect the real economy through various channels (Claessens and Laeven, 2005).[2] How does the competition in the banking sector affect the innovation activities? Moreover, how does the relationship between banking competition and innovation differ for firms with different ownership structures?

Recently, the finance literature has found that innovation activities are positively related to the degree to banking competition (Benfratello, Schiantarelli, and Sembenelli, 2008; Chava et al., 2013; Cornaggia et al., 2015). These empirical studies indicate that banking competition can affect innovation through several channels. First, increased banking competition can alleviate financial constraint faced by small and young firms. Second, banking competition will stimulate banks to finance riskier innovation projects to earn profits. This strand of literature, however, pays little attention to two interesting questions. First, none of these studies has taken the role of firm ownership into consideration. In many countries, especially some developing countries like China, firm ownership matters because it determines how the bank loans are reallocated when the banking sector is more competitive. In China, bank discrimination and relationship lending prevail: private firms (PFs hereafter) are discriminated against state-owned firms (SOFs hereafter) in obtaining the banking credits (Cull and Xu, 2003; Ge and Qiu, 2007; Guariglia, Liu, and Song, 2011). In this context, it is questionable

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[1]See Cole and Wolken (1995); Benfratello, Schiantarelli, and Sembenelli (2008); Robb and Robinson (2012) and related references therein.

[2]These can be the efficiency of providing banking services, the quality of products, the degree of financial statbility, the innovation activity, etc.

whether banking competition can stimulate innovation unanimously. Second, banking competition can affect the allocation of credits, and further the innovation investment by firms differently at different margins.[3] At the extensive margin, bank competition affects the number of firms that borrow from banks; at the intensive margin, the degree of competition in the banking sector can influence the amount of loans the firm obtained from the bank.

In this study, we analyze the relationship between banking competition and firm-level innovation investment. To analyze the impact of firm ownership, we allow banking competition to influence SOFs and PFs asymmetrically. In order to consider the credit allocation effect at different margins, we consider the R&D activity both at the extensive margin and the intensive margin. Using a combined dataset that contains information on firm-level innovation activities and city-level bank loans, we show that only the probability of innovation by SOFs is positively related to banking competition, while only the level of innovation investment by PFs is encouraged by increasing the degree of banking competition. These results remain stable after a series of robustness checks.

To the best of our knowledge, these empirical findings are new to extant literature. In order to better our understanding of these results, we also build a simple theoretical model to explain our results. The model is based on three important assumptions, all of which are supported by existing literature to some extent. First, SOFs are less likely to default than PFs; second, banks face adverse selection problem when lending to PFs because banks cannot observed riskiness of R&D projects; third, banks compete with each other in a Bertrand-Edgeworth game in the loan market. We numerically solve the model and show that our model generates results similar to our empirical findings. The important underlying mechanism is that only PFs face credit rationing and increased banking competition will increase the credit supply to PFs at the intensive margin and to SOFs at the extensive margin. Employing the theoretical model, we are able to conduct counterfactual experiments to analyze the welfare implication of banking deregulation that promotes banking competition. Interestingly, we find that the welfare gains is much more sensitive to increased banking competition if we remove the loan guarantees provided to SOFs.

This study contributes to existing literature in several ways. First, this study deepens the understanding of the relationship between banking competition and innovation by consider the possible impact of firm ownership. The ownership perspective is new to related literature. Second, we decompose the change in innovation investment into intensive margin and extensive margin and relate them to banking competition. Although a large body of literature has investigated the impact of banking competition on innovation, none has jointly analyzed the change in the intensive margin and extensive margin of innovation investment. Therefore, our results provide a more complete picture of the response of firm-level innovation activities under intensified competition in the banking sector. Third, we extend the Grossman and Helpman (1991) model to incorporate banking sector and adverse selection. Under certain parameter restrictions, the model generates results that are consistent with our empirical findings. Moreover, this allows us to translate the innovation effect into economic growth and welfare change.

The rest of this paper is structured as follows. Section 2 discusses the related literature. Section 3 is the background, data and preliminary graphical evidence. In Section 4, we present the formal empirical evidence. We build a model to explain our empirical findings in Section 5. Section 6 is the numerical analysis of the theoretical model. Section 7 concludes the paper.

2 Related Literature

2.1 Banking competition and innovation

This study is closely related to the strand of literature the investigates the impact of bank competition on innovation. A large body of literature has documented the stimulating effect of increased bank competition on innovation. Using a dataset of Italian firms over the 1990s, Benfratello, Schiantarelli, and Sembenelli (2008) find that banking development affects innovation along the extensive margin. Particularly, they find that banking development, which is measured by the number of branches over population, increases the probability of process innovation, but not for product innovation. They further document that the effects are more significant for firms operating in high-tech sectors and in sectors that relies more on external financing, and small firms.While Benfratello, Schiantarelli, and Sembenelli (2008) focuses on the impact of banking development in different types of innovation in terms of the extensive margin, Chava et al. (2013) concentrate more on the intensive margin of innovation responses under banking deregulation. Using a dataset on patents filed

[3] The reallocation effect and the welfare consequences of competition in the presence of adverse selection is extensively discussed in the industrial organization literature. See Mahoney and Weyl (2017) for a literature review and a general analytical framework incorporating different competition environments.

by U.S. firms with the United States Patent and Trademark Office and citations to these patents compiled in the National Bureau of Economic Research (NBER) Patents File, Chava et al. (2013) find that intrastate banking deregulation which increased the local market power of banks, decreased the level and risk of innovation by young, private firms, but interstate banking deregulation increased the level and risk of innovation by young, private firms. Using a similar database, Cornaggia et al. (2015) investigate the innovation responses of different firms under the banking deregulation. Their findings are twofold. For public corporation whose headquarters located in the deregulating states, banking competition hampers their innovation. For private firms which rely on external financing to invest in innovation, banking competition increases their investment in innovation by securing the financing from the banking sector.

Existing literature also attempt to explain possible channels through which banking competition may affect innovation, but the conclusion is far from reached. The most important mechanism is that bank competition may release the credit constraint of small and young firms, which stimulates their innovation output (Benfratello, Schiantarelli, and Sembenelli, 2008; Cornaggia et al., 2015). This explanation relies heavily on the fact the small and young firms need external finance to undertake risky innovation projects. The second explanation is based on the level of risk of innovation investment, which is dependent on the specific type of the innovation project. When the banking system is more competitive, riskier innovative projects are more likely to be financed by bank loans (Chava et al., 2013). The last explanation centers on the merger and acquisition behavior of public corporations. Cornaggia et al. (2015) argue that banking deregulation, which release the credit constraint of small, young firms, reduces the probability that public corporations acquire innovative target firms. We can know from the these studies that bank competition may affect innovation through various channels, which depends on the institutional background. Different from existing literature which focus on developed economies. Our study focuses on the relationship between bank competition on innovative activities in the largest developing economy–China. More importantly, we analyze the change in R&D activities through two margins: the extensive margin that captures the change in the portion of firms investing in R&D; the intensive margin that represents the variation in the level of R&D investment conditional on firms with positive R&D investment.

2.2 Impact of ownership on firm innovation

It has been pointed out that SOFs have lower profitability than private firms because the government's choices is more targeted at social and political policy goals rather than profit maximization (Boardman and Vining, 1989; Dewenter and Malatesta, 2001; Bai, Lu, and Tao, 2006). The importance of firm ownership on innovation has also been extensively discussed.[4] As Choi, Lee, and Williams (2011) point out, different countries have different models of ownership structures for firms due to high institutional divergence, which increases the difficulty of establishing a generalized model that can be applied to all countries. More recently, Aghion, Van Reenen, and Zingales (2013) show that greater institutional ownership leads to more innovation. For the purpose of this study, we narrow our attention to discussing studies on the relationship between ownership and innovation in transition economies like China.

It is documented that government ownership has a negative effect on firm performance because of its inefficient structure and lack of managerial knowledge (Child and Yuan, 1996; Song, Storesletten, and Zilibotti, 2011). As the evidence supporting this argument, Dollar and Wei (2007) find that SOFs have significantly lower returns to capital than domestic private firms using the data from a survey between 2002 and 2004. In contrast, much less is known about how has the state ownership affected the firm's innovation performance. In China, the government plays a deterministic role in developing national innovation capabilities through various policies. SOFs that have access to important infrastructure that facilitate government-initiated innovation, will outperform private firms in terms of innovation (Chang, Chung, and Mahmood, 2006; Li, 2012). This suggests that the relative innovation performance of SOFs depends on the sectors in which SOFs operate. On the other hand, one would expect that SOFs are less efficient in generating innovation outcomes due to their managerial inefficiency. Employing a dataset of 548 Chinese firms, Choi, Lee, and Williams (2011) find that the influence of state ownership is positive but lagged. Hu and Jefferson (2009) find that private firms have more patents applications than SOFs after controlling for R&D input and other various factors that may explain the the output of patents. Overall, this suggests that private firms are more efficient firms in innovating although they are less investment in innovation compared with SOFs.

[4]Choi, Lee, and Williams (2011) provides an excellent overview of the existing literature on empirical studies on the relationship between firm ownership and innovation

2.3 Firm ownership and access to bank credits

Even though previous studies have shed light on the impact of banking competition on the innovation and the influence of ownership on innovation, little is known about the interactive effect of them on the firm's innovation performance. A large body of literature have documented that ownership affects the firm's access to the bank credits. In the context of China, SOFs are found to have better access to the credit market dominated by state-owned banks because of the loan guarantees provided by the government (e.g.Brandt and Li 2003; Ge and Qiu 2007; Song, Storesletten, and Zilibotti 2011; Lu, Zhu, and Zhang 2012). This implies that Chinese private firms rely more on their internal cash flow, while state-owned firms depends more on external financing (Allen, Qian, and Qian, 2005; Guariglia, Liu, and Song, 2011). These results remind us to take the firm ownership into consideration when we analyze the impact of bank competition on innovation performance. The intuition is that if SOFs are perceived to be less risky than PFs, then banking competition favors SOFs more than PFs. Therefore, banking competition will have asymmetric effects on SOFs and PFs in terms of easing their access to credits. In this paper, the empirical evidence shows that banking competition has difference impact on the innovation performance of SOFs and PFs. We formally consider the unequal status facing PFs and SOFs in the credit market in our model in order to explain our empirical results. In this sense, our study contributes to this strand literature by consider the consequence of banking deregulation under the unequal treatment between SOFs and PFs.

3 Background, data, and preliminary evidence

3.1 Institutional background

Before we introduce the datasets, we discuss the institutional background in this subsection. To provide a clear map, we divide the development of China's commercial banks after the establishment of P.R. China into three phases.[5] The first stage is 1949-1978, during which the financial sector in China was monopolized by People's Bank of China (PBOC) owned and controlled by the Ministry of Finance. There is barely no bank competition during this stage. PBOC controls about 93% of the total finance assets of the country and manages almost all transactions (Allen, Qian, and Qian, 2008). This situation is altered after 1978 when the banking structure was changed.

The second stage of China's banking development is between 1978 and 1995. In this period, banking competition was promoted to some extent because Chinese government established five big state-owned commercial banks and introduces various financial intermediaries into the credit market[6]. The biggest four state-owned banks are The Bank of China (BOC), the People's Construction Bank of China (PCBC), the Agriculture Bank of China (ABC), and the the Industrial and Commercial Banks of China (ICBC). ICBC is the fourth state-owned commercial banks which was formed in 1984. These four banks took over all the commercial transactions of the PBOC.[7] Since their establishment, the four state-owned banks have remained to be the biggest four banks in China's banking system. Being a big state-owned banks, Bank of Communications (BOCOM) was established as another state-owned commercial bank in 1986. The difference is that BOCOM is a state-owned joint-stock commercial bank. In addition to the five biggest state-owned banks, several joint-stock commercial banks are established during this period, which further intensifies the banking competition.[8] Moreover, in this stage regional banks were formed in the Special Economic Zones in the coastal areas; Rural Credit Cooperatives (RCCs) and Urban Credit Cooperatives (UCCs) were founded (Allen, Qian, and Qian, 2008). The implement of Commercial Bank Law of China in 1995 symbolized the end of the third stage. According to this law, the state-owned banks were re-defined as "commercial banks" and they are required to operate based on market principles instead of policy lending. Overall, after the second stage, China's banking sector is characterized by five big commercial banks and several smaller joint-stock banks.

In the third stage of China banking development is the deregulation. The first feature of this stage is the transforming of UCCs into city commercial banks, which greatly enhances the banking competition. In

[5]Lin, Sun, and Wu (2015) also classified the development of China's banking sector after 1949 into three stages. However, we focus on the discussion of China's commercial banks because they are the main provider of loans to firms. Readers are referenced to Allen, Qian, and Qian (2008) for an excellent analysis of the financial development of China in pre-1949.

[6]These financial intermediaries include policy banks, rural credit cooperative, urban credit cooperative, join-stock banks, and some non-bank financial intermediaries.

[7]As indicated by their names, the four state-owned banks have different focuses on the business. BOC specializes in transaction associated with foreign trade and investment, PCBC concentrates on financing fixed investment, ABC deals with banking businesses in rural areas, and ICBC handles all the rest of commercial transactions.

[8]CITIC Industrial Bank and China Merchants Bank (CMB) were established in 1987; China Industrial Bank (CIB) and China Guangfa Bank (CGB) were formed in 1988; China Everbright Bank (CEB), Shanghai Pudong Development Bank (SPDB), and Hua Xia Bank (HXB) were founded in 1992.

1995, the first city commercial bank, Shenzhen City Cooperation Bank, was founded with the aim of serving medium- and small-sized enterprises, and local citizens. In 2017, the number of city commercial banks has reached 134. The second symbolic event is the formation of China Banking Regulatory Commission (CBRC). After its establishment, CBRC has initiated a series of reforms aimed at removing the banking regulations to promote banking competition. In 2006, CBRC issued a policy document titled as "management methods on city commercial bank branches in places other than the headquarter". The core of this policy is to permit city commercial banks in multiple cities within the range of the local bureau of CBRC. The restriction on city commercial banks is further removed in 2009 when CRBC started to allow joint-stock banks and the city commercial banks to open branches across the country. This provides us relatively exogenous variation of the local banking competition, which enables us to evaluate the impact of banking competition on innovation.

3.2 Data source

This paper uses two major datasets. The first dataset we use is the Chinese Manufacturing Firms Database (CMFD hereafter) compiled by the China National Bureau of Statistics from 2006 to 2007. CMFD is widely used in empirical studies on Chinese manufacturing firms since it contains information on ownership, location, and other financial characteristics. More importantly, it contains information on R&D investment, which suits the goal of this study.

The second database we employ a city-level dataset on all the bank branches of China's banking system collected by a survey conducted by CBRC between 2006 and 2011. To link the firm-level information with the city-level data on the banking sector, we use the data between 2006 and 2007 in our final database. This survey covers 1,719 counties located in 31 regions (including autonomous regions and municipalities). According to the classification by CRBC, there are 14 groups of financial institutions in the dataset.[9] For each type of the financial institutions, this dataset provides information on the number of banking branches, the amount of bank loans, and non-performing loans, and etc. We focus on the commercial banks because they are the major provider of bank credits to firms; we expect that the competition among commercial banks will influence the innovation activities of firms. Therefore we use the information on three groups of banks: the five biggest state-owned commercial banks, the joint-stock commercial banks, and the city commercial banks. These banks account for around 5 percent of the total loans by all the financial institutions in the data, and around 55 percent in terms of employment.[10] One limitation of the dataset is the information is relatively aggregated. Because the bank-level information is not available to us, we rely on the aggregate classification of banks to compute the banking competition index. Our final sample contains 362,771 observations, with 163,001 firms in 2006 and 199,770 firms in 2007, respectively.

3.3 Variables and graphical evidence

In this subsection, we explain the definition for three most important indicators in our empirical analysis: the banking competition, innovation, and firm ownership. The definition of other variables used in our analysis are presented in the data appendix.

3.3.1 Banking competition

Herfindahl-Hirschman Index We use market shares of banks in the local credit market to measure the bank competition. China's banking system is classified as state-owned, joint-stock, and city commercial banks, we therefore follow Degryse and Ongena (2007) and Chong, Lu, and Ongena (2013) to construct a city-level index of bank competition. Specifically, we evaluate the intensity of bank competition using the Herfindahl-Hirschman Index (HHI). Similar to the literature in industrial organization, we treat the share of bank loans within a city as bank's market share and construct the HHI index for city c in year t as:

$$HHI_{ct} = \sum_{n=1}^{3} \left(\frac{loan_{cnt}}{\sum_{n=1}^{3} loan_{cnt}} \right)^2 \tag{1}$$

where n represents the aforementioned three types of banks in the same city: $n = 1$ for the five largest state-owned banks, $n = 2$ for joint-stock banks, and $n = 3$ for city commercial banks. $loan_{cnt}$ is the amount of loans issued by the banks of type n in city c in year t. HHI_{ct} ranges from 0 to 1. It is equal to 1 when the loan

[9] In the data appendix, we display the details of all the bank classifications. A complete classification and details on the institutions in each category can be found at the webpage of CRBC: `http://www.cbrc.gov.cn/chinese/jrjg/index.html`.

[10] The numbers are computed for the sample period between 2006 and 2011.

market is monopolistic and close to 0 when the loan market is close to perfect competition. Table 1 presents the summary statistics of HHI_{ct} used in our final sample. As we can find, the mean HHI_{ct} remain relatively stable during the sample period. In contrast, the minimum this competition index drops from .330 to .321. Lastly, we the median of this index increases from .685 to .696. This summary statistics, however, do not clearly describe the change in the intensity of banking competition in Chinese cities.

Insert Table 1 here

How has the level of banking competition changed during the sample period? In Figure 1 we plot the difference between HHI_{c2007} and HHI_{c2006} against HHI_{c2006}. We find that most of cities experienced a decrease in the level of banking competition between 2006 and 2007. Moreover, there is a slightly negative relationship between $(HHI_{c2007} - HHI_{c2006})$ and HHI_{c2006}, implying that cities with more concentrated banking sector turn to have a more competitive banking sector after the bank reform initiated in 2006. However, we observe that the level of banking competition decreased in some cities. This might reflect that some banks changed their strategy by exiting some cities and re-establish business in other cities. More detailed statistics show that: of all 339 cities, 151 cities had a decrease in the index of banking competition, 108 cities remained constant in HHI_{ct}, while only 80 cities underwent a deteriorated competition environment of the banking sector. Furthermore, we also find that cities where the banking sector becomes more competitive have higher GDP growth rate, larger export intensity, larger import intensity, and more innovative firms.[11]

Insert Figure 1 here

Market power of big five banks China's banking sector is dominated by the five largest state-owned commercial banks. These big five banks account for the largest market share in terms of acquiring deposits and offering loans. Considering this, the decrease in the market power of the big five banks can represent a more competitive loan market. Following this logic, we also use the share of total loans offered by the big five banks as a measure of the level of competition in China's banking sector. We define the market power index as:

$$CR5_{ct} = \frac{loan_{ct}^{big5}}{loan_{ct}^{total}} \tag{2}$$

where $loan_{ct}^{big5}$ is the total loans provided by the largest five state-owned banks and $loan_{ct}^{total}$ is the total loans provided by all the banks including joint-stock banks and other commercial banks. We present the summary statistics of $CR5_{ct}$ in the last four columns of Table 1. We can find a similar pattern of the summary statistics as we observe for HHI_{ct}.

Insert Table 2 here

We also display the change in this index between 2007 and 2006 in Figure 2. Overall, the pattern of change is very similar as we found for HHI_{ct}.

Insert Figure 2 here

As a check on the consistency between these two indices measuring banking competition. We check the correlation between HHI_{ct} and $CR5_{ct}$.[12] Not surprisingly, these two indices are highly correlated. The reason is that both of them captures the change in the market power of state-owned banks to a large extent.

3.3.2 Measure of innovation activities

Our measure for the firm's innovation activities is the R&D expenditures recorded in the firm-level dataset. We use rd_{it} to represent the observed expenditures on R&D. In order to evaluate the change of innovation investment along the extensive margin, we also create a dummy rdd_{it} which equal to one if the firm has positive investment in R&D and zero otherwise. Obviously, taking a simple average of rd_{it} will mix the information on the extensive margin of R&D with that on the intensive margin of R&D. To see this, note that that

$$\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T} rd_{it} = \frac{\sum_i \sum_t rdd_{it}}{NT} \times \frac{\sum_i \sum_t rd_{it} \cdot rdd_{it}}{\sum_i \sum_t rdd_{it}}$$

[11] The full results are displayed in Table A1.

[12] The plot for the correlation between $CR5$ and HHI is shown in Figure A1 in the appendix.

where $\sum_i \sum_t rdd_{it} / (NT)$ is the probability of innovation (the extensive margin) and $\sum_i \sum_t (rd_{it} \cdot rdd_{it}) / \sum_i \sum_t rdd_{it}$ is the mean of R&D conditional on the firms have positive investment in R&D (the intensive margin). Taking rd_{it} for the whole sample and directly evaluate how this variable changes in respond to other factors can be misleading, because it contains information both on the extensive margin and the intensive margin. In our data set, mean value of rdd_{it} is around 10%, indicating that only 10 percent of the firms participate in innovation activities. Moreover, this value is 10.4% in 2006 and 10.5% in 2007. This implies that there is 0.1% increase in the share of innovative firms. The mean of R&D expenditures also shows an increasing pattern. The mean R&D expenditure is 373.52 thousand Chinese yuan in 2006 and 424.85 thousand Chinese yuan in 2007. Our goal of the empirical analysis is to relate this change in the firm-level innovation activities to the increased banking competition caused by the structural reform in China's banking sector.

3.3.3 Classification of ownership structures

We classify the firm's ownership type based on the relative importance of the origins of pay-in capital when the firm is registered. There are six categories of investors: the state; the collective investors; legal entities; individuals; foreign investors excluding those from Hong Kong, Macao and Taiwan; and investors from Hong Kong , Macao, and Taiwan. Guariglia, Liu, and Song (2011) groups firms into three categories of ownership structure: state-owned firms (including firms owned by the state and by collective investors), foreign owned firms (from HMT, other parts of the world), and private firms (owned by legal entities, and individuals). Specifically, they classify firms according to the majority average ownership shares. That is, a firm will be classified as state-owned firms if its paid-in-capital owned by state and the collective investors is no less than 50%. We adopt a similar approach of classifying ownership structures similar to that employed in Guariglia, Liu, and Song (2011). We, however, focus on private firms (PFs hereafter) and state-owned firms (SOFs hereafter) in our study because we think that the innovation activity of foreign firms is determined to their headquarters rather than the status of local credit market. Specifically, we classify a firm to be state-owned (private) if the share of paid-in-capital owned by the state and the collective investors (legal entities and individuals) is over 95%. In our empirical analysis, we use soe_{it} to denote state owned firms and pe_{it} to represent private firms. In the end, we obtain 14,583 observations for SOFs and 324,959 observations for PFs. These observations correspond to 12,983 SOFs and 294,622 PFs.[13]

3.4 Correlation between banking competition and innovation

Before we perform the formal empirical analysis, we present the graphical evidence from the data to show the correlation between banking competition and investment in R&D. Then we check the role of firm ownership in affecting this correlation. Throughout this section, we decompose the investment in R&D into two different margins: the extensive margin and the intensive margin. The first is the extensive margin that captures the firm's probability of investing in R&D; the second is the intensive margin that captures the level of R&D expenditures conditional on the firms have positive investment in R&D. In all of the results, we use HHI_{ct} to measure the level of banking competition. The results are similar if we use $CR5_{ct}$.

3.4.1 Banking competition and city-level R&D activities

We first construct the city-level R&D activities by taking average over the firm's R&D expenditures for each city. Specifically, we take the average of rdd_{it} for each city to obtain the probability of innovating and rd_{it} for all the firms that have positive investment in R&D to construct the average of R&D investment. We present the scatters plot in Figure 3. Each circle in the figure represents a city. As we can find, there is a slightly negative correlation between HHI_{ct} and the R&D activities both measured at the intensive margin or the extensive margin. Because a larger HHI_{ct} means the banking sector is less competitive, the plots actually show that, on average, more R&D investment are undertaken in cities where the banking sector is more competitive. Note that we have a line of data points accumulating at $HHI_{ct} = 1$, this is because these cities are only served by one type of banks. We also try to exclude these cities and a negative correlation between R&D activities and HHI_{ct} still exists.

Insert Figure 3 here

[13] Our classification strategy for the ownership structure affects the final sample size. We also tried other threshold for the classification: 50%, 70%, and 90%; the results are stable to all of these classifications.

3.4.2 Role of ownership

We are interested in the role of ownership in affecting the relationship between banking competition and the firm's participation in innovation activities. In Table 2, we present summary statistics of R&D activities for different types of firms. At the extensive margin, we find that SOFs are more active in innovation than PFs. In data of 2006, of all 6363 SOFs, 18.2% of them have positive investment in R&D. While only 9.3% of the private firms participate in R&D activities. This gap become smaller in 2007. We also find that SOFs invests more in R&D at the intensive margin. These statistics suggest that SOFs are more active in R&D investment than PFs. We find this results to be very interesting. Because if R&D is the fundamental source of productivity growth, then we should expect that the productivity of SOFs to grow faster than that of the PFs. However, the contrary is found in existing literature (Guariglia, Liu, and Song, 2011; Song, Storesletten, and Zilibotti, 2011). This may imply that the innovation investment in SOFs are less efficient than PFs.[14] We will come back to this discussion in the part of theoretical model.

Insert Table 2 here

We begin to investigate the possible heterogeneous effects of banking compeition on innovation by dividing firms into SOFs and PFs and check the correlation between banking competition and innovation separately. First, we plot the probability of innovating against banking competition for SOFs and PFs, respectively. The results are presented in Figure 4. In the left panel, we present the results using the full sample. While in the right panel, we only keep city observations with $HHI_{ct} < 1$. In either of the plots, we see the slope of the fitted lines are negative for both SOFs and PFs. The slope for SOFs, however, is larger than that for PFs in absolute value. To some extent, this suggests that the increased banking competition has a larger impact on encouraging the participation in innovation for SOFs than for PFs.

Insert Figure 4 here

We continue to look at how the correlation between the intensive margin of R&D and HHI_{ct} differs by ownership. The correlation are plotted in Figure 5. We can barely see any difference between the slope of the fitted line for SOFs and that for the PFs in both of panels. This may suggests that the impact of increased banking competition along the intensive margin is not affected by the firm ownership.

Insert Figure 5 here

Despite of these interesting correlation patterns, we need to bear in mind that the correlation does not necessarily imply causality; other hidden factors could drive this correlation pattern. In the next section, we will discuss the estimation of the partial impact of banking competition on innovation and how it differs by firm ownership.

4 Empirical evidence

In this section, we first present the empirical results for banking competition and extensive margin of R&D investment, then we show the results for banking competition and intensive margin of R&D spending. We also provide several robustness checks to support our empirical findings. In the last subsection, we discuss our empirical findings and provide additional empirical tests.

4.1 Model specification and results

Probability of innovating To begin with, we investigate the relationship between bank competition and the probability of investing in R&D by estimating following probabilistic model:

$$\begin{aligned}\mathbf{P}\left(rdd_{ict}=1|\mathbf{X}\right) &= \mathbf{P}\left(rdd^{*}>0|\mathbf{X}\right) \\ &= \Phi\left(\alpha_0+\beta_1 HHI_{ct}+\beta_2 PF_{ict}+\gamma\mathbf{Z}'\right),\end{aligned} \tag{3}$$

where rdd_{ict} is a dummy variable equal to one when the firm has positive investment in R&D and zero otherwise. rdd^{*} is a latent variable. $\Phi(\cdot)$ is the cumulative distribution function for standard normal distribution.[15]

[14] Dollar and Wei (2007) find that the investment efficiency of SOFs are lower than PFs.

[15] Our results are robust if we use a logit model by assuming the the error term has a logistic distribution.

HHI_{ct} is the city-year level bank competition measured by the HHI index calculated for banks in city c at given year t, PF_{ict} is a dummy variable which is equal to one when the firm is a private firms and zero otherwise. We add the indicator for private firms into our basic econometric specification because there is a large body of literature that has documented the difference in organizational efficiency between SOFs and non SOFs in China (Boardman and Vining, 1989; Song, Storesletten, and Zilibotti, 2011). $\boldsymbol{Z}'$ is a vector of other control variables. In the benchmark results, we include age as the additional control to account for the possibility that young firms are more innovative than old firms. For the purpose of this study, we further include interaction between HHI and PF, $HHI \times PF$, and interaction between HHI_{ct} and SOF, $HHI \times SOF$ to investigate the different effects of banking competition on firms with different ownership structures. By doing this, we allow the partial effect of banking competition on innovation differs between SOFs and PFs because the coefficient of $HHI \times PF$ and $HHI \times SOF$ may differ. For all the models, we also include a full set of year dummies of control for the time trend in R&D activities, province fixed effects to control the province-level factors that are correlated with the banking competition and affect innovation, and also industrial fixed effects to control for heterogeneity innovation participation caused by unobserved time invariant sector-level characteristics. The estimation results are displayed in Table 3.

As we can see in column (1) in Table 3, the coefficient of HHI_{ct} is negative but not statistically significant. This may suggest that the increased banking competition has no significant effect on the firm's probability of undertaking R&D investment. In column (2) of Table 3, both the coefficient of $HHI \times PF$ and $HHI \times SOF$ are negative, but only the coefficient of the latter one is statistically significant at 1% level. This implies that increasing the banking competition has only induced more SOFs to undertake R&D investment. Also note that the coefficient of PF is negative and significant, which implies that a larger ratio of SOFs invest in R&D than that of PFs, ceteris parabus. This result suggests that SOFs have better access to the credit market, hence more capable of obtaining external financing to invest in innovation projects. To avoid the possibility that the estimation results are driven by other firm characteristics, we try to control other firm-level information. Specifically, we includ the subsidy a firm receives to take the variation in R&D subsidy into account, and export intensity to capture the effect of participating international trade on innovation, and the financial costs to control the variation in firm's financial costs that are caused by factors[16] other than banking competition. In columns (3) and (4), we further add controls of the subsidy a firm receives[17], the export intensity, and the firm's financial costs as additional control variables and re-estimate the model. Columns (3) and (4) show that our estimation results remain stable. Comparing the results in Column (4) with Column (2), we notice that the absolute value of the coefficient of $HHI \times SOF$ decreases from -0.438 to -0.396, indicating that other controls include in the last column contributes to the effect of banking competition on the participation in innovation in Column (2).

Insert Table 3 here

Intensive margin of R&D investment We continue to analyze how the level of R&D investment is related to the banking competition and how this relation differ for different types of firms. Now we focus on the sample of firms that have positive investment in R&D to separate the firm's adjustment of R&D investment along the intensive margin from the aggregate change in R&D spending. Our model specification assumes that there is a linear relationship between banking competition and innovation.[18] The linear model is:

$$rd_{ict} = \beta_0 + \gamma_1 HHI_{ct} + \gamma_2 PF_{ict} + \boldsymbol{\theta}\boldsymbol{Z}' + \epsilon_{ict} \tag{4}$$

where ϵ_{ict} is the error term. The estimation results are reported in Table 4. As we did for the analysis on the extensive margin of R&D investment, we add other firm-level control variables in columns (3) and (4). The estimation results show that: First, overall there is a positive relationship between banking competition and the average level of investment in R&D; Second, increasing banking competition has larger and more significant impact on increasing the investment in R&D by private firms. The latter result is in sharp contrast with what we found in the extensive margin of R&D investment. We will carefully discuss these two contrasting and interesting results after we provide a series of robustness checks for our benchmark results.

Insert Table 4 here

[16] These factors could be change in the monetary policy.

[17] The variable for subsidy is the total amount subsidy a firm receives; part of them is R&D subsidy.

[18] We also tried to include a quadratic term of HHI_{ct} to see there is non-linear relationship between the level of R&D investment and banking competition; only the linear term is found to be significant and negative.

4.2 Robustness

The empirical results in previous section presents us a puzzling result: increased banking competition has a larger impact on the innovation probability by SOFs while a larger impact on the investment in R&D by PFs. In the theoretical part of this paper, we will build up a model to provide a possible mechanism based on which we can rationalize these seemingly puzzling results. For now, let us discuss a series of robustness checks to our empirical findings. To save space, we present all the results in the appendix.

The first concern for our results is whether our results are driven by other firm characteristics that are not controlled in our econometric model. This leads to the endogeneity problem caused by omitted variables. To deal with this problem, we consider several firm-level variables that correlate with banking competition and/or firm ownership, and affect the firm's innovation activities. In particular, we consider the capital intensity, productivity efficiency, and the cash flow. Capital intensity may be increasing with intensified banking competition because banking competition may decrease the interest rate the firm pays to rent capital, which encourages firm to make investment. Therefore the observed innovation effect of banking competition may be a spillover effect of firm's new investment. Also, capital intensity is correlated with firm ownership since SOFs are concentrated in sectors that are more capital intensive. Productivity is an important determinant of the firm's investment in R&D because firms at different productivity levels receive different net benefits of innovation. If firms choose their location based on their productivity due to the selection effect, then banking competition can be correlated with the firm's productivity. Guariglia, Liu, and Song (2011) find that cash flow is important for Chinese private firms to overcome the liquidity constraint and achieve fast growth. Moreover, cash flow is the most important source of finance of R&D because external investors face the problem of asymmetric information (Hall and Lerner, 2010). These findings suggest that cash flow is probably the most important source of R&D financing for private firms. Therefore we also try to control cash flow in our estimation. In implementation, we try to control these variables separately, then we put them together in the model.[19] The estimation results consistently show that our results are stable to the inclusion of other firm characteristics.

We then consider the concern that the possibility that the result is driven by the entry and exit decisions of firms. To deal with this concern, we construct two variables that characterize the entry and exit behaviors of the firms.[20] We include them into the estimation of model (3) to account for the impact of firm entry and exit behavior on the firm's innovation activities. Note that our estimation for analyzing the change at the intensive margin of R&D spending also suffers from the impact of the firm's entry and exit decisions. We tackle with this concern by restrict our sample to contain the firms that have consecutive observations and are active in R&D during the sample period. Our results are stable to these tests.[21]

Lastly, we use $CR5$ an the measure of banking concentration. We replace HHI_{ct} with $CR5$ and re-estimate our model with a full control of the variables we discussed. Not surprisingly, the estimation results are similar to that we presented in the benchmark analysis. The estimates are shown in Table A6 in the appendix.

4.3 Discussion on possible mechanisms

In this section, we discuss several possible explanations based on existing literature on banking competition and firm innovation. We start our discussion by summarizing our main empirical finding into two facts. For the relationship between banking competition and innovation, we have following three empirical facts:

Fact 1. *Increased banking competition has increased probabilities of investing in R&D significantly for state-owned firms, but not for private firms.*

Fact 2. *Increased banking competition has significantly increased the level of R&D investment by private firms, but not by state-owned firms.*

To the best of our knowledge, the empirical results in previous section are new to existing literature.[22] In what follows, we check different hypotheses proposed by extant literature and discuss how these theories can square with our empirical findings.[23] The challenge facing an explanation is the different impacts of banking competition on the margins of R&D investment for different types of firms. We first discuss the financing of

[19]The estimation results are presented in Table A3 and Table A4 of the appendix.

[20]A firm entry (exit) is defined when it only appears in year 2007 (2006).

[21]We present the estimation results in Table A5 of the appendix.

[22]See the section of literature on the empirical findings on the existing literature.

[23]Throughout our discussion, we view R&D and an input of innovation rather than output of innovation. Therefore we do not consider theoretical explanation that treats financial intermediaries as a factor of innovation input in addition to R&D investment (See, for example, Benfratello, Schiantarelli, and Sembenelli, 2008).

R&D as indicated by our empirical results. Then we discuss how the increased banking competition affect the allocation of credits between PFs and SOFs, which leads to change in the innovation activities.

4.3.1 Finance of R&D investment

We take the neoclassical approach to analyze the R&D financing in a way similar to the analysis of investment financing.[24] The source of finance of R&D investment depends on the costs of different financial resources. Since banks play a dominant role in allocating credits in China, we only consider debt and retained earnings as two important resources of finance.[25] Existing literature has documented that PFs have disadvantages than SOFs in acquiring loans from State-Owned banks because of political reasons. Bai, Lu, and Tao (2006) argue that state owned enterprises are supported by the government and are able to obtain bank credits easily. Allen, Qian, and Qian (2005) document that private firms are usually discriminated against when accessing to external funding. Firth et al. (2009) find that private firms that have political connection with the banks have better access to bank financing. Consistent with these literature, Guariglia, Liu, and Song (2011) document that the growth of Chinese private firms are sensitive to their cash flow while state owned firms are not. Based on these findings, we expect that SOFs relies more on bank credits to finance the R&D projects, and PFs rely more on the internal cash flow to finance R&D. This institutional setting will have strong implication for the understanding of the heterogeneous impact of banking competition on innovation activities for PFs and SOFs. In discussing the possible mechanisms through which banking competition may affect innovation activities, we take this institutional setting as given and analyze how the banking competition affect the relative costs of obtaining funds for PFs and SOFs.

4.3.2 Effect of intensified banking competition

Availability of funds There are two important channels through which banking competition can affect the supply of credits, which further influences the firm's innovation activities. The first channel is based on the standard conduct-performance hypothesis that increased competition among banks will reduce each bank's market power and increase credits supply to all firms (Berger, Molyneux, and Wilson, 2010; Rice and Strahan, 2010). The second conduit through which banking competition affects the availability of funds is the relationship lending. Increased banking competition has unfavorable effects of the formation of lending relationships between banks and small businesses (Petersen and Rajan, 1995). This has negative impact on the availability of credits for small and young firms. The empirical evidence is mixed and both of the channels have their support (Berger, Molyneux, and Wilson, 2010). The different situation facing PFs and SOFs implies that banking competition will probably decrease the credit supply to PFs through the harmful effects on relationship lending. While the availability of credits for SOFs will be increased through the the first channel. For SOFs, whether the credits are allocated to more firms or to the same firms that obtained credits before, increased banking competition will stimulate the innovation activities of the SOFs. In sharp contrast, we expect that this will stifle the R&D investment by PFs. These predictions, however, are inconsistent with our empirical findings that banking competition has positive impact on the level of investment of private firms at the intensive margin.

Asymmetric information The problem of asymmetric information exists in the R&D financing when the innovator and financier are different entities. As the provider of external financing, banks can not observe all the information on the innovation projects. This asymmetric information can cause credit rationing that firms will not be financed even though they are willing to pay a higher interest rate. This phenomenon is formally modeled in the seminal work of Stiglitz and Weiss (1981). Two consequences follow after the banking competition increases. The first effect is the price effect that decreases the interest rate of borrowing for the marginal borrowers. The second effect the credit rationing effect that determines that allocation of credits to borrowers. While the direction of the first channel is certain, the second effect is ambiguous at most. Rice and Strahan (2010) find that small firms operating in states that were more open to branching borrowed at significantly lower interest rate than firms in states that were less open. Although more firms used bank debt in states opened to interstate branching, the increase in bank debt did not lead to an increase in the total borrowing, higher rates of credit approval, or changed in debt maturity. As Chava et al. (2013) point out,

[24] R&D investment has three main differences from investment in physical capital. The first is that it is extremely risky; the second is that over 50% of R&D expenditures is the wages and salaries paid to scientists; the third is that investment in R&D produce intangible assets such as tacit knowledge (Hall and Lerner, 2010).

[25] We also exclude the discussion on the venture capital financing because it is mainly for startup financing and our sample contains only large and medium sized SOFs and PFs.

these results suggest that competition may increase credit rationing even as the average borrowing interest rate falls. Recent theoretical studies have found that certain monopolistic power may be required to offset the distorting effect of adverse selection (Lester, 2017; Mahoney and Weyl, 2017).

Because SOFs receive loan guarantees from the local government, they face less credit rationing and can borrow from banks more easily in the presence of asymmetric information. When banking competition increases, the price effect will drive down the interest rate facing the marginal borrowers of SOFs. This potentially increases the loans allocated to SOFs by lending to more SOFs. The PFs, however, face the credit rationing. Therefore, the interest rate of borrowing by PFs will not be affected by the banking competition as long as the pool of risk facing PFs does not change. Under this circumstance, the demand of loans by PFs will not change. The change of loans allocated to PFs will be affected by the supply side, which is determined by the form of competition among banks. To be fully consistent with the empirical results, this again requires us to return to the discussion on how the banking competition affects the availability of funds.

In summary, the discussion indicates that neither the funds availability hypothesis and the asymmetric information hypothesis alone can provide a sound explanation to our empirical findings. We need combine these two hypotheses in order to illustrate the results. In next section, we include these two mechanisms into a theoretical model that generates results consistent with our empirical findings.

5 Model

In this section, we build a model to rationalize the empirical findings discussed in the previous section, and discuss the implications of the changes in banking competition. We consider a quality-ladder growth model as in Grossman and Helpman (1991), Aghion and Howitt (1992, 2009). It consists of three sectors: a final good sector, an intermediate goods sector made up of state-owned firms (SOEs) and private-owned firms (POEs) and a financial sector made up of banks. The economy is in discrete time indexed by $t = 0, 1, 2, ...$, and consists of an infinite sequence of two-period-lived, overlapping generations as well as a set of initial old agents present at $t = 0$. Each generation contains a group of workers and a group of enterpreneurs. The size of workers is a constant L and the size of enterpreneurs is normalized to 1.

5.1 Environment

Workers Workers have one unit of labor that is supplied inelastically when they are young, and have no labor endowment when they are old. Each of them seeks to maximize the following lifetime utility

$$U_t^w = \frac{\left(c_t^y\right)^{1-\gamma} - 1}{1-\gamma} + \beta \frac{\left(c_{t+1}^o\right)^{1-\gamma} - 1}{1-\gamma} \tag{5}$$

where $\beta > 0$ is the discount rate, γ is the inverse of the elasticity of intertemporal substitution, c_t^y is the consumption of final good at period t (when they are young), and c_{t+1}^o is the consumption of final good at period $t+1$ (when they are old). For the generation born in period t, the workers can deposit their income to the bank at deposit rate r_{t+1} to smooth their consumption. Therefore, each agent maximizes the utility function subject to the budget constraint

$$\begin{aligned} c_t^y + s_t &= w_t, \\ c_{t+1}^o &= (1 + r_{t+1})\, s_t, \end{aligned}$$

where s_t is the deposits, and w_t is the wage rate. The standard optimization theory implies that the agent's optimal choice of deposits is

$$s_t = \frac{w_t}{1 + \beta^{-1/\gamma} (1 + r_{t+1})^{1-1/\gamma}}, \tag{6}$$

and the consumption choices are

$$c_t^y = \frac{w_t}{1 + \beta^{1/\gamma} (1 + r_{t+1})^{1/\gamma - 1}}, \tag{7}$$

$$c_{t+1}^o = \frac{(1 + r_{t+1})\, w_t}{1 + \beta^{-1/\gamma} (1 + r_{t+1})^{1-1/\gamma}}. \tag{8}$$

Final goods sector There is only one type of final good, which is produced by identical and perfectly competitive firms in the final good sector.[26] The final good is produced via the following technology:

$$Y_t = \int_0^1 Q_t(i)^{1-\alpha} X_t(i)^{\alpha} di \cdot L_t^{1-\alpha}, \tag{9}$$

where $K_t(i)$ is the amount of intermediate goods $i \in [0,1]$ used in final good production, L_t is the amount of labor input, $Q_t(i)$ is the highest quality level of intermediate goods in industry i at time t, and it is given by $Q_t(i) = \prod_{j=1}^{m_t(i)} q_j(i)$. The integer $m_t(i)$ is the number of successful innovations that have occurred in industry i as of time t, and $q_j(i)$ is the step size of the j-th innovation in industry i. In this model, innovation is represented by quality improvement of intermediate goods, and $q_j(i)$ is a random variable that depends on the firm that creates this innovation and the size of R&D input.[27] We denote $\bar{Q}_t \equiv \int_0^1 Q_t(i)\, di$ as the aggregate technology level, and normalize $\bar{Q}_0 = 1$.

The production of final good takes as given the output price and input prices. From profit maximization, the conditional demand function for $X_t(i)$ is

$$X_t(i) = \left(\frac{\alpha}{P_t(i)}\right)^{\frac{1}{1-\alpha}} Q_t(i) L_t,$$

where we assume the final goods as numeraire and normalize its price to be one, and $P_t(i)$ is the price of intermediate goods $i \in [0,1]$. In this model, we assume the labor input is only used in the production of final good. So in equilibrium, we always have $L_t = L$.

Intermediate goods sector The intermediate goods sector is monopolistically competitive across industries. Within each industry, there is one incumbent firm that owns the technology of $Q_t(i)$, and a group of potential entrant firms that can take place of the incumbent by creating a new intermediate good with higher quality level. An intermediate good firm inputs one unit of final good to produce one unit of intermediate good. The incumbent charges a markup over the marginal cost to maximize profit. We assume the markup is a constant $\eta > 1$, which depends on a country's policy on intellectual property rights.[28] Therefore, the monopolistic price of each incumbent is given by

$$P_t(i) = \eta.$$

As a result, the amount of profit generated by the incumbent in industry i is

$$\pi_t(i) = (\eta - 1)\left(\frac{\alpha}{\eta}\right)^{\frac{1}{1-\alpha}} Q_t(i) L \equiv \bar{\pi} Q_t(i), \tag{10}$$

where $\bar{\pi} \equiv (\eta - 1)\left(\frac{\alpha}{\eta}\right)^{\frac{1}{1-\alpha}} L$ is a constant for any industry i.

In each intermediate good industry, firms are divided into two types: state-owned enterprises (SOF) and privately-owned enterprises (PF). These two types of firms are heterogeneous in two aspects. First, PFs and SOFs differ in the easiness of external financing in financial market. Second, the firms are heterogeneous in the R&D activities. These two types of characteristics are described in details below.

Entrepreneurs, R&D and innovation In addition to workers, each generation also contains a group of two-period-lived entrepreneurs. An entrepreneur is born to own either an SOF or a PF, and has no initial wealth or no labor endowment at all. We assume the entrepreneurs are risk-neutral and only care about the consumption when they are old, so their utility function is $U_t^e = \tilde{c}_{t+1}^o$, where $\tilde{c}_{t+1}^o$ is the consumption of an entrepreneur who is born in period t and when she is old.

The entrepreneurs of intermediate good firms conduct R&D activities, and an R&D project creates a new design of intermediate good with higher quality level. When a new design is created at the end of period t, the patent holder replaces the incumbent and starts production in period $t+1$. Therefore, if an entrepreneur successfully innovates in period t, she will become the intermediate monopolist in some industry i in the next

[26] Basically, the production of final good is not risky and firms are not financially constrained. Therefore, we do not distinguish the ownership of firms in this sector.

[27] If $q_j(i) = q$ for all $j \in \{1, ..., m_t(i)\}$ and for all $i \in [0,1]$, then $Q_t(i)$ simplifies to $q^{m_t(i)}$ as in the canonical quality-ladder model.

[28] This parameter is used in calibration. Since the profit-maximizing markup is $1/\alpha$, we assume $\eta \leq 1/\alpha$.

period. Otherwise, the incumbent will pass to someone else chosen at random who is able to produce last period's product.[29]

For the R&D process, we assume that in each period and each industry, there is at most one firm that randomly gets an opportunity to work on a new R&D project, and whether this firm is SOF or PF is random. We assume the probability that a SOF gets the project is λ_s, and use λ_p to denote the probability that a PF gets the project. An R&D project is risky and its output is a new design of intermediate good with a random step size of quality improvement. The entrepreneurs use final good as R&D inputs and an entrepreneur in industry i can only create new designs of intermediary goods i.

We assume that the intermediate firms are heterogeneous in the R&D efficiency and R&D riskiness. That is, an intermediate-good firm has a tuple of characteristics (o, μ_o, θ), where o is the ownership type, μ_o is a constant that captures the R&D efficiency of a type-o firm and θ is another constant that represents the riskiness of an individual firm's R&D activity. The pair (μ_o, θ) specifies the firm's R&D production function. If the firm is in industry i and employs Z_t units of final goods as R&D inputs at time t, then the R&D project output is a new design of intermediate good i with a random size of quality improvement[30]

$$q_t(i) = \mu_o q z_t(i),$$

where $z_t(i) = Z_t / Q_t(i)$ and q is a random variable that follows a Pareto distribution with a shape parameter $1/\theta$ and a scale parameter $(1-\theta)\tilde{q}$. The CDF of this distribution is given by[31]

$$F(q, \theta) = 1 - \left[\frac{(1-\theta)\tilde{q}}{q}\right]^{1/\theta}, \qquad q \in [(1-\theta)\tilde{q}, \infty),$$

for any $\theta \in (0,1)$. Notice that this distribution has a mean equal to $\tilde{q}$. Parameter θ characterizes the risk of the entrepreneur's R&D project, such that greater θ corresponds to greater risk in the sense of mean preserving spreads, i.e., for any $\theta_1 > \theta_2$,

$$\int q dF(q, \theta_1) = \int q dF(q, \theta_2) \equiv \tilde{q}, \tag{11}$$

where $\tilde{q}$ is the expected value of q, and for any y,

$$\int_{q \le y} F(q, \theta_1) dq \ge \int_{q \le y} F(q, \theta_2) dq.$$

Therefore, given same level of R&D input and same characteristic μ_o, greater θ implies larger volatility of R&D output. Moreover, we assume that μ_o is a character that can be observed by both the firm and outside investors, while θ is a character that is only known by the firm itself. This means the outside investors can only distinguish the average size of quality improvement of a firm's R&D project.[32] Moreover, we assume that firms of same ownership has same observable character μ_o, while are heterogeneous in θ. In particular, the character θ follows a known distribution with CDF $H(\theta)$ and PDF $h(\theta)$.[33]

Next we derive the value of an innovation. Since an entrepreneur only lives for two periods, the reward to a successful R&D project is the profit in the next period, which is

$$\pi_{t+1}(i) = \bar{\pi} q_t(i) Q_t(i) \tag{12}$$

where $q_t(i)$ is the size of quality improvement of this innovation.

As a summary of this section, the R&D function describes that the average size of quality improvement depends on firm's R&D efficiency and R&D inputs, which are complementary. $Q_t(i)$ in the denominator captures the effect that the average size of quality improvement is lower when the technology level $Q_t(i)$ is

[29] This assumption follows Aghion and Howitt (2009, Chapter 4.2.4). An alternative assumption is that only the entrant entrepreneurs have incentive to conduct R&D. Due to Arrow's replacement effect, the incumbent entrepreneur does not participate in R&D activities and will inherit the firm in the next period if there is no innovation by the others.

[30] We implicit assume that $q_t(i)$ is always larger than 1 along the balanced growth path, and calibrate parameters to match this assumption in the numerical analysis.

[31] The distribution of quality improvement is adopted from Minniti et al (2011). This assumption is mainly used for quantitative analysis. We can actually get all the theoretical results under general form of F by imposing some shape conditions. However, this would complicates our analysis.

[32] This setup follows Stiglitz and Weiss (1981) and is essential to generate credit rationing in loan market. A more general assumption on firm's R&D output is that the distribution of the size of quality improvement depends on both observable and unobservable characteristics. However, this would complicates our analysis but does not change the main conclusion.

[33] In the rest of the paper, we assume that θ follows a truncated normal distribution over $[\underline{\theta}, \bar{\theta}] \subset (0,1)$, where the original normal distribution is $N(\tilde{\theta}, \sigma^2)$.

already high. Parameter θ captures the riskiness of the firm's R&D project, where a higher θ implies higher volatility in R&D output. Notice that the above setup of R&D function does not rule out the case of R&D failure, which is represented by $q_t(i) = 1$, i.e. the quality level does not improve in this project. Another point that should be noted is that the value of new patent produced in this R&D project is $\pi_{t+1}(i) = \bar{\pi} q_t(i) Q_t(i)$, which is proportional to the step size of quality improvement.

R&D financing This section describes the financing of R&D firms in the banking market, where the asymmetric information on firms' R&D risk generates adverse selection problem. We assume that R&D activities are totally financed by external funds. Considering that bank lending is the main source of external financing in China, we assume firms in this model can only ask for loans from banks. There are two types of asymmetric information problem in the financing activities. First, before financing, the banks cannot distinguish the risks of the R&D projects undertaken by firms. This generates adverse selection problem of loan allocation. Second, after financing, the entrepreneur's moral hazard problem can exist, since they may use the loans in the other activities. Following Stiglitz and Weiss (1981) we focus on adverse selection, and eliminate the moral hazard problem by assuming that the banks can monitor the output of each financed projects costlessly. Moral hazard problem will not change the effects of adverse selection problem on loan allocation and competition in the financial market, but complicates the structure of loan contract.

The difference between state-owned firms and private-owned firms in R&D financing is as follows. A state-owned firm is less likely to default on bank loans, even if the output of risky project does not cover the repayment to banks. One stylized fact for this assumption is that the SOFs in China have better access to credit market. Moreover, because of the partial support of government, SOFs are less likely to default on bank loans even if their risky projects fail. However, the PFs cannot get enough support from the government, and usually do not have sufficient internal financing. As long as the risky project fails, the PFs will default on loans with some probability. This means from the perspective of banks, lending to SOFs is less risky than to PFs, even though the latter are more productive. This is the key assumption that creates the misallocation of banking loans, which deviates the equilibrium from the socially optimal.

When a SOF does not get enough output to repay the loan, then the firm can get subsidy or a transfer from a third party (e.g. government) to cover the loan repayment with probability δ. The amount of transfer is equal to the difference between loan repayment and the real output. In this case, we assume that the firm is taken over by the third party and the third party is in charge of paying the interest to the bank. That means, the firm will lose the collateral in this case. Therefore, the default decision for PFs and SOFs should be the same, the difference is that the bank can still get interest repayment when an SOF chooses to default.

In the rest of the paper, we focus on the balanced growth path of the equilibrium and drop the time index as long as it does not cause any confusion. The borrowing contract is one-period and specified as follows. If a PF borrows the amount $zQ(i)$ and the loan interest rate is r_l^p, then the collateral is $\kappa z Q(i)$ and the interest payment in the next period is $\left(1 + r_l^p\right) zQ(i)$. The PF defaults as long as the R&D output net of loan repayment is smaller than the collateral loss due to default. That is, the expected payoff of a firm with investment $zQ(i)$ is $\pi_p\left(r_l^p; i, \theta\right) zQ(i)$, where[34]

$$\begin{aligned} \pi_p\left(r_l^p; i, \theta\right) &= \mathbb{E}\left[\max\left((1+r)\mu_p \bar{\pi} q - \left(1 + r_l^p\right), -\kappa\right) | i, p, \theta\right] \\ &= \left[\frac{(1-\theta)\tilde{q}(1+r)\mu_p\bar{\pi}}{1 + r_l^p - \kappa}\right]^{\frac{1}{\theta}} \frac{\theta\left(1 + r_l^p - \kappa\right)}{1-\theta} - \kappa. \end{aligned} \tag{13}$$

Notice that the payoff function $\max\left((1+r)\mu_o\bar{\pi}q - (1+r_l), -\kappa\right)$ is convex in q. By Jensen's inequality, it implies that $\pi_p\left(r_l^p; i, \theta\right)$ is increasing in θ when r_l^p is given. Therefore, a PF is willing to borrow if and only if θ is large enough.

If a SOF borrows the amount $zQ(i)$ and the loan interest rate is r_l^s, the firm chooses the default cutoff of R&D output by solving the following problem:

$$\pi_s\left(r_l^s; i, \theta\right) = \max_{\hat{q}} \int_{\hat{q}}^{\infty} \left[(1+r)\mu_s\bar{\pi}q - (1 + r_l^s)\right] dF(q, \theta) - \int_{(1-\theta)\tilde{q}}^{\hat{q}} (1-\delta)\kappa dF(q, \theta),$$

where $\hat{q}$ is the cutoff of default. The first-order condition with respect to $\hat{q}$ implies that $\hat{q}\left(r_l^s; i, \theta\right) = \frac{1 + r_l^s - (1-\delta)\kappa}{(1+r)\mu_s\bar{\pi}}$.

[34]The derivations of the equations below are in the Appendix.

This implies that

$$\pi_s\left(r_l^s;i,\theta\right)=\left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu_s\bar{\pi}}{1+r_l^s-(1-\delta)\,\kappa}\right]^{\frac{1}{\theta}}\frac{\theta\left[1+r_l^s-(1-\delta)\,\kappa\right]}{1-\theta}-(1-\delta)\,\kappa$$

We impose the following assumption to guarantee the existence of a interior cutoff for θ above which the firms are willing to borrow:

Assumption 1. $\left[\frac{(1-\bar{\theta})\tilde{q}(1+r)\mu_p\bar{\pi}}{1+r_l^p-\kappa}\right]^{\frac{1}{\bar{\theta}}}\frac{\bar{\theta}\left(1+r_l^p-\kappa\right)}{1-\bar{\theta}}>\kappa>\left[\frac{(1-\underline{\theta})\tilde{q}(1+r)\mu_p\bar{\pi}}{1+r_l^p-\kappa}\right]^{\frac{1}{\underline{\theta}}}\frac{\underline{\theta}\left(1+r_l^p-\kappa\right)}{1-\underline{\theta}}$, *and* $\left[\frac{(1-\bar{\theta})\tilde{q}(1+r)\mu_s\bar{\pi}}{1+r_l^s-(1-\delta)\kappa}\right]^{\frac{1}{\bar{\theta}}}\frac{\bar{\theta}\left[1+r_l^s-(1-\delta)\kappa\right]}{1-\bar{\theta}}>(1-\delta)\,\kappa>\left[\frac{(1-\underline{\theta})\tilde{q}(1+r)\mu_s\bar{\pi}}{1+r_l^s-(1-\delta)\kappa}\right]^{\frac{1}{\underline{\theta}}}\frac{\underline{\theta}\left[1+r_l^s-(1-\delta)\kappa\right]}{1-\underline{\theta}}$.

Assumption 1 implies that the projects with low risks are non-profitable, and a project is profitable if and only if its riskiness is sufficiently large. Suppose the firm receive zero profit from the outside option. Therefore, the cutoff of borrowing, i.e. $\hat{\theta}_o\left(r_l^o;i\right)$ are given by

$$\left[\frac{\left(1-\hat{\theta}_p\right)\tilde{q}\,(1+r)\,\mu_p\bar{\pi}}{1+r_l^p-\kappa}\right]^{\frac{1}{\hat{\theta}_p}}\frac{\hat{\theta}_p\left(1+r_l^p-\kappa\right)}{1-\hat{\theta}_p}=\kappa, \tag{14}$$

$$\left[\frac{\left(1-\hat{\theta}_s\right)\tilde{q}\,(1+r)\,\mu_s\bar{\pi}}{1+r_l^s-(1-\delta)\,\kappa}\right]^{\frac{1}{\hat{\theta}_s}}\frac{\hat{\theta}_s\left[1+r_l^s-(1-\delta)\,\kappa\right]}{1-\hat{\theta}_s}=(1-\delta)\,\kappa. \tag{15}$$

This implies that $\hat{\theta}_o$ is only a function in the loan rate r_l^o. So in the rest of the paper, we drop industry index i for simplicity of notation. It is obvious that the threshold is increasing in r_l^o.[35]

Banks In the banking sector, there are n homogeneous and risk-neutral banks in discrete measure. As is described below, banks participate in deposit market to compete for deposits from households in Bertrand competition, and enter loan market to provide loans to firms in Bertrand-Edgeworth competition. The Bertrand-Edgeworth competition is a model where there is a limit to the output of the oligopolies which they are willing and able to sell at a particular price. It is different from the Bertrand competition model where the firms are willing and able to meet all demand. As we will see later, n also measures the degree of competition in banking sector. Without special notice, we will treat n as the measure of banking competition. As n increases, the level of banking competition increases.

The banks are able to invest the deposits in three types of assets: loans to SOFs, loans to PFs and reserves. Reserves are riskless assets with a constant return rate ρ_r. We assume banks need to pay costs to manage these assets. In particular, the total management cost of loans to type-o firms is $\frac{\chi_o}{2}\left(\frac{L_o}{\bar{Q}}\right)^2\bar{Q}$, where $o=p,s$ represents the firm ownership, L_o is the aggregate amount of loans to type-o firms, and $\bar{Q}$ is the aggregate quality level across industries. The management cost of reserves is $\frac{\chi_r}{2}\left(\frac{L_r}{\bar{Q}}\right)^2\bar{Q}$, where L_r is the amount of reserves. The quadratic cost function guarantees the interior solutions of asset allocations, and $\bar{Q}$ is added to guarantee a balanced growth path.

In the deposit market, banks compete for deposits in a Bertrand game. That is, banks collect deposits by posting deposit rates $(r_1,r_2,...,r_n)$. Households choose to deposit their wealth in the bank with highest deposit rate, and are indifferent between two banks with same deposit rate. Based on the fact that all banks in China set the deposit rate at the rate ceiling, we assume all banks offer their deposit rates at an exogenous level r_d, i.e. $r=r_d$. Therefore, given that all banks post same deposit rate, the aggregate deposit is equally divided among banks. This means each bank can collect $1/n$ share of total deposits, where the total deposit is

$$\bar{D}_t=\frac{w_tL}{1+\beta^{-1/\gamma}\left(1+r_d\right)^{1-1/\gamma}}. \tag{16}$$

[35] Note that

$$\hat{\theta}_p'\left(r_l^p\right)=\frac{-\hat{\theta}_p\left(1-\hat{\theta}_p\right)}{\left(1+r_l^p-\kappa\right)\ln\left[\frac{\left(1-\hat{\theta}_p\right)\tilde{q}(1+r)\mu_p\bar{\pi}}{1+r_l^p-\kappa}\right]}>0$$

and

$$\hat{\theta}_s'\left(r_l^s\right)=\frac{-\hat{\theta}_s\left(1-\hat{\theta}_s\right)}{\left[1+r_l^s-(1-\delta)\,\kappa\right]\ln\left[\frac{\left(1-\hat{\theta}_s\right)\tilde{q}(1+r)\mu_s\bar{\pi}}{1+r_l^s-\kappa}\right]}>0.$$

If we denote the aggregate deposit supply at interest rate r_d and number of banks n as $\bar{D}(n)$, then the deposit supply of each bank is $D_t(n) = \bar{D}_t/n$.

In the loan market, banks compete for lending to firms in a Bertrand-Edgeworth game, where the bank compete with each other in loan rates (the price) and loan amounts (the quantity). The timing of the game is as follows. At the beginning of each period, each bank decides on the loan rates to each type of banks in each industry, and posts them to the public before the firms enter the loan market. After that, the firms that demand external financing observe the loan rates and contact the bank with lowest loan rate. Upon the contact, the bank observes the firm's ownership type and R&D efficiency, but cannot observe the firm's riskiness type θ.[36] Then the bank decides on whether to supply the loan and the amount of loan if the bank decides to supply. If the firm gets financed, it devotes all the loan into R&D and we assume there is no moral hazard problem. Otherwise, the firm exits the market and the R&D project is wasted. This gives rise to the credit rationing problem as stated in Stiglitz and Weiss (1981), where the banks use loan interest rate as a tool to select the firms, and use the loan amount as another tool to control loan allocation.

The expected return of a size-z loan to a PF given interest rate r is

$$\begin{aligned}\rho_p\left(r_l^p;\theta\right) &= \mathbb{E}\left[\min\left((1+r)\,\mu_p\bar{\pi}q+\kappa,\left(1+r_l^p\right)\right)|p,\theta\right] \\ &= \kappa+(1+r)\,\mu_p\bar{\pi}\tilde{q}-\left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu_p\bar{\pi}}{1+r_l-\kappa}\right]^{\frac{1}{\theta}}\frac{\theta\left(1+r_l^p-\kappa\right)}{1-\theta},\end{aligned} \tag{17}$$

and the average return of one unit of loan to PFs given interest rate r_l^p is

$$\bar{\rho}_p\left(r_l^p\right) = \frac{\int_{\hat{\theta}_p\left(r_l^p\right)}^1 \rho_p\left(r_l^p;\theta\right)h(\theta)\,d\theta}{1-H\left(\hat{\theta}_p\left(r_l^p\right)\right)}. \tag{18}$$

Lemma 1. *Under reasonable assumptions of the shape of $H(\cdot)$, there is a global maximum for $\bar{\rho}_p\left(r_l^p\right)$ such that $\bar{\rho}_p'\left(r_l^p\right)=0$.*

Proof. See math appendix. □

We denote the solution of maximizing $\bar{\rho}_p\left(r_l^p\right)$ as r_l^{p*}. This lemma captures the adverse-selection effect in Stiglitz and Weiss (1981). Equation (17) shows that the expected return on a loan to a bank is decreasing in the riskiness of the loan, and this gives rise to a negative adverse-selection effect on the average return rate $\bar{\rho}_p\left(r_l^p\right)$ by raising the loan rate r_l^p. Lemma 1 implies that the adverse-selection effect is strong enough in the PF loan market such that there exists a loan rate that maximizes the average return of a unit loan. As a consequence, there exists credit rationing in the PF loan market, where some PFs are screened out of the loan market by loan interest rate, and supply of bank loans may not meet the total loan demand of the PFs that are not screened out.

For SOFs, recall that with probability δ the loan repayment can be subsidized by a third party were the innovation projects fail, hence the unit return functions are:

$$\begin{aligned}\rho_s\left(r_l^s;\theta\right) = \kappa+\delta\left(1+r_l^s-\kappa\right)+(1-\delta)\,(1+r)\,\mu\bar{\pi}\tilde{q} \\ -(1-\delta)\left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu\bar{\pi}}{1+r_l-(1-\delta)\,\kappa}\right]^{\frac{1}{\theta}}\left[\frac{\theta\left(1+r_l^s-\kappa\right)+\delta\kappa}{1-\theta}\right].\end{aligned} \tag{19}$$

Similarly, the average return of one unit of loan to SOFs is:

$$\bar{\rho}_s\left(r_l^s\right) = \frac{\int_{\hat{\theta}_s\left(r_l^s\right)}^1 \rho_s\left(r_l^s;\theta\right)h(\theta)\,d\theta}{1-H\left(\hat{\theta}_s\left(r_l^s\right)\right)},$$

Lemma 2. *When δ approximates 1, $\bar{\rho}_s\left(r_l^s\right)$ is strictly increasing in r_l^s.*

Proof. See math appendix. □

[36] That is, the banks can only observe the institutional type and the mean return of a firm's R&D project, but cannot distinguish the riskiness. Since the mean returns of all projects are same, the assumption of distinguishing mean returns is quite trivial.

The implication of this Lemma is that the credit rationing problem does not exist in SOFs as long as the third party's guarantee on default subsidy is sufficiently strong. Therefore, the banks are willing to lend at an interest rate as high as possible given the market is clear. Hence, given the loan interest rate $r_l^o(i)$ for any o and i, a bank chooses loan allocation to solve following problem:

$$\begin{aligned}\max_{l_o(i)} \pi^b =\ & R_s + R_p + \rho_r \left(D(n) - L_s - L_p\right)(n) \\ & - C_s - C_p - \frac{\chi_r}{2}\left(\frac{D(n) - L_s - L_p}{\bar{Q}}\right)^2 \bar{Q} - (1+r) D, \\ \text{s.t.} \quad & L_s + L_p \le D(n) \\ & l_o(i) \le \bar{z} Q(i)\end{aligned} \tag{20}$$

where we define

$$\begin{aligned} R_o &\equiv \int_0^1 \lambda_o \left[1 - H\left(\hat{\theta}_o\left(r_l^o(i)\right)\right)\right] \bar{\rho}_o\left(r_l^o(i)\right) l_o(i)\, di \\ L_o &\equiv \int_0^1 \lambda_o \left[1 - H\left(\hat{\theta}_o\left(r_l^o(i)\right)\right)\right] l_o(i)\, di \\ C_o &\equiv \frac{\chi_o}{2}\left(\frac{L_o}{\bar{Q}}\right)^2 \bar{Q}\end{aligned}$$

for $o \in \{p, s\}$. FOC with respect to $l_o(i)$ is

$$\left[\bar{\rho}_o\left(r_l^o(i)\right) - \rho_r\right]\bar{Q} + \chi_r\left[D(n) - L_s - L_p\right] = \chi_o L_o. \tag{21}$$

This implies that in equilibrium the loan rate across industries should be same, i.e. $r_l^o(i) = r_l^o$. Given lending rates, the optimal choice of loan supply of an individual bank is

$$D(n) - L_s - L_p = \frac{\chi_s\chi_p D(n) - \left[\chi_p\bar{\rho}_s\left(r_l^s\right) + \chi_s\bar{\rho}_p\left(r_l^p\right) - \left(\chi_p + \chi_s\right)\rho_r\right]\bar{Q}}{\chi_s\chi_p + \chi_r\chi_s + \chi_r\chi_p}, \tag{22}$$

$$L_s = \frac{\chi_p\chi_r D(n) + \left[\left(\chi_p + \chi_r\right)\bar{\rho}_s\left(r_l^s\right) - \chi_p\rho_r - \chi_r\bar{\rho}_p\left(r_l^p\right)\right]\bar{Q}}{\chi_s\chi_p + \chi_r\chi_s + \chi_r\chi_p}, \tag{23}$$

$$L_p = \frac{\chi_s\chi_r D(n) + \left[\left(\chi_s + \chi_r\right)\bar{\rho}_p\left(r_l^p\right) - \chi_s\rho_r - \chi_r\bar{\rho}_s\left(r_l^s\right)\right]\bar{Q}}{\chi_s\chi_p + \chi_r\chi_s + \chi_r\chi_p}. \tag{24}$$

5.2 Equilibrium

In this subsection we focus on characterizing the pure-strategy Nash equilibrium of this model. We consider a specific equilibrium by assuming $\lambda_s\bar{z}\bar{Q} < \bar{D} < \left(\lambda_p + \lambda_s\right)\bar{z}\bar{Q}$, which means the deposits are enough to support maximal amount of financing demand of SOFs, but not enough to support SOFs and PFs. This equilibrium characterizes the imbalance between loan supply and demand in China at present. The equilibrium is as follows. In the SOF loan market, the market equilibrium loan rate is pinned down by equating demand and supply, where each SOF that is not screened out of the market gets fully financed, and the loan supply is aggregated from equation (23). In the PF loan market, all banks choose the loan rate $r_l^{p*}$and the loan suuply is aggregated from equation (24).[37] Notice that $\bar{\rho}_s(r) > \bar{\rho}_p(r)$ for any r, banks are willing to allocate loan resources to SOFs first. The market clearing conditions in both markets are

$$nL_s = \int_0^1 \lambda_s\left[1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]\bar{z}Q(i)\, di = \lambda_s\left[1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]\bar{z}\bar{Q} \tag{25}$$

$$nL_p = \int_0^1 \lambda_p\left[1 - H\left(\hat{\theta}_p\left(r_l^p\right)\right)\right] l_p(i)\, di = \lambda_p\left[1 - H\left(\hat{\theta}_p\left(r_l^p\right)\right)\right]\int_0^1 l_p(i)\, di \tag{26}$$

[37] Notice that the distribution of loans obtained by each firm is indeterminate since the banks only care about the loan allocation between SOFs and PFs, but not the allocation among individual firms. However, as is described below, the aggregate measures of loan allocation and growth and welfare measures are independent of this distribution. Therefore, the growth path of the economy is determinate.

where $l_p(i)$ is loan to the R&D firm in industry i. In this equilibrium, the SOF market is in the Bertrand-Edgeworth equilibrium condition. Each firm that can borrow from banks are able to fully financed, and the equilibrium loan rate is determined by equating loan demand with loan supply. In the PF market, firms are not fully financed due to credit rationing, which gives an equilibrium loan rate that is independent of the number of banks. Therefore, the market clearing condition of PF market pins down the average loan size for each firm, which corresponds to the empirical intensive margin. The market clearing condition of SOF market characterizes the loan rate to SOFs r_l^s, and therefore the fraction of SOFs that have positive R&D input $1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)$. The latter is the theoretical counterpart of extensive margin in the empirical model.

5.3 Effects of bank competition

In the following analysis, we explore the effects of bank competition on financial market and the whole economy in the equilibrium described above. The discussions are divided into two parts. First, we relate the equilibrium results to the empirical findings. In the second part of our analysis, we further examine the implication of our model which enables us to discuss the welfare consequence of banking deregulation to some extent.

Loan resource allocation Using the first equilibrium condition (25), the right-hand side is decreasing in r_l^s, and the left-hand side is increasing in r_l^s and n. Hence an increase in n leads to an decrease in r_s, i.e.

$$\frac{\partial r_l^s}{\partial n} < 0, \Rightarrow \frac{\partial \lambda_s\left[1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]}{\partial n} < 0, \Rightarrow \text{ Extensive margin of SOEs increases in } n.$$

At the same time, the loan demand of an individual SOF is $\bar{z}$. So the intensive margin of SOF is always $\bar{z}$, which is independent of n.

In the second equilibrium condition, the aggregate supply of loans to PFs is increasing in n and decreasing in r_l^s. Since the equilibrium loan rate to PFs is fixed at r_l^{p*}, this equation gives the average loan size of PFs, which is $\bar{l}_p = \int_0^1 l_p(i)\, di$. This implies that an increase in n leads to an increase in $\bar{l}_p$, i.e.

$$\frac{\partial \bar{l}_p}{\partial n} > 0, \Rightarrow \text{ Intensive margin of POEs increases in } n.$$

At the same time, the extensive margin is always $\hat{\theta}\left(r_p^*\right)$, which is independent of n. As a summary, we have the following proposition.

Proposition 1. *A higher degree of bank competition will increase the extensive margin of SOFs borrowing and increase the average intensive margin of PFs borrowing. Therefore, the aggregate loan resources for R&D financing increases.*

Proof. Shown in the text. □

The intuition of the proposition above is as follows. In the SOF loan market, there is no credit rationing and banks are willing to meet all the loan demand. Therefore, the market equilibrium loan rate is determined by equating loan demand and supply. For each individual firm, the loan demand is equal to $\bar{z}Q_t(i)$ in industry i at time t as long as the project is profitable. So the aggregate loan demand only depends on the loan rate and is independent of the number of banks. For the supply side, an increase in the number of banks leads to an increase of loan supply to SOFs, as long as the unit loan return to SOFs is higher than a combination of the unit returns to the other two assets. Since the borrowing SOFs are fully financed, this implies a decrease in the equilibrium loan rate and an increase in loan allocation in SOF market that is captured by the increasing extensive margin. In the PF loan market, the loan rate is fixed at r_l^{p*} due to credit rationing, and the loan supply depends on the number of banks and the SOF loan rate. An increase in the number of banks increases aggregate loan supply to PFs through two effects. First, it directly increases the aggregate loan supply as long as the unit return to PF loans is higher than a combination of the return to the other two assets. Second, it indirectly increases loan supply to PFs by decreasing the loan rate to SOFs. The indirect effect implies the substitution between SOF loans and PF loans allocation due to bank competition.

Next we explore how the loan allocation between two groups of firms varies in response to the changes of bank competition. The loan allocation ratio is

$$\frac{L_s}{L_p} = \frac{\chi_p \chi_r D(n) + \left[(\chi_p + \chi_r)\bar{\rho}_s\left(r_l^s\right) - \chi_p \rho_r - \chi_r \bar{\rho}_p\left(r_l^p\right)\right]\bar{Q}}{\chi_s \chi_r D(n) + \left[(\chi_s + \chi_r)\bar{\rho}_p\left(r_l^p\right) - \chi_s \rho_r - \chi_r \bar{\rho}_s\left(r_l^s\right)\right]\bar{Q}}$$

The derivative with respect to n is

$$\frac{d}{dn}\left(\frac{L_s}{L_p}\right) \propto \chi_r D(n)\left[\bar{\rho}_s'\left(r_l^s\right)\frac{dr_l^s}{dn}+\frac{1}{n}\left(\bar{\rho}_s\left(r_l^s\right)-\bar{\rho}_p\left(r_l^{p*}\right)\right)\right]$$
$$+\bar{\rho}_s'\left(r_l^s\right)\frac{dr_l^s}{dn}\bar{Q}\left(\bar{\rho}_p\left(r_l^{p*}\right)-\rho_r\right)\left(\chi_s\chi_p+\chi_r\chi_s+\chi_r\chi_p\right)$$

Notice that in equilibrium $\bar{\rho}_p\left(r_l^{p*}\right) > \rho_r$ and hence the second term in the derivative is negative, it implies that the derivative is negative as long as $\frac{\chi_r}{\chi_s\chi_p+\chi_r\chi_s+\chi_r\chi_p}$ is close to 0. This implies the following proposition:

Proposition 2. *When $\frac{\chi_r}{\chi_s\chi_p+\chi_r\chi_s+\chi_r\chi_p}$ is close to 0, $\frac{d}{dn}\left(\frac{L_s}{L_p}\right) < 0$. That is, loan resources are more allocated to PFs.*

Proof. Notice that when $\frac{\chi_r}{\chi_s\chi_p+\chi_r\chi_s+\chi_r\chi_p}$ is close to 0, the term $\bar{\rho}_s'\left(r_l^s\right)\frac{dr_l^s}{dn}\bar{Q}\left(\bar{\rho}_p\left(r_l^{p*}\right)-\rho_r\right)$ dominates in $\frac{d}{dn}\left(\frac{L_s}{L_p}\right)$. Since $\bar{\rho}_s'\left(r_l^s\right)\frac{dr_l^s}{dn} < 0$ and $\bar{\rho}_p\left(r_l^{p*}\right) > \rho_r$, it implies that $\frac{d}{dn}\left(\frac{L_s}{L_p}\right) < 0$. □

This proposition states that bank competition drives more loan resources allocated to PFs when the cost of managing bank reserves is small compared to the other two assets. This implies the indirect effect should dominate in this case.

Risk taking We consider the effects of bank competition on bank risk taking. The probability of a loan default for a type-o firm is

$$Prob^{default} = F\left(\frac{1+r_l^o-\kappa}{(1+r)\mu_o\bar{v}},\theta\right) \tag{27}$$

Therefore, the share of default loans in total loans, which is the non-performance share, is defined as:

$$\text{Non-performance share} = \frac{L_s}{L_s+L_p}\frac{(1-\delta)\int_{\hat{\theta}_s\left(r_l^s\right)}^1 F\left(\frac{1+r_l^s-\kappa}{(1+r)\mu_s\bar{\pi}},\theta\right)h(\theta)\,d\theta}{1-H\left(\hat{\theta}_s\left(r_l^s\right)\right)}$$
$$+\frac{L_p}{L_s+L_p}\frac{\int_{\hat{\theta}_p\left(r_l^{p*}\right)}^1 F\left(\frac{1+r_l^{p*}-\kappa}{(1+r)\mu_p\bar{\pi}},\theta\right)h(\theta)\,d\theta}{1-H\left(\hat{\theta}_p\left(r_l^{p*}\right)\right)} \tag{28}$$

Proposition 3. *When δ is large enough and $\frac{\chi_r}{\chi_s\chi_p+\chi_r\chi_s+\chi_r\chi_p}$ is close to 0, a higher degree of bank competition drives banks to take more risks.*

Proof. As shown in equation (28), Proposition 2 implies that the second term on the right-hand side is increasing in the number of banks. If $\delta = 1$, there is no default of SOF loans and the non-performance share is just equal to the second term of (28) and is increasing in n. Therefore, as long as δ is large enough (close to 1), the non-performance share is increasing in the degree of bank competition. □

This proposition implies that the government support for SOF borrowing can lead to a higher default rate of bank loans under stronger bank competition. When the number of banks increases, the share of PF loans increases. Since the default risk is higher in PF loans, this leads to an increase in the total non-performance loan share. Although the default probability of a SOF loan is decreasing in the number of banks, this is still dominated by the former effect due to δ close to 1.

5.3.1 Growth, welfare and misallocation

In this section we study the growth and welfare effects of bank competition and explore possible misallocation effects. The law of motion of the aggregate quality level $\bar{Q}_t$ is

$$\bar{Q}_{t+1} = \left\{\lambda_s\left[1-H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]\mu_s\tilde{q}\tilde{z}\bar{Q}_t+\mu_p\tilde{q}nL_{p,t}\right\}$$
$$+\left\{1-\lambda_s\left[1-H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]-\lambda_p\left[1-H\left(\hat{\theta}_p\left(r_l^{p*}\right)\right)\right]\right\}\bar{Q}_t.$$

Since the quality improvement is the unique source of growth, the balanced growth rate of the economy is

$$g = \frac{\bar{Q}_{t+1}-\bar{Q}_t}{\bar{Q}_t} = \lambda_s\left[1-H\left(\hat{\theta}_s\left(r_l^s\right)\right)\right]\left(\mu_s\tilde{q}\tilde{z}-1\right)+\mu_p\tilde{q}\frac{nL_p}{\bar{Q}}-\lambda_p\left[1-H\left(\hat{\theta}_p\left(r_l^{p*}\right)\right)\right]. \tag{29}$$

By Proposition 4, r_l^s is decreasing in n and nL_p is increasing in n, we have the following proposition.

Proposition 4. *Growth rate is increasing in bank competition.*

Proof. Shown in the text. □

Intuitively, bank competition increases the extensive margin of SOF loan and intensive margin of PF loan, and both of them increases the R&D input into firms. Therefore, the economic growth rate is monotonically increasing in bank competition.

Next we explore the welfare effects of bank competition on three groups of agents. Suppose the social planner discounts the payoffs of agents at an exogenous rate $\tilde{\beta}$. Since the wealth of old generation in period 0 is exogenously given, we ignore the welfare of this group of workers and focus on all the other generations. Therefore, the welfare of workers along balanced growth path is

$$\begin{aligned} S^W &= \frac{\left(c_0^y\right)^{1-\gamma} - 1}{1-\gamma} L + \sum_{t=1}^{\infty} \tilde{\beta}^t \left[\frac{\left(c_t^y\right)^{1-\gamma} - 1}{1-\gamma} + \frac{\left(c_t^o\right)^{1-\gamma} - 1}{1-\gamma} \right] L \\ &= \frac{\left(c_0^y\right)^{1-\gamma} L}{(1-\gamma)\left[1 - \tilde{\beta}(1+g)\right]} + \frac{\tilde{\beta}\left(c_1^o\right)^{1-\gamma} L}{(1-\gamma)\left[1 - \tilde{\beta}(1+g)\right]} - \frac{\left(1+\tilde{\beta}\right) L}{(1-\gamma)\left(1-\tilde{\beta}\right)}, \end{aligned}$$

where

$$\begin{aligned} c_0^y &= \frac{(1-\alpha)(\alpha/\eta)^{\alpha/(1-\alpha)}}{1 + \beta^{1/\gamma}(1+r)^{1/\gamma - 1}}, \\ c_1^o &= \frac{(1+r)(1-\alpha)(\alpha/\eta)^{\alpha/(1-\alpha)}}{1 + \beta^{-1/\gamma}(1+r)^{1-1/\gamma}}. \end{aligned}$$

Notice that in the expression of the worker's welfare, only the growth rate g depends on bank competition. Since the worker's welfare is increasing in growth rate, we obtain that it is also increasing in the number of bank competition. Second, the aggregate profit of firms is

$$\begin{aligned} S^{SOF} &= \int_{\hat{\theta}_s\left(r_l^s\right)}^{\bar{\theta}} \pi_s\left(r_l^s;\theta\right) h(\theta)\, d\theta \cdot \lambda_s \bar{z} \bar{Q} \\ S^{PF} &= \int_{\hat{\theta}_p\left(r_l^{p*}\right)}^{\bar{\theta}} \pi_p\left(r_l^{p*};\theta\right) h(\theta)\, d\theta \cdot \lambda_p \int_0^1 l_p(i)\, di \\ &= \int_{\hat{\theta}_p\left(r_l^{p*}\right)}^{\bar{\theta}} \pi_p\left(r_l^{p*};\theta\right) h(\theta)\, d\theta \cdot \frac{nL_p}{1 - H\left(\hat{\theta}_p\left(r_l^{p*}\right)\right)}. \end{aligned}$$

Since $\pi_s\left(r_l^s;\theta\right)$ is increasing in r_l^s, r_l^s is decreasing in n, and nL_p is increasing in n, we can get that the aggregate profits to both groups of firms are increasing in the degree of bank competition. Third, the aggregate profits of banks is defined as

$$\begin{aligned} S^B = n\pi_b &= \left(\bar{\rho}_s\left(r_l^s\right) - \rho_r\right) nL_s + \left(\bar{\rho}_p\left(r_l^p\right) - \rho_r\right) nL_p + \left(\rho_r - 1 - r\right)\bar{D} \\ &\quad - \frac{n\chi_s}{2}\left(\frac{L_s}{\bar{Q}}\right)^2 \bar{Q} - \frac{n\chi_s}{2}\left(\frac{L_s}{\bar{Q}}\right)^2 \bar{Q} - \frac{n\chi_r}{2}\left(\frac{D(n) - L_s - L_p}{\bar{Q}}\right)^2 \bar{Q}. \end{aligned}$$

Since $\partial S^B/\partial n = \pi_b - (\rho_r - 1 - r) D(n) + \chi_r D(n)\left(D(n) - L_s - L_p\right)/\bar{Q} > 0$ and $\partial S^B/\partial r_l^s > 0$, the effect of bank competition on bank profits is indeterminate. As will be shown in the numerical analysis, this effect depends on parameters. Therefore, as a summary, we have the following proposition.

Proposition 5. *An increase in the degree of bank competition will increase aggregate welfare of workers and aggregate profits of firms, while the effect on bank profits is indeterminate.*

Proof. Shown in the text. □

Intuitively, an increase in the degree of bank competition will increase economic growth rate and allocate more loan resources to both SOFs and PFs. The former effect will increase workers' welfare by raising the growth rate of wages, and the latter effect will increase firms' profits by increasing the size of R&D inputs. However, the effect of bank competition on banks' profits is indeterminate. First, the expansion of loan supply under stronger bank competition increases banks' profits through scale effect. Second, an increase in bank competition lowers the unit return of SOF loans, which has a negative effect on banks' profits. Therefore, the aggregate effect on banks' profits depends on which effect dominates.

6 Numerical Analysis

Comparative statics In this section, we numerically solve the model and conduct counterfactual analysis. The choice of parameters are as follows. The distribution of θ is a truncated normal on $[0.1, 0.9]$ where the original normal distribution is $\mathcal{N}(0.35, 0.01)$. For the parameters of R&D function, notice that $\tilde{q}$ and μ cannot be identified separately, so we normalize $\mu_p = 1$ and choose $\tilde{q} = 37.6$, and $\mu_s = 0.8$ assuming SOFs are less efficient in R&D. For the production parameters, we choose $\alpha = 0.3$ to match the share of labor income equal to $1 - \alpha = 0.7$. Moreover, we choose the markup $\eta = 1.2$, which is close to the average markup of Chinese firms estimated by Lu and Yu (2015). We assume symmetry between SOFs and PFs in the arrival rate of R&D projects and collateral ratio, where we choose $\lambda_p = \lambda_s = 0.1$ and $\kappa_p = \kappa_s = 0.3$. We assume the support of government for SOFs is strong and choose $\delta = 0.9$. For banks' payoff function, we choose $\chi_s = \chi_p = 200$, $\chi_r = 1$, the return rate of reserve balances is normalized to $\rho_r = 1$, and the deposit rate is $r = 1\%$. For the other parameters, we choose $\beta = \tilde{\beta} = 0.95$, $\gamma = 2$, $\bar{z} = 0.07$. We set the initial number of banks as $n = 10$. Given these parameters, the calibrated extensive margin of SOFs is 9.02%, the relative intensive margin of PFs to SOFs is 0.3878, the economic growth rate is 10.13%, the equilibrium loan rate to PFs is 4.8%, the equilibrium loan rate to SOFs is 13.42%.

Figure 1 below plots the comparative statics of bank competition in the baseline case. In each panel, the horizontal line is the number of banks and it takes values from 10 to 30. As is shown in the figure, the SOF loan rate is decreasing in n while the PF loan rate is fixed. The loans per bank to two groups of firms are both decreasing in n and the aggregate loans to two groups of firms are increasing in n. Moreover, the loan ratio of SOF to PF decreases from 3.14 to 1.58. For the margins, the extensive margin of SOFs increases from 0.0902 to 0.0938, while the extensive margin of PFs keeps fixed at 0.0741. The ratio of PFs' intensive margin to SOFs' intensive margin increases from 0.3878 to 0.8006. In addition, the aggregate non-performance loan share increases from 12.85% to 15.77%, and the non-performance loan share of SOFs decreases from 7.10% to 6.19%. For unit loan return, the return to SOFs loan decreases from 1.1076 to 1.0376, while the return to PFs is fixed at 1.0215.

Insert Figure 6 here

Counterfactual analysis Next we conduct counterfactual analysis to explore how the existence of government support for SOFs' loan default can affect the effects of bank competition. Notice that under our choice of parameters, SOFs are less efficient in R&D activities. However, due to the support from government, the SOFs are still fully financed if they can borrow from banks and the extensive margin of SOFs is higher than PFs. Therefore, the main loss of loan misallocation is generated by the government support for SOFs' loan default. Therefore, we conduct a counterfactual analysis by eliminating the government support, i.e. setting $\delta = 0$. In this case, SOFs and PFs are identical except that SOFs are less efficient in R&D than PFs. Therefore, for banks, the unit return of SOFs loans is strictly lower than that of PFs. Then the banks are willing to allocate all loan resources to PFs while nothing to SOFs.[38] As shown in Figure 2, the removal of loan guarantee leads to more loans provided to PFs relative to SOFs when bank competition intensifies. Moreover, although the qualitative welfare effect on workers is the same as the baseline case, the change of welfare is more sensitive to the banking deregulation in the counterfactual analysis. However, in the counterfactual case, banks' aggregate profits decrease in n while that in the baseline case increases in n. This is consistent with the conclusion in Proposition 5.

Insert Figure 7 here

7 Conclusion

This paper investigates the effect of bank competition on different margins of innovation and how the effect is dependent on the ownership structure of the firms by providing empirical evidence and a theoretical explana-

[38]We obtain this from numerical solution.

tion. We utilize the firm-level data set and city-level bank branching data from China and empirically analyze the relationship between banking competition and different margins of innovation. The econometric estimation shows: first, for the extensive margin of innovation, intensified bank competition has a positive impact on the probability of investing in R&D of State-Owned Firms (SOFs), but not Private Firms (PFs); second, for the intensive margin of innovation, increased banking competition only enhances the level of investment in R&D of PFs. These results are new to related literature. To explain the empirical findings, we build a model that generates predictions consistent with our empirical results. The model relies on the assumptions that: SOFs are less likely to default; asymmetric information on the riskiness of R&D exists between firms and banks; banks compete with each other in a Bertrand-Edgeworth game in the loan market. Overall, our results show that the institutional setting is important in shaping the effect of banking competition on innovation at different margins. In this sense, studies focusing only on the average effect of banking competition on innovation may have failed to account for the rich responses of innovation investment by firms.

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Math Appendix

Derivation of $\pi_p\left(r_l^p;\, i,\, \theta\right)$:

$$\begin{aligned}
\pi_p\left(r_l^p; i, \theta\right) &= \mathbb{E}\left[\max\left((1+r)\,\mu_p \bar{\pi} q - \left(1+r_l^p\right), -\kappa\right) | i, p, \theta\right] \\
&= \int_{q \geq \frac{1+r_l^p-\kappa}{(1+r)\mu_p\bar{\pi}}} \left[(1+r)\,\mu_p \bar{\pi} q - \left(1+r_l^p\right)\right] dF\left(q,\theta\right) - \int_{q < \frac{1+r_l^p-\kappa}{(1+r)\mu_p\bar{\pi}}} \kappa dF\left(q,\theta\right) \\
&= (1+r)\,\mu_p \bar{\pi} \int_{q \geq \frac{1+r_l^p-\kappa}{(1+r)\mu_p\bar{\pi}}} q dF\left(q,\theta\right) - \left(1+r_l^p\right)\left[1 - F\left(\frac{1+r_l^p-\kappa}{(1+r)\,\mu_p\bar{\pi}}, \theta\right)\right] - \kappa F\left(\frac{1+r_l^p-\kappa}{(1+r)\,\mu_p\bar{\pi}}, \theta\right) \\
&= \left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu_p\bar{\pi}}{1+r_l^p-\kappa}\right]^{\frac{1}{\theta}} \frac{\theta\left(1+r_l^p-\kappa\right)}{1-\theta} - \kappa
\end{aligned}$$

Derivation of $\pi_s\left(r_l^s;\, i,\, \theta\right)$: The first-order condition with respect to $\hat{q}$ implies

$$-\,(1+r)\,\mu_s\bar{\pi}\hat{q} + 1 + r_l^s - (1-\delta)\,\kappa = 0.$$

This gives $\hat{q}\left(r_l^s; i, \theta\right) = \frac{1+r_l^s-(1-\delta)\kappa}{(1+r)\mu_s\bar{\pi}}$. Therefore, the profit function is

$$\begin{aligned}
\pi_s\left(r_l^s; i, \theta\right) &= \int_{\hat{q}\left(r_l^s; i,\theta\right)}^{\infty} \left[(1+r)\,\mu_s\bar{\pi}q - \left(1+r_l^s\right)\right] dF\left(q,\theta\right) - \int_{(1-\theta)\tilde{q}}^{\hat{q}\left(r_l^s;i,\theta\right)} (1-\delta)\,\kappa dF\left(q,\theta\right) \\
&= (1+r)\,\mu_s\bar{\pi}\int_{\hat{q}\left(r_l^s;i,\theta\right)}^{\infty} q dF\left(q,\theta\right) - \left(1+r_l^s\right)\left[1 - F\left(\hat{q}\left(r_l^s; i,\theta\right),\theta\right)\right] - (1-\delta)\,\kappa F\left(\hat{q}\left(r_l^s;i,\theta\right),\theta\right) \\
&= \left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu_s\bar{\pi}}{1+r_l^s-(1-\delta)\,\kappa}\right]^{\frac{1}{\theta}} \frac{\theta\left[1+r_l^s-(1-\delta)\,\kappa\right]}{1-\theta} - (1-\delta)\,\kappa.
\end{aligned}$$

Derivation of $\rho_p\left(r_l^p;\, \theta\right)$:

$$\begin{aligned}
\rho_p\left(r_l^p; \theta\right) &= \mathbb{E}\left[\min\left((1+r)\,\mu_p\bar{\pi}q + \kappa, \left(1+r_l^p\right)\right) | p, \theta\right] \\
&= \int_{\frac{1+r_l-\kappa}{(1+r)\mu_p\bar{\pi}}}^{\bar{q}} \left(1+r_l^p\right) dF\left(q,\theta\right) + \int_{\underline{q}}^{\frac{1+r_l-\kappa}{(1+r)\mu_p\bar{\pi}}} \left[(1+r)\,\mu_p\bar{\pi}q + \kappa\right] dF\left(q,\theta\right) \\
&= \kappa + (1+r)\,\mu_p\bar{\pi}\tilde{q} - \left[\frac{(1-\theta)\,\tilde{q}\,(1+r)\,\mu_p\bar{\pi}}{1+r_l-\kappa}\right]^{\frac{1}{\theta}} \frac{\theta\left(1+r_l^p-\kappa\right)}{1-\theta}
\end{aligned}$$

Proof of Lemma 1:

Proof. The first-order differentiation with respect to r_l^p is

$$\bar{\rho}_p'\left(r_l^p\right) = \frac{\int_{\hat{\theta}_p\left(r_l^p\right)}^1 \left[1 - F\left(\frac{1+r_l^p-\kappa}{(1+r)\mu_p\bar{\pi}}, \theta\right)\right] h(\theta)\, d\theta}{1 - H\left(\hat{\theta}_p\left(r_l^p\right)\right)}$$
$$- \frac{\hat{\theta}'\left(r_l^p\right) h\left(\hat{\theta}_p\left(r_l^p\right)\right)}{1 - H\left(\hat{\theta}_p\left(r_l^p\right)\right)} \left[\hat{\rho}_p\left(r_l^p\right) - \bar{\rho}_p\left(r_l^p\right)\right],$$

where $\hat{\rho}_p\left(r_l^p\right) = \rho_p\left(r_l^p; \hat{\theta}_p\left(r_l^p\right)\right)$. The concavity of $\min\left((1+r)\mu_p\bar{\pi}q + \kappa, \left(1 + r_l^p\right)\right)$ in terms of q implies that $\rho_p\left(r_l^p; \theta\right)$ is decreasing in riskiness θ. Therefore, under reasonable assumptions,[39] we can find a global maximum of $\bar{\rho}_p\left(r_l^p\right)$ by setting $\bar{\rho}_p'\left(r_l^p\right) = 0$. □

Derivation of $\rho_s\left(r_l^s; \theta\right)$:

$$\begin{aligned}
\rho_s\left(r_l^s; \theta\right) &= \int_{\hat{q}\left(r_l^s;\theta\right)}^{\infty} \left(1 + r_l^s\right) dF(q,\theta) + \int_{q_m}^{\hat{q}\left(r_l^s;i,\theta\right)} \delta\left(1 + r_l^s\right) dF(q,\theta) \\
&\quad + \int_{q_m}^{\hat{q}\left(r_l^s;i,\theta\right)} (1-\delta)\left[(1+r)\mu\bar{\pi}q + \kappa\right] dF(q,\theta) \\
&= \kappa + \delta\left(1 + r_l^s - \kappa\right) + (1-\delta)(1+r)\mu\bar{\pi}\tilde{q} \\
&\quad - (1-\delta)\left[\frac{(1-\theta)\tilde{q}(1+r)\mu\bar{\pi}}{1 + r_l - (1-\delta)\kappa}\right]^{\frac{1}{\theta}} \left[\frac{\theta\left(1 + r_l^s - \kappa\right) + \delta\kappa}{1-\theta}\right].
\end{aligned}$$

Proof of Lemma 2:

Proof. The first-order derivative of $\bar{\rho}_s\left(r_l^s\right)$ with respect to r_l^s is

$$\begin{aligned}
\bar{\rho}_s'\left(r_l^s\right) &= \frac{\int_{\hat{\theta}_s\left(r_l^s\right)}^1 \left[1 - (1-\delta) F\left(\frac{1+r_l^s-\kappa}{(1+r)\mu\bar{\pi}}, \theta\right)\right] h(\theta)\, d\theta}{1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)} \\
&\quad - \frac{\hat{\theta}_s'\left(r_l^s\right) h\left(\hat{\theta}_s\left(r_l^s\right)\right)}{1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)} \left[\hat{\rho}_s\left(r_l^s\right) - \bar{\rho}_s\left(r_l^s\right)\right] \\
&= \frac{\int_{\hat{\theta}_s\left(r_l^s\right)}^1 \left[1 - (1-\delta) F\left(\frac{1+r_l^s-(1-\delta)\kappa}{(1+r)\mu\bar{\pi}}, \theta\right)\right] h(\theta)\, d\theta}{1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)} \\
&\quad - \frac{(1-\delta)\hat{\theta}_s'\left(r_l^s\right) h\left(\hat{\theta}_s\left(r_l^s\right)\right)}{1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)} \frac{\int_{\hat{\theta}_s\left(r_l^s\right)}^1 \left\{\left[\frac{(1-\theta)\tilde{q}(1+r)\mu\bar{\pi}}{1+r_l-(1-\delta)\kappa}\right]^{\frac{1}{\theta}} \frac{\theta\left[1+r_l^s-(1-\delta)\kappa\right]}{1-\theta} - (1-\delta)\kappa\right\} h(\theta)\, d\theta}{1 - H\left(\hat{\theta}_s\left(r_l^s\right)\right)}
\end{aligned}$$

□

Notice that the term in the last line is proportional to $(1-\delta)$ and is bounded, then as long as δ is sufficiently close to 1, we have $\bar{\rho}_s'(r) > 0$.[40]

[39] We do not impose a theoretical assumption here, since it depends on the function H and h. However, in the quantitative analysis, we show that such global maximum does exist under some parameters.

[40] We can assume that the range of r_l^s is finite by imposing an upper bound of $\bar{r}_l^s$. This is guaranteed as long as the project output R has a finite upper bound.

Tables and Figures

4 Data and Preliminary Evidence

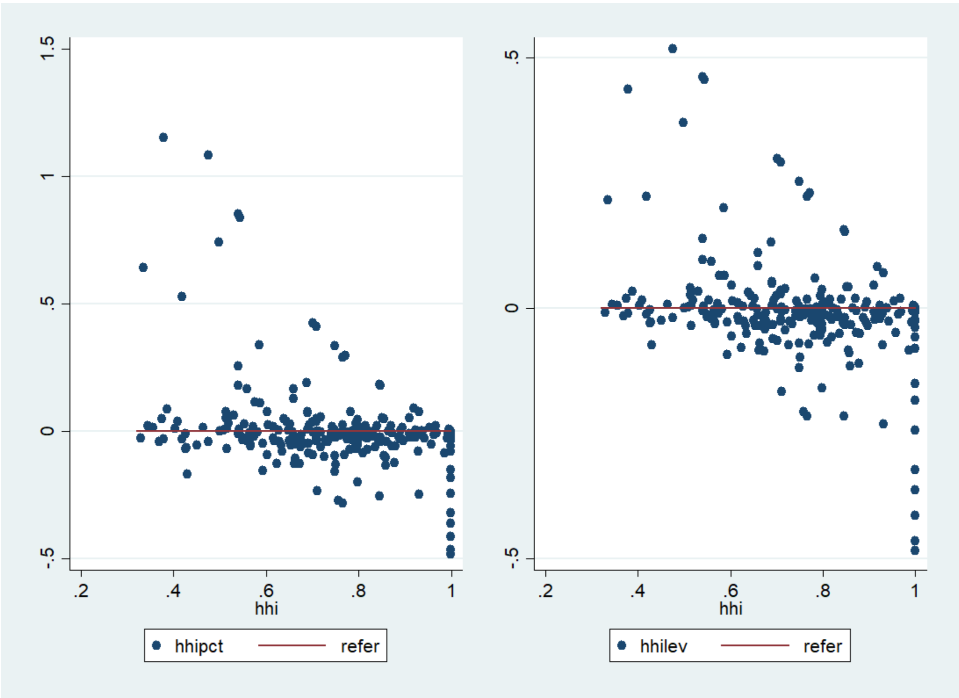
4.2 Variables and summary statistics

Table 1: Summary statistics of bank HHI and CR5

variables	HHI_{ct}				$CR5_{ct}$			
year	mean	min	max	p50	mean	min	max	p50
2006	.682	.330	1	.685	.799	.496	1	.820
2007	.683	.321	1	.696	.800	.430	1	.814
Total	.683	.321	1	.685	.799	.430	1	.820

Figure 1: Change in the HHI of banking between 2006 and 2007

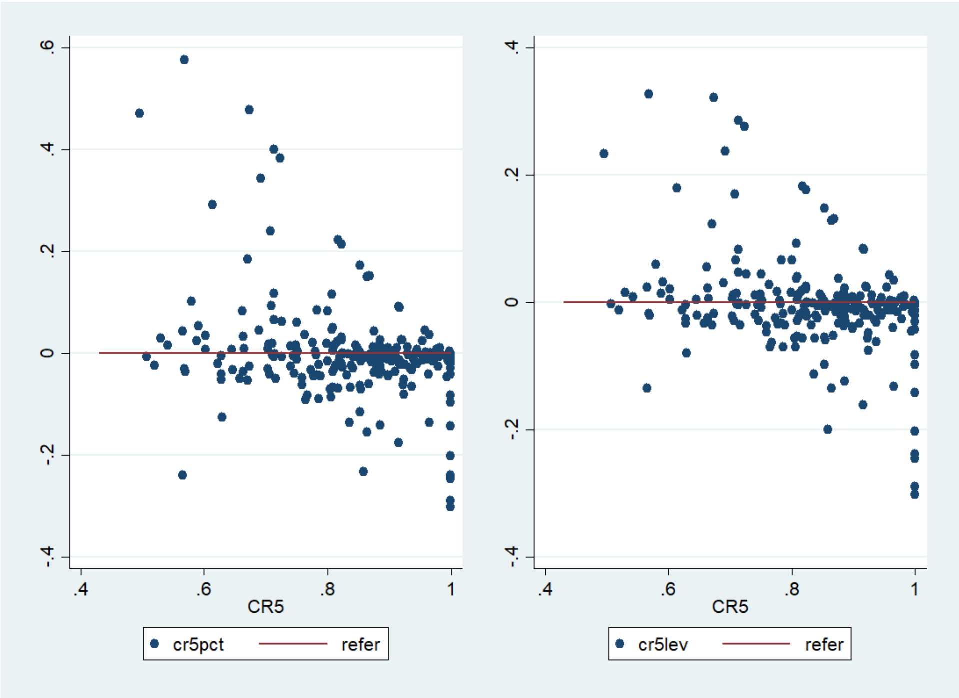
Panel A: percentage change in HHI_{ct} Panel B: absolute change in HHI_{ct}



Note: the reference line is $HHI_{2007} - HHI_{2006} = 0$.

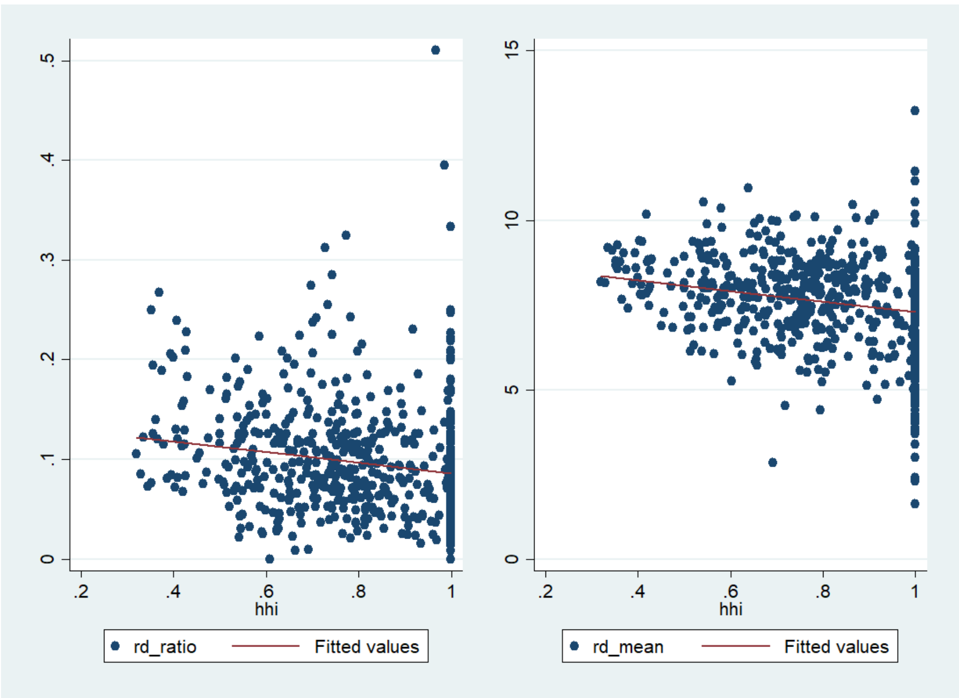
4.3 Correlation between banking competition and innovation

Figure 2: Change in Percentage and Level of $CR5$



Note: the reference line is $CR5_{2007} - CR5_{2006} = 0$. The percentage change is computed using $(CR5_{2007} - CR5_{2006})/CR5_{2006}$ while the level change is $CR5_{2007} - CR5_{2006}$.

Figure 3: Simple correlation between banking competition and R&D activities



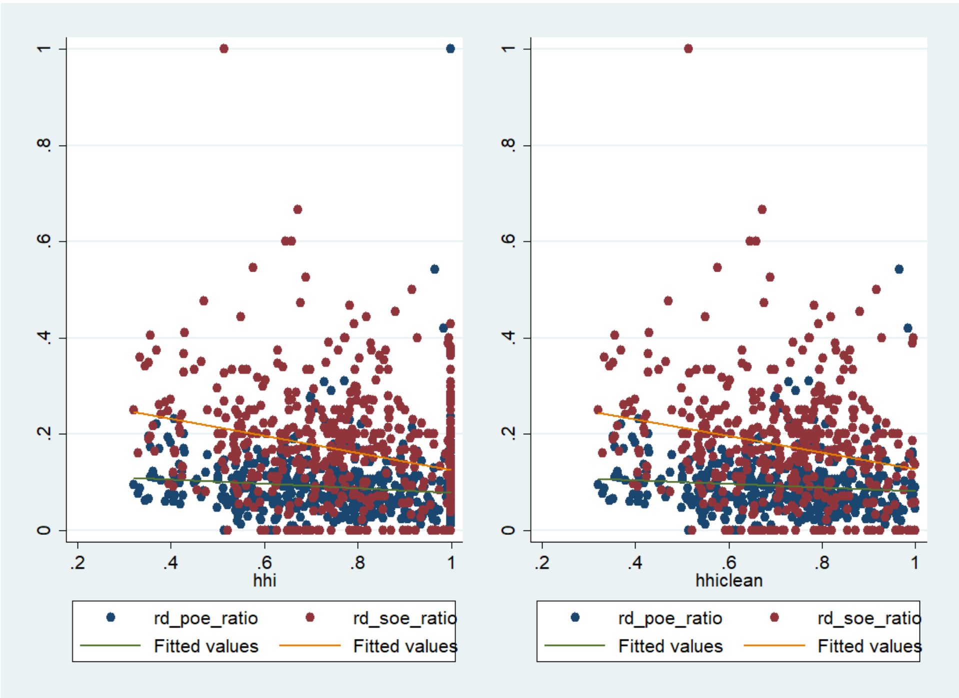
Note: Pr(rd > 0) is probability of investing in R&D; mean(rd > 0) is the mean of R&D spending conditional on firms have positive investment in R&D.

Table 2: Extensive and intensive margins of R&D by ownership

Margins	Extensive margin: $Pr(rdd_{it} = 1)$		Intensive margin: $mean(rd_{it} \vert rdd_{it} > 0)$	
Firm Type	SOFs	PFs	SOFs	PFs
2006	.182	.093	11379.95	2337.42
Obs	6363	145120	1158	13518
2007	.165	.095	14523.68	2575.99
Obs	8220	179859	1356	17147

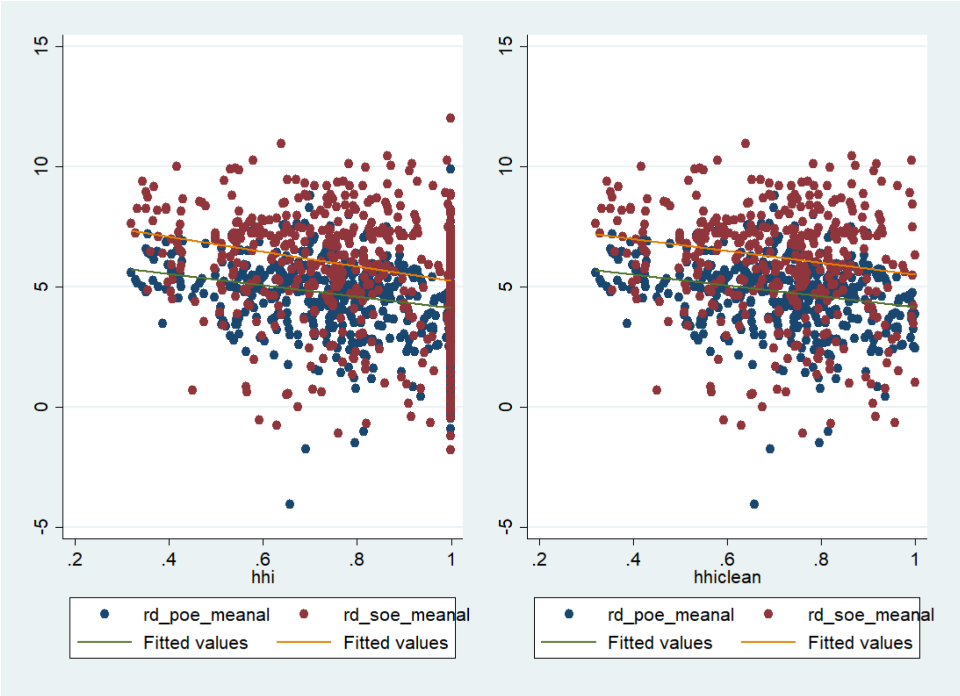
Note: Obs is the number of observations. Extensive margin is computed using all the observations; intensive margin is obtained using the observations with positive investment in R&D. The units of the intensive margin of R&D is 1000 yuan.

Figure 4: Correlation between extensive margin of R&D and HHI_{ct} by ownership



Note: rd_poe_ratio and rd_soe_ratio represent the probability of investing in R&D for private firms and state-owned firms, respectively. In the left panel, all cities are included. While only observations with $HHI_{ct} < 1$ are included in the right panel.

Figure 5: Correlation between the intensive margin of R&D and HHI_{ct} by ownership



Note: rd_poe_meanal and rd_soe_meanal represent the mean value of log of R&D for all private firms and state-owned firms that have positive investment in R&D. In the left panel, all cities are included; only observations with $HHI_{ct} < 1$ are included in the right panel.

5 Empirical Evidence

5.1 Benchmark econometric models and results

Table 3: Estimation results of Probit models

dependent variable: rdd	PROBIT MODEL (1)	(2)	(3)	(4)
HHI	-0.158		-0.0957	
	(-1.43)		(-0.86)	
HHI × PF		-0.138		-0.0749
		(-1.21)		(-0.64)
HHI × SOF		-0.438***		-0.396***
		(-4.19)		(-3.75)
PF	-0.239***	-0.470***	-0.0523***	-0.119***
	(-8.05)	(-4.86)	(-13.53)	(-4.68)
age	0.416***	0.416***	0.0766***	0.0767***
	(22.86)	(22.83)	(51.84)	(20.31)
constant	-1.502***	-1.299***	-2.978***	-2.761***
	(-12.63)	(-11.65)	(-21.54)	(-22.23)
Other Controls	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	330109	330109	328208	328208

Note: Other firm-level control variables include the subsidy the firm receives, the export intensity, and the firm's financial costs. All standard errors are clustered at city level.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Banking competition and intensive margin of R&D investment

dependent variable: rd	OLS MODEL (1)	(2)	(3)	(4)
HHI	-0.0117***		-0.0114***	
	(-3.43)		(-3.40)	
HHI × PF		-0.0123***		-0.0119***
		(-3.34)		(-3.30)
HHI × SOF		-0.00551		-0.00549
		(-1.44)		(-1.45)
PF	-0.000113	0.00446	0.000159	0.00451
	(-0.09)	(1.26)	(0.12)	(1.28)
age	-0.000810	-0.000810	-0.00108**	-0.00108**
	(-1.59)	(-1.59)	(-2.14)	(-2.14)
constant	0.0257***	0.0212***	0.0254***	0.0211***
	(5.28)	(3.45)	(5.28)	(3.45)
Other Controls	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
R^2	0.048	0.048	0.055	0.055
Observations	31560	31560	31525	31525

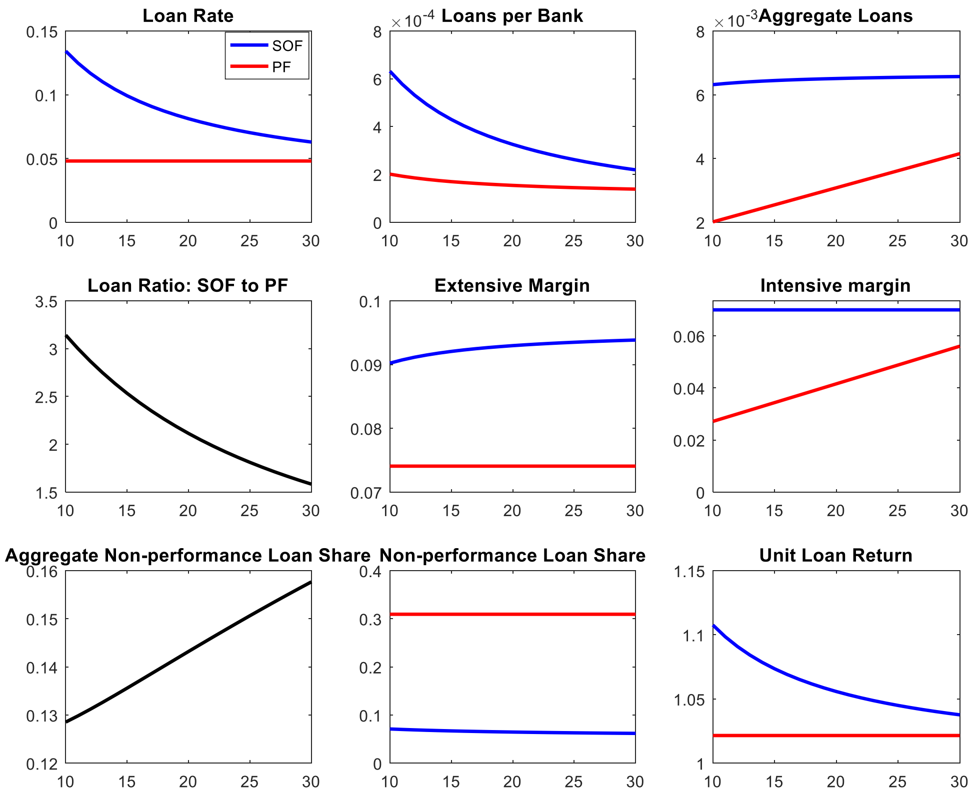
Note: the sample for the estimation is all the firms that have positive investment in R&D. All standard errors are heteroskedastic and are clustered at the city level.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

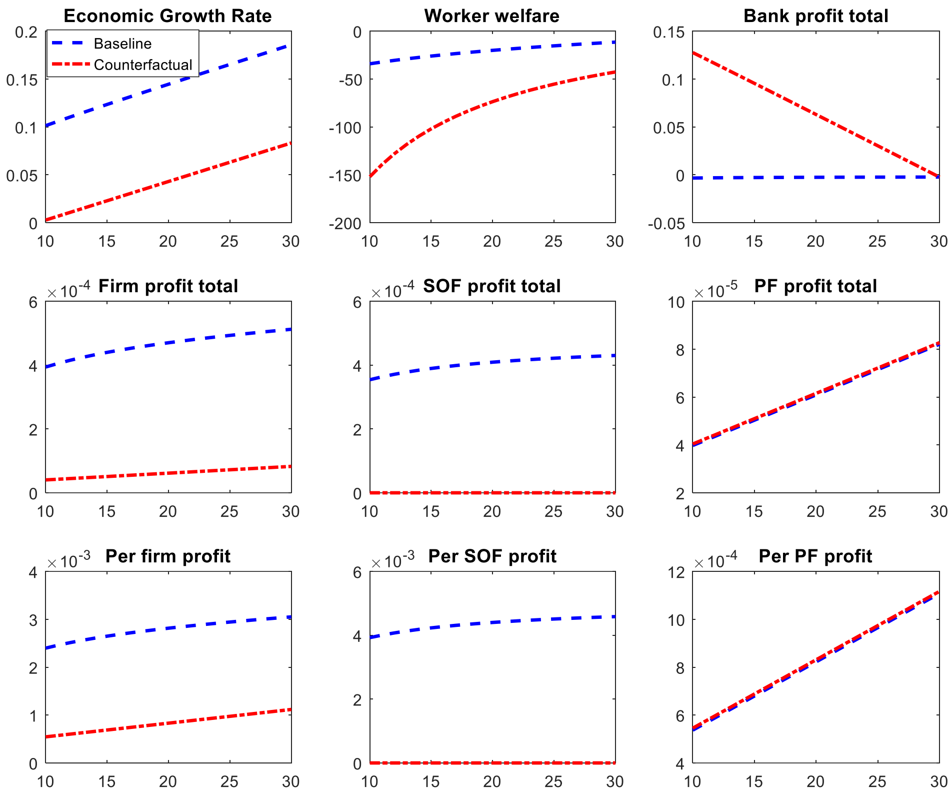
6 Numerical Analysis

Figure 6 Numerical analysis on the comparative statics of banking competition in the baseline model



Note: in all the figures, the horizontal axis is the number of banks. Choice of all parameters are presented in the main text.

Figure 7 Counterfactual analysis: removing the loan guarantee provided to SOFs



Note: in all the figures, the horizontal axis is the number of banks. Choice of all parameters are presented in the main text.

Appendix

Appendix A: Supplementary Empirical Results

In this appendix, we present the supplementary tables and figures discussed in the main text.

Table A1: Distribution of the Change of City-level HHI and Characteristics of Cities and Firms

ΔHHI	# of Cities	GDP per capita	GDP growth	export (%)	import (%)	Pr(RDD=1)	R&D
-	151	24.97	.054	.355	.187	.106	350.91
0	108	84.01	.007	.058	.036	.086	179.05
+	80	25.75	.137	.226	.153	.104	467.19

Note: ΔHHI is equal to $(HHI_{2007} - HHI_{2006})$. RDD is a dummy equal to one when a firm has positive investment in R&D and zero otherwise; $\Pr(RDD = 1)$ is the ratio of firms that have positive R&D spending to the total number of firms. Both GDP per capita and R&D are measured in 1,000 Chinese yuan (around 150 US dollars).

Table A2: Distribution of the Change of City-level CR5 and Characteristics of Cities and Firms

$\Delta CR5$	# of Cities	GDP per capita	GDP growth	export	import	Pr(RDD=1)	R&D
-	151	24.91	.054	.354	.186	.106	349.93
0	108	84.01	.007	.058	.036	.086	179.05
+	80	25.91	.138	.227	.154	.105	471.05

Note: $\Delta CR5$ is equal to $(CR5_{2007} - CR5_{2006})$. RDD is a dummy equal to one when a firm has positive investment in R&D and zero otherwise; $\Pr(RDD = 1)$ is the ratio of firms that have positive R&D spending to the total number of firms. Both GDP per capita and R&D are measured in 1,000 Chinese yuan (around 150 US dollars).

Figure A1: Correlation between HHI_{ct} and $CR5_{ct}$

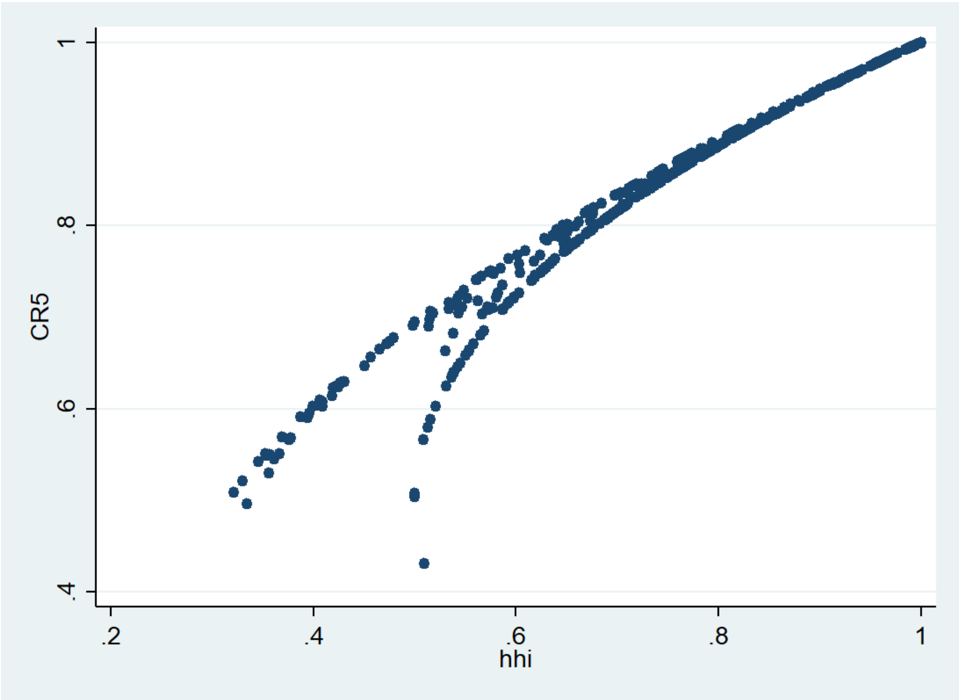


Table A3: Estimation results controlling for other firm-level information separately

variables	capital intensity		labor productivity		cash flow	
	rdd	rd	rdd	rd	rdd	rd
HHI × PF	-0.0642	-0.0117^{***}	-0.0206	-0.0117^{***}	-0.0285	-1.325^{***}
	(-0.53)	(-3.12)	(-0.17)	(-3.17)	(-0.22)	(-3.95)
HHI × SOF	-0.311^{***}	-0.00392	-0.349^{***}	-0.00468	-0.316^{***}	-0.364
	(-2.86)	(-0.94)	(-3.05)	(-1.08)	(-2.75)	(-0.85)
PF	-0.374^{***}	0.00573	-0.487^{***}	0.00553	-0.400^{***}	0.704^{*}
	(-3.74)	(1.48)	(-4.75)	(1.39)	(-3.76)	(1.89)
capital intensity	0.144^{***}	0.000653^{**}				
	(11.35)	(2.04)				
labor productivity			0.112^{***}	-0.00170^{***}		
			(7.87)	(-4.74)		
cash flow					0.180^{***}	0.752^{***}
					(8.52)	(3.54)
Observations	284302	28904	282181	28620	261468	26317
Adjusted R^2		0.051		0.054		0.058
pseudo R^2	0.101		0.094		0.094	
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: all estimations include age, subsidy, the export intensity, financial costs as firm-level controls. All standard errors are clustered at city level.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Estimation results controlling other firm-level information together

variables	rdd		rd	
	(1)	(2)	(3)	(4)
HHI	-0.0377		-0.0125***	
	(-0.29)		(-3.96)	
HHI × PF		-0.0235		-0.0133***
		(-0.18)		(-3.97)
HHI × SOF		-0.241**		-0.00358
		(-2.03)		(-0.80)
PF	-0.215***	-0.366***	0.00117	0.00770**
	(-6.97)	(-3.35)	(0.79)	(1.97)
cash flow	0.126***	0.125***	0.00745***	0.00737***
	(5.36)	(5.34)	(3.36)	(3.34)
labor productivity	0.0692***	0.0691***	-0.00163***	-0.00163***
	(4.16)	(4.16)	(-4.35)	(-4.33)
capital intensity	0.116***	0.116***	0.000929***	0.000943***
	(7.60)	(7.59)	(2.90)	(2.94)
Observations	258750	258750	26041	26041
adj. R^2	--	--	0.062	0.062
pseudo R^2	0.106	0.106	--	--
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: all estimations include age, subsidy, the export intensity, financial costs as firm-level controls. All standard errors are clustered at city level.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A5: Estimation results controlling for entry and exit

variables	rdd		rd	
	(1)	(2)	(3)	(4)
HHI	-0.0757		-1.669***	
	(-0.66)		(-5.06)	
HHI × PF		-0.0536		-1.783***
		(-0.45)		(-4.99)
HHI × SOF		-0.385***		-0.696
		(-3.48)		(-1.14)
PF	-0.230***	-0.461***	-0.148	0.567
	(-7.93)	(-4.58)	(-0.84)	(1.10)
enter	-0.179***	-0.179***		
	(-5.19)	(-5.18)		
exit	-0.228***	-0.227***		
	(-8.70)	(-8.69)		
Observations	284720	284720	15743	15743
Adjusted R^2	--	--	0.082	0.082
Pseudo R^2	0.090	0.090	--	--
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: all estimations include age, subsidy, the export intensity, financial costs as firm-level controls. All standard errors are clustered at city level. Estimation results for columns (3) and (4) use sample of firms have consecutive observations and are active in R&D during the sample period.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A6: Estimation results using alternative measure for banking competition

variables	rdd		rd	
	(1)	(2)	(3)	(4)
CR5	-0.0601		-0.0178^{***}	
	(-0.34)		(-3.80)	
CR5 × PF		-0.0413		-0.0191^{***}
		(-0.23)		(-3.84)
CR5 × SOF		-0.242^{**}		-0.00370
		(-2.04)		(-0.84)
PF	-0.215^{***}	-0.350^{**}	0.00119	0.0138^{***}
	(-6.97)	(-2.36)	(0.80)	(2.82)
cash flow	0.126^{***}	0.125^{***}	0.00746^{***}	0.00738^{***}
	(5.35)	(5.33)	(3.36)	(3.35)
labor productivity	0.0692^{***}	0.0691^{***}	-0.00162^{***}	-0.00161^{***}
	(4.14)	(4.14)	(-4.30)	(-4.28)
capital intensity	0.116^{***}	0.116^{***}	0.000923^{***}	0.000936^{***}
	(7.59)	(7.59)	(2.88)	(2.91)
Observations	258750	258750	26041	26041
adj. R^2			0.062	0.062
pseudo R^2	0.106	0.106		
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Note: all estimations include age, subsidy, the export intensity, financial costs as firm-level controls. All standard errors are clustered at city level.

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$