



Bank competition, information specialization and innovation

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Abstract

Complementary to rich existing evidence on bank competition and corporate innovation, this paper aims to investigate the impacts of bank competition on innovation efficiencies, in terms of both R&D input and output at firm level. By acknowledging the role played by information asymmetries in financing innovation, we also examine the moderating effects of information specialization at both industry and firm level on corporate innovation. Analyzing innovation and bank structure data from U.S. between 1992 and 2010, we show novel evidence that increased bank competition improves innovation efficiencies in terms of both R&D input (investment) and output (patents and profits generated by R&D). In addition, we find bank competition has a greater favorable effect on innovation for those firms with more specialized information, such as those operating in an industry with more dispersed productivity growth and those with more concentrated patent types. Overall, our findings support market power hypothesis and banking strategic theory where bank competition improves credit supply to corporate innovation.

Keywords Bank market · Competition · Corporate innovation · Efficiencies · Information specialization

JEL Classification G20 · L10 · O30

1 Introduction

Recent empirical studies have identified the favorable effects of improved competition in banking markets on corporate innovation (e.g. Amore et al. 2013) because of the increased credit supply and lowered costs of finance (Rice and Strahan 2010). Prior studies have also

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attempted to examine the moderating roles played by firm level characteristics in a ‘bank competition – corporate innovation’ relationship, such as firm age (e.g. Chava et al. 2013), nature of business in terms of public listing (e.g. Cornaggia et al. 2015), dependence on external finance (e.g. Amore et al. 2013) and financial constraints (e.g. Guariglia and Liu 2014). What is little known is about the role played by information specialization when financing corporate innovation activities. This is particularly important because corporate innovation carries a nature of being informationally opaque (Hall et al. 2005; Lobo and Xie 2018) and such a feature may moderate or mediate the favorable effects of bank competition on corporate innovation and the role played by banks in alleviating asymmetric information problems (Hadlock and James 2002). Moreover, bank market deregulation on interstate banking and branching has enabled banks to better diversify risk geographically (Amore et al. 2013). Banks still face a trade-off between funding more diversified innovation activities for risk diversification purpose and financing more specialized innovation for cost efficiency reasons in acquiring information from innovative borrowers.

This paper aims to advance our understanding around the bank market effects on corporate innovation. We commence our baseline analysis by revisiting the favorable effects of bank competition on corporate innovation to test the validity of our key bank competition measure, H-statistic, and our empirical model specification. Our results show robust evidence on the favorable and economically sizable effects of bank competition on corporate innovation where an increase of H-statistic by 0.1 raises patent and citation counts by 16% and 53% respectively. This paper differs from prior literature in three aspects. Firstly, we use unique ‘information’ measures at both industry (productivity growth dispersion) and firm (patent type distribution) level to capture information specialization and asymmetries of innovative firms. We show novel evidence that banking competition has stronger favorable effects on more concentrated patenting activities which are characterized by a higher degree of specialized proprietary information. For example, the marginal effects of improved banking competition are 16% greater for those firms with more concentrated patents than for those with dispersed patents. This result reveals that, in the presence of information asymmetries when financing corporate innovation, banks benefit from the economies of scale in acquiring more specialized information.

This paper also differs from prior literature by offering additional evidence on the favorable effects of bank competition on innovation efficiencies. Recent empirical studies (e.g. Amore et al. 2013) have mainly focused on such effects on the quantity (e.g. number of patents) and quality (e.g. citation, originality) of corporate innovation. This paper, instead, focuses on the efficiencies of corporate innovation and shows that bank competition improves innovation efficiencies, in terms of the numbers of patents per million dollar R&D investment and the profits generated by R&D spending, which have been neglected by recent empirical studies. Our results suggest that bank competition does not only increase credit supply but also improves the efficiencies of resource allocation where bank finance could be channeled to the most productive innovation activities.

Finally, when investigating banking competition effects, existing research has predominantly used *exogenous* banking market deregulation (e.g. Chava et al. 2013; Amore et al. 2013) and market development (e.g. Benfratello et al. 2008; Hsu et al. 2014) as a measure of market structure. In this paper, we show evidence on the existence of endogeneity of banking market structure and use a variety of measures, including Panzar-Rosse H-statistic (Panzar and Rosse 1984), RS Index (Rice and Strahan 2010), branch density and Herfindahl–Hirschman Index (HHI) in the analysis. The endogenous issue exists because, first, unobserved state (local) characteristics could jointly determine banking market competition and corporate innovation activities (Butler and Cornaggia 2011). Second, there could

be a causal issue where bank finances support corporate innovation while innovation could also lead bank finance to follow (Audretsch et al. 2012). To address this concern, we employ an instrumental variable approach and use ‘state median¹ Tier 1 capital ratio’ as an instrument for banking market competition. The underlying validation of our instrument lies in that the incumbent banks with higher Tier 1 capital ratio would have better ability to accumulate capital to build a buffer against failure and to set up a higher entry barriers for new players on the equilibrium path and thus, market concentration occurs (Corbae and D’Erasmus 2014).

The remainder of the paper proceeds as follows. Section 2 reviews relevant literature on the effects of bank market competition on credit availability and corporate innovation. Section 3 describes the data and methodology. Section 4 presents the empirical results. Section 5 concludes and summarizes the paper.

2 Related literature

Corporate innovation has been an important research topic for decades and recent empirical studies have provided additional empirical evidence on the importance of R&D and innovation. For example, innovation enhances the performance and survival of firms by offering new growth opportunities (Artz et al. 2010). However, due to the inflexibility of R&D investment, R&D may also increase corporate distress risk especially for those financially constrained firms and during the economic downturns (Zhang 2015). In financing corporate innovation activities, venture capital investors have exhibited location bias (Cumming and Dai 2010) and focused more on the commercialization of existing innovations and the growth of the invested innovative firms (Engel and Keilbach 2007). Moreover, their exit strategies rely on the success of innovation activities (e.g. number of patents) of the firms they invested (Wang and Wang 2012).

As one of the most important external finance suppliers to firms, banks play an important role in credit supply, determining cost of finance and bank-firm relationship (e.g. Giannetti 2012) with corporate innovation. There has been ample theoretical and empirical evidence on the roles played by banks and banking market structure in financing innovative firms but empirical evidence is never conclusive. Literature built on the traditional market power hypothesis (e.g. Ongena and Smith 2001; Jayaratne and Strahan 1996) suggests that a decrease in competition restricts the supply of credit and, thereby, decreases innovation. This is because the monopoly power in banking sector would drive interest rates high and credit supply low, resulting in a loss of overall market efficiencies (Stein 2002; Beck et al. 2004). Competition, instead, improves the availability of external finance and lowers the costs of finance for businesses (Lian 2018; Mi and Han 2018).

In contrast, according to the information-based hypothesis, market power enables banks to extract informational rent (e.g. Stiglitz 2002) and banks would have stronger incentives to acquire private information in a concentrated banking market because of their ability to subsidize credit-constrained firms at the beginning of the relationship and to extract the rent later (Sharpe 1990; Petersen and Rajan 1995). Such relationships, however, are not sustainable in a competitive market because of the free-riding problem (Dell’Ariccia

¹ Instead of regulatory minimum ratio, we use a median ratio as instrument to reflect a performed capital ratio with a market equilibrium. This is also because banks may be still undercapitalized even their capital ratio is above the minimum.

and Marquez 2004) and increased capital market competition reduces relationship lending (Fraser et al. 2012). Therefore, credit supply to those informationally opaque and financially constrained firms could be greater in a concentrated banking market. For example, Han et al. (2009) have shown that small firms are less likely to be financially constrained in terms of being discouraged from borrowing in a more concentrated banking market than in a competitive market. Additional evidence is available from Petersen and Rajan (1995), Black and Strahan (2002), and Cetorelli (2004). Indeed, banks have to face problems of asymmetric information when financing informationally opaque businesses. Instead of the traditional arguments on relationship lending, banking strategic theory proposes that greater competition in local credit markets would improve bank cost efficiency (Chortareas et al. 2016) and drive banks to increase credit supply to small, proximate and opaque borrowers (McKee and Kagan 2018). As a result, banks would create a competitive edge that helps insulate themselves from pure price competition from outside banks (Boot and Thakor 2000; Dell’Ariccia and Marquez 2004).

This paper is motivated by recent research development in bank competition and corporate innovation (e.g. Cornaggia et al. 2015) which has shown consistent evidence on the favorable effects of bank competition and financial development on corporate innovation in Italy (Benfratello et al. 2008), U.S. (Cornaggia et al. 2015), China (Hsu et al. 2013) and cross country (Hsu et al. 2014). The favorable effects come from the increased credit supply (Amore et al. 2013) and reduced cost of finance for businesses (Rice and Strahan 2010) when bank market becomes more competitive and the improved capability of banks to diversify risk after bank deregulation (Amore et al. 2013). The favorable effects are also driven by the improved pricing mechanism of equity markets (Hsu et al. 2014) and the nurturing role of financial systems on innovation (Hsu et al. 2013) in both developed and emerging economies.

The widely accepted favorable effects of bank competition and financial development on corporate innovation have been found to vary over firm level characteristics and the nature of innovation, such as firm age (Acs and Audretsch 1988), dependence on external finance (Cohen and Klepper 1996), financial constraints (Amore et al. 2013), private vs. public firms (Chava et al. 2013), and process vs. product innovation (Boer and During 2001). Overall, it has been shown that firms with a greater dependence on bank credit for innovation, such as those young, small and private firms would benefit more from bank market competition and financial development (e.g. Petersen and Rajan 2002; Rajan and Zingales 1998; Cetorelli and Strahan 2006). However, what is less known about the ‘bank competition—corporate innovation’ relationship is how information moderates the effects of bank competition on innovation and the economic consequences of bank competition to innovation efficiencies. In light of the innovation literature, knowledge-intensive firms have intrinsically higher information and knowledge gap with firm outsiders (Jia 2019). The higher information specialization poses a problem for the innovative firms to terminate or initiate a lending relationship with banks, so that information differentiation captures the degree of specialization in relationship building (Boot and Thakor 2000). Because of the high level of switching costs, firms with intensive proprietary information would not switch banks easily even if the rival banks tend to reduce loan pricing when competition is introduced. In this scene, banks are able to extract information rents in the range of switching costs and the higher the degree of specialization of the information, the steadier the rent of such information will be. Therefore, it is expected that the greater competition among banks frequently facilitates more for the financing of those informationally opaque firms through producing the high degree of proprietary information which avoids the adverse effect of ongoing competition on profits.

Overall, the two under-studied areas are important to deepen our understanding on the roles of bank competition and financial development in facilitating corporate innovation because corporate innovation activities are risky and informationally opaque (Hall et al. 2005) and further empirical studies are called to investigate if increased credit supply has been channeled to the most productive innovation activities. To fill in these research gaps, this paper is aimed to examine the moderating effects of information opaqueness and the effects of bank competition on innovation efficiencies.

3 Data and methodology

3.1 Data

Our data are collected from various sources. To measure corporate innovation, we collect data from National Bureau of Economics Research (NBER) patent database and Hall et al. (2001) and Li et al. (2014) with detailed information on the patents granted by United States Patent and Trademark Office (USPTO) from 1976 to 2010. We exclude sample patents granted to universities, governments and foreign companies who rely weakly on local banking markets. We collect local (state level) bank information from Federal Deposit Insurance Corporation (FDIC) and firm level data from COMPUSTAT. In addition, we also collect state level venture capital investment information from National Venture Capital Association (NVCA) as a proxy for alternative sources of finance for innovation and state level controls from Federal Reserve Bank of ST. Louis. Our analysis is based on 44,567 firm-year observations between 1992 and 2010² which allow us to use both innovation data and bank data and to consider the effects of banking market deregulation in U.S. (Amore et al. 2013).

3.2 Measuring corporate innovation and innovation efficiencies

We measure corporate innovation by a widely used patent-metrics (Nelson et al. 2014) which prevents the problems arising from accounting practices, such as R&D expenditure (Dugan et al. 2016), and represents the output or the commercialization of innovation activities (Ciftci and Zhou 2016). Corporate innovative outputs are captured by the 'weight-adjusted' numbers (see detail from Hall et al. 2001) of patents ($Patent_{ijt}$) filed by company i in state j in year t and citations ($Citation_{ijt}$) as a measure of the economic importance of innovation activities. We measure innovation efficiency by (1) the number of patents generated by per million dollar R&D investment ($Patent/R\&D$) and (2) return on R&D ($Profit/R\&D$). We also examine the bank competition effects on R&D expenditure as a measure of innovation inputs.

² More recent data on bank market structure are available from FDIC and we find bank market has become less competitive (measured by Panzar-Rosse H Statistics) since financial crisis. Upon availability of more recent data on patents, future research could look into how financial crisis and reduced bank competition affect corporate innovation. We appreciate an anonymous referee for raising this point.

3.3 Measuring banking market competition and controlling for endogeneity

To measure banking market competition, we use Panzar-Rosse H -statistic³ (H henceforth) (Panzar and Rosse 1984) with long term equilibrium in the main tests and *RSIndex*, *HHI* and *Branch Density* in the robustness tests. H has been acknowledged to be robust and superior to other competition measures, being derived from profit-maximizing equilibrium conditions (Shaffer 2004; Claessens and Laeven 2004) and widely used to test banking market competition (e.g. Molyneux et al. 1994; Bikker and Haaf 2002), with a range between 0 (monopolistic markets) and 1 (competitive markets).

A potential endogeneity issue of banking market competition may arise if the level of competition in a local banking market and corporate innovation decisions are jointly determined by unobserved state characteristics. We employ an instrumental variable (IV) approach by using ‘state median Tier 1 risk-based capital ratio’ as an instrument,⁴ relying on the fundamental feature of competitive markets with ‘free entry’ for new players and ‘free exit’ for those that fail (Tian and Han 2019). Tier 1 ratio measures how well a bank is capitalized in terms of the amount of core capital that it holds in comparison to the size and risk profile of the bank. In U.S., current capital requirement is based on Basel III accord and a bank is defined as being undercapitalized if its Tier 1 risk-based capital ratio is less than 6%. This rule was enforced jointly by Office of the Comptroller of the Currency (OCC), Board of Governors of the Federal Reserve System and FDIC. Existing literature has shown a strong impact of bank capital on the stability of banks where banks with a high capital ratio have a greater ability to accumulate capital to build a buffer against unexpected losses. For example, a 50% increase in capital requirement in U.S. banking industry would reduce the exit rates of small banks by 45% and lead to a more concentrated industry (Corbae and D’Erasmus 2014). In addition, the capital regulation directly places a constraint on banks’ potential to entry in a local market. Therefore, a state with lower Tier 1 capital ratio would have a more competitive banking market (greater H). Our statistical evidence shows that the correlation between Tier 1 ratio and H is -0.1718 ($p < 0.01$). Moreover, we have no reason to believe that performed capital ratio of banks directly affects corporate innovation activities.⁵

3.4 Industry information asymmetries and innovation information specialization

We measure the degree of information asymmetries at both industry and firm levels. At industry level, we follow Duchin et al. (2010) and measure information asymmetries by productivity growth dispersion which is defined as the standard deviation of productivity (the ratio of sales to number of employees) growth rate based on a 3-digit SIC industry classification. Innovative firms in a specific industry with a greater productivity growth dispersion are deemed to be more informationally opaque because their corporate performance carries a greater degree of idiosyncratic risk.

Because of the information-sensitivity nature of innovation activities (Jia 2019), a greater information specialization would create a problem for the innovative firms to terminate an

³ The derivation of H is available from the authors on request.

⁴ Our empirical results are still robust when an alternative instrument (bank tangible capital ratio) is used. Results are available from the authors on request.

⁵ We empirically test the validity of the instrument by examining (1) if the performed Tier 1 ratio has any impacts on corporate innovation trends and (2) if the implementation of Basal Core Principles for Effective Banking Supervision in 1997, on which Tier 1 ratio is based, has altered corporate innovation. Our results, not reported but available on request, show little evidence on such relationships and therefore validate the instrument we use. We appreciate an anonymous referee for raising this point.

existing or initiate a new borrowing relationship with banks. The dynamic nature of innovation, in both the evolutionary and resource-based perspectives, implies that firms with unique innovative capabilities would innovate in particular areas of the technological frontier more efficiently than others (Dosi 1982). This would lead to an increase of information rents over time. Therefore, more concentrated patenting activities are characterized by a higher degree of proprietary information specialization. At firm level, we follow Hall et al. (2001) and categorize patents into six types, including chemical (excluding drugs), computers and communications, drugs and medical, electrical and electronics, mechanical and other. We then measure information specialization by the *kurtosis* and variance of distribution of patent types at firm level, which can better reflect the probability of extreme outliers produced by the distribution. We define a sample firm having dispersed patents (*Dispersed patent*=1) if its distribution of patent types has a kurtosis (variance) lower than 3 (greater than cross-industry median); concentrated patents (*Dispersed patent*=0) otherwise, where kurtosis is greater than 3.

3.5 Additional control variables

We also control for firm, industry and state characteristics that may affect corporate innovation outputs in our analysis, such as firm size and age, profitability (ROA), cash holding, growth opportunity (sales and Tobin's Q), asset tangibility, leverage, capital to labor ratio, industry concentration, state-level coincident index and venture capital ratio. We winsorize these variables at 1st/99th percentile in the following analysis and variable definitions are provided in Appendix.

3.6 Summary statistics

Table 1 reports the descriptive statistics for the variables used in the empirical analysis. Our main samples are 32,910 firm-year observations between 1992 and 2010. Averagely, each sample firm obtains 11 patents which receive 137 citations per year. In terms of innovation efficiencies, a typical firm invests US\$79 m in R&D and every one dollar R&D investment generates US\$0.65 profits. Averagely, every million dollar R&D investment would generate 0.8 patent.

Overall, the local (state) banking market is monopolistic competitive, measured by either *H*, *RSIndex*, *HHI* or *Branch Density*. A typical sample firm is 15 years old and has book value assets of US\$5.188 billion, ROA of—%, cash-to-assets ratio (cash holding) of 22.7%, Tobin's Q of 2.519, net property, plants and equipment (PPE)-to-assets ratio (tangibility) of 24.1%, leverage of 1.1%, capital to labor ratio of 4.32, and industry HHI of 0.014. On average, the kurtosis of patent type distribution is 3.8, indicating more concentrated patents generated by the sample firms.

3.7 Baseline specifications

Our basic econometric model⁶ (Eq. 1) focuses on the effects of banking market competition measured by Panzar-Rosse H-statistic (H_{jt}) on corporate innovation:

⁶ Our estimations are established by conjecturing that prevailing lending conditions over state areas where firms headquarter would place the most significant effects on corporate financing for innovation (e.g. Chava et al. 2013; Cornaggia et al. 2015). To ascertain if there are any domestic effects of the foreign activities of multinationals, in additional robustness tests, we particularly focus on the R&D spending performed by U.S. parent companies which have foreign affiliates and also separate sample firms into 'Domestic' and 'Multinational' according to COMPUSTAT data sources. We find that our reported empirical evidence is virtually unaffected but those multinational firms would be less sensitive to the state banking market conditions. Results are not reported but available on request from the authors. We thank an anonymous referee for raising this point.

Table 1 Descriptive statistics

Variables	Obs	Mean	Std. dev.	Min	Max
<i>Innovation variables</i>					
Number of patents ($Patent$) _{it}	44,567	17	136	0	6460
Number of citations ($Citation$) _{it}	44,567	99	1123	0	71,827
R&D (\$m) ($R\&D$) _{it+1}	42,706	102.849	455.128	0.000	4297.000
Profits/R&D ($Pr\ ofit/R\&D$) _{it}	44,567	10.644	28.152	-3.432	237.920
Patents/R&D in \$m ($Patent/R\&D$) _{it}	44,567	36.413	191.699	-3.432	14,263.881
Kurtosis of patent types distribution	21,002	3.935	2.930	-3.333	6.000
Variance of patent types distribution	35,158	47.491	217.813	0.000	1363.5
<i>Banking market competition variables</i>					
H-statistic (H_{jt})	41,016	0.568	0.241	0.104	1.000
RSIndex ($RSIndex_{jt}$)	27,982	2.603	1.381	0	4
HHI (HHI_{jt})	36,992	0.012	0.026	0.001	0.465
Branch density ($Density_{jt}$)	36,992	0.033	0.065	0.001	1.390
<i>Other control variables</i>					
Size (\$m)	42,784	4223.405	15,046.143	0.428	132,000.000
Age	44,567	14.538	9.015	1.000	35.000
Return on assets (ROA)	43,916	-0.052	0.492	-3.155	0.391
Cash holding	43,617	0.161	0.188	0.000	0.880
Asset tangibility	43,921	0.228	0.189	0.000	0.824
Capital to labor ratio	43,688	172.673	368.204	5.800	3126.051
Bank loan ratio	44,547	0.469	0.458	0.000	1.000
Leverage	43,926	0.106	0.464	-1.685	2.766
Sales (\$m)	43,925	2861.428	8869.681	0.000	72,102.047
Tobin's Q	40,066	2.159	3.188	0.061	21.884
Product market HHI	44,567	0.094	0.172	0.003	1.000
Industry standard deviation of productivity growth	42,880	171.065	133.540	0.000	1393.517
Coincident Index	41,189	82.264	12.035	57.343	108.243
Venture capital	43,993	2972.408	6398.523	0.415	42,868.500

Descriptive statistics of the key variables in the empirical analysis. Detailed variables definitions are shown in Appendix

$$\ln(\text{Innovation})_{ijt} = \alpha_2 + \beta_2 \widehat{H}_{jt} + \gamma_{2n} \sum Z_{it} + \text{Industry}_k + \text{Year}_t + \varepsilon_{2it} \quad (1)$$

where i , t , j and k denote company, year, state and industry respectively. Innovation_{ijt} is the measure of the level ($Patent$, $Citation$) and efficiency ($Patent/R\&D$, $Profit/R\&D$) of innovation activities at firm level. \widehat{H}_{jt} is the predicted value of H after controlling for endogeneity by using 'state median Tier 1 capital ratio' as an instrument in the first stage and therefore, β_2 is expected to capture the unbiased effect of H on innovative outcomes. Z_{it} denotes a vector of firm-level controls. Given that the U.S. patenting activity increased substantially from mid-1980s (Hall 2004), we also control for the aggregate trends by Industry_k and Year_t to capture industry and year fixed effects respectively, so that the estimated effect of banking competition on innovation is not driven by an industry- or time-specific trend.

4 Empirical results

4.1 Banking market competition and corporate innovation: a revisit

We commence our analysis by revisiting the favorable effects of bank competition on corporate innovation which have been documented by recent empirical studies (e.g. Amore et al. 2013). We run a rich set of models with a variety of bank competition measures (e.g. *HHI*, *Branch Density*, *H*), model specifications (e.g. OLS, 2SLS, Poisson) and sampling approaches (e.g. after 1997 when IBBEA was fully implemented in U.S). Table 2 shows consistent and robust evidence that bank competition improves corporate innovation, in terms of quantity (Patents) and quality (Citations). Our results also confirm the validity of *H*, as a measure of bank competition with long term equilibrium. The favorable effects of bank competition on corporate innovation are economically sizeable. For example, an increase of *H* (mean=0.594, $\delta=0.239$) by 0.1 would increase patent counts by 19% and citations by 47% (Models 3 and 4). Compared with the average number of patents (citations) produced by a company, this is equivalent to 2 additional patents and 64 more citations generated averagely for each sample firm per year, with an improved bank competition of *H* by 0.1.

4.2 Banking market competition and industrial information asymmetries

Due to the riskiness and informationally opaque nature of corporate innovation, it is anticipated that informationally opaque firms may benefit more from the improved bank competition by having a better access to credit which they would not access in a more concentrated bank market. Whereas, it is also likely that informationally more transparent firms would enjoy more benefits from increased bank competition where in a competitive bank market, banks rely more heavily on hard information (e.g. firm size, accounting information, tangibility) and have weaker motives to collect private information from informationally more opaque borrowers (Han et al. 2009).

To test these two competing possibilities, we divide samples into informationally *opaque* and *transparent* groups where the former (latter) has a higher (lower) industry productivity growth dispersion than cross-industry median in year *t* (Duchin et al. 2010). Table 3 shows that improved banking market competition increases innovation outputs for both informationally opaque and transparent businesses but the favorable effects are much stronger in the '*opaque*' group. The difference is statistically significant at 1% level and economically large. For example, with an increase of bank competition *H* by 0.1, informationally opaque firms would increase their patent counts by 28%, compared with 11% for informationally transparent samples. The citation counts also increased by 76% and 37% for informationally opaque and transparent firms, respectively. This finding⁷ is compatible with the view that informationally opaque firms would benefit more from increased credit supply due to the improved bank competition and their innovation activities would be less financially constrained in a more competitive bank market.

⁷ This result is also robust to other measures of bank competition, such as *HHI*, *RSIndex* and *Branch Density*, and to an interaction approach. Results are not reported by available on request from the authors.

Table 2 Banking market competition and corporate innovation—a revisit

Models	Bank market concentration measures and model specification	Number of observations	$\ln(\text{Patents})_{it}$	$\ln(\text{Citations})_{it}$
1 and 2	H_{jt} (OLS model)	35,966	0.006 (0.031)	0.144*** (0.046)
3 and 4	H_{jt} (2SLS model)	34,465	1.471*** (0.217)	4.234*** (0.367)
5 and 6	H_{jt} (Poisson model)	35,966	0.024 (0.032)	0.094*** (0.198)
7 and 8	H_{jt} (IV-Poisson model)	35,937	2.03*** (0.250)	2.696*** (0.329)
9 and 10	H_{jt} (2SLS model with samples since 1997)	27,047	1.19*** (0.224)	3.059*** (0.329)
11 and 12	H_{jt} (2SLS model with samples nascent firms)	23,055	1.422*** (0.290)	4.543*** (0.497)
13 and 14	H_{jt} (2SLS model with samples available in all years)	15,111	1.354*** (0.427)	4.807*** (0.700)
15 and 16	H_{jt} (2SLS model with samples excluding the tech bubble period 1995 – 2000)	22,950	2.294*** (0.492)	5.090*** (0.724)
17 and 18	$RSIndex_{jt}$ (OLS model)	22,912	-0.226*** (0.006)	-0.497*** (0.011)
19 and 20	$Branch\ Density_{jt}$ (OLS model)	36,131	0.051*** (0.018)	0.186*** (0.027)
21 and 22	$Branch\ Density_{jt}$ (2SLS model)	34,630	0.787*** (0.116)	2.264*** (0.197)
23 and 24	HHI_{jt} (OLS model)	33,030	-0.463* (0.246)	-0.621* (0.357)
25 and 26	HHI_{jt} (2SLS model)	33,030	-12.137*** (1.955)	-34.361*** (3.544)

In a set of tests, we use different bank competition measures and model specifications (first column) to regress the quantity (Patents) and quality (Citations) of corporate innovation by controlling for the same set of control variables and fixed effects as specified in baseline model Eq. (1). We only report the estimate of the key variables and all other results are available from the authors on request. Standard errors are clustered at lender-firm year level and reported in parentheses. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. ***, **, and * denotes statistical significant level of 1, 5 and 10% respectively

4.3 Banking market competition and information specialization of corporate innovation

Our earlier evidence, along with existing literature, consistently shows a favorable effect of improved banking market competition on corporate innovation in terms of both quantity and quality of innovation. However, how banks allocate additional credit supply with increased market competition is less understood. Corporate innovation activities carry a nature of being both risky (Amit et al. 1990) and informationally opaque (Hall et al. 2005)

Table 3 Banking market competition and industry information asymmetries

Dependent variable	$\ln(\text{Patent})_{it}$		$\ln(\text{Citation})_{it}$	
	(1)	(2)	(3)	(4)
	Opaque	Transparent	Opaque	Transparent
H_{jt}	2.448*** (0.592)	1.025*** (0.191)	5.653*** (0.868)	3.114*** (0.349)
Size	0.269*** (0.010)	0.257*** (0.010)	0.215*** (0.013)	0.329*** (0.018)
Age	-0.176*** (0.030)	-0.192*** (0.023)	-0.231*** (0.049)	-0.315*** (0.043)
ROA	-0.206*** (0.020)	-0.180*** (0.021)	-0.143*** (0.031)	-0.184*** (0.041)
Cash holding	0.195*** (0.053)	0.231*** (0.053)	0.328*** (0.078)	0.526*** (0.097)
Asset tangibility	-0.570*** (0.078)	-0.651*** (0.072)	-0.315*** (0.117)	-0.877*** (0.130)
Capital to labour ratio	0.153*** (0.013)	0.227*** (0.013)	0.092*** (0.018)	0.278*** (0.024)
Bank loan ratio	-0.055*** (0.020)	-0.057*** (0.019)	-0.063** (0.029)	-0.020 (0.033)
Leverage	0.001** (0.001)	0.001 (0.001)	0.002 (0.001)	-0.004* (0.002)
Ln(Sales)	0.011 (0.008)	0.027*** (0.008)	0.006 (0.012)	0.018 (0.017)
Tobin's Q	0.001 (0.001)	0.017*** (0.003)	0.002 (0.001)	0.025*** (0.005)
Product market HHI	-0.845* (0.490)	-1.652 (1.076)	3.117*** (0.755)	1.848 (1.816)
Product market HHI ²	0.555 (0.356)	2.008 (1.608)	-1.388** (0.562)	0.254 (2.726)
Coincident Index	0.003 (0.003)	-0.001 (0.002)	0.008* (0.005)	-0.002 (0.003)
Venture capital	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Industry fixed effect	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Observations	17,076	17,221	17,076	17,221
Chi2 test of coefficient difference	$p < 0.01$		$p < 0.01$	
R-squared	0.240	0.286	0.139	0.184
F-statistic	25.442***	71.499***	23.303***	66.526***

The table presents regression coefficients and standard errors (in parentheses). Models employed are 2SLS. All estimations include year and industry fixed effects. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

Table 4 Banking market competition and patent types distribution

Dependent variable: $\ln(Patent)_{it}$	Interaction		Concentrated		Dispersed	Interaction
	(1)	(2)	(3)	(4)	(5)	(6)
	All sample	Restricted	All sample	Restricted	All sample	All sample
H_{jt}	2.102*** (0.404)	2.621*** (0.473)	2.189*** (0.703)	2.065*** (0.430)	1.762*** (0.356)	0.744** (0.316)
$H_{jt} \times Patent\ distribution_{it}$	-1.388*** (0.303)	-1.765*** (0.347)				-0.692*** (0.220)
$Patent\ distribution_{it}$	0.945*** (0.175)	1.173*** (0.201)				1.372*** (0.127)
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16,606	13,470	10,418	8259	6188	28,953
R-squared	0.491	0.495	0.498	0.493	0.495	0.5485
F-statistic	157.70***	188.78***	103.13***	113.13***	155.95***	112.61***

The table presents regression coefficients and standard errors (in parentheses). Models employed are 2SLS. In Models 1–5, we define the firms with higher kurtosis of the empirical distribution of patents among 6 different categories than 3 in year t to be ‘concentrated’ ($Patent\ distribution_{it} = 0$). To address the concern that extreme case may bias the identification, we remove the sample firms which only has one patent granted in year t from the estimation and the results are reported in Models 2 and 4. In Model 6, we define the firms having concentrated patents ($Patent\ distribution_{it} = 0$) if its variance of patent types distribution is greater than the across-industry median value and dispersed patents otherwise. All estimations include year and industry fixed effects. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. The results for firm control variables are not reported but available from the authors on request. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

and more concentrated patenting activities are characterized by a higher degree of proprietary information specialization. With a greater market competition, banks face a trade-off between risk diversification by allocating additional credit supply to firms with more diversified innovation activities, and the benefit of economies of scale in specialized information acquisition by financing a specific range of innovation, such as biomedical sector only.

To test the moderating role of information specialization which is measured as the kurtosis of patent type distribution, we employ various analysis (interaction vs. grouping) and sampling approaches (all and restricted samples by excluding observations with 1 patent only) and report results in Table 4. Models 1 and 2 in Table 4 show that the favorable effects from banking market competition (H) are weaker for firms with dispersed patent types ($Dispersed\ patent = 1$) than for those with concentrated patent types ($Dispersed\ patent = 0$), being also reflected by the negative coefficients of the interaction terms. This result is also robust to grouping approach (Models 3–5) and the use of an alternative measure (variance) of patent types distribution (Model 6), supporting our conjecture that with improved market

Table 5 The effects of banking market competition on corporate innovation efficiency

Dependent variable	$\ln(R\&D)_{it+1}$ (1)	$\ln(Patent/R\&D)_{it}$ (2)	$\ln(Profit/R\&D)_{it}$ (3)
H_{jt}	0.681*** (0.229)	0.245*** (0.084)	2.196*** (0.284)
Firm- and state-level controls	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Observations	33,323	34,465	34,087
R-squared	0.629	0.111	0.295
F-statistic	223.09***	18.14***	62.27***

The table presents regression coefficients and standard errors (in parentheses). Models employed are 2SLS. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. All estimations include year and industry fixed effects. The results for firm control variables are not reported but available from the authors on request. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

competition, banks would channel their funds to finance more concentrated types of innovation because of the economies of scale in collecting more specialized information.⁸

4.4 Banking market competition and innovative efficiencies

As a synthetic investment-driven process, innovation activities may show different efficiencies over R&D investment (e.g. Harhoff et al. 1999) and the effects of bank competition on innovation efficiencies are, however, less understood. In this section, we fill in this gap and examine the effects of bank competition, measured by H , on innovation inputs (R&D expenditure), innovation efficiencies in terms of the number of patents generated by per million dollar R&D investment and the return on R&D investment.⁹ Table 5 shows that improved banking market competition increases credit supply to innovative businesses in R&D expenditure (Model 1). For example, an increase of banking market competition (H) by 0.1 leads to an increase of annual R&D investment by \$89.52 m averagely for each firm.

⁸ Another possible reason is that firms with more concentrated patenting activities rely more heavily on external finance. We test the correlation between patent distribution and dependence on external finance (capital expenditures—cash flow from operations)/capital expenditures) and find the correlation is economically weak ($\rho=0.0373$; $p<0.01$). In addition, concerning that firms holding the large part of a market specific patent would practice a monopoly price on the patent and be more profitable, we re-test bank competition effects on corporate innovative efficiency by focusing on the ‘dominant’ firms (firms with higher ‘Sales/Total sales’ ratio than the industry median and the five largest sample firms at the three-digit SIC code level) only, which perform relatively more research and the persistence of monopoly. We find that competition in state banking industry would also exert a beneficial effect on innovative activities of firms which can practice a monopoly price on the patents due to the large part of market specific expertise of the project vocation. Results are not reported by available on request from the authors. We appreciate an anonymous referee for raising this valuable point.

⁹ This research focuses on the productions of U.S. companies only and the main proposition of estimations is that possessing a patent would be the result of successful previous R&D, which therefore signals the general R&D competencies of a firm. Upon the availability of data, future research could explore further on the understanding of the synergy effect on firms’ R&D portfolio. We appreciate an anonymous referee for raising this insightful point.

In addition, banking market competition improves innovation efficiencies in terms of the number of patents generated by per million dollar R&D investment (Model 2) and return on R&D investment (Model 3). On one hand, firms that are at a more advanced stage in their development would be better placed to innovate, and on the other hand, the increased innovation stemming from the developed banking market would foster creative destruction since output reallocation towards the more successful and efficient firms. This novel evidence on the effects of bank competition on innovation efficiencies suggests that with improved bank market competition, the increased credit supply has been channeled to the most productive innovation activities. To investigate a longer term effect of improved bank competition on innovation efficiency, we also use three year averaged R&D, patent numbers and profit, over $t+1$ and $t+3$, and our results, not reported but available on request from the authors, still hold.

To delve deeper into the extent to which banking market competition drives the efficiency of innovative projects, we follow the literature (e.g. Butler and Cornaggia 2011) and investigate two possible mechanisms, the credit supply and pricing mechanism respectively, through which the banking competition promotes corporate innovation. Our key conjecture is that if banking competition directly improves the access to credit, reduces the cost of capital and hence alleviates financial constraints of innovative firms.

We start by comparing different marginal effects of banking competition on innovation based on firms' reliance on external capital. Following Duchin et al. (2010), we consider a firm's dependence on external finance as its capital expenditures minus cash flow from operations divided by capital expenditures and define a dummy variable, $Dependence_{it}$, which is coded as one for corporation-years below the industry median external finance dependence value (i.e., less external financial dependence) and zero otherwise. By interacting $Dependence_{it}$ with bank competition H , Models 1–3 in Table 6 show consistent evidence on the positive of banking market competition on corporate innovation. In particular, the negative and significant coefficient of the interaction term (Model 1) suggests that the beneficial effect of banking market competition is more prevalent among firms with greater dependence on external finance. It is expected that increasing competition among banks would provide easier access to credit for firms. The results are also confirmed by grouping samples according to the proxy of external financial dependence (Models 2 and 3). We take this as a 'credit supply' mechanism where with increased bank competition, credit supply increases.

Furthermore, we regress interest expenses/total debt of innovative firms on H in order to ascertain the effects of banking market competition on firms' lending rates, given the limited data matching corporate lending relationships. According to Models 4–9 (Table 6), the improved banking market competition would reduce the costs of finance for sample firms, and such effect is only statistically significant for more innovative firms (Models 5) and firms producing more concentrated patents (Models 8). We take this as a 'pricing' mechanism. Overall, our evidence suggests that increasing competition among banks would provide easier access to credit for firms, and the cheaper external finance frequently promotes entrepreneurial incentives toward undertaking excessively risky projects.

Table 6 Banking market competition and corporate innovation: credit supply and pricing mechanisms

Dependent variable	$\ln(Interest)_it$						$\ln\left(\frac{Interest}{Totaldebt}\right)_{it}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Interaction	High	Low	All sample	All sample	High R&D intensity	Low R&D intensity	Concentrated patenting	Dispersed patenting
H_{it}	2.852*** (0.325)	1.999*** (0.253)	1.344*** (0.295)	-0.714*** (0.256)	-0.688** (0.336)	-1.324*** (0.498)	-0.247 (0.418)	-1.237*** (0.579)	-0.851 (0.818)
$H_{it} \times Dependence_{it}$	-2.007*** (0.242)								
$Dependence_{it}$	1.187*** (0.144)								
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	26,821	13,392	13,429	22,714	19,880	7834	8959	6838	3217
R-squared	0.2468	0.2291	0.3643	0.7874	0.0290	0.0129	0.0356	0.0099	0.0378
F-statistic	215.68***	111.95***	143.25***	3115.45***	24.32***	8.75***	12.28***	6.31***	7.91***

The table presents regression coefficients and standard errors (in parentheses). The dependent variables are the natural logarithm of one plus the total number of patent, the natural logarithm of total interest expenses of firms and the ratio of interest expenses to total debt. In Models 1–3, firms’ external finance dependence ($Dependence_{it}$) is measured by the capital expenditures minus cash flow from operations divided by capital expenditures, and firms with external finance dependence value above the across-industry median ($Dependence_{it} = 0$) in year t to be financially dependent. The subsamples in Models 6 and 7 comprise firms with the ratio of total R&D expenditures to sales above (Model 6) and below (Model 7) the industry median at the three-digit SIC code level. In Models 8 and 9, the ‘Concentrated’ (‘Dispersed’) patenting are defined if sample firms have higher (lower) kurtosis of the empirical distribution of patents among 6 different categories than 3. All models employed are instrumental two-stage least squares (2SLS) with full set of control variables and year and industry fixed effects. The instrument variable used is $Tier1\ ratio_{jt}$. The *, **, and *** denote statistical significance at 10, 5 and 1% level for which the null hypothesis is rejected

4.5 Robustness tests

Table 2 has shown that our findings on the overall favorable effects of bank competition on corporate innovation are robust to various alternative bank competition measures (*HHI*, *RSIndex*, *Branch Density*), model specifications (OLS, SLS, Poisson, IV-Poisson) and sampling approaches. Notably that the substantial increase of alternative financing sources for R&D activities during the second half of the 1990s may potentially bias the estimates of banking financing (Brown et al. 2009), in particular, we re-test the specifications by restricting the observations excluding (1) the tech stock bubble period 1995–2000 (Models 15 and 16 in Table 2) and (2) the observations from California and New York which experienced a dramatic increase in both innovation activities and alternative financing sources during the period considered.¹⁰

Adding value to existing literature by focusing on the information issue at both industry and firm level on corporate innovation and innovation efficiencies, we run a rich set of tests on the robustness of our early results. First, following Table 2, we use various alternative bank competition measures and our results still hold where firms with more opaque information at both industry and innovation level would benefit more from improved bank competition (Table 7). For example, Table 7 shows that the estimates of *HHI* are all negative and statistically significant. To gauge the economic significance, one standard deviation increase of *HHI* would result in 51% decrease in patent counts for informationally opaque firms (Model 5) and 23% for those informationally transparent samples (Model 6).

The beneficial effects of the improved banking competition on innovative efficiencies also closely mirror those of our earlier findings (Table 8). By assuming an exogenous banking market deregulation, the OLS result in Model 1 (Table 8) shows that firms in the states with the most restrictions on interstate branching would have 83% less R&D expenditure than firms in the states that completely open to interstate branching. Second, we use an alternative instrument (bank tangible capital ratio) to control for the endogeneity of bank market competition and all our above results hold.¹¹ Finally, we use alternative sampling approaches¹² and Tables 9 and 10 show that the findings are not driven by those nascent innovative firms and they are not affected by the time trend if addressing the policies concern that potentially affecting innovation. Given an example, the results reported in Models 1 and 2 in Table 9 consistently show the negative and statistically significant estimates for the interaction terms. Empirically, around 10% more successful patents generated from the firms with more concentrated patents between 1997 and 2010 and such gap is identified up to 27% in citation outputs. In contrast, an increase of *H* by 0.1 would only increase 5% in patent counts and 10% in citations for firms which produce more dispersed patents.

¹⁰ Results are not reported by available on request from the authors. We thank an anonymous referee for raising this point.

¹¹ Results are not reported by available from the authors on request.

¹² To justify that, in the presence of alternative financing sources, that the favorable effects of bank competition on corporate innovation would long hold for both R&D-intensive firms and others, we re-test our baseline specifications by grouping sample firms according to the industrial R&D intensity, where R&D intensity was calculated as the ratio of total R&D expenditures to sales at a three-digit SIC industry-level. We find that our baseline results are robust and by comparison, the economic magnitude of the positive effect of banking market competition is greater among firms operating in high R&D intensity industries. It additionally supports our findings that the increased local bank competition would drive the efficiency of innovative projects. Results are not reported by available on request from the authors. We thank an anonymous referee for raising this point.

Table 7 Robustness tests—alternative banking market competition measures

	(1)	(2)	(3)	(4)	(5)	(6)
	Opaque	Transparent	Opaque	Transparent	Opaque	Transparent
	OLS	OLS	2SLS	2SLS	2SLS	2SLS
<i>Panel A: Banking market competition and industry information asymmetries</i>						
<i>RSIndex_{jt}</i>	-0.227*** (0.010)	-0.112*** (0.006)				
<i>Branch Density_{jt}</i>			1.513*** (0.359)	0.566*** (0.100)		
<i>HHI_{jt}</i>					-1.726*** (0.404)	-1.091*** (0.230)
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effect	Yes	Yes				
Observations	10,603	12,191	17,310	17,320	16,964	16,066
Chi2 test of coefficient difference	$P < 0.1$		$P < 0.01$		$P < 0.05$	
R-squared	0.4266	0.3512	0.270	0.262	0.276	0.227
F-statistic	64.56***	134.11***	34.90***	69.69***	38.02***	91.06***
	(7)	(8)	(9)	(10)	(11)	(12)
	Concentrated	Dispersed	Concentrated	Dispersed	Concentrated	Dispersed
	OLS	OLS	2SLS	2SLS	2SLS	2SLS
<i>Panel B: Banking market competition and patent types distribution</i>						
<i>RSIndex_{jt}</i>	-0.173*** (0.013)	-0.053 (0.046)				
<i>Branch Density_{jt}</i>			0.983*** (0.139)	0.654*** (0.240)		

Table 7 (continued)

	(7)	(8)	(9)	(10)	(11)	(12)
	Concentrated	Dispersed	Concentrated	Dispersed	Concentrated	Dispersed
	OLS	OLS	2SLS	2SLS	2SLS	2SLS
HHI_{jt}					-2.128*** (0.626)	-0.735* (0.511)
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effect	Yes	Yes				
Observations	7390	2551	9971	5958	9457	5652
Chi2 test of coefficient difference	$P < 0.1$		$p < 0.01$		$p < 0.01$	
R-squared	0.4033	0.5161	0.399	0.321	0.320	0.397
F-statistic	41.48***	35.19***	2623.39***	773.66***	2104.84***	784.19***

The table presents regression coefficients and standard errors (in parentheses) for robustness tests of alternative measures banking market competition. The dependent variable is the natural logarithm of one plus the total number of patent ($\ln(Patent)_{jt}$). Models employed are OLS with robust standard errors (Models 1, 2, 7 and 8) and 2SLS (Models 3–6 and 9–12). We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. All estimations include year and industry fixed effects, and full set of control variables. Specifically, Models 1, 2, 7 and 8 also include state fixed effects to control for the state-specific variations. The results for firm control variables are not reported but available from the authors on request. *, **, and *** denote statistical significance at 10, 5 and 1% level respectively

Table 8 Robustness tests—Alternative banking market competition measures (cons.)

	$\ln(R\&D)_{it+1}$		$\ln(Patent/R\&D)_{it}$		$\ln(Profit/R\&D)_{it}$				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$R\&Dindex_{jt}$	OLS	2SLS	2SLS	OLS	2SLS	2SLS	OLS	2SLS	2SLS
	-0.048*** (0.009)	0.376*** (0.125)	-0.428*** (0.198)	-0.067*** (0.004)	0.131*** (0.047)	-0.207*** (0.074)	-0.091*** (0.031)	1.179** (0.149)	-2.162*** (0.256)
$Density_{jt}$									
HHI_{jt}									
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State fixed effect	Yes								
Observations	17,194	33,480	31,880	17,194	34,630	33,030	16,985	34,240	32,641
R-squared	0.7927	0.633	0.632	0.1802	0.112	0.113	0.5942	0.328	0.236
F-statistic	807.81***	226.64***	316.39***	46.45***	18.30***	17.78***	313.36***	65.67***	55.86***

The table presents regression coefficients and standard errors (in parentheses) for robustness tests of the effects of alternative banking market competition on corporate innovation efficiency. Models employed are OLS with robust standard errors (Models 1, 4 and 7) and 2SLS (Models 2-3, 5-6 and 8-9). We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. All estimations include year and industry fixed effects, and full set of control variables. Specifically, Models 1, 4 and 7 also include state fixed effects to control for the state-specific variations. The results for firm control variables are not reported but available from the authors on request. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

Table 9 Robustness tests—alternative sampling

	Year > 1997		Nascent firms		Firms in all observed years	
	(1)	(2)	(3)	(4)	(6)	(7)
	Patent	Citation	Patent	Citation	Patent	Citation
H_{jt}	0.949*** (0.287)	2.779*** (0.507)	2.728*** (0.576)	5.201*** (0.838)	2.913*** (0.706)	5.247*** (1.003)
$H_{jt} \times Patent\ distribution_{it}$	-0.458** (0.197)	-1.904*** (0.362)	-1.880*** (0.431)	-3.803*** (0.625)	-2.035*** (0.527)	-3.857*** (0.746)
$Patent\ distribution_{it}$	0.716*** (0.130)	1.499*** (0.213)	1.227*** (0.246)	2.618*** (0.357)	1.276*** (0.299)	2.613*** (0.423)
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8116	11,945	11,472	11,472	7693	7693
R-squared	0.4130	0.629	0.511	0.517	0.558	0.607
F-statistic	117.87***	380.49***	146.84***	237.80***	147.76***	124.88***

The table presents regression coefficients and standard errors (in parentheses) for robustness tests of the alternative subsamples. The dependent variable is the natural logarithm of one plus the total number of patent ($\ln(Patent)_{it}$). Models 1 and 2 consider subsample of 1997–2010. Models 3 and 4 restrict the analysis to firms that are present in the sample since the first year of the sample, i.e. 1992. Models 5 and 6 estimate sample firms that remain fully from 1992 to 2010. Models employed are 2SLS. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. All estimations include year and industry fixed effects, and full set of control variables. The results for firm control variables are not reported but available from the authors on request. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

5 Conclusions

Since the implementation of IBBEA in 1990s, U.S. banking market has become more competitive. Differing from literature on the financial aspects of banks and firms (e.g. Rice and Strahan 2010), this paper investigates the impacts of state-level banking market competition on firm level corporate innovation. Our results reinforce the favorable effects of the improved local banking market competition on corporate innovation. We show bank competition increases innovation outputs, such as patents and citations and inputs, such as R&D expenditures. Our results also show that bank competition improves innovation efficiencies in terms of outputs per \$m R&D investment and enables informationally more opaque innovative firms to be less financially constrained and to benefit more from the increased credit supply. Our empirical evidence strongly supports market power hypothesis where with improved banking competition, firms would have better access to bank finance with lower costs to support their innovation activities.

What is less understood in literature is how banks deal with asymmetric information issues in financing innovation activities, with improved market competition. We propose that there could be two strategies for banks to allocate additional credit supply in more competitive markets, which are not necessarily mutually exclusive. Banks could diversify risk by investing a

Table 10 Robustness tests—alternative sampling (cons.)

	Year > 1997			Nascent firms			Firms in all observed years		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
	<i>R</i> & <i>D</i>	<i>Patent</i> <i>R</i> & <i>D</i>	<i>Profit</i> <i>R</i> & <i>D</i>	<i>R</i> & <i>D</i>	<i>Patent</i> <i>R</i> & <i>D</i>	<i>Profit</i> <i>R</i> & <i>D</i>	<i>R</i> & <i>D</i>	<i>Patent</i> <i>R</i> & <i>D</i>	<i>Profit</i> <i>R</i> & <i>D</i>
H_{jt}	0.987** (0.171)	0.177*** (0.096)	2.961*** (0.316)	0.767*** (0.390)	0.311** (0.148)	1.545*** (0.471)	1.173*** (0.514)	0.498*** (0.186)	2.630*** (0.588)
Firm- and state-level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,546	27,045	26,671	23,905	24,547	24,391	15,905	15,939	15,836
R-squared	0.7772	0.118	0.266	0.668	0.112	0.338	0.708	0.122	0.395
F-statistic	1338.82***	28.82***	97.05***	285.92***	26.534***	212.06***	351.36***	21.69***	170.44***

The table presents regression coefficients and standard errors (in parentheses) for robustness tests of the alternative subsamples. The dependent variables are the measures of innovative efficiencies. Models 1 and 2 consider subsample of 1997–2010. Models 3 and 4 restrict the analysis to firms that are present in the sample since the first year of the sample, i.e. 1992. Models 5 and 6 estimate sample firms that remain fully from 1992 to 2010. Models employed are 2SLS. We run F tests and Durbin and Wu-Hausman tests in all 2SLS models and our results, not reported but available on request, supports the existence of bank competition endogeneity and the validates our IV approach. All estimations include year and industry fixed effects, and full set of control variables. The results for firm control variables are not reported but available from the authors on request. *, ** and *** denote statistical significance at 10, 5 and 1% level respectively

wider range of innovation activities and alternatively, they could finance a certain types of innovation to benefit from the economies of scale in more specialized information acquisition. Our results show that the additional credit supply stemming from improved banking competition provides a much stronger support to those innovative firms operating in informationally opaque industries and firms with more specialized information (more concentrated patent types). Therefore, our finding reveals that banks would channel their additional credit supply to a certain types of innovation activities to take advantages of the economies of scale in collecting more specialized information.

Our findings provide important implications. Our results suggest that improving banking market competition is an effective way to enhance firms' effectiveness in generating innovations because of the increased credit supply and reduced costs of finance. The greater competition in local banking sector would strengthen the exclusive ties between banks and firms and drive banks to reallocate more resources to the borrowers which are mostly affected by information problems. Therefore, policy makers should target those innovative firms which rely more heavily on bank finance when they have difficulties to access external finance, in a scenario of credit supply decrease for example. Due to the unavailability of relevant data, this paper has not considered the impacts of non-negligible government subsidies and government supports to corporate innovation via taxes breaks for instance. We call for future research to further investigate such effects upon the availability of relevant data. In addition, we also call for future research on the possible over-investment with unbridled market competition.

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Appendix: Variable construction

Innovation variables

$Patent_{it}$: Weight adjusted average number of patents filed by company i over years t to $t+2$.

$Citation_{it}$: Weight adjusted average number of citations received by the patents filed by company i over years t to $t+2$.

$R\&D_{it+1}$: R&D expenditures (in \$m) reported by company i in year $t+1$.

$Patent/R\&D_{it}$: Number of patents generated by per \$m R&D expenditures for company i year t .

$Profit/R\&D_{it}$: Company i 's gross profit (\$m) in year t generated by per \$m R&D expenditure in year $t-1$.

Banking market competition variables

H_{jt} : Panzar and Rosse (1984) H-statistic of banking market competition in state j year t , ranging from 0 to 1. The detailed derivation is available upon request.

$RSIndex_{jt}$: Rice and Strahan (2010)'s categorical index of banking market competition in state j year t , ranging from 0 (deregulated) to 4 (highly regulated).

HHI_{jt} : Herfindahl–Hirschman Index of the banking market in state j year t . We take weighted averages across markets for banking institutions in multiple local markets using the proportions of total deposits as the weights.

$Density_{jt}$: The number of branches per km^2 in state j year t .

Other control variables

$Size_{it}$: Book value of total assets in \$m of company i measured at the end of year t .

Age_{it} : Number of years that the company i has been in COMPUSTAT.

ROA_{it} : EBITDA to total assets for company i in year t .

$Cash\ holding_{it}$: Cash and marketable securities to total assets for company i in year t .

$Asset\ tangibility_{it}$: Ratio of net property, plants and equipment (PPE) to total assets for company i in year t .

$Capital\ to\ labor\ ratio_{it}$: Natural logarithm of the ratio between property, plants and equipment (PPE) and the number of employees for company i in year t .

$Bank\ loan\ ratio_{it}$: Bank loan to total debt ratio of company i in year t .

$Leverage_{it}$: Debt to equity ratio of company i in year t .

$Sales_{it}$: Total sales in \$m of company i year t .

$Tobin's\ Q_{it}$: Ratio between market value and total assets, for company i in year t .

$Product\ market\ HHI_{it}$: Herfindahl–Hirschman Index of the industry (3-digit SIC) in which company i operates in year t .

$Coincident\ index_{jt-1}$: An index used to control for regional economic trend, which combines data on nonfarm payroll employment, average hours worked in manufacturing, unemployment rate, and wage and salary disbursements deflated by the consumer price index. More details are available from Crone and Clayton-Matthews (2005).

$Venture\ capital_{jt}$: Ratio of total venture capital investments to total investment in state j year t .

$Productivity\ growth\ dispersion$: A measure of industry level asymmetric information, where productivity is defined as the ratio of sales to number of employees and dispersion is standard deviation of productivity growth at industry (3-digit SIC) level.

$Dispersed\ patents_{it}$: A dummy variable coded as 1 if company i in year t has 'dispersed patent types (kurtosis < 3) and 0 otherwise.

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