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Venture capital and technology commercialization: evidence from China

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Abstract

Although the importance of venture capital has been recognized in innovation literature, we know relatively little about how and to what extent it influences regional technology commercialization. Using a city-level data set that includes 225 cities in China, we identify the possible economic channels through which regional venture capital development affects technology commercialization. Our findings indicate that cities with better developed venture capital market exhibit higher technology commercialization performance. Furthermore, enhancing technology search efficiency, strengthening collaboration between universities and businesses, and providing sufficient funding are three possible channels that allow venture capital to promote technology commercialization. Our results offer new insights into the effects of venture capital development on technology innovation, especially complementing the literature on innovation from the perspective of technology commercialization.

Keywords Venture capital · Technology commercialization · Innovation · Cooperation

JEL Classification G24 · O18 · O33

1 Introduction

Technological innovation is vital to ensure the long-term economic growth and competitive advantage of a region or even a country (Solow, 1957; Liu et al., 2020). However, after technology is created through R&D activities, it will not spontaneously promote economic growth. Rather, it needs to be integrated into production activities and transformed into advanced productivity (Liu et al., 2019). This process could be regarded as technology commercialization accompanied by transfer or flow of technology factors, which essentially connect the industry technology demand and innovation supply (Teece, 1977, 1993, 2023; Furman et al., 2002; Liu et al., 2017, 2021, 2023a, 2023b; Arora et al., 2023). Therefore, technology by itself may not directly bring about tangible economic growth

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since the economic value is generated when technology is commercialized (Dasilva, 2013). Indeed, from the stage of technology creation to the stage of commercialization, technological innovation is a protracted, unpredictable, and systematic process, accompanied by a high probability of failure (Holmstrom, 1989; Manso, 2011). Therefore, both cultivating technology creation and encouraging technology commercialization are fraught with difficulties.

Venture capital may be a catalyst for technology innovation. Many studies focus on the stage of technology creation, revealing that venture capitalists extends beyond that of traditional financial intermediaries such as banks. They play critical roles in addressing information asymmetry, evaluating innovative projects, and providing other value-added services (Chemmanur et al., 2014; Hellmann & Puri, 2002; Sun et al., 2020; Tian & Wang, 2014), thereby cultivating technology creation (Cumming & Johan, 2016). However, limited attention has been given to the role of venture capital in the technology commercialization stage. As research in finance increasingly focuses on the core issues of technology commercialization or technology transfer (Audretsch et al., 2016), evidence supporting the role of venture capital in facilitating innovative and visionary entrepreneurship is emerging in these related studies (Block et al., 2022). Colombo et al. (2016) review the research on entrepreneurial finance and provide a systematic overview of the role of government venture capital in innovative young firms, which serve as crucial vehicles for transferring and commercializing technology. Kelly and Kim (2018) provide empirical evidence that venture capital ramps up R&D expenditures, reflecting increased efforts to quickly commercialize existing research. However, we believe that in addition to indirectly observing technology commercialization efforts through R&D input or entrepreneurship, it is crucial to directly observe technology commercialization activities and distinguish them from technology creation activities. Research in this area remains notably insufficient. Moreover, although some studies have identified venture capital's positive role in university technology commercialization (Croce et al., 2014; Bock et al., 2018; Fu et al., 2022), there is still a gap in empirical research on overall technology commercialization from a regional perspective.

The technology commercialization activities at the regional level covers a more systematic range of innovation partners, including businesses, universities, research institutions, and individuals, as well as cooperation and transactions between them. And the development of venture capital at the regional level can comprehensively reflect the integrated effects of the behavior of regional venture capitalists, the investment market environment, and the operation of the investment market within the region. Therefore, our focus is on the overall level of regional venture capital development. Whether the development of venture capital will promote regional technology commercialization and the economic mechanisms involved remains a subject worthy of in-depth research. The aim of our research is to provide cross-city empirical evidence in China for the real effects of venture capital development on the innovation from the perspective of technology commercialization stage. Specifically, we examine the impact of venture capital development on technology commercialization based on patent transfer activities and identify the economic mechanisms through which it occurs.

A major challenge of our study is to identify the causal effects of venture capital development on technology commercialization, which is due to the existence of reverse causality and omitted variable concerns. With the development of endogenous growth theory, the theoretical research on endogenous technological change has emphasized Schumpeterian vision of creative destruction (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990), which also intensifies the debate between finance and innovation (King & Levine, 1993). A large body of literature supporting Schumpeter's view believe that the services provided by financial intermediaries, such as mobilizing savings, evaluating projects, monitoring risks, and facilitating transactions, are essential for technological innovation and economic development (Goldsmith, 1969; King & Levine, 1993; McKinnon, 1973; Schumpeter, 1911). However, numerous economists believe that financial services simultaneously develop following with economic growth. Specifically, economies with innovative opportunities develop financial intermediaries to provide the capital and resources necessary to support their innovative projects (Lucas, 1988; Robinson, 1952). As an active financial intermediary, venture capital may also be driven by technological innovation. That is, cities with better technology commercialization performance are more likely to attract venture capital. In addition, unobservable regional characteristics related to both venture capital development and technology commercialization may make correct statistical inferences hard to draw.

We employ two identification strategies to address the potential endogeneity issues. First, we adopt the two-stage least square (2SLS) approach by using instrumental variables. We select the initial public offering (IPO) rate as our instrumental variable. The validity of this IV is ensured by the fact that the successful exit of venture capital through IPOs in the city contributes to boosting the returns, reputation, and confidence, thereby stimulating increased activity in subsequent venture capital investments within the city. But the IPO rates will not directly influence the technology commercialization activities. Second, we use the difference-in-differences method by treating the amendments to the Partnership Enterprise Law of the People's Republic of China in 2006 as an exogenous "experiment shock". The revised law provides a legal basis for the establishment of limited partnership funds. This shock can directly contribute to the development of venture capital. Compared to cities less affected by the establishment of the limited partnership system, we can observe the technology commercialization performance of cities more affected by this "experiment shock". The result may demonstrate the real effects of the venture capital on technology commercialization.

We observe the different stages of commercialization and explore the possible economic channels through which venture capital development affects technology commercialization. Firstly, during the technology search stage, venture capital can contribute to expanding the scope of technology search through venture capitalists' social network resources, as well as improving technology search efficiency by providing professional consulting and monitoring services. (Sofka & Grimpe, 2010). To test whether the search channel is an underlying economic mechanism for venture capital to promote technology commercialization, we examine whether venture capital can shorten the time interval from technology creation to commercialization.

Secondly, after the technology search, collaboration and transactions between supply and demand entities become crucial. Venture capital can have a broader impact on the innovation of the investee firms by providing value-added inputs, such as marketing and human resource management (Hellmann & Puri, 2002), which may contribute to establish more stable technology market cooperation relationship. Therefore, venture capitalists may play an important role in the connection between universities and enterprises, in which the former has numerous technological achievements but lack of commercialization conditions, while the latter possesses rich resources for technology commercialization. Hence, to test whether the cooperation channel is an underlying economic mechanism of venture capital to promote technology commercialization, we examine whether the development of venture capital will promote university-based technology transfer, which reflects the cooperation between universities, scientific research institutions and enterprises.

Third, in various stages of technology commercialization, particularly in the final stage involving technology utilization, product testing, and market promotion, sufficient financial support is crucial. Fortunately, the most critical function of financial intermediaries is to facilitate the circulation of necessary funds. Compared with other types of financial intermediaries, venture capital tends to invest in firms with risky and positively skewed return distributions (Fenn et al., 1995; Sahlman, 1990). The investment preference of venture capital exactly matches technology transformation activities, which meet small probability of high returns and high probability of weak returns or even negative returns. To test whether the financing channel is an underlying economic mechanism, we examine whether cities with greater financing demand exhibit disproportionally higher technology commercialization performance. To further investigate the robustness of financing channel, we examine whether the financing channel only exists in emerging industries which are characterized by high technology content, high added value, and high financing demand.

We focus on the overall level of regional venture capital development. Previous studies have typically used whether a company receives venture capital as a measure (Arqué-Castells, 2012; Sun et al., 2020). Therefore, from a regional perspective, we characterize the level of regional venture capital development based on the total number of companies receiving venture capital in each city each year. We collect venture capital development and technology commercialization data for 225 cities in China from the incoPat Global Patent Database, the Center for Enterprise Research (CER) of Peking University and the China City Statistical Yearbook. Our sample includes vice-provincial cities and prefecture-level cities. Our results show that cities with better development of venture capital exhibit higher technology commercialization performance than cities with lower levels of venture capital development. The results are robust to alternative instrumental variables (such as the multiples of returns and the internal rates for venture capital firms within the city), alternative venture capital measures (such as the number of financing events involving venture capital institutions), different measures for independent according different types of patents, and alternative regression models (such as seemingly unrelated regression model, the ordinary least squares model, panel tobit model, panel negative binomial model and zero-inflated negative binomial model). And our empirical results demonstrate the existence of three possible economic channels (search channel, cooperation channel, and financing channel) through which venture capital development affects technology commercialization.

This paper offers new insights into the real effects of venture capital development and contributes to the literature in several ways. First, it contributes to the emerging literature on the relationships between venture capital development and innovation. Kortum and Lerner (2000) found that venture capital greatly promoted patented innovations in the United States. Starting from this first empirical study, the following studies gradually extend to multi-perspectives, different industries and diversified indicator, the sample countries also extend from the United States to Germany, Italy, Canada and China (Baum & Silverman, 2004; Bertoni & Tykvová, 2015; Caselli et al., 2009; Engel & Keilbach, 2007; Popov & Roosenboom, 2013; Sun et al., 2020). Most of previous studies focus on the effect of venture capital on innovation from the perspective of technology creation, while we focus on the commercialization of technology which reflects the transformation from innovative achievements into advanced productivity. Our paper complements this emerging body of the literature.

Second, this paper contributes to the literature on venture capital and commercialization by conducting systematic empirical research. From some existing researches, such as exploring the impact of venture capital on the performance of university spin off companies (Fini et al., 2023), innovative young companies (Colombo et al., 2016), and corporate innovation strategies (Hsu et al., 2006; Wonglimpiyarat, 2010; Da Rin & Penas, 2017; Karlson, 2021), we can find some indirect evidence about the positive impact of venture capital on technology commercialization. Different from these studies, we use rich cross-city data set to directly examine the specific impact mechanisms of venture capital development on technology commercialization. Particularly, Samila and Sorenson (2010) observe commercialization through patenting and the birth of companies, and they argue that a local venture capital might serve as a critical catalyst to commercialization. However, we study the similar issue by observing patent transfer activities that more accurately reflect technology commercialization and distinguish it from technology creation, and reached similar conclusions, but explored the mechanism behind it.

Third, we offer a method for causal identification between venture capital development and technology commercialization by taking the IPO rate as an instrumental variable. In addition, we also offer novel identification to measure the causal effects of a change of limited partnership system by exploiting a natural experiment in which the shock was exogenous to regional venture capital development. In fact, our natural experiment approximates a setting in which the development of venture capital in some cities is more affected by the “experiment shock” than others. These results all demonstrate a causal effect of venture capital development on technology commercialization.

Fourth, we identify three channels through which venture capital development promote technology commercialization. The first channel operates via the ability of providing professional consulting and monitoring services and social network resources of venture capital to improve technology search efficiency. The second channel operates through the ability of venture capital to provide cooperative resources, which stably connect enterprises and universities to promote technology commercialization. The last channel operates via the financing ability of venture capital to cultivate technology commercialization with high failure probability and high capital demand.

The remainder of the paper is organized as follows. In Sect. 2, we discuss various economic theories and develop our testable hypotheses. In Sect. 3, we describe our empirical strategy and provide summary statistics. In Sect. 4, we report our main empirical results. In Sect. 5, we examine three channels through which venture capital affects technology commercialization. Finally, we conclude the study with some implications and limitations.

2 Theoretical analysis and research hypothesis

2.1 Venture capital development and technology commercialization

Previous literature argued that financial development is crucial to a country’s innovation (Ding et al., 2022; Hsu et al., 2014; Nanda & Rhodes-Kropf, 2017; Schumpeter, 1911). Venture capital and technology commercialization are important components of financial market and technology innovation respectively. Therefore, it can be inferred from the existing literature that better development of venture capital means better financial development, which leads to higher levels of technology commercialization, and the "Silicon Valley Miracle" and "Cambridge Phenomenon" are just real-life verifications.

Technology commercialization, also known as the transformation of scientific and technological achievements, refers to the process of effectively utilizing the technological achievements or transforming the technology factors into commodities in the market (Liu et al., 2017, 2021; Min et al., 2019). There is often a considerable gap between technology factors supply and utilization demand or market demand (Liu et al., 2023a, 2023b; Min et al., 2020). This gap is the source of unexpected costs and high risks (Hellmann, 2007). However, venture capital is better at dealing with high costs and risks due to its ability to mitigate information asymmetry, evaluate innovative projects, explore the potential of market utilization and provide other value-added services, while traditional financial intermediaries may not do well (Chemmanur et al., 2014; Hellmann & Puri, 2002; Sun et al., 2020; Tian & Wang, 2014).

From the perspective of commercialization stage, venture capitalists usually rely on its own financial and non-financial resources to remove the barriers faced by the investee firms at the various stages of technology commercialization—technology search, technology acquisition, and product testing and manufacturing stages. During the technology search stage, venture capitalists leverage their specialized knowledge to optimize the technology search strategy of their investee firms based on comprehensive consideration of market demand and technological advance, thereby efficiently identifying target technologies for commercialization. In the subsequent stage of technology acquisition, venture capitalists leverage their social network resources to support the technology commercialization cooperation among various partners in the innovation system, thereby facilitating technology transactions and helping investee firms acquire technology. During the product testing and manufacturing stage after acquiring technology, venture capitalists provide substantial financial support to help the investee firms complete the final process of technology development, prototype testing, and product production (Jung et al., 2015), thereby transforming technology into commodities and real productivity. Therefore, in theory, the development of venture capital will promote the commercialization of technology with the characteristics of high costs and risks. The above discussion leads to our hypothesis.

Hypothesis 1 Venture capital development has a positive effect on regional technology commercialization.

2.2 Economic channels for the impact of venture capital on technology commercialization

In this section, we will specifically discuss how the development of venture capital can catalyze the commercialization of technology from three aspects based on the various stages of technology commercialization. We regard technology commercialization as a finite process, from technology search, acquisition, to productization. Notably, the various stages of technology commercialization process may be subject to overlap to some degree (Jung et al., 2015). Therefore, we consider the main technology activities and the role of venture capital in each stage.

Technology search is the first stage of technology commercialization. To enhance their competitiveness, an increasing number of companies search and identify promising technologies from a wide range of external sources such as customers, suppliers, competitors, or universities (Laursen & Salter, 2006). In the search process, the transaction cost and search cost for either inventors or enterprises to establish matching in technology market are very high (Liu et al., 2017, 2023a, 2023b). Building and sustaining deep links and stable match with external technology sources in technology market, as well as designing optimal search or match strategies, both require professional knowledge and substantial resource investment (Zhang et al., 2019). Venture capital may be able to meet these needs. On the one hand, venture capitalists contribute to expanding the scope of technology search through its social network resources. Gompers and Mukharlyamov (2022) pointed out that prior to launching career as venture investor, many venture capitalists founded a startup, worked in a consulting company, studied in universities, etc. And venture capitalists can facilitate the exchanges of innovation resources related to patent reassignments between companies sharing common venture capitalists (González-Uribe, 2020). The diversified experience makes venture capitalists have more social network resources, which may reduce the search cost transaction cost in technology market. Therefore, the development of regional venture capital will provide more technology selection opportunities for enterprises in the region.

On the other hand, venture capitalists enhance technology search efficiency by providing professional consulting and monitoring services. Venture capitalists typically possess both technical and market knowledge, enabling them to rapidly search for and identify the required technology for the investee firms based on market demand, and optimize the technology search strategy for investee firms. This specialized technology search strategy can improve the efficiency of technology search activities and minimize search costs (Sofka & Grimpe, 2010).

Therefore, the development of venture capital contributes to the rapid identification and discovery of technology within the region, thus promoting the commercialization of technology activities. The above discussion leads to our hypothesis.

Hypothesis 2 The development of venture capital promotes regional technology commercialization by improving technology search efficiency.

After identifying the required technologies, the next stage involves collaboration and transaction between investee firms and technology owners. Universities and scientific research institutes, as crucial technology owners in the innovation system, generate a substantial amount of research results including highly novel technologies (Chang et al., 2017; Cohen et al., 2002; Liu et al., 2020; Sofka & Grimpe, 2010). However, these technologies may be far from being applied and developed into final products because commercialize technology requires capabilities derived from prior industry and entrepreneurial experience, which universities and scientific research institutions may lack (Bonardo et al., 2010). Meanwhile, many enterprises aim to take advantage of the rich accumulated knowledge and existing technologies of universities and scientific research institutes based on diverse motivations, such as reducing the R&D cost, learning about uncertain and turbulent technological change, achieving innovation intended to open new markets etc. (Dodgson, 1993; Min et al., 2019; Nieto & Santamaría, 2007). Therefore, more and more enterprises are seeking to cooperate with universities and scientific research institutes, and vice versa. Moreover, Carayannis et al. (2016) defines technology commercialization as the process of turning the research results of universities into products that can be sold in the marketplace. This underscores the significance of technology collaboration between universities and industry in technology commercialization activities.

Teece (1993) argue that the successful commercialization of a technology requires the technology be utilized in conjunction with other innovation resources that the original technology owners lack and seldom develop themselves. The challenge lies in the high cooperation cost that can obstruct the exchanges of innovation resources among different innovation subjects such as enterprises, universities, and scientific research institutions (Liu et al., 2017, 2023b). However, venture capital institutions have great advantages in rich capital, strong social network of contacts and diversified information resources. Unlike traditional financial intermediaries, venture capital plays a broader role in the companies they finance (Gorman & Sahlman, 1989). Their active involvement in enterprise management could help enterprises find innovation partners through its own network resources and risk sharing capacity (Arqué-Castells, 2012). Therefore, the development of venture capital will promote the cooperation between universities, which possess abundant technologies but lack commercialization capabilities, and business with rich technology commercialization resources. As such, we anticipate that the development of venture capital will facilitate university-based technology commercialization, which reflects the cooperation between universities, scientific research institutions and businesses. Based on the above analysis, the hypothesis is put forward as:

Hypothesis 3 The development of venture capital promotes regional technology commercialization by promoting the cooperation between universities, scientific research institutions and businesses.

Although sufficient financial support is crucial in each stage, it becomes especially vital in the final commercialization stage (how to stride over "valley of death"), such as technology utilization scenarios, product testing, and market promotion. Technology commercialization, as an applied innovation activity, differs from technology creation that primarily focuses on scientific content. Instead, it involves aspects such as market, production, and capital, etc. (Carayannis et al., 2016; Liu et al., 2017). For instance, to progressively narrow the gap between technology factors supply and utilization or market requirements, multiple experiments and explorations are necessary. This is particularly true for the technology commercialization of emerging industries, where there are more unknown factors, leading to greater capital requirements and higher risks. This is why not all technologies generated through research and development can successfully become market products. Therefore, the technology commercialization is a high-risk investment process with high capital demand and high uncertainty. As a results, the technology transformation, like R&D, will also suffer from limited external finance.

Fortunately, venture capital is usually viewed as the market solution to financing. As a form of private equity financing, venture capital is more willing to provide long-term investment for early small and medium-sized enterprises, which are the main body of technology commercialization activities. Venture capital is viewed by many as an important financing method for technology-based companies because of its ability to address the information asymmetries affecting innovative firms (Hall & Lerner, 2010). For instance, venture capital often plays a role at the top of the organization (Hellmann & Puri, 2002), separately allocates control rights including cash flow rights, board rights, voting rights (Kaplan & Strömberg, 2003), and sign a time-varying share contract which provides intertemporal risk-sharing between venture capitalist and entrepreneur (Bergemann & Hege, 1998). These abilities and the purpose of venture capital to obtain high returns from high-risk activities make venture capital more willing to invest innovation activities than other types of financial intermediaries. Accordingly, the hypothesis 4 is put forward:

Hypothesis 4 The development of venture capital promotes regional technology commercialization by providing sufficient funds.

3 Data, variables, and empirical specifications

3.1 Data and sample

For the empirical analysis, we use a panel data of 225 cities in China during 2002 to 2017 due to data availability constraints.

In this panel data, municipalities directly under the Central Government are excluded from this sample because they have incomparable advantages in terms of policy and economy. We also excluded cities that had previously undergone administrative level adjustments (such as upgrading from county-level cities to prefecture level cities), city name changes, as well as cities with missing data. These 225 sample cities are from eastern, central, and western regions of China, with a wide geographical distribution. Each city exhibits certain variations in the development of venture capital and innovation activities. These cities' boundaries are based on administrative boundaries. The data in city level includes all administrative regions of the city. These cities' economic data is collected form the China City Statistical Yearbook.

3.2 Empirical specifications

This study examines the above hypotheses through panel data at the city level. To examine how the development of venture capital affects technology commercialization, we estimate the following baseline empirical model:

$$ln\_transfer_{it} = \alpha_0 + \alpha_1 VC_{it-1} + \alpha_2 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where i and t index the city and the year, respectively. $ln\_transfer_{it}$ is the logarithm of one plus the number of patents that have been commercialized, which can be represented by the total number of city i's patents transferred within the city i and to other cities; VC_{it-1} represents the development of venture capital in city i in year $t-1$; $\mathbf{X}_{it}$ is a vector of the control variables which are related with the local technology commercialization. City fixed effects μ_i control for time-invariant characteristics of cities that might both attract venture capital and influence technology commercialization. Year fixed effects λ_t control for economic factors that might commonly influence the outcomes and venture capital for all cities, and ε_{it} is the idiosyncratic error term.

To handle potential endogeneity problems, we employ two-stage least squares instrumental variable (2SLS-IV) model. Hence, we can alleviate potential omitted variable bias and reverse causality issues. The first stage of 2SLS regression is:

$$VC_{it} = \alpha_0 + \alpha_1 IPO\_rate_{it} + \alpha_2 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

where IPO_rate_{it} is our instrumental variable for city i in year t. Following the work of Nanda et al. (2020) on the construction of instrumental variables, we select the IPO rate of enterprises that have received venture capital funding as our instrumental variable.

3.3 Measurement

3.3.1 Technology commercialization

Using patent data to measure innovation performance has been widely adopted in previous studies (Ding et al., 2022; Liu et al., 2019; Hu & Liu, 2022; Hsu et al., 2014), we also focus on the technology of patents. Stimulated by the growing industry technology demand, technology commercialization is always based on patent transfer (Liu et al., 2021) and spatial flow of technology factors among cities (Liu et al., 2023a, 2023b). So we employ the total number of city's patents that are transferred within the city and to other cities based on the assignment of patent in each city as the indicator of technology commercialization. The data about cities' technology commercialization performances come from the patent information in incoPat Global Patent Database. The patent database contains patent transfer information and provides annual information regarding the type of patent, the type of patent applicant, the city where the patent inventor is located, the city where the patent assignee is located, the industry category of patent and the year in which a patent application was filed. Therefore, we construct four technology commercialization measure, including the total number of patent commercialization ($transfer^{total}$), the number of invention patents commercialization ($transfer^{invent}$), the number of utility model patents commercialization ($transfer^{utility}$) and the number of industrial design patents commercialization ($transfer^{design}$) in the 225 cities.

3.3.2 Venture capital

The data about the development level of city venture capital come from the Center for Enterprise Research (CER) of Peking University. The CER use the full amount of enterprise information in the national industrial and commercial enterprise registration database and constructs the Index of Regional Innovation and Entrepreneurship in China (IRIEC) from five dimensions, one of which is venture capital development level. This sub-dimension indicator is based on the number of enterprises that receive venture capital in each city each year. After logarithmic and within-group standardization processing, the quantile of each city each year is calculated as the index to measure the development of venture capital. More detailed information on the indicator construction method can be found in Dai et al. (2021), where the index is specifically introduced as a primary research outcome.[1]

3.3.3 Instrumental variable

Our instrumental variable is the IPO rate of enterprises in a city that have received venture capital funding. The specific construction method is as follows:

$$IPO\_rate_{it} = \sum_{s=t-1}^{t-3} \frac{Exit\_ipo_{is}}{Exit_{is}} \quad (3)$$

[1] The index is sourced from Peking University Open Research Data (https://doi.org/10.18170/DVN/NJIVQB).

where $Exit\_ipo_{is}$ is the number of investment exit events in city i where venture capital firms exit through investee firms' initial public offerings (IPOs) in year s. $Exit_{is}$ represents the total number of investment exit events for venture capital firms in city i in year s. The IPOs is considered successful exit pathways in the existing literature, and as such, IPO exits typically yield positive returns. Venture capital firms, in turn, enhance their reputation and confidence through successful investments via IPO exits. Therefore, the sum of IPO rates from the past three years will directly influence the current year's venture capital activities. However, the IPO rates may not directly impact the commercialization of technology. Nevertheless, considering that our study is conducted at the city level and macroeconomic factors may affect both IPO and technology commercialization simultaneously, we have included GDP growth rate as a control variable to ensure that the IPO rates meet exogenous conditions as much as possible.

As a robustness test, following the research of Samila and Sorenson (2011), we also constructed two alternative instrumental variables: the multiples of returns for venture capital firms within the city (*Return*) and the internal rates of return (IRR) for venture capital firms within the city (*IRR*). The construction method of these two instrumental variables is as follows:

$$Return_{it} = \sum_{s=t-1}^{t-3} \frac{\sum_j R_{ijs}}{N_{is}} \tag{4}$$

$$IRR_{it} = \sum_{s=t-1}^{t-3} \frac{\sum_j I_{ijs}}{N_{is}} \tag{5}$$

where R_{ijs} represents the investment return of venture capital firm j within city i in year $s.I_{ijs}$ represents the internal rates of return of venture capital firm j within city i in year s. N_{is} represents the total number of venture capital firms within city i in year s. Higher investment return and IRR over the recent past will encourage venture capital firms to engage in more proactive investment activities in the coming years. Therefore, the higher the average return for venture capital firms within the city, the more active the venture capital activities in the city. The data related to instrumental variables are sourced from PEDATA MAX, a professional SaaS system under Qingke Entrepreneurship that focuses on private equity investment.

To avoid endogeneity problems, we also control for a vector of city characteristics ($\mathbf{X}_{it}$) that may affect a city's technology commercialization. In the baseline regressions, $\mathbf{X}_{it}$ includes the development level (*cgdp*), innovation level (*innovation*), government public education service level (*edu*), city size (*pop*), industrial structure (*industry*), investment structure (*investment*), degree of fiscal autonomy (*fd*), population aggregation degree (*popindens*), geographical distance to technology trading centers (*distance*), and the number of firms in the city (*firm*).

The detailed definitions and sources of the variables used in this study are presented in Table 1, while Table 2 provide the summary statistics, and Table 3 shows the correlation matrix for the variables used in our analysis. In Table 2, the rows (1) to (4) show the actual values of patent commercialization, invention patents commercialization, utility model patents commercialization and industrial design patents commercialization. The average number of invention patent commercialization is slightly smaller than the average number of utility model commercialization. However, according to the data released by the National

Table 1 Description of the variables

Variables	Description and measurement
$ln\_transfer_{it}^{total}$	Patent commercialization is measured by the natural logarithm of one plus the number of transferred patents, including inventions, utility models, and industrial designs. The data is sourced from incoPat Global Patent Database
$ln\_transfer_{it}^{invent}$	Invention patent commercialization is measured by the natural logarithm of one plus the number of transferred invention patents. The data is sourced from incoPat Global Patent Database
$ln\_transfer_{it}^{utility}$	Utility model patent commercialization is measured by the natural logarithm of one plus the number of transferred utility model patents. The data is sourced from incoPat Global Patent Database
$ln\_transfer_{it}^{design}$	Industrial design patent commercialization is measured by the natural logarithm of one plus the number of transferred industrial design patents. The data is sourced from incoPat Global Patent Database
VC	Venture capital development is measured by the sub-dimension indicator of IRIEC, which is constructed by the number of firms that receive venture capital. The data is sourced from Peking University Open Research Data[a]
cgdp	Economic development level is measured by GDP growth rate. The data is sourced from the China City Statistical Yearbook
edu	Government public education service level is measured by the shares of the education expenditure in total government expenditures. The data is sourced from the China City Statistical Yearbook
pop	City size is measured by the resident population, and its unit is 10,000 people. The data is sourced from the China City Statistical Yearbook
industry	Industrial structure is measured by the percentage of tertiary industry to GDP. The data is sourced from the China City Statistical Yearbook
investment	Investment structure is measured by the proportion of real estate investment in fixed asset investment. The data is sourced from the China City Statistical Yearbook
innovation	Innovation level is measured by the number of invention patents granted. The data is sourced from incoPat Global Patent Database
fd	Degree of fiscal autonomy is measured by the ratio of budget revenue to budget expenditure. The data is sourced from the China City Statistical Yearbook
popindens	Population aggregation degree is measured by population divided by area, and its unit is 1/km2. The data is sourced from the China City Statistical Yearbook
firm	Firms in city is measured by the number of industrial enterprises. The data is sourced from the China City Statistical Yearbook
distance	Geographical distance[b] to technology trading centers is measured by the minimum spatial distance between the city and the four major technology transaction center cities[c] in China. The data is based on the straight-line distance between city centers calculated using ArcGIS and its unit is km
IPO_rate	The sum of IPO rates in the past three years for firms invested by venture capital. The data is sourced from PEDATA MAX
Return	The sum of the average multiples of returns for venture capital firms over the past three years. The data is sourced from PEDATA MAX
IRR	The sum of the average IRR of venture capital firms over the past three years. The data is sourced from PEDATA MAX

[a] https://doi.org/10.18170/DVN/NJIVQB

[b] One limitation of geographical distance is that it is time-invariant. Therefore, we multiply the geographical distance by the year dummy variable in the regression, rendering it time-variant

[c] The four cities are Beijing (located in northern China), Shanghai (located in eastern China), Shenzhen (located in southern China), and Xi'an (located in western China). The selection of these four cities as technology trading centers is based on the "Annual Report on Statistics of China Technology Market " published by the Torch High Technology Industry Development Center of the Ministry of Science and Technology of China. This report provides statistics on the number and transaction volume of technology

Table 1 (continued)

trading institutions in various cities, and the technology trading institutions in these four cities are relatively active

Table 2 Summary statistics

Variables	N	mean	SD	min	max
$transfer_{it}^{total}$	3600	156.4172	571.2384	0	15,608
$transfer_{it}^{invent}$	3600	65.7342	292.3405	0	8,835
$transfer_{it}^{utility}$	3600	70.4881	241.8152	0	4,962
$transfer_{it}^{design}$	3600	20.1950	76.9977	0	1,811
$ln\_transfer_{it}^{total}$	3600	2.9438	2.0665	0	9.6556
$ln\_transfer_{it}^{invent}$	3600	2.1036	1.8581	0	9.0866
$ln\_transfer_{it}^{utility}$	3600	2.3050	1.9332	0	8.5098
$ln\_transfer_{it}^{design}$	3600	1.2480	1.5751	0	7.5022
VC	3600	68.8970	14.1754	55.1168	100
cgdp	3596	11.5815	3.9276	-15.3000	32.9000
edu	3597	18.7051	4.7296	0	39.5124
pop	3600	460.6898	237.2269	0	1,435
industry	3597	37.0785	8.4141	0	77.4900
investment	3597	15.1154	11.1767	0	142.6650
innovation	3598	378.6434	1,170.0026	0	18,041
fd	3600	0.5064	0.2261	0.0555	1.7392
popindens	3534	465.8208	312.8795	0	2,661.5400
firm	3596	6.6311	0.9992	3.9512	9.5267
distance	3600	473.5856	274.819	0	1,384.7744
IPO_rate	3600	0.2309	0.5003	0	3
Return	3600	2.3479	7.3028	0	120.9100
IRR	3600	29.9629	72.7857	0	546.4400

This table reports summary statistics of variables used in the regressions estimated with the full sample consisting of city-year observations; Venture capital variables (*VC*) are lagged by one year

Bureau of Statistics, the number of domestic utility model patent applications accepted in China is far greater than that of domestic invention patents accepted.[2] Therefore, compared with the utility model patents, the number of invention patent applications is much less, but the number of invention patents transferred is not correspondingly less, which reflects that the technical level and the value of invention patents is higher and it is more likely to be commercialized than the utility model. Given that the technology commercialization variables have sizable standard deviations and the measures are highly skewed, we use the logarithm of these variables in the regression analyses, which showed in rows (5) to (8). To avoid losing city-year observation with zero patents, we add one to the actual values when

[2] According to the national statistical database query, in 2020, the number of domestic invention patents accepted was 1,344,817, and the number of domestic utility model patent applications accepted was 2,918,874, which is much higher than the former.

Table 3 Correlation coefficients for the key variables

Variables	1	2	3	4	5	6	7	8	9	10
1. $transfer_{it}^{total}$	1									
2. $transfer_{it}^{invent}$	0.955***	1								
3. $transfer_{it}^{utility}$	0.955***	0.839***	1							
4. $transfer_{it}^{design}$	0.792***	0.654***	0.761***	1						
5. $ln\_transfer_{it}^{total}$	0.514***	0.440***	0.534***	0.468***	1					
6. $ln\_transfer_{it}^{invent}$	0.552***	0.499***	0.560***	0.443***	0.944***	1				
7.$ln\_transfer_{it}^{utility}$	0.519***	0.433***	0.556***	0.459***	0.963***	0.898***	1			
8. $ln\_transfer_{it}^{design}$	0.538***	0.425***	0.554***	0.634***	0.807***	0.723***	0.752***	1		
9. *VC*	0.418***	0.372***	0.426***	0.349***	0.724***	0.740***	0.702***	0.613***	1	
10. *cgdp*	− 0.151***	− 0.135***	− 0.167***	− 0.084***	− 0.287***	− 0.319***	− 0.297***	− 0.140***	− 0.228***	1
11. *edu*	− 0.074***	− 0.088***	− 0.061***	− 0.0260	− 0.106***	− 0.137***	− 0.086***	− 0.030*	− 0.183***	0.031*
12. *pop*	0.130***	0.123***	0.136***	0.071***	0.280***	0.285***	0.265***	0.251***	0.226***	− 0.0150
13. *industry*	0.361***	0.332***	0.358***	0.291***	0.484***	0.517***	0.460***	0.455***	0.494***	− 0.310***
14. *investment*	0.407***	0.358***	0.416***	0.357***	0.511***	0.509***	0.494***	0.506***	0.452***	− 0.114***
15. *innovation*	0.510***	0.448***	0.520***	0.452***	0.495***	0.535***	0.498***	0.508***	0.472***	− 0.078***
16. *fd*	0.316***	0.266***	0.322***	0.320***	0.471***	0.459***	0.436***	0.507***	0.476***	0.079***
17. *popindens*	0.301***	0.260***	0.291***	0.331***	0.376***	0.343***	0.346***	0.429***	0.299***	0.036**
18. *firm*	0.390***	0.319***	0.405***	0.407***	0.723***	0.666***	0.690***	0.679***	0.568***	0.0240
19. *distance*	− 0.179***	− 0.139***	− 0.184***	− 0.222***	− 0.238***	− 0.189***	− 0.228***	− 0.295***	− 0.220***	− 0.0230
20. *IPO_rate*	0.344***	0.271***	0.376***	0.341***	0.527***	0.531***	0.530***	0.528***	0.451***	− 0.098***
21. *Return*	0.326***	0.275***	0.332***	0.332***	0.403***	0.408***	0.405***	0.404***	0.361***	− 0.093***
22. *IRR*	0.343***	0.276***	0.363***	0.354***	0.508***	0.522***	0.518***	0.508***	0.450***	− 0.126***

Variables	11	12	13	14	15	16	17	19	20	21	22
1. $transfer_{it}^{total}$											
2. $transfer_{it}^{invent}$											

Table 3 (continued)

Variables	11	12	13	14	15	16	17	19	20	21	22
3. $transfer_{it}^{utility}$											
4. $transfer_{it}^{design}$											
5. $ln\_transfer_{it}^{total}$											
6. $ln\_transfer_{it}^{invent}$											
7.$ln\_transfer_{it}^{utility}$											
8. $ln\_transfer_{it}^{design}$											
9. *VC*											
10. *cgdp*											
11. *edu*	1										
12. *pop*	0.205***	1									
13. *industry*	− 0.125***	0.155***	1								
14. *investment*	− 0.114***	0.128***	0.481***	1							
15. *innovation*	− 0.136***	0.171***	0.364***	0.312***	1						
16. *fd*	− 0.167***	0.053***	0.217***	0.319***	0.408***	1					
17. *popindens*	0.048***	0.356***	0.109***	0.242***	0.302***	0.374***	1				
18. *firm*	− 0.0240	0.448***	0.267***	0.364***	0.425***	0.636***	0.513***				
19. *distance*	− 0.157***	− 0.113***	− 0.085***	− 0.128***	− 0.182***	− 0.293***	− 0.334***	1			
20. *IPO_rate*	− 0.031*	0.142***	0.267***	0.327***	0.442***	0.394***	0.256***	− 0.175***	1		
21. *Return*	− 0.0150	0.098***	0.219***	0.236***	0.403***	0.303***	0.195***	− 0.153***	0.553***	1	
22. *IRR*	− 0.047***	0.163***	0.264***	0.289***	0.512***	0.359***	0.267***	− 0.157***	0.706***	0.558***	1

taking natural logarithm. For independent variable, we use one-period lagged of the development of venture capital as the independent variable (*VC*).

4 Empirical analysis

4.1 Baseline findings

In this section, we present the regression results using the instrumental variable (*IPO_rate*). Table 4 reports the 2SLS regression results on the influence of venture capital on the technology commercialization, while in Tables 15 and 16 of the "Appendix", we provide the regression results based on the other two instrumental variables.

Since $ln\_transfer_{it}$ is in the logarithmic forms, the regression coefficient estimate gives us the semi elasticity of technology commercialization to venture capital. All regressions include year fixed effects and city fixed effects. The robust standard errors are clustered by cities. Columns (1) and (2) show the first stage regression results. The coefficient of instrumental variable is very significant and F statistic of the first stage is larger than 10, which suggesting that an increase in successful exits of venture capital investments will promote the development of local venture capital.

Columns (3) to (6) show the IV results. Column (3) shows the effect of venture capital on technology commercialization, where technology includes invention patents, utility model patents and industrial design patents. With variables representing urban characteristics controlled, the estimated coefficient of patents to venture capital is 0.13. This means that 1 unit of increase in the development of venture capital on average leads to a 13% increase in the number of patents transferred. Column (4) shows the effect of venture capital on the commercialization of invention patents, column (5) shows the effect of venture capital on the commercialization of utility model patents and column (6) shows the effect of venture capital on the commercialization of industrial design patents. By comparing the coefficients of different models in columns (3) to (6), we find that venture capital development has a more substantial promotion effect on the commercialization of invention patent technologies. This might be attributed to the fact that invention patents are more innovative and possess higher value, which results in the potential for greater returns upon their commercialization. Therefore, the commercialization of invention patents becomes a focal investment activity for many venture capital firms.

Columns (3) to (6) show that the CDW F statistic (Cragg-Donald Wald F statistic) and KPW F statistic (Kleibergen-Paap rk Wald F statistic) are much larger than the Stock-YOGO weak identification test critical value with 15% maximal IV size (8.96), which verify again that the IV we select is relative to independent variables. The IV estimation results indicates that the effect of venture capital development on technology commercialization is significantly positive after excluding the endogeneity. Our Hypothesis 1 is verified.

When measuring the commercialization of technology, we consider both technology transferred locally and technology transferred to other cities. As shown in Table 5, the average percentage of various types of patents transferred locally among all transferred patents ranges from 0.4093 to 0.5091, which indicates the number of technologies transferred locally and to other cities are similar, although there are slightly more technologies transferred to other cities.

Table 4 Influence of venture capital on the technology commercialization

Variables	First stage		2SLS-IV: Technology commercialization			
	VC		Patent	Invention	Utility model	Industrial design
	(1)	(2)	(3)	(4)	(5)	(6)
IPO_rate	1.3975***	1.2547***				
	(0.4095)	(0.4062)				
VC			0.1344**	0.2379***	0.2170***	0.1801***
			(0.0549)	(0.0811)	(0.0787)	(0.0678)
cgdp		0.0251	− 0.0077	− 0.0056	− 0.0160	0.0009
		(0.0618)	(0.0101)	(0.0150)	(0.0138)	(0.0124)
edu		− 0.0069	0.0130	0.0197*	0.0169	0.0003
		(0.0507)	(0.0082)	(0.0118)	(0.0117)	(0.0093)
pop		0.0046	0.0011	0.0003	0.0006	0.0009
		(0.0073)	(0.0011)	(0.0019)	(0.0017)	(0.0014)
industry		0.1286***	− 0.0097	− 0.0179	− 0.0258*	− 0.0155
		(0.0486)	(0.0096)	(0.0145)	(0.0140)	(0.0124)
investment		− 0.0048	0.0056*	0.0077	0.0076	0.0066
		(0.0227)	(0.0030)	(0.0049)	(0.0051)	(0.0047)
innovation		− 0.0001	0.0000	0.0002***	0.0002***	0.0001**
		(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
fd		2.1148	− 0.1772	− 0.2003	− 0.3104	− 0.0315
		(1.7634)	(0.3446)	(0.4817)	(0.5084)	(0.4203)
popindens		− 0.0068*	0.0003	0.0015	0.0015	0.0012
		(0.0035)	(0.0007)	(0.0011)	(0.0011)	(0.0009)
firm		1.1355	0.3213***	0.0644	0.1190	− 0.1725
		(0.7193)	(0.1096)	(0.1772)	(0.1598)	(0.1429)
Constant	61.4105***	69.6732***				
	(0.4338)	(5.7096)				
distance	NO	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
F statistic	79.54	39.03	66.42	23.03	28.34	8.37
CDW F statistic			12.337	12.337	12.337	12.337
KPW F statistic			9.542	9.542	9.542	9.542
Observations	3600	3489	3489	3489	3489	3489
R^2	0.464	0.471	0.421	− 0.649	− 0.263	− 1.294

The observation unit in this analysis is city-year. The dependent variable in columns (1) and (2) is the development of venture capital, which mean estimated result of IV estimate first stage. The dependent variable in column (3) is the natural logarithm of one plus the number of patents including invention, utility model and industrial design that are transferred in a year. The dependent variable in column (4) is the natural logarithm of one plus the number of invention patents that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of utility model patents that are transferred in a year; The dependent variable in column (6) is the natural logarithm of one plus the number of industrial Design patents that are transferred in a year. All models in columns (1) to (6) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; F statistic in columns (1) and (2) is the statistic for correlation test between IV and independent variable. CDW F statistic (Cragg-Donald Wald F statistic) and KPW F statistic (Kleibergen-Paap rk Wald F statistic) are the statistic for weak identification test. The Stock-YOGO weak identification test critical value with 15% maximal IV size is 8.96 and the value with 10% maximal IV size is 16.38. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

Table 5 Summary statistics on the proportion of technology transfer locally

	N	Mean	SD
The percentage of patents transferred locally among all transferred patents	3133	0.4093	0.3179
The percentage of invention patents transferred locally among all transferred patents	2764	0.4346	0.3340
The percentage of utility mode patents transferred locally among all transferred patents	2761	0.4252	0.3529
The percentage of industrial design patents transferred locally among all transferred patents	1923	0.5091	0.4068

The observation unit is city-year

Table 6 The impact of venture capital on the commercialization of technology transferred locally and out of city

	Patent		Patent for invention		Patent for utility model		Patent for industrial design	
	Local	Non local	Local	Non local	Local	Non local	Local	Non local
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VC	0.2599***	0.1344**	0.3331***	0.1916***	0.3035***	0.2054***	0.2427***	0.0816*
	(0.0929)	(0.0546)	(0.1130)	(0.0676)	(0.1047)	(0.0785)	(0.0917)	(0.0465)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
N	3489	3489	3489	3489	3489	3489	3489	3489
R^2	−0.405	0.138	−1.879	−0.687	−1.028	−0.852	−3.413	−0.226

The observation unit in this analysis is city-year; The first-stage regression results are same to the results in columns (1) and (2) of Table 4. Therefore, only the final regression results are presented here; The dependent variable in odd columns is the natural logarithm of one plus the number of patents that are transferred to local city in a year; The dependent variable in even columns is the natural logarithm of one plus the number of patents that are transferred to other cities in a year; All models in columns (1) to (8) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

Therefore, we further examine whether there are differences in the impact of venture capital on the commercialization of technology transferred locally and technology transferred to other cities. Table 6 reports the 2SLS regression results on the influence of venture capital on the technology commercialization after distinguishing technology transfer locations. The odd columns show the impact of venture capital on the commercialization of locally transferred technology, while even columns show the impact of venture capital on the commercialization of technology transferred to other cities, with a slightly smaller venture capital coefficient. The results indicate that the local development of venture capital is more conducive to the local application and commercialization of various types of patent technologies.

4.2 Alternative regression models

As shown in Table 3, there is a correlation among the commercialization of various types of patent technologies. Therefore, the error terms of regressions reported in Table 4 may be correlated as well. To mitigate this estimation bias and as a robustness check, we employ a Seemingly Unrelated Regression (SUR) model. The results in Table 7 demonstrate that even after employing the SUR model, the development of venture capital continues to have a promoting effect on technology commercialization. Moreover, its effect on the commercialization of invention patent technologies is greater than on other types, which is consistent with the conclusion obtained using the 2SLS model.

Furthermore, we also report the ordinary least squares (OLS) regression results on the influence of venture capital on the technology commercialization in Columns (1) and (2) of Table 8. Considering that the value of *technology commercialization* is greater than or equal to 0, we use the panel tobit model that fits for panel data where the outcome variable is censored. Columns (3) and (4) of Table 8 show the regression results based on panel tobit model including year fixed effects and province fixed effects and the robust standard errors (in parentheses) are based on a bootstrap method. The estimated coefficient of technology commercialization to venture capital is also positive.

Taking into consideration the nonnegative nature and the discrete nature of patent data, we also use a negative binomial model. Columns (5) and (6) show that the regression results based on panel negative binomial model including year fixed effects and city fixed effects and the robust standard errors are based on a bootstrap method, the results suggest that the coefficient estimates of venture capital variables are all positive and significant. Because there is a situation that the number of technology commercialization in many cities is zero. Therefore, columns (7) and (8) show the results based a zero-inflated negative binomial model. The results show that the coefficient estimates of venture capital variables are all positive and significant. All these results show that the higher the development level of venture capital in a city, the more likely the technology of the city is to realize commercialization and industrialization through technology transfer, confirming that capital factor from venture capital is important for the transforming technology into practical productive forces. In this section, we focus exclusively on the commercialization of invention patent technologies, given their higher commercialization value. The estimation results including all types of patent technologies are provided in Table 17 of the "Appendix".

4.3 Alternative measure

Our main venture capital measure is conducted by standardizing the number of new VC-backed enterprises using Z-score method and then calculating the quantile, which is one of the dimensions of the index of Regional Innovation and Entrepreneurship in China. Alternatively, we have used the number of financing events involving venture capital firms (*ln_VC_events*) to measure venture capital. The more financing events that venture capital firms participate in, the better the development of venture capital in the city. Columns (1) and (2) of Table 9 show the first stage regression results. The coefficient of instrumental variable is very significant and F statistic of the first stage is larger than 10, which suggesting that an increase in successful exits of venture capital investments will encourage more venture capital firms to initiate additional investment activities. The results in Columns (3) to (6) show that the number of financing events involving venture capital institutions has a

Table 7 Influence of venture capital on the technology commercialization based on SUR model

Variables	Patent	Patent for invention	Patent for utility model	Patent for industrial design
	(1)	(2)	(3)	(4)
VC	0.0185***	0.0203***	0.0165***	0.0122***
	(0.0016)	(0.0015)	(0.0016)	(0.0018)
cgdp	−0.0111**	−0.0036	−0.0196***	−0.0032
	(0.0052)	(0.0048)	(0.0053)	(0.0059)
edu	−0.0153***	−0.0168***	−0.0099***	0.0236***
	(0.0034)	(0.0032)	(0.0035)	(0.0039)
pop	0.0001*	0.0006***	0.0002*	−0.0005***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
industry	0.0250***	0.0216***	0.0167***	0.0261***
	(0.0023)	(0.0021)	(0.0023)	(0.0026)
investment	0.0166***	0.0121***	0.0151***	0.0202***
	(0.0016)	(0.0015)	(0.0016)	(0.0018)
innovation	0.0001***	0.0002***	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
fd	1.2099***	1.4503***	1.0769***	0.3707***
	(0.1038)	(0.0962)	(0.1058)	(0.1190)
popindens	0.0002***	0.0001	0.0001*	0.0005***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
firm	0.7069***	0.3982***	0.6003***	0.6198***
	(0.0275)	(0.0255)	(0.0280)	(0.0315)
distance	YES	YES	YES	YES
Constant	−3.1052***	−1.8065***	−2.3469***	−5.1608***
	(0.2404)	(0.2229)	(0.2450)	(0.2756)
Year fixed effects	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES
Observations	3489	3489	3489	3489
R^2	0.841	0.841	0.841	0.841

The observation unit in this analysis is city-year; The results are based on the SUR model including year fixed effects and city fixed effects; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

significant positive impact on technology commercialization, which is consistent with the baseline findings. All these results indicate our baseline results are robust to alternative venture capital measure.

4.4 Further tests on identification

4.4.1 Identification by using difference in differences (DID) method

Considering the endogeneity issues, we further examine a natural experiment in which some cities witnessed an exogenous promotion in the development of venture capital. The

Table 8 Influence of venture capital on the technology commercialization based on different models

Variables	OLS		Panel tobit model		Panel NB model		Zero-inflated NB model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VC	0.0087***	0.0067***	0.0104***	0.0102***	0.0097***	0.0032**	0.0636***	0.0207***
	(0.0022)	(0.0020)	(0.0018)	(0.0022)	(0.0019)	(0.0014)	(0.0016)	(0.0018)
cgdp		−0.0011		−0.0012		0.0140*		0.0034
		(0.0068)		(0.0092)		(0.0075)		(0.0067)
edu		0.0194***		−0.0090		−0.0085		−0.0376***
		(0.0060)		(0.0075)		(0.0064)		(0.0047)
pop		0.0015*		0.0005**		0.0002		0.0007***
		(0.0009)		(0.0002)		(0.0003)		(0.0001)
industry		0.0112*		0.0241***		0.0094**		0.0239***
		(0.0058)		(0.0040)		(0.0042)		(0.0027)
investment		0.0069***		0.0092***		0.0031*		0.0110***
		(0.0025)		(0.0022)		(0.0017)		(0.0019)
innovation		0.0002***		0.0001***		0.0000		0.0001***
		(0.0000)		(0.0000)		(0.0000)		(0.0000)
fd		0.3180		1.2301***		0.3716*		1.7425***
		(0.2081)		(0.2533)		(0.1911)		(0.1357)
popindens		−0.0001		0.0003***		−0.0001		0.0001
		(0.0003)		(0.0001)		(0.0002)		(0.0001)
firm		0.2981***		0.6678***		0.3759***		0.5820***
		(0.0842)		(0.0718)		(0.0681)		(0.0357)
distance	NO	YES	NO	YES	NO	YES	NO	YES
Constant	−0.0211	−0.2621	−1.0485***	−2.8946***	−2.1023***	−0.7601	−18.3765	−19.6645
	(0.1468)	(0.7151)	(0.2790)	(0.5827)	(0.1633)	(0.5680)	(607.4716)	(565.2239)
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	NO	NO	YES	YES	NO	NO

Table 8 (continued)

Variables	OLS		Panel tobit model		Panel NB model		Zero-inflated NB model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Observations	3600	3489	3600	3489	3600	3489	3600	3489

The observation unit in this analysis is city-year. * * *, * *, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The dependent variable is the natural logarithm of one plus the number of invention patents that are transferred in a year. Columns (1) and (2) use the panel OLS model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; Columns (3) and (4) use the panel tobit model including year fixed effects and province fixed effects and the robust standard errors (in parentheses) are based on a bootstrap method; Columns (5) and (6) use the panel negative binomial model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are based on a bootstrap method; Columns (7) and (8) use the zero-inflated negative binomial model including year fixed effects and the standard errors (in parentheses) are general

Table 9 Robustness test using alternative measure method for venture capital

Variables	First stage		2SLS-IV: Technology commercialization			
	ln_VC_events		Patent	Invention	Utility model	Industrial design
	(1)	(2)	(3)	(4)	(5)	(6)
IPO_rate	0.2075***	0.1255***				
	(0.0378)	(0.0328)				
ln_VC_events			0.9004***	1.7940***	1.3372***	1.2716***
			(0.2996)	(0.4288)	(0.3366)	(0.3825)
cgdp		0.0048	−0.0065	−0.0038	−0.0107	0.0008
		(0.0047)	(0.0080)	(0.0093)	(0.0082)	(0.0087)
edu		0.0101**	−0.0027	−0.0042	−0.0038	−0.0210**
		(0.0044)	(0.0087)	(0.0101)	(0.0103)	(0.0097)
pop		0.0017**	0.0002	−0.0019	−0.0009	−0.0007
		(0.0007)	(0.0011)	(0.0015)	(0.0013)	(0.0013)
industry		−0.0006	0.0058	0.0116*	−0.0006	0.0060
		(0.0035)	(0.0047)	(0.0062)	(0.0052)	(0.0052)
investment		0.0062***	−0.0002	−0.0022	−0.0009	−0.0015
		(0.0023)	(0.0030)	(0.0047)	(0.0037)	(0.0040)
innovation		0.0002***	−0.0001**	−0.0002*	−0.0002**	−0.0002*
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
fd		0.2226*	0.0246	0.1407	−0.0571	0.2611
		(0.1341)	(0.2305)	(0.2854)	(0.2686)	(0.2650)
popindens		0.0003	−0.0012**	−0.0011	−0.0011*	−0.0008
		(0.0005)	(0.0006)	(0.0009)	(0.0007)	(0.0006)
firm		0.0000	0.5129***	0.4015***	0.4065***	0.0627
		(0.0578)	(0.0900)	(0.1195)	(0.0886)	(0.0897)
Constant	0.1984***	0.0012				
	(0.0367)	(0.4802)				
distance	NO	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
F statistic	33.64	26.26	111.13	61.44	94.39	20.36
CDW F statistic			37.999	37.999	37.999	37.999
KPW F statistic			16.829	16.829	16.829	16.829
Observations	3600	3489	3267	3267	3267	3267
R^2	0.457	0.539	0.723	0.512	0.604	0.068

The results are based on the 2SLS model including year fixed effects and city fixed effects. The observation unit in this analysis is city-year. The dependent variable in columns (1) and (2) the natural logarithm of one plus the number of financing events involving venture capital institutions in a year, which mean estimated result of IV estimate first stage. The dependent variable in column (3) is the natural logarithm of one plus the number of patents including invention, utility model and industrial design that are transferred in a year. The dependent variable in column (4) is the natural logarithm of one plus the number of invention patents that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of utility model patents that are transferred in a year; The dependent variable in column (6) is the natural logarithm of one plus the number of industrial Design patents that are transferred in a year. All models in columns (1) to (6) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; F statistic in columns (1) and (2) is the statistic for correlation test between IV and independent variable. CDW F statistic (Cragg-Donald Wald F statistic) and KPW F statistic (Kleibergen-Paap rk Wald F statistic) are the statistic for weak identification test. The Stock-YOGO

Table 9 (continued)

weak identification test critical value with 15% maximal IV size is 8.96 and the value with 10% maximal IV size is 16.38. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

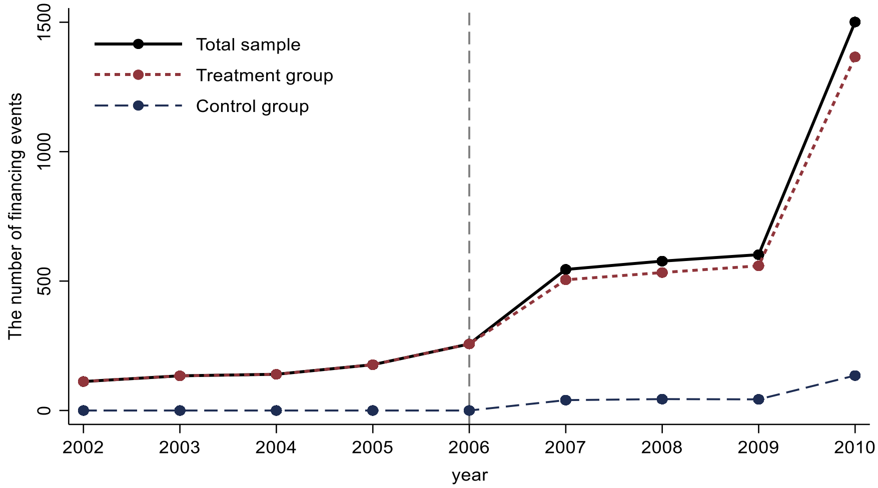
promotion was sparked by the amendments to the Partnership Enterprise Law of the People's Republic of China in 2006. The amendments mainly include two aspects: firstly, the amended Partnership Enterprise Law expands the scope of partners to include "legal persons and other organizations," not only to natural persons prescribed before the amendment. Secondly, it adds a new form of partnership, the limited partnership. Compared with the general partnership, the limited partnership allows investors to participate as limited partners with limited liability, which is conducive to stimulating the enthusiasm of investors. Therefore, the amendments to the Partnership Enterprise Law of the People's Republic of China provides a legal basis for the establishment of limited partnership funds, resulting in a large influx of capital to VC funds and a significant change of VC investment activities since 2006. If we capture this shift empirically only through a dummy variable taking on the value of zero before 2006 and one thereafter. We might face a problem that venture capital development across in all cities may change over time for a variety of reasons.

However, we note that the 2006 policy shift should have had a predictable greater impact on venture capital development in some cities than others. Cities with high levels of the development of venture capital before the policy change usually possess certain resources, such as a favorable investment environment, relevant professionals, funding, and most importantly, the investment demand driven by the growth of high-tech industries. Therefore, when the law is amended to be more conducive to venture capital, these cities can further develop venture capital based on these resources, resulting in more pronounced policy effects in these areas. Conversely, in cities with low levels of the development of venture capital, especially in cities where there has never been a financing event involving venture capital institutions before the policy change, the law amendment should hardly promote the development of venture capital. This is because the essential resources mentioned above will not suddenly be available with the law amendment. Thus, we divide those cities where there has never occurred a financing event involving venture capital institutions before the policy change into control group (composed of 112 cities), others as treatment group (composed of 113 other cities).[3] The promotion in the development of venture capital in treatment group is also evident in the data. As illustrated in Fig. 1, in the treatment group, the number of financing events involving venture capital institutions (Panel A) and the number of venture capital institutions (Panel B) both raised following the amendments to the Partnership Enterprise Law, while the number of financing events in other cities remained within their prior range, with little increase.

Thus, we examine the effect of the development of venture capital on technology commercialization by using a DID estimation framework. We estimate the following city-level OLS regression over the period from 2002 to 2017:

[3] Furthermore, it's conceivable that different cities may have experienced policy shocks to varying degrees, not just whether they were exposed to them. Therefore, in the next section, we conduct a more nuanced examination using a generalized difference-in-differences (GDID) approach, accounting for the extent of policy impact. We also show that our results are very robust (see Sect. 4.2.2).

Panel A: Number of financing events involving venture capital institutions



Panel B: Number of venture capital institutions

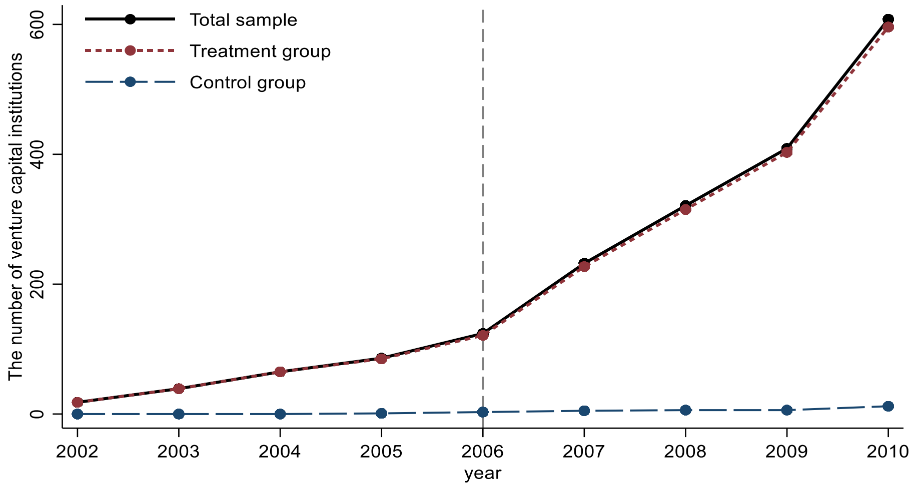


Fig. 1 Development trend of venture capital. This figure shows patterns for financing events involving venture capital institutions (**A**) and venture capital institutions (**B**). Solid lines represent the average number of financing events (venture capital institutions) of total sample four years before and after the year of 2006 (the year of impact). Short dash line represents the average number of financing events (venture capital institutions) of treatment group. Long dash line represents the average number of financing events (venture capital institutions) of control group. The control group includes those cities that the number of financing events involving venture capital institutions during 2002 to 2006 is zero. The treat group includes those cities that the number of financing events involving venture capital institutions during 2002 to 2006 is not zero. The main data sources are the CVSource database

$$ln\_transfer_{it} = \alpha_0 + \alpha_1(Post_t \times Treatment_i) + \alpha_2 Post_t + \alpha_3 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (6)$$

where $ln\_transfer_{it}$ is the outcome variable of technology commercialization, $Post_t$ is a dummy variable that indicates all observation from 2006 onward, and $Treatment_i$

is a dummy variable that takes the value of one if city i is in the treatment group and zero if it is in the control group. The primary variable of interest is the interaction term $Post_t \times Treatment_i$, which loads for observations in the treatment group in the post-treatment period beginning in 2006, such that α_1 measures the change in technology commercialization following the development of venture capital of treated cities relative to the untreated cities (control group). Table 10 presents the results. Columns (1) to (8) use the panel OLS model including year fixed effects and city fixed effects. For the commercialization of different types of patent technologies, the coefficients of the average treatment effects are all positive. The results show that the technology commercialization activity of the treated cities in the post-treatment period was significantly increased than the control group, which also demonstrates the promotion effect of the venture capital on technology commercialization.

In Fig. 1, we also observed a significant leap in venture capital development between 2009 and 2010, which may be due to the gradual reinvigoration of venture capital activities in the wake of the global economic recovery. Moreover, in China, the establishment of the Growth Enterprises Market (GEM) in 2009 provided venture capital funds with a flexible and direct exit channel, igniting a new wave of development in the venture capital. However, economic recovery and the establishment of the GEM might have also had an impact on technology commercialization, so we believe that the shock from 2009 to 2010 is unlikely to be exogenous. As a result, we primarily focus on testing the 2006 policy shock and treat the law amendments as a natural experiment that allows us to measure the effect of an exogenous promotion in the development of venture capital in and of itself. Nevertheless, as a robustness check, we also conducted a DID analysis on the sample from 2002 to 2010, and the results are presented in Table 18 of the "Appendix", yielding similar outcomes.

Figure 2 presents visual confirmation of parallel trends in technology commercialization between treatment group and control group. Conditional on fixed effects, the parallel trends in the before the policy change (2006) are evident. And we observe a clear increase in technology commercialization following the policy change, supporting the causal relationship between venture capital and technology commercialization.

4.4.2 Robustness test

Considering the possibility that different cities may have experienced varying degrees of policy shocks, we draw inspiration from Nunn and Qian (2011) and employ a generalized difference-in-differences (GDID) approach as our estimation strategy. This estimation strategy is based on the following assumption: the intensity of policy impact on cities is positively related to their pre-policy level of venture capital development. This assumption is reasonable because cities with more developed venture capital markets likely have more entrepreneurial companies, venture capitalists and potential investment opportunities, making the effects of policy more pronounced in these areas. Conversely, in cities with lower levels of venture capital development, policy impact may take longer to become significant due to the relatively immature market. Therefore, we employ a continuous measure of the treatment intensity based on the pre-policy level of venture capital development in cities. The specification is as follows:

$$ln\_transfer_{it} = \alpha_0 + \alpha_1(Post_t \times VC\_Treat_i) + \alpha_2 Post_t + \alpha_3 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (7)$$

Table 10 Robustness test using DID method

Variables	Patent		Patent for invention		Patent for utility model		Patent for industrial design	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post × Treatment	0.5245***	0.3567***	0.8538***	0.5718***	0.8198***	0.5657***	0.6121***	0.4584***
	(0.0913)	(0.0900)	(0.1032)	(0.0962)	(0.1011)	(0.1008)	(0.0914)	(0.0945)
Post	4.1008***	3.3337***	3.3081***	3.2789***	3.9144***	2.9399***	1.6957***	1.6667***
	(0.0875)	(0.1740)	(0.0888)	(0.1985)	(0.1042)	(0.1987)	(0.0892)	(0.1922)
cgdp		−0.0041		0.0006		−0.0103		0.0056
		(0.0072)		(0.0068)		(0.0079)		(0.0065)
edu		0.0104		0.0155**		0.0127*		−0.0031
		(0.0068)		(0.0060)		(0.0077)		(0.0060)
pop		0.0016**		0.0013		0.0015**		0.0017***
		(0.0008)		(0.0008)		(0.0007)		(0.0006)
industry		0.0066		0.0112**		0.0007		0.0065
		(0.0047)		(0.0056)		(0.0050)		(0.0046)
investment		0.0051***		0.0068***		0.0067***		0.0058***
		(0.0018)		(0.0025)		(0.0019)		(0.0021)
innovation		0.0000		0.0001***		0.0001***		0.0001**
		(0.0000)		(0.0000)		(0.0000)		(0.0000)
fd		0.1073		0.3063		0.1496		0.3506
		(0.2038)		(0.2171)		(0.2731)		(0.2485)
popindens		−0.0007**		−0.0002		−0.0001		−0.0002
		(0.0003)		(0.0003)		(0.0003)		(0.0003)
firm		0.4466***		0.2881***		0.3217***		−0.0040
		(0.0745)		(0.0854)		(0.0789)		(0.0720)
distance	NO	YES	NO	YES	NO	YES	NO	YES
Constant	0.7632***	−2.5726***	0.5131***	−2.9782***	0.0000	−2.2270***	0.4281***	−0.8051
	(0.0561)	(0.5645)	(0.0489)	(0.6247)	(0.0744)	(0.6183)	(0.0523)	(0.5138)

Table 10 (continued)

Variables	Patent		Patent for invention		Patent for utility model		Patent for industrial design	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3600	3489	3600	3489	3600	3489	3600	3489
R^2	0.780	0.796	0.761	0.788	0.741	0.762	0.350	0.375

The observation unit in this analysis is city-year. The dependent variable is the natural logarithm of one plus the number of patents that are transferred in a year. Columns (1) to (8) use the panel OLS model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

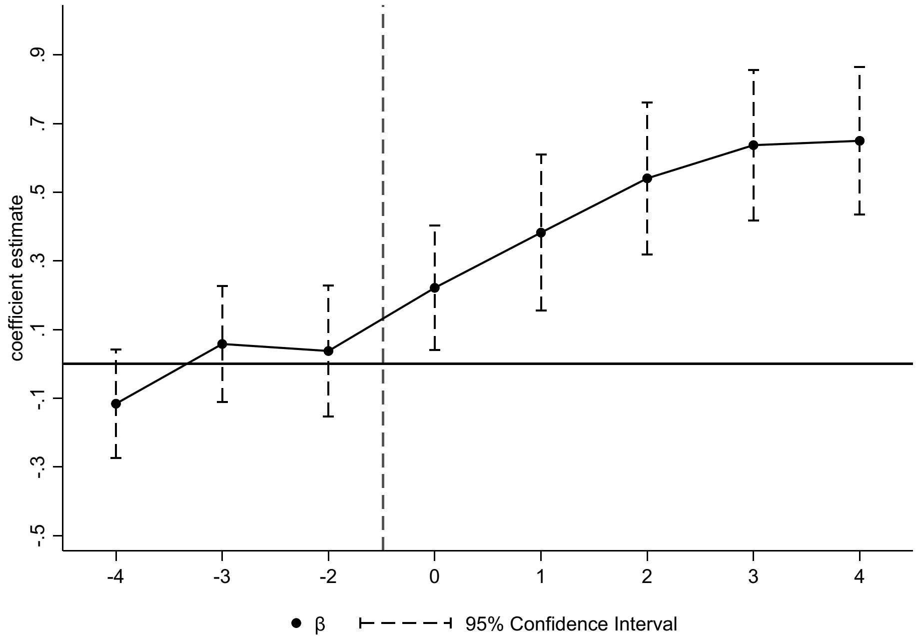


Fig. 2 Time path of the treatment effect. The figure plots the time path of the coefficient (α_1) for the period from 2002 to 2010 basing on OLS model including year fixed effects and city fixed effects and the robust standard errors are clustered by city. Dashed lines represent the 95% confidence interval

where VC_Treat_i is average level of venture capital development in city i prior to the law amendments (from 2002 to 2006), and $Post_t$ is an indicator variable that equals one for the periods after 2006. The coefficient of interest is α_1, which measures the additional change in technology commercialization experienced by cities that with more developed venture capital markets (relative to those that are not) after the establishment of the limited partnership system. A positive coefficient indicates that cities with more developed venture capital markets witnessed a greater increase in technology commercialization after 2006 relative to before 2006.

Estimates of Eq. (7) are reported in Table 11. Columns (1) to (4) report estimates for the commercialization of various types of patents including year fixed effects and city fixed effects. The results show that the coefficients of the average treatment effects are all positive, which indicate that cities with higher levels of venture capital development are more active in technology commercialization activities following the amendments to the Partnership Enterprise Law of the People's Republic of China (the revised law provides a legal basis for the establishment of limited partnership funds). Therefore, these results demonstrate the promotion effect of the venture capital on technology commercialization.

Table 11 Robustness Test Using GDID Model

Variables	Patent	Patent for invention	Patent for utility model	Patent for industrial design
	(1)	(2)	(3)	(4)
Post × *VC_Treat*	0.0236***	0.0397***	0.0436***	0.0345***
	(0.0040)	(0.0046)	(0.0041)	(0.0049)
Post	1.9815***	0.9795***	0.3765	−0.3537
	(0.3085)	(0.3361)	(0.3242)	(0.3647)
cgdp	−0.0031	0.0023	−0.0082	0.0072
	(0.0071)	(0.0067)	(0.0076)	(0.0064)
edu	0.0100	0.0147**	0.0114	−0.0041
	(0.0067)	(0.0060)	(0.0076)	(0.0061)
pop	0.0015**	0.0011	0.0013*	0.0015**
	(0.0008)	(0.0008)	(0.0007)	(0.0006)
industry	0.0074	0.0123**	0.0018	0.0074
	(0.0047)	(0.0056)	(0.0050)	(0.0045)
investment	0.0047***	0.0062**	0.0060***	0.0053***
	(0.0018)	(0.0026)	(0.0019)	(0.0020)
innovation	−0.0000	0.0001*	0.0000*	−0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
fd	0.0459	0.2014	0.0317	0.2579
	(0.2002)	(0.2065)	(0.2599)	(0.2308)
popindens	−0.0008**	−0.0005	−0.0003	−0.0004
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
firm	0.4811***	0.3455***	0.3828***	0.0447
	(0.0752)	(0.0845)	(0.0776)	(0.0693)
distance	YES	YES	YES	YES
Constant	−2.6507***	−3.0861***	−2.2959***	−0.8684*
	(0.5545)	(0.6217)	(0.5842)	(0.5174)
Year fixed effects	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES
Observations	3489	3489	3489	3489
R^2	0.797	0.791	0.767	0.382

The observation unit in this analysis is city-year. The dependent variable is the natural logarithm of one plus the number of patents that are transferred in a year. Columns (1) to (4) use the panel OLS model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; ***, **, and* indicate significance at the 1%, 5%, and 10% levels, respectively

5 Possible economic channels

So far, we conduct a set of robustness test for our baseline results on alternative econometric specifications. The results are also robust to using alternative regression models, alternative measurement method for venture capital and alternative causal identification by using DID method. Our analysis shows that regional venture capital development has a robust and positive effect on technology commercialization. The next natural question is what the potential economic channels are that allow venture capital to have a positive effect on technology commercialization. In this section, we explore three potential channels: (1) the search channel (2) the cooperation channel, and (3) the financing channel.

5.1 The search channel

In this section, we empirically study whether the search channel is an underlying economic mechanism of venture capital to promote technology commercialization. We believe that venture capital firms can reduce the cost of technology search, helping technology providers and commercialization implementers connect and match more efficiently. The implies that, for the technology itself, venture capital can shorten the time interval from technology creation to commercialization, facilitating the "immediate" transformation of more technologies. Therefore, we construct the “age” variable of the patent at the time of transfer, measured by the number of days between the application date and the first transfer date.

Firstly, we focus on the minimum age of patent transfer, which reflects the highest level of patent search efficiency in cities. We only focus on invention patents in this section. Columns (1) and (2) of Table 12 show the impact of venture capital development on the minimum age of patents at the time of commercialization. The coefficient estimate of venture capital is significantly negative, which indicate that venture capital development will promote the commercialization of patents at a “young” age. The regression results confirm that the development of venture capital facilitates the transfer of some patents in a relatively short period after their creation.

Secondly, we focus on the skewness of the distribution of patent transfer age. The greater the skewness, the more patents are transferred and commercialized at a younger age. We calculated the skewness of the age distribution of all patents transferred within each city and year. Given that the overall distribution of patent age is expected to change over time, then we calculated the skewness of the age distribution for all patents transferred within each year in the entire city sample. Then we introduced a dummy variable (*dum_ skew*) that takes the value of one if the age distribution skewness of city i is greater than the overall skewness of that year. The results in columns (3) and (4) show that the coefficient estimates of venture capital are significantly positive, which indicate that venture capital development will promote more patents to be commercialized at a young age.

Finally, we consider both the skewness of the age distribution and the average age. We introduced a dummy variable (*dum_ skew_ave*) that takes the value of one if *dum_ skew* equals one and the average age of patent transfer in a city is smaller than the average age of patent transfer in the entire city sample in that year. The results in columns (5) and (6) show that the coefficient estimates of venture capital are significantly positive, which indicate that venture capital development will promote more patents to be commercialized at a young age, and the average age of commercialized patents is smaller. All regression results in Table 12 confirm that the development of venture capital reduces the search costs of patents and shortens the time interval from creation to commercialization, thereby promoting technological commercialization activities in cities. We can conjecture that the search channel is a plausible channel through which the development venture capital development stimulates city technology commercialization. These findings lend support to Hypothesis 2.

Table 12 Testing the search channel

Variables	The minimum age of patent transfer		The skewness of the distribution of patent transfer age		The skewness and average of the distribution of patent transfer age	
	(1)	(2)	(3)	(4)	(5)	(6)
VC	−2.4701**	−2.2926*	0.0331***	0.0126*	0.0384***	0.0135*
	(1.2380)	(1.2582)	(0.0050)	(0.0066)	(0.0059)	(0.0072)
cgdp		−6.7095		−0.0113		−0.0150
		(4.1397)		(0.0220)		(0.0236)
edu		6.6742		0.0098		0.0058
		(5.2018)		(0.0174)		(0.0195)
pop		0.1863		0.0006		0.0006
		(0.3981)		(0.0004)		(0.0004)
industry		2.3990		0.0023		−0.0128
		(2.9077)		(0.0105)		(0.0116)
investment		0.2893		−0.0021		0.0012
		(1.0149)		(0.0055)		(0.0057)
innovation		0.0602***		−0.0000		−0.0000
		(0.0126)		(0.0001)		(0.0000)
fd		−163.8254		0.9712*		1.2685**
		(146.4127)		(0.5664)		(0.5560)
popindens		0.2913		0.0001		−0.0002
		(0.2629)		(0.0003)		(0.0002)
firm		−155.7951**		0.4097***		0.4996***
		(65.2693)		(0.1427)		(0.1585)
distance	NO	YES	NO	YES	NO	YES
Constant	1158.3440***	1098.6310**	−4.3434***	−5.7555***	−5.5520***	−5.9928***
	(111.4198)	(529.5320)	(0.5190)	(1.1383)	(0.6148)	(1.2890)
Year fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	NO	NO	NO	NO
Observations	2742	2664	2319	2245	2742	2664

The observation unit in this analysis is city-year. We use the number of days between the patent transfer date and the application date to measure the "age" of the patent at the time of transfer; The dependent variable in columns (1) and (2) is the minimum age of invention patents that are transferred in a year; The dependent variable in columns (3) and (4) is a dummy variable that takes the value of one if the skewness of the age distribution of patents transferred in city i is greater than the skewness of the age distribution of patents transferred in all sample cities in that year. The dependent variable in columns (5) and (6) is a dummy variable that takes the value of one if dummy variable of the skewness of patent distribution (the dependent variable in columns 3) equals one and the average age of patents transferred in city i is smaller than the average age of patents transferred in all sample cities in that year. Columns (1) and (2) use the panel OLS model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; Columns (3) to (6) use the panel logit model including year fixed effects and robust standard errors (in parentheses), due to the non-convergence of individual fixed effects in this model, we use a random fixed-effects model. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

5.2 The cooperation channel

After the technology search stage, it comes to the cooperation stage between technology providers and demanders. As stated in the theoretical hypothesis section, bridging universities, usually rich of technologies but lack marketing and commercialization tools, and companies, that can assist inventors in commercializing their technologies, is a crucial form of technology commercialization. Therefore, if the cooperation channel is an underlying economic mechanism of venture capital to promote technology commercialization, the development of universities in cities (such as more universities, teachers, and students) is likely to enhance the positive impact of venture capital on technology commercialization.

Specifically, we examine the influence of the university development by introducing three variables in to Eq. (1) respectively.

$$ln\_transfer_{it} = \alpha_0 + \alpha_1 VC_{it-1} + \alpha_2 VC_{it-1} \cdot university_{it} + \alpha_3 university_{it} + \alpha_4 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{8}$$

$$ln\_transfer_{it} = \alpha_0 + \alpha_1 VC_{it-1} + \alpha_2 VC_{it-1} \cdot teacher_{it} + \alpha_3 teacher_{it} + \alpha_4 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{9}$$

$$ln\_transfer_{it} = \alpha_0 + \alpha_1 VC_{it-1} + \alpha_2 VC_{it-1} \cdot student_{it} + \alpha_3 student_{it} + \alpha_4 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{10}$$

where $university_{it}$, $teacher_{it}$, and $student_{it}$ is the number of regular institutions of higher education, full-time teachers in regular institutions of higher education, and student enrollment in undergraduate in regular higher education institutions, respectively. These three variables represent the development level of regular institutions of higher education.

Columns (1) to (3) in Table 13 show the final regression results using the instrumental variable (*IPO_rate*) based on the 2SLS model for Eqs. (8) to (10).[4] The coefficient of the interaction term $VC_{it-1} \cdot university_{it}$, $VC_{it-1} \cdot teacher_{it}$ and $VC_{it-1} \cdot student_{it}$ are all significantly positive, which means that the development level of higher education institutions will provide a talent base for industry-university-institute cooperation, so as to promote venture capital to play a role in promoting university and scientific research institutions technology commercialization.

We further focus on the commercialization of university and scientific research institution technology, which more accurately reflects the cooperation between universities, scientific research institutions and enterprises. The dependent variables are $transfer^{university}$ and $transfer^{uni\_com}$.$transfer^{university}$ is measured by the natural logarithm of one plus the number of patents with the applicant type of universities and scientific research institutions that are transferred in a year. $transfer^{uni\_com}$ is measured by the natural logarithm of one plus the number of patents jointly applied by enterprises and universities or enterprises and scientific research institutions that are transferred in a year. Considering that the quality and prestige of universities may affect the commercialization of university technology, we add three new control variables to the baseline regression. On the one hand, we use *dum*_211 to measure university quality, which is a dummy variable representing whether a city has universities involved in the "211 Program".[5] On the other hand, following Colombo et al. (2019), which measured university prestige based on academic papers citation, we

[4] We also provide the regression results based on the other instrumental variable (*Return*) in Table 20 of the "Appendix". The results also support our conclusions.

[5] In 1995, China launched the "211 Program" to develop world-class universities and its 116 universities not only received substantial funding, but also house the most productive researchers and most advanced laboratories (Freeman and Huang, 2015).

Table 13 Testing the cooperation channel

Variables	Patent for invention			$transfer^{university}$	$transfer^{uni\_com}$	In emerging industries	In non-emerging industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VC	− 0.5809*	− 0.7003***	− 0.8725***	0.1382**	0.0489*	0.1016*	0.1513
	(0.3145)	(0.2121)	(0.3091)	(0.0655)	(0.0296)	(0.0544)	(0.5079)
VC · university	0.2619*						
	(0.1362)						
VC · teacher		0.0893***					
		(0.0268)					
VC · student			0.0819***				
			(0.0289)				
ln_university	− 18.1359*						
	(9.4292)						
ln_teacher		− 5.3188***					
		(1.5079)					
ln_student			− 4.9331***				
			(1.6640)				
*dum*_211				0.2855	− 0.0556	0.1760	− 0.9144
				(0.2747)	(0.1520)	(0.2928)	(1.4619)
prestige_citation				− 0.0023***	− 0.0020***	− 0.0022***	− 0.0995***
				(0.0008)	(0.0004)	(0.0007)	(0.0094)
prestige_value				0.0015***	0.0010***	0.0014***	0.0457***
				(0.0003)	(0.0002)	(0.0002)	(0.0028)
Other control variables	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES
N	3485	3478	3480	3489	3489	3489	3489

Table 13 (continued)

Variables	Patent for invention			$transfer^{university}$	$transfer^{uni\_com}$	In emerging industries	In non-emerging industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
R^2	− 1.728	0.271	− 0.127	− 0.972	− 0.157	− 0.641	0.572

The observation unit in this analysis is city-year. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively. The above table only shows the final regression results of 2SLS model. The instrumental variable is the IPO rate of enterprises in a city that have received venture capital funding (*IPO_rate*). In column (1) to (3), the dependent variable is the natural logarithm of one plus the number of invention patents that are transferred in a year, row 2 represents the effect of interaction term of venture capital and the natural logarithm of the number of regular institutions of higher education, row 3 represents the effect of interaction term of venture capital and the natural logarithm of the number of full-time teachers in regular institutions of higher education, and row 4 represents the effect of interaction term of venture capital and the natural logarithm of the number of students enrollment in undergraduate in regular higher education institutions; The dependent variable in column (4) is the natural logarithm of one plus the number of invention patents with the applicant type of universities and scientific research institutions that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of invention patents jointly applied by enterprises and universities or enterprises and scientific research institutions that are transferred in a year. The dependent variable in column (6) is the natural logarithm of one plus the number of invention patents with the applicant type of universities and scientific research institutions that are transferred in in emerging industries in a year. The dependent variable in column (7) is the natural logarithm of one plus the number of invention patents with the applicant type of universities and scientific research institutions that are transferred in in non-emerging industries in a year innovatively construct the measure of university prestige based on patent citation and patent value. The first measure of university prestige is the total number of citations received by all patents granted to universities in a city (*prestige_citation*). The second measure of university prestige is the total "patent value"[6] of all patents granted to universities in a city (*prestige_value*). As shown in Table 19 of the "Appendix", although the proportion of university technology commercialization in the entire city's technology commercialization is not very high, there is still a significant correlation between the two. And if there are "211 Program" universities in the city, then this proportion will be higher. This also provides rationality for us to select *dum*_211 as the control variable.

Column (4) in Table 13 shows the effect of venture capital on the university and institute technology commercialization. The coefficient estimates of venture capital are significantly positive. In addition, we also focus on the commercialization of patents jointly applied by enterprises and universities or enterprises and scientific research institutions. The column (5) shows that venture capital also has a positive effect on the innovation cooperation between industry and academia. These results suggest that venture capital plays a positive and active role in promoting university and scientific research institutions technology commercialization, which is in concert with the reality that university and scientific research institutions are the source of innovation but lacks of commercialization conditions, while the enterprise is the best carrier of combining science and technology with production. Therefore, the development of venture capital will promote cooperation among innovation entities, facilitate more university and scientific research institutions to transfer technologies to enterprise, and thus achieve commercialization and industrialization.

Universities and scientific research institutions are the frontier of scientific and technological innovation. The frontier technologies created by universities and scientific research institutions have spawned numerous emerging industries. Therefore, we expect that innovation cooperation between universities and enterprises will occur more in emerging industries. To examine this conjecture, we collected the number of technology commercialization of emerging industries and non-emerging industries in the city according to the *Classification of Strategic Emerging Industries (2018)*. Then we examine the cooperation channel in emerging industries and non-emerging industries respectively. Column (6) presents the results of our testing for cooperation channel in emerging industries, which show the development of venture capital has a positive effect on the technology commercialization of universities and scientific research institutions in emerging industries. Column (7) presents the results of our testing for cooperation channel in non-emerging industries, which show the coefficient estimate of venture capital variables is not significant. Therefore, there is not enough evidence to support the existence of cooperation channel in non-emerging industries.

These results illustrate that a city's venture capital development promotes universities and scientific research institutions to transfer more technology to enterprises, especially in emerging industries. We can conjecture that the cooperation channel is a plausible channel through which the development venture capital development stimulates city technology commercialization. These findings lend support to Hypothesis 3.

[6] The "Patent Value" index developed by BEIJING INCOPAT TECHNOLOGY CO., LTD (incoPat), which includes more than 20 technical indicators such as technical stability, technical advancement, and scope of protection. The scores for all indicators varied from 1 to 10. The higher the score for a patent, the higher its value.

5.3 The financing channel

In this section, we empirically study whether the financing channel is an underlying economic mechanism of venture capital to promote technology commercialization. Specifically, we examine how venture capital development affects technology commercialization differently across cities with different degrees of financing demand. The specification is as follows:

$$ln\_transfer_{it} = \alpha_0 + \alpha_1 VC_{it-1} \cdot demand_{it-1} + \alpha_2 VC_{it-1} + \alpha_3 demand_{it-1} + \alpha_4 \mathbf{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{11}$$

where $demand_{it-1}$ is the financing demand in city i in year $t-1$, which is measured by the year-end loan balance of financial institutions in a city. The larger the loan balance, the greater the financing demand. We include the interaction term of the venture capital development and financing demand ($VC \cdot demand$). All other variables are defined as in Eq. (1). Our key variable of interest is the coefficient estimate of $VC \cdot demand$,α_1, which captures the effect of venture capital on technology commercialization between cities with higher and lower financing demand. If the venture capital effect is more pronounced in cities with higher financing demand, we expect α_1 to be positive and significant. To handle potential endogeneity problems, we also employ 2SLS-IV model. We employed two instrumental variables in Eq. (11): the IPO rate of enterprises in a city that have received venture capital funding (*IPO_rate*) and the interaction term of the IPO rate and financing demand ($IPO\_rate \cdot demand$).

We present the first stage regression results with *VC* and $VC \cdot demand$ as the dependent variables in Columns (1) to (4) of Table 14. The odd columns show the results without controlling for variables, while the even columns include the results with controlled variables. The first stage reveals a positive partial correlation between venture capital and successful exits of venture capital investments, as well as a positive partial correlation between $VC \cdot demand$ and $IPO\_rate \cdot demand$. We then use the predicted *VC* and $VC \cdot demand$ to run the regression following in Eq. (11), which is the second stage shown in columns (5) and (6), the coefficients of interaction term of venture capital development and financing demand are positive, although it is only significant when control variables are not included. Therefore, we conduct further examinations for different industries with varying financing demand.

With the emergence of new scientific breakthroughs and cutting-edge technologies, various new sectors known as emerging industries have gradually taken shape. These emerging industries differ from traditional ones in that they feature high technological complexity, increased value addition, and greater capital requirements. Therefore, we can predict that the financing channel will be more pronounced in emerging industries compared to non-emerging industries. We examine the financing channel in emerging industries and non-emerging industries respectively. Column (7) presents the second stage of our testing for financing channel in emerging industries. The dependent variable is the natural logarithm of one plus the number of patents in emerging industries that are transferred in a year. All the control variables are also included. The coefficients of interaction term of venture capital development and financing demand ($VC \cdot demand$) are significantly positive, which confirms that the financing channel is a potential economic mechanism through which venture capital promotes the technology commercialization in emerging industries. Indeed, emerging industries are precisely the investment focus of venture capital. These industries hold enormous growth potential and require funding urgently. Column (8) presents the second stage of our testing for financing channel in non-emerging industries.

Table 14 Testing the financing channel

Variables	First stage				2SLS-IV: Technology commercialization			
	VC		*VC · demand*		Patent for Invention		Emerging industries	Non-emerging industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IPO_rate	1.3267**	1.3545**	− 6.8855***	− 4.5878***				
	(0.5901)	(0.5677)	(1.4228)	(1.0503)				
IPO_rate · demand	− 0.1979	− 0.3053	11.0263***	7.2328***				
	(0.2723)	(0.2685)	(0.8061)	(0.7201)				
VC · demand					0.0092**	0.0050	0.0131***	0.0131
					(0.0044)	(0.0070)	(0.0048)	(0.0084)
demand	0.7071	0.1458	2.4645	3.2947	0.0524	0.0204	− 0.0140	− 0.0028
	(0.8249)	(0.8401)	(2.9030)	(2.6451)	(0.1653)	(0.1765)	(0.1182)	(0.2029)
VC					0.1936**	0.2079**	0.1304**	0.2418**
					(0.0838)	(0.0890)	(0.0629)	(0.1040)
Control variables	NO	YES	NO	YES	NO	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	3112	3017	3112	3017	3112	3017	3017	3017
R^2	0.450	0.456	0.231	0.376	− 0.326	− 0.457	0.096	− 1.078

The observation unit in this analysis is city-year. The dependent variable in columns (1) and (2) is the development of venture capital, which mean estimated result of IV estimate first stage; The dependent variable in columns (3) and (4) is the interaction term of venture capital development and financing demand; The dependent variable in columns (5) and (6) is the natural logarithm of one plus the number of invention patents that are transferred in a year; The dependent variable in column (7) is the natural logarithm of one plus the number of patents in emerging industries that are transferred in a year; The dependent variable in column (8) is the natural logarithm of one plus the number of patents in non-emerging industries that are transferred in a year. All models in columns (1) to (8) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

The dependent variable is the natural logarithm of one plus the number of patents in non-emerging industries that are transferred in a year. The results show that the coefficient estimation of the interaction term of venture capital development and financing demand ($VC \cdot demand$) are insignificant. There is not enough evidence to support the existence of financing channels in non-emerging industries. Therefore, our results illustrate that venture capital development exerts a disproportionately positive effect on technology commercialization in cities with high-capital-demand. We can conjecture that the financing channel is a plausible channel through which the development venture capital development stimulates city technology commercialization, supporting our Hypothesis 4.

6 Conclusion

With the integration of technology and finance, how to make financial development contribute to innovative development has become an important issue worth discussing. As an active investor in the financial market, venture capital may be a catalyst for technology innovation. Most of previous studies focus on the effect of venture capital on innovation from the perspective of technology creation, while we focus on the commercialization of technology which reflects the transformation from innovative achievements into advanced productivity. This paper presents cross-city evidence on how the development of venture capital affects technology commercialization. Using a large data set that includes 225 cities in China between 2002 and 2017, we identify economic mechanisms through which the development of regional venture capital affects technology commercialization.

The empirical results based on 2SLS model show that regional venture capital development significantly promotes technology commercialization, and the results are also robust to using alternative regression models, alternative measurement method for venture capital, and alternative causal identification by using DID method. Furthermore, the first possible economic channel is that the development of venture capital contributes to the rapid identification, discovery, and efficient trading of technology within the region, thus promoting the commercialization of technology activities. It can be verified from the empirical results that the development of venture capital significantly shortens the time interval from creation to commercialization. The second possible economic channel is that the development of venture capital will promote the cooperation of technology commercialization among innovation entities. It can be verified from the empirical results that the effect of venture capital on the commercialization of university and scientific research institution technology is significantly positive. The third possible economic channel is that the development of regional venture capital is likely to provide sufficient funds for regional technology commercialization. It can be verified from the empirical results that the effect of venture capital on the technology commercialization is stronger in cities with greater financing demand.

6.1 Theoretical implications and practical implications

Our study offers new insights into the real effects of venture capital development on technology innovation, especially complementing the literature on innovation from the perspective of technology commercialization. Prior research focused mainly on the effect of venture capital on innovation from the perspective of technology creation (Baum

& Silverman, 2004; Bertoni & Tykvová, 2015; Caselli et al., 2009; Engel & Keilbach, 2007; Kortum & Lerner, 2000; Popov & Roosenboom, 2013; Sun et al., 2020) and most of research indicated that venture capital play critical roles in addressing information asymmetry, evaluating innovative projects, and providing other value-added services (Chemmanur et al., 2014; Hellmann & Puri, 2002; Sun et al., 2020; Tian & Wang, 2014), thereby cultivating technology creation (Cumming & Johan, 2016). However, there is relatively little research on the role of venture capital in the technology commercialization stage. Therefore, our paper complements this emerging body of the literature by providing empirical evidence for the positive role of venture capital in technology commercialization.

In addition, as research in finance increasingly focuses on the core issues of technology commercialization or technology transfer (Audretsch et al., 2016), evidence supporting the role of venture capital in facilitating technology commercialization is emerging in these related studies (Block et al., 2022; Colombo et al., 2016; Kelly & Kim, 2018). We enhance this research stream by conducting our empirical research at the city level. To the best of our knowledge, there is still a lack of systematic empirical research on the impact of venture capital development on technology commercialization from an overall regional perspective. Our study covers the technology commercialization activities of various entities, including individuals, businesses, universities, and research institutions, enabling us to observe the overall level of technological commercialization activities and venture capital development.

This city-level research also enables us to observe the efficiency of searching for all technologies within the region, as well as to conduct specific analysis of university commercialization to identify economic mechanisms through which the development of regional venture capital affects technology commercialization. We found that cities with higher levels of venture capital development exhibit a younger "age" of technology when commercialized. This reflects that the development of regional venture capital market spurs the activity of the technology market, enabling more technologies to be exposed and exploited more efficiently. The development of venture capital has brought abundant resources such as funds, human resources, social network resources, and more professional search strategies, which helps to create a munificent context with slack resources. Especially, venture capitalists usually have both technical and market knowledge, which helps to improve the efficiency of technology search in cities. In addition, we also conduct specific analysis of university commercialization. University research serves as a source of knowledge spillovers and a catalyst for regional economic growth (Liu et al., 2020; Wonglimpiyarat, 2010). Our empirical research provides reference for the commercialization of university knowledge from the perspective of venture capital. We find that cities with higher levels of venture capital development exhibit better technology commercialization outcomes of universities. The result is consistent with relevant researches that have identified venture capital's positive role in university technology commercialization (Croce et al., 2014; Bock et al., 2018; Fu et al., 2022).

Regarding the practical significance, empirical analysis of the influence of regional venture capital development on technology commercialization is conducive to understanding the innovation process in which there is a technology market ecosystem driven by search, match, collaboration and vital financing (Liu et al., 2017, 2021, 2023a, 2023b). It can provide reasonable references and innovative paths about search, cooperation and emerging industry growth for entrepreneurs and venture capital investors. It also provides suggestion for public governance or urban managers to promote positive interaction between venture capital institutions and innovative entities such as enterprises and universities, and spur the establishment of stable cooperation to stride over "valley of death" of technology commercialization. The policy implication of this research may be that public sectors could strengthen public services related to innovation exchange and intellectual property right cooperation among talents, and they might pay attention to the coordinated development of public service and market service to support the venture capital and science technology financing development. On the one hand, it is crucial to enhance the attractiveness of regions for inventors, intellectuals, talents, entrepreneurs and venture capital to generate technology factor agglomeration and comparative advantages for technology commercialization. On the other hand, it is also important to reduce search and transaction cost to further develop an integrated ecosystem that brings together finance, science, entrepreneurship education, and collaboration.

6.2 Limitation and future research

This study also has several limitations and suggestions for future studies. First, we only measure the technology commercialization based on patent transfer. It would be worth considering various measures of technology commercialization from multiple perspectives such as technology pledge and new industrial product or services. Second, this study examines the potential economic channels from the perspective of whole process and different stages of technology commercialization, which is suitable for explaining the mechanisms at the macro level. However, there is a certain degree of overlap in each stage. Therefore, it is necessary to supplement with more micro level mechanism evidence. Future studies on the potential economic channels of venture capital can be conducted from the perspective of venture capital ‘s functions, which requires corresponding firm level samples to supplement this research. Third, this study mainlyconsiders the cooperation between universities, scientific research institutions and enterprises. Thus, more empirical evidence about financing, public services and intellectual property right can be gained by observing the collaboration between enterprises and individuals, and collaboration between enterprises and public organizations in the process of technological commercialization. Finally, our research is limited to considering the primary effect in the final stage of technology commercialization, that is the financing channel. The other functions of venture capital in this final stage remain enigmatic, and future research could break down this process into more granular stages, enabling a more detailed examination of “valley of death” where venture capital influences technology commercialization.

Appendix

See Tables 15, 16, 17, 18, 19 and 20.

Table 15 Multiples of returns as instrumental variable

Variables	First stage		2SLS-IV: Technology commercialization			
	VC		Patent	Patent for Invention	Patent for Utility Model	Patent for Industrial Design
	(1)	(2)	(3)	(4)	(5)	(6)
Return	0.0847***	0.0703***				
	(0.0203)	(0.0173)				
VC			0.0584*	0.1084**	0.1016**	0.1047***
			(0.0319)	(0.0476)	(0.0408)	(0.0357)
cgdp		0.0254	− 0.0062	− 0.0031	− 0.0138	0.0023
		(0.0618)	(0.0075)	(0.0086)	(0.0088)	(0.0086)
edu		− 0.0067	0.0129**	0.0195***	0.0167**	0.0002
		(0.0508)	(0.0065)	(0.0069)	(0.0080)	(0.0067)
pop		0.0047	0.0015*	0.0010	0.0012	0.0013
		(0.0075)	(0.0008)	(0.0011)	(0.0010)	(0.0009)
industry		0.1225**	− 0.0002	− 0.0016	− 0.0112	− 0.0060
		(0.0481)	(0.0067)	(0.0086)	(0.0084)	(0.0074)
investment		− 0.0029	0.0053***	0.0072***	0.0071**	0.0063*
		(0.0229)	(0.0018)	(0.0027)	(0.0028)	(0.0033)
innovation		− 0.0001	0.0000**	0.0002***	0.0002***	0.0001***
		(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
fd		2.0026	− 0.0069	0.0900	− 0.0516	0.1375
		(1.7698)	(0.2464)	(0.2917)	(0.3444)	(0.3021)
popindens		− 0.0072*	− 0.0002	0.0006	0.0007	0.0006
		(0.0039)	(0.0004)	(0.0006)	(0.0006)	(0.0006)
firm		0.9765	0.3981***	0.1953*	0.2356**	− 0.0963
		(0.7211)	(0.0778)	(0.1014)	(0.0935)	(0.0948)
Constant	61.4209***	71.3350***				
	(0.4381)	(5.7253)				
distance	NO	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
F statistic	79.67	39.84	154.07	69.85	88.47	15.6
CDW F statistic			10.136	10.136	10.136	10.136
KPW F statistic			16.588	16.588	16.588	16.588
Observations	3600	3489	3489	3489	3489	3489
R^2	0.464	0.471	0.732	0.504	0.552	− 0.168

The observation unit in this analysis is city-year. The dependent variable in columns (1) and (2) is the development of venture capital, which mean estimated result of IV estimate first stage. The dependent variable in column (3) is the natural logarithm of one plus the number of patents including invention, utility model and industrial design that are transferred in a year. The dependent variable in column (4) is the natural logarithm of one plus the number of invention patents that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of utility model patents that are transferred in a year; The dependent variable in column (6) is the natural logarithm of one plus the number of industrial Design patents that are transferred in a year. All models in columns (1) to (6) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; F statistic in columns (1) and (2) is the statistic for correlation test between IV and independent variable. CDW F statistic (Cragg-Donald Wald F statistic) and KPW F statistic (Kleibergen-Paap rk Wald F statistic) are the statistic for weak identification test. The Stock-YOGO weak identification test critical value with 15% maximal IV size is 8.96 and the value with 10% maximal IV size is 16.38. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

Table 16 IRR as Instrumental Variable

Variables	First stage		2SLS-IV: Technology commercialization			
	VC		Patent	Patent	Patent for Invention	Patent for Utility Model
	(1)	(2)	(3)	(4)	(5)	(6)
IRR	0.0107***	0.0099***				
	(0.0024)	(0.0026)				
VC			0.0730**	0.1630***	0.1439***	0.1880***
			(0.0344)	(0.0481)	(0.0497)	(0.0663)
cgdp		0.0256	− 0.0065	− 0.0041	− 0.0146	0.0007
		(0.0618)	(0.0078)	(0.0109)	(0.0102)	(0.0127)
edu		− 0.0025	0.0129*	0.0196**	0.0168*	0.0003
		(0.0504)	(0.0067)	(0.0087)	(0.0091)	(0.0096)
pop		0.0042	0.0014*	0.0007	0.0010	0.0009
		(0.0072)	(0.0008)	(0.0014)	(0.0012)	(0.0014)
industry		0.1250**	− 0.0020	− 0.0085	− 0.0166*	− 0.0165
		(0.0484)	(0.0065)	(0.0095)	(0.0094)	(0.0120)
investment		− 0.0042	0.0054***	0.0074**	0.0073**	0.0066
		(0.0227)	(0.0020)	(0.0035)	(0.0036)	(0.0049)
innovation		-0.0002	0.0000**	0.0002***	0.0002***	0.0001**
		(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
fd		2.0716	− 0.0396	− 0.0324	− 0.1464	− 0.0494
		(1.7590)	(0.2563)	(0.3494)	(0.3940)	(0.4206)
popindens		− 0.0074*	− 0.0001	0.0010	0.0010	0.0012
		(0.0038)	(0.0005)	(0.0008)	(0.0008)	(0.0009)
firm		1.0725	0.3833***	0.1401	0.1929*	− 0.1805
		(0.7221)	(0.0802)	(0.1258)	(0.1103)	(0.1507)
Constant	61.4276***	70.7262***				
	(0.4382)	(5.7112)				
distance	NO	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
F statistic	80.31	39.74	133.09	43.49	55.14	7.96
CDW F statistic			15.604	15.604	15.604	15.604
KPW F statistic			14.040	14.040	14.040	14.040
Observations	3600	3489	3489	3489	3489	3489
R^2	0.465	0.471	0.693	0.127	0.326	− 1.449

The observation unit in this analysis is city-year. The dependent variable in columns (1) and (2) is the development of venture capital, which mean estimated result of IV estimate first stage. The dependent variable in column (3) is the natural logarithm of one plus the number of patents including invention, utility model and industrial design that are transferred in a year. The dependent variable in column (4) is the natural logarithm of one plus the number of invention patents that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of utility model patents that are transferred in a year; The dependent variable in column (6) is the natural logarithm of one plus the number of industrial Design patents that are transferred in a year. All models in columns (1) to (6) are including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; F statistic in columns (1) and (2) is the statistic for correlation test between IV and independent variable. CDW F statistic (Cragg-Donald Wald F statistic) and KPW F statistic (Kleibergen-Paap rk Wald F statistic) are the statistic for weak identification test. The Stock-YOGO weak identification test critical value with 15% maximal IV size is 8.96 and the value with 10% maximal IV size is 16.38. ***, **, and* indicate significance at the 1%, 5%, and 10% levels, respectively

Table 17 Influence of venture capital on the commercialization of various types of patents based on different models

Variables	OLS		Panel tobit model		Panel NB model		Zero-inflated NB model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VC	0.0087***	0.0067***	0.0103***	0.0103***	0.0126***	0.0039***	0.0610***	0.0159***
	(0.0022)	(0.0020)	(0.0016)	(0.0021)	(0.0016)	(0.0012)	(0.0016)	(0.0017)
cgdp		−0.0011		−0.0075		0.0058		−0.0213***
		(0.0068)		(0.0094)		(0.0074)		(0.0063)
edu		0.0194***		−0.0116		−0.0112*		−0.0183***
		(0.0060)		(0.0086)		(0.0059)		(0.0041)
pop		0.0015*		0.0003*		0.0003		0.0001
		(0.0009)		(0.0002)		(0.0002)		(0.0001)
industry		0.0112*		0.0211***		0.0075**		0.0224***
		(0.0058)		(0.0038)		(0.0036)		(0.0025)
investment		0.0069***		0.0085***		0.0032***		0.0171***
		(0.0025)		(0.0015)		(0.0011)		(0.0021)
innovation		0.0002***		0.0001**		0.0000		0.0001***
		(0.0000)		(0.0000)		(0.0000)		(0.0000)
fd		0.3180		1.0746***		0.4430***		1.3001***
		(0.2081)		(0.2115)		(0.1235)		(0.1252)
popindens		−0.0001		0.0004***		0.0000		0.0002***
		(0.0003)		(0.0001)		(0.0001)		(0.0001)
firm		0.2981***		0.8067***		0.4192***		0.8253***
		(0.0842)		(0.0604)		(0.0480)		(0.0325)
distance	NO	YES	NO	YES	NO	YES	NO	YES
Constant	−0.0211	−0.2621	−0.6303**	−2.6793***	−2.3682***	−1.3526***	−20.1066	−19.2088
	(0.1468)	(0.7151)	(0.2769)	(0.5554)	(0.1314)	(0.5083)	(807.8407)	(444.9714)
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	NO	NO	NO	NO	YES	YES	NO	NO

Table 17 (continued)

Variables	OLS		Panel tobit model		Panel NB model		Zero-inflated NB model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Observations	3600	3489	3600	3489	3600	3489	3600	3489

The observation unit in this analysis is city-year. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The dependent variable is the natural logarithm of one plus the number of all type patents that are transferred in a year. Columns (1) and (2) use the panel tobit model including year fixed effects and province fixed effects and the robust standard errors (in parentheses) are based on a bootstrap method; Columns (3) and (4) use the panel negative binomial model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are based on a bootstrap method; Columns (5) and (6) use the zero-inflated negative binomial model including year fixed effects and the standard errors (in parentheses) are general

Table 18 Robustness test using DID method during 2002 to 2010

Variables	Patent		Patent for invention		Patent for utility model		Patent for industrial design	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post × Treatment	0.5552***	0.4005***	0.6890***	0.4706***	0.8004***	0.5513***	0.5724***	0.4410***
	(0.0899)	(0.0938)	(0.0853)	(0.0865)	(0.1006)	(0.1046)	(0.0897)	(0.0954)
Post	2.0327***	1.3496***	1.2689***	0.9975***	2.0124***	0.9555***	0.5547***	0.6395***
	(0.0904)	(0.1725)	(0.0760)	(0.1554)	(0.1054)	(0.1813)	(0.0736)	(0.1704)
cgdp		−0.0247***		−0.0207***		−0.0310***		−0.0130*
		(0.0083)		(0.0070)		(0.0098)		(0.0078)
edu		0.0061		0.0055		0.0069		−0.0029
		(0.0065)		(0.0055)		(0.0073)		(0.0053)
pop		−0.0004		−0.0014		0.0018		0.0005
		(0.0019)		(0.0016)		(0.0023)		(0.0021)
industry		0.0128*		0.0116*		0.0142**		0.0191***
		(0.0068)		(0.0059)		(0.0065)		(0.0069)
investment		0.0032		0.0042		0.0067		0.0085*
		(0.0059)		(0.0048)		(0.0071)		(0.0049)
innovation		0.0001		0.0002**		0.0003**		0.0001*
		(0.0001)		(0.0001)		(0.0001)		(0.0001)
fd		0.0190		0.2789		0.1983		0.2253
		(0.2480)		(0.2514)		(0.3183)		(0.2333)
popindens		−0.0000		0.0005		−0.0004		−0.0002
		(0.0005)		(0.0004)		(0.0006)		(0.0005)
firm		0.2923***		0.1864**		0.3230***		0.0189
		(0.1062)		(0.0927)		(0.1108)		(0.0888)
distance	NO	YES	NO	YES	NO	YES	NO	YES
Constant	0.7632***	−0.6029	0.5131***	−0.4734	−0.0000	−2.1978*	0.4281***	−0.5763
	(0.0504)	(1.0387)	(0.0372)	(0.9145)	(0.0670)	(1.1948)	(0.0456)	(0.9662)

Table 18 (continued)

Variables	Patent		Patent for invention		Patent for utility model		Patent for industrial design	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Observations	2025	1938	2025	1938	2025	1938	2025	1938
R^2	0.531	0.534	0.486	0.505	0.532	0.559	0.174	0.190

The sample period spans from 2002 to 2010. The observation unit in this analysis is city-year. The dependent variable is the natural logarithm of one plus the number of patents that are transferred in a year. Columns (1) to (8) use the panel OLS model including year fixed effects and city fixed effects and the robust standard errors (in parentheses) are clustered by city; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively

Table 19 Summary statistics and correlation coefficients for the university technology commercialization

Variables	N	mean	SD	$transfer^{invent}$	$transfer^{university}$	$transfer^{uni\_com}$
$transfer^{invent}$	3600	65.7342	292.3405	1		
$transfer^{university}$	3600	6.7836	31.2980	0.668***	1	
$transfer^{uni\_com}$	3600	0.8133	4.2730	0.714***	0.706***	1
rate	2764	0.0680	0.1452			
rate (cities with "211 Program" universities)	524	0.1740	0.1661			
rate (cities without "211 Program" universities)	2240	0.0432	0.1278			

rate is calculated based on the ratio of the transfer of university invention patents ($transfer^{university}$) to the transfer of all invention patents in the city ($transfer^{invent}$); $transfer^{invent}$ is the number of transferred invention patents in a year;$transfer^{university}$ is the number invention patents with the applicant type of universities and scientific research institutions that are transferred in a year;$transfer^{uni\_com}$ is the number of invention patents jointly applied by enterprises and universities or enterprises and scientific research institutions that are transferred in a year

Table 20 Robustness test using multiples of returns as instrumental variable

Variables	Patent for invention			$transfer^{university}$	$transfer^{uni\_com}$	In emerging industries	In non-emerging industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VC	−0.3349	−0.4125**	−0.3798***	0.1130**	0.0376*	0.0872***	0.6308
	(0.2325)	(0.1622)	(0.1122)	(0.0479)	(0.0207)	(0.0336)	(0.5246)
VC · university	0.1537						
	(0.1022)						
VC · teacher		0.0531***					
		(0.0205)					
VC · student			0.0362***				
			(0.0105)				
ln_university	−10.6303						
	(7.0652)						
ln_teacher		−3.2065***					
		(1.1724)					
ln_student			−2.2218***				
			(0.6068)				
dum_211				0.3007	−0.0488	0.1847	−1.2031
				(0.2874)	(0.1557)	(0.3062)	(1.4509)
prestige_citation				−0.0020***	−0.0019***	−0.0020***	−0.1047***
				(0.0006)	(0.0004)	(0.0005)	(0.0099)
prestige_value				0.0014***	0.0010***	0.0014***	0.0475***
				(0.0002)	(0.0001)	(0.0002)	(0.0036)
Other control variables	YES	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES
N	3485	3478	3480	3489	3489	3489	3489

Table 20 (continued)

Variables	Patent for invention			$transfer^{university}$	$transfer^{uni\_com}$	In emerging industries	In non-emerging industries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
R^2	−0.024	0.635	0.641	−0.450	0.083	−0.321	0.432

The observation unit in this analysis is city-year. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The above table only shows the final regression results of 2SLS model. The instrumental variable is the sum of the average multiples of returns for venture capital firms over the past three years in a city (*Return*). In column (1) to (3), the dependent variable is the natural logarithm of one plus the number of invention patents that are transferred in a year, row 2 represents the effect of interaction term of venture capital and the natural logarithm of the number of regular institutions of higher education, row 3 represents the effect of interaction term of venture capital and the natural logarithm of the number of full-time teachers in regular institutions of higher education, and row 4 represents the effect of interaction term of venture capital and the natural logarithm of the number of students enrollment in undergraduate in regular higher education institutions; The dependent variable in column (4) is the natural logarithm of one plus the number of patents with the applicant type of universities and scientific research institutions that are transferred in a year; The dependent variable in column (5) is the natural logarithm of one plus the number of patents jointly applied by enterprises and universities or enterprises and scientific research institutions that are transferred in a year. The dependent variable in column (6) is the natural logarithm of one plus the number of patents with the applicant type of universities and scientific research institutions that are transferred in in emerging industries in a year. The dependent variable in column (7) is the natural logarithm of one plus the number of patents with the applicant type of universities and scientific research institutions that are transferred in in non-emerging industries in a year

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