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Broadband internet and enterprise innovation

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ABSTRACT

Based on microdata from China's listed companies and macrodata for broadband internet access in prefecture-level cities, this paper explores the relationship between broadband internet and enterprise innovation. Using the change in market concentration caused by the North–South separation reform of China Telecom in 2002 as an instrumental variable, the results show that in general, a 1% increase in broadband internet access results in a 1.395% increase in the number of corporate patents. Specifically, the number of valid patents, patent citations and valid patent citations, reflecting patent quality, increases by 1.499%, 0.920% and 0.763%, respectively. The mechanistic analysis shows that broadband internet access contributes to increasing the number of R&D personnel and personal innovation efficiency, enhancing enterprises' willingness to innovate, and easing financing constraints. Further analysis suggests that broadband internet access mainly promotes invention patents rather than design patents. The innovation effect is more evident among high-tech, inventor-intensive, state-owned enterprises and enterprises located in the non-southeastern coastal region of China.

1. Introduction

Innovation is an important theme of China's current transformation and development. Since 2011, the actual GDP growth rate in China has fallen below 10%, ending the rapid growth stage since the reform and opening up.[1] As the demographic dividend, investment drive, and institutional dividend caused by the shift from a planned economy to a market economy are gradually fading, how to maintain steady and healthy economic development has become an important topic of current macroeconomic concern in China (Wei, Xie, & Zhang, 2017). Divergent views exist among political and academic circles. The key idea is to promote and upgrade the industrial structure and transform the overall economy from factor-driven and investment-driven to innovation-driven (People's Daily Online, 2015; Zheng & Li, 2020; Zhu, Zhang, & Peng, 2019).

Furthermore, China's internet infrastructure has rapidly developed, and China has become the largest internet market worldwide. As of December 2020, the number of Chinese internet users reached 989 million, and the internet penetration rate was 70.4%.[2] The internet has increasingly penetrated and changed people's lives. In particular, the integration of food, clothing, housing, transportation, financial management, medical and environmental protection, and other fields with the internet has deepened.

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[1] Based on data from the National Bureau of Statistics of China, the prices are the 2000 level.

[2] The data are derived from the 47th statistical report on the development of the internet in China issued by the China internet Network Information Center (CNNIC).

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Considerable studies have explored the internet's effects on unemployment (Kuhn & Skuterud, 2004), wages (Forman, Goldfarb, & Greenstein, 2012), labor productivity (Akerman, Gaarder, & Mogstad, 2015), economic growth (Kolko, 2012; Koutroumpis, 2009), political elections (Falck, Gold, & Heblich, 2014; Gavazza, Nardotto, & Valletti, 2018), etc. However, few studies consider the causal relationship between internet popularization and enterprise technological innovation. Understanding this causal effect holds great significance for building an innovative country.

By matching patent data from the IncoPat Global Patent Database with the Wind database of listed companies and incorporating local broadband internet data from the Annual Report on China's Communications Statistics, this paper employs the first-difference method to explore the relationship between broadband internet and enterprise innovation. To alleviate the endogeneity problem, we use the change in telecom market concentration caused by the North–South separation reform of China Telecom in 2002 as an instrumental variable. The instrumental variable model suggests that in general, a 1% increase in broadband internet access results in a 1.395% increase in the number of corporate patents. Specifically, the number of valid patents, patent citations and valid patent citations reflecting patent quality increases by 1.499%, 0.920% and 0.763%, respectively. After testing the robustness of the model specification, changing the measurement of the dependent variables, screening the samples, adjusting the year of the first-difference model, adopting the counting model, and further considering the exogeneity of the instrumental variable, the empirical results remain robust. The mechanistic analysis shows that broadband internet access contributes to increasing the number of R&D personnel and personal innovation efficiency, enhancing enterprises' willingness to innovate, and easing financing constraints. Further analysis suggests that broadband internet access mainly promotes invention patents rather than design patents and that the innovation effect is more obvious among high-tech enterprises, inventor-intensive companies, state-owned enterprises, and enterprises located in the non-southeastern coastal region of China.

Compared with existing research, this article makes the following contributions. First, the existing studies mainly focus on the relationship between innovation and "tangible" infrastructure, such as highways (Agrawal, Galasso, & Oettl, 2017; Wang, Xie, Zhang, & Huang, 2018), street network density (Roche, 2020), and high-speed railways (Wang & Cai, 2020; Yang, Zhang, Lin, Zhang, & Zeng, 2021), while few studies pay attention to how "invisible" internet infrastructure affects innovation. Second, to identify the causal relationship, this paper first attempts to employ the change in market concentration caused by the telecom North–South separation reform as an instrumental variable. Third, compared with an existing case analysis (Sawhney, Verona, & Prandelli, 2005) or empirical analyses based on data from questionnaires (Hall, Lotti, & Mairesse, 2013; Kaufmann, Lehner, & Tödtling, 2003; Lin & Svetlik, 2007), the panel data of Chinese listed companies in this paper contribute to drawing more reliable conclusions. Finally, to gain deep insight into the impact of internet popularization on enterprise innovation, this paper discusses the underlying mechanism in detail.

The remainder of this paper is organized as follows. The second section provides the background and literature review. The third section introduces the model and data. The fourth section reports the estimation results. The fifth section discusses the driving mechanism and conducts a heterogeneity analysis. The final section concludes the paper and provides further discussion.

2. Background and literature review

2.1. Telecom reform in China

Before the mid-1990s, China's telecommunications industry was still in a complete monopoly by China Telecom. To break the monopoly and improve the speed of telecom development as soon as possible, a new telecom operator, China Unicom, was established on July 19, 1994. However, all funds and personnel of China Telecom were directly provided by the Ministry of Posts and Telecommunications, placing China Unicom at a serious competitive disadvantage (Tan, 1999). In March 1998, the Ministry of Information Industry was established based on the former Ministry of Posts and Telecommunications and the Ministry of Electronics. The corporate functions related to operation and management were given to telecommunications companies or corporate groups. In 1999, the Ministry of Information Industry adopted a vertical split to split China Telecom into China Telecom and China Mobile. After these reforms, there were greater opportunities in the telecommunications industry, and operators emerged.[3] However, until 2001, among the five major telecom operators, China Telecom still accounted for more than half of the country's market share (see Fig. 1), and the regulatory goal of effective competition was far from achieved.

In 2002, to break the monopoly situation in the field of fixed telecommunications, form a market environment of fair competition, optimize the allocation of resources and strengthen the supervision of the telecommunications industry, a new round of telecommunications enterprise reorganization was carried out according to the telecommunications system reform plan of the State Council. The original resources of China Telecom were divided into the following two parts: the north and the south.[4] The northern part of China Telecom, China Netcom and China GBnet were reorganized into China Network Communication Group Corporation, namely, the new China Netcom. The enterprises in the southern part of China continued to retain the name China Telecom Corporation. In May 2002, the restructured new China Netcom and new China Telecom were officially listed. The new China Telecom and China Netcom

[3] At that time, China's telecom market has already owned several telecom operators from China Telecom, China Unicom, China Mobile, China Netcom, China Railcom, China GBnet, and China Satcom.

[4] The telecom companies in 10 provinces in North China (Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia), Northeast China (Liaoning, Jilin and Heilongjiang), Henan and Shandong belonged to the northern part of China Telecom, and the remainder (telecom companies in Shanghai, Guangdong, Zhejiang, Jiangsu, Anhui, Fujian, Jiangxi, Guangxi, Chongqing, Sichuan, Hubei, Hunan, Hainan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Tibet and Xinjiang) belonged to the southern part of China Telecom.

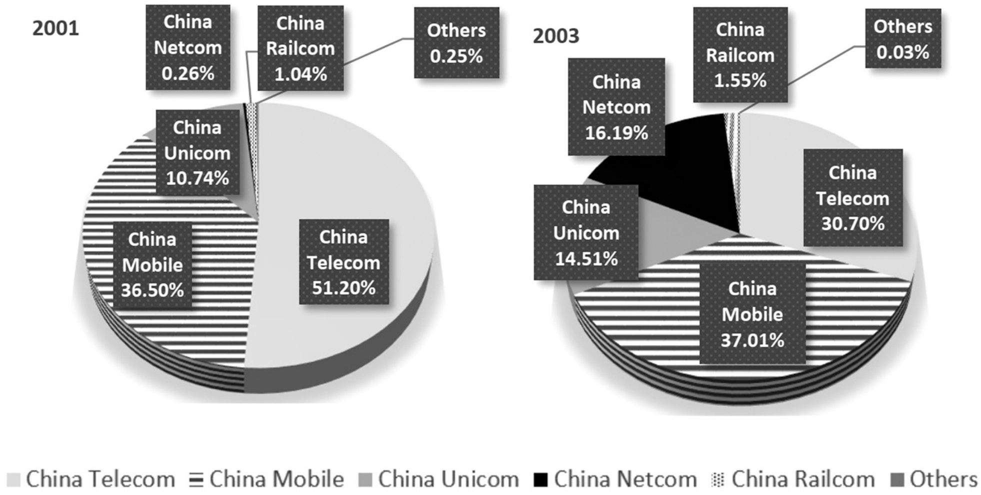

Fig. 1. Market share of the major telecom operators in 2001 (left) and 2003 (right).
(Source: Own calculations based on China Communications Yearbooks.)

both had a complete long-distance trunk transmission network and a complete local telephone network in their respective regions and could enter each other's provinces to compete for fixed network communication. Therefore, the fixed communication field formed a basic pattern in which two leading enterprises competed and emerging enterprises actively participated. In the later stage, although different operators merged and reorganized, the basic competitive situation of the telecommunications industry did not change.

By reviewing the reform process of the telecommunications industry, it can be observed that since the reform and opening up in 1978, China's telecommunications industry has rapidly developed. This industry has grown from the bottleneck restricting the development of the national economy to the pillar driving the growth of the national economy and has achieved a historic leap forward (China Communications Yearbook, 2003). The North–South separation reform of China Telecom in 2002 ended the situation in which China Telecom exceeded half of the national telecom business share for decades (see Fig. 1) and had a far-reaching impact on the subsequent telecom market competition and vigorous development of the internet. Therefore, this paper uses the change in the market competition pattern caused by the North–South separation reform of the telecom market as an instrumental variable of regional internet development.

2.2. *The patent system in China*

Since implementing the first patent law in 1985, China's patent system has grown from scratch, and the number of patents has grown from small to large. According to the China National Intellectual Property Administration statistics, since 2011, China has accepted more invention patent applications than the United States. Since 2015, China has surpassed the United States in the number of invention patents authorized, becoming the largest country worldwide in the number of invention patent applications and authorizations. It takes only 30 years for China to rise from scratch to become the world's first patent power, which can be called a miracle of the development of the patent industry.

Fig. 2 shows the development of Chinese patents from 2007 to 2015. China's patents have rapidly developed, and the number of cities with more than 5000 annual patent applications has increased from 21 to 75. Furthermore, the number of broadband internet users in China is also rapidly increasing, and the development of patents and broadband presents similar temporal and spatial distribution characteristics (as illustrated in Fig. 2). However, patent innovation still has some problems. According to the 2015 data, first, the proportion of invention patents among the total number of patents is too low, reflecting the low quality of the patents applied for in China. Invention patents accounts for only 41.32% of China's patent applications, which is far lower than that in the United States (93.61%), Europe (74.83%), Japan (90.26%) and South Korea (70.69%) during the same period (as shown in Appendix Fig. A1). Second, the development is uneven. At the regional level, among the top ten cities in terms of patent applications, only Chongqing and Chengdu are not located in eastern China. At the enterprise level, the number of patents applied for by the top 100 of the 2841 listed companies in 2015 accounts for 64.33%.

2.3. *Literature review*

With the acceleration of commercialization, the large potential of the internet in the fields of personnel communication, information retrieval, and customer service has gradually been tapped, and research concerning the internet has attracted increasing attention from scholars. One branch of the literature examines the impact of internet development on domestic economic growth. Stiroh (2002) found that in the 1980s and early 1990s, the industries that invest the most in computer hardware, software, and telecommunications equipment in the United States have faster productivity growth after 1995. Koutroumpis (2009) used panel data

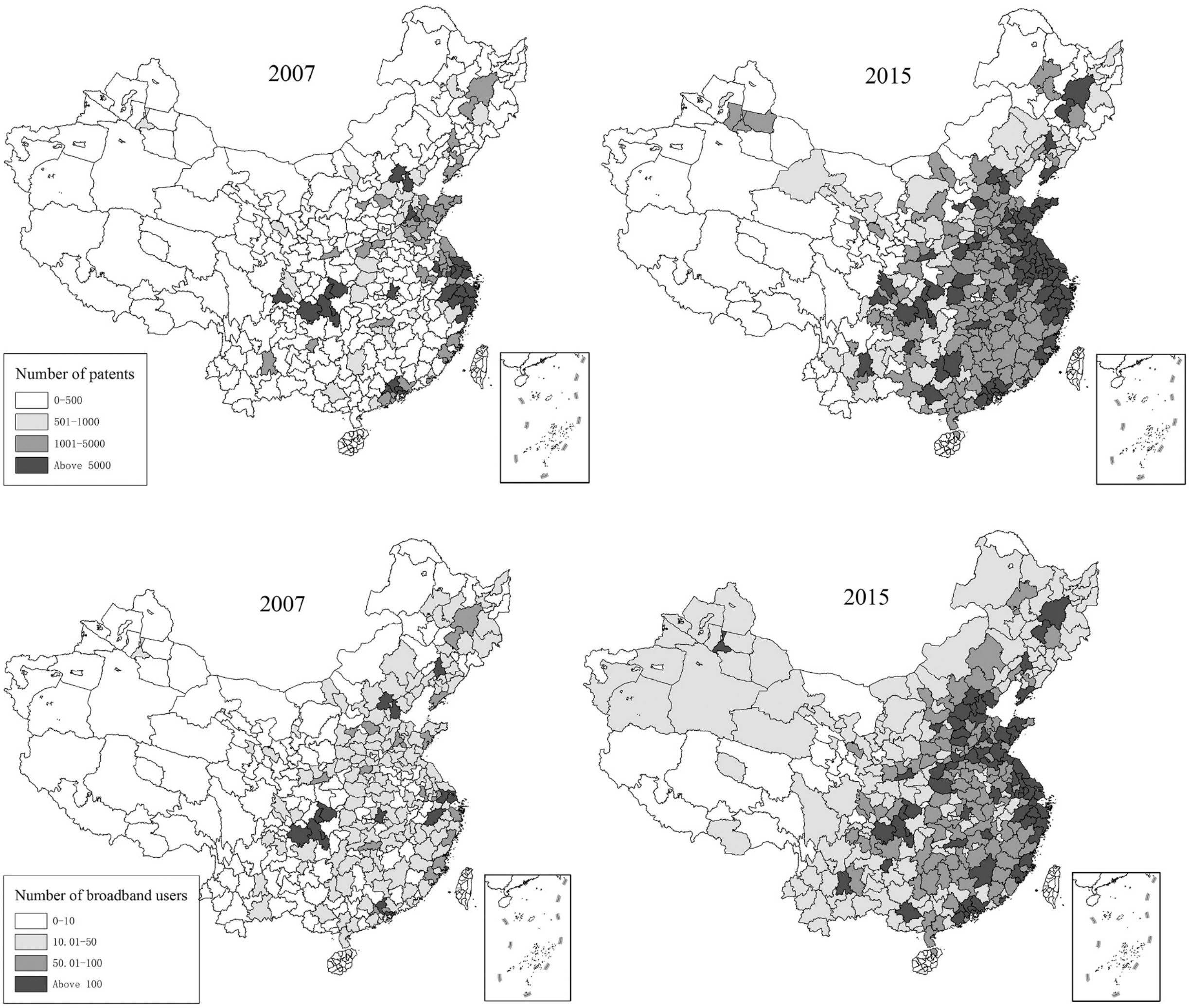

Fig. 2. The distribution of patents (upper panel) and broadband (lower panel) in China.
Notes: 1. Regions for which data are unavailable are represented as 0. The unit of patents is one, and the unit of broadband users is ten thousand. 2. Source: IncoPat Global Patent Database and Annual Report on China's Communications Statistics.

from 15 EU countries from 2003 to 2006 and found that the rate of the contribution of the broadband internet to the countries' economic growth is increasing, which can be attributed to network externalities. In addition, Hjort and Poulsen (2019) found that a fast internet greatly promote the employment rate in areas in Africa with access and has a greater impact on highly skilled workers. However, the influence of the internet on the domestic economy is still controversial. Kolko (2012) noted that although the development of broadband internet is significantly positively related to employment, the employment rate and per capita wage in areas with high broadband penetration have not increased faster, and the median household income is even lower.

Another branch of the literature mainly discusses the influence of the development of the internet on international trade. Freund and Weinhold (2004) used a gravity model to study 56 countries and found that from 1997 to 1999, the rate of the contribution of the internet to export growth is approximately 1%. Clarke (2008) examined the impact of the internet on the exports of some low- and middle-income countries in Eastern Europe and Central Asia and found that enterprises with internet connections export more and that the impact on industry and services is similar. In addition, Vemuri and Siddiqi (2009) used balanced panel data from 1985 to 2005 (a more extended period compared to that in previous studies) of 64 countries (representing multiple development stages) and used instrumental variables and a series of other measurement methods to further verify the role of the internet in promoting international trade. Regarding the mechanism, Bojnec and Ferto (2010) found that the internet improves access to information, intensifies competition, and reduces trade costs, thereby promoting food industry exports in OECD countries. Yadav (2014) argued that the network could reduce the cost of enterprises entering the international market and mainly impact the extensive margin rather than the intensive margin of enterprises' imports and exports.

Importantly, early research concerning the internet mainly focused on the macrolevel, and fewer studies focused on the microlevel.

Furthermore, some disputes exist regarding the impact of the internet on the economy.

Currently, the literature has begun to focus on the impact of the internet on technological innovation. Lee, Nam, Lee, and Son (2016) investigated the determinants of information and communication technology (ICT) patents granted in 40 countries from 1999 to 2013 and found that broadband infrastructure has a long-term impact on ICT innovation. Based on county-level data from the United States, a positive correlation exists between internet access and the number of patent applications in the county. In addition, internet access is more important than network speed (Xu, Watts, & Reed, 2019). However, the literature concerning the impact of the internet on enterprise innovation is relatively small. Kaufmann et al. (2003) found that the internet is conducive to establishing innovation partnerships between enterprises and the outside world, but its scope is mainly within Europe. In addition, compared with establishing new partnerships, the role of the internet is more reflected in improving the internal communication of existing innovation networks. Sawhney et al. (2005) noted that with the rapid development of information technology, enterprises have increasingly realized that the internet can be used as a platform for themselves and customers to cocreate value. Taking advantage of the flexibility, high speed, wide coverage and interactivity of the network platform, customer feedback can be applied to product design in a timely manner, resulting in enterprise technological innovation. The authors also used two typical cases, the Italian company Ducati and the American pharmaceutical company Lilly, to support this view. Regarding the mechanism of the impact of the internet on enterprise innovation, Lin and Svetlik (2007) used survey data from 172 employees in 50 large companies in Taiwan and found that the knowledge contribution and knowledge collection willingness of employees are significantly related to the enterprise innovation ability. The use of ICT mainly affects enterprise innovation by improving employees' knowledge collection rather than their knowledge contribution. Hall et al. (2013) used the UniCredit Bank of Italy to investigate 9850 manufacturing enterprises from 1995 to 2006 and found that ICT and research and development (R&D) investment significantly promote innovation, with R&D investment playing a greater role in innovation and ICT playing a more important role in enterprise productivity growth.

The data used in the studies above are mainly based on questionnaire surveys and case analyses, which involve a certain level of subjectivity. In addition, a detailed discussion concerning endogeneity is lacking; thus, the findings concern only correlational relationships. Accordingly, this paper uses the data of all listed companies in the Wind database and the exogenous impact of the telecommunication reform in 2002 as an instrumental variable to empirically explore the causal effect of the internet on enterprise technological innovation.

3. Econometric model and data

3.1. Identification strategy

To explore the relationship between broadband internet access and enterprise innovation, this paper uses the first-difference model for causal identification. The advantage of using the first-difference model is that as long as the first-difference of the disturbance term is not related to the first-difference of the core explanatory variable, the consistency of the coefficient estimation can be guaranteed. This consistency condition is weaker and easier to satisfy than the strict exogenous assumption to ensure the consistency of coefficients in a fixed effect model. In addition, because the effect of internet infrastructure may be long-term and a serious serial correlation problem may exist between adjacent years, a long-difference regression is more in line with the research design of our paper. The construction process of the first-difference model in this paper is as follows.

For the initial year of the sample period (2007), the regression model is as follows:

$$Innovation_{ic2007} = \alpha_0 + \alpha_1 {}^{*}Broadband_{ic2007} + \lambda_j \sum_{j=1}^{n} FirmControl_{ji2007} + \theta_k \sum_{k=1}^{n} CityControl_{kc2007} + \gamma_i + \varepsilon_{ic2007} \quad (1)$$

where the subscripts i, c and 2007 represent the listed company, city and observation period in 2007, respectively, and j and k represent the j- or k-th control variable. Therefore, $Innovation_{ic2007}$ represents the technological innovation performance of enterprise i in city c in 2007. $Broadband_{ic2007}$ is the penetration rate of broadband internet in 2007 in city c, where company i is located. *FirmControl* and *CityControl* refer to a set of control variables at the firm and city levels, respectively. In addition, γ_i represents the firm fixed effect, which controls for characteristics that change only with individuals but not over time, such as corporate culture and corporate status.

Similar to model (1), for 2015 at the end of the sample period, the regression model is as follows: $\alpha_0 + \delta_0$ is the new intercept term, and the other variables are defined in the same way as described in model (1), except for the subscripts are changed from 2007 to 2015.

$$Innovation_{ic2015} = (\alpha_0 + \delta_0) + \alpha_1 {}^{*}Broadband_{ic2015} + \lambda_j \sum_{j=1}^{n} FirmControl_{ji2015} + \theta_k \sum_{k=1}^{n} CityControl_{kc2015} + \gamma_i + \varepsilon_{ic2015} \quad (2)$$

Then, we subtract model (1) from model (2) to obtain the final first-difference model (3). Although model (3) is a cross-sectional regression model, after the difference, the core variable regression coefficient is equivalent to the result after controlling for the individual fixed effect and the year fixed effect (the individual fixed effect is eliminated, and the year effect is included in the intercept term). Moreover, historical, geographical, cultural and other cross-sectional types of commonly used instrumental variables can be directly applied to model (3), which is one of the main reasons for choosing the first-difference model in this article. In addition, the standard errors in this article are clustered at the city level.

$$dInnovation_{ic} = \delta_0 + \alpha_1 * dBroadband_{ic} + \lambda_j \sum_{j=1}^{n} dFirmControl_{ji} + \theta_k \sum_{k=1}^{n} dCityControl_{kc} + d\varepsilon_{ic} \tag{3}$$

If an endogeneity problem exists in the econometric model, the estimation results of the basic regression will be biased. Omitted variables are one reason for endogeneity. Although this paper attempts to control for individual and time fixed effects and includes company- and city-level control variables, some unobservable missing variables may exist, such as the investment preferences of local governments and the migration of inventors. Another form of endogeneity is reverse causality. Regions with more substantial corporate innovation tend to have more vibrant economies; thus, these regions have a higher internet penetration rate.

To alleviate the endogeneity problem, this paper uses the change in the market competition pattern caused by the exogenous impact of the policy of the North–South separation of China Telecom as an instrumental variable. An ideal instrumental variable must satisfy the following two conditions: relevance and exogeneity. From the perspective of relevance, because industry competition reduces market prices and consumer choice mainly depends on income and commodity prices, the North–South separation of telecommunications can have a profound impact on the subsequent growth of regional internet users. From the perspective of exogeneity, first, the telecommunications reform plan is issued by the State Council. The reform object is China telecom companies covering the whole country, and its promulgation is not affected by a single province- or prefecture-level municipal government. Second, since the split new China Telecom and new China Netcom are officially listed in May 2002, considering that there may be a time lag in the effect of the policy in the region, the market concentration in 2003 is used to measure the competition pattern in the telecom market. Finally, although we controll for economic variables, such as the economic development level, industrial structure, foreign direct investment and financial pressure of prefecture-level cities, some other missing variables that could affect the telecommunications reform process and local enterprise innovation, such as pro-competitive government, may exist. Therefore, the subsequent robustness test further controls for the marketization degree of each province in the year of the reform, the degree of openness, the degree of nationalization, and the characteristics of fiscal decentralization and officials at the prefecture level. As the policy impact mainly affects the telecom market concentration in the latest year, the changes in the market concentration in subsequent years are likely affected by other economic variables, resulting in serious endogeneity problems. Therefore, this article adopts the reformed 2003 Herfindahl index of the telecommunications market and continues to carry out causal identification based on the first-difference model, i.e., data from 2007 and 2015. The first-stage regression model constructed in this paper is as follows:

$$dBroadband_{ic} = \beta_0 + \beta_1 * HHI_{c2003} + \phi_j \sum_{j=1}^{n} dFirmControl_{ji} + \gamma_k \sum_{k=1}^{n} dCityControl_{kc} + d\varepsilon_{ic} \tag{4}$$

where HHI_{c2003} refers to the concentration of the telecommunications market in city c in 2003.

3.2. Data

The empirical analysis presented in this study is based on the following four primary data sources. First, we obtain patent information from the IncoPat Global Patent Database, which contains information regarding more than 100 million patents from 120 countries/organizations/regions worldwide and collects data from national intellectual property officials and commercial institutions. In addition, IncoPat contains all types of patent-related information, such as the classification number, applicant, application date, authorization announcement date, citation, and legal status of each publicly announced patent. Second, the broadband internet user data are obtained from the Annual Report on China's Communications Statistics issued by China's Ministry of Industry and Information, which begins to provide detailed data and information concerning the annual development of the communication industry to society as of 2002. In this annual report, in terms of the development of telecom users, there are only provincial-level statistical indicators from 2003 to 2006, and there are prefecture-level city data after 2007, which is also a main reason for adopting 2007 as the initial year of our paper. Third, we collect the basic attribute information and financial information of Chinese listed companies from the Wind database. The content of the Wind database covers stocks, bonds, funds, foreign exchange, financial derivatives, bulk commodities, financial news, and other fields. Among them, the stock data include the basic information of enterprises, equity indicators, shareholder indicators, valuation indicators, risk analysis, profit forecast, financial analysis, and additional issuance indicators. Fourth, we also obtain various control variables at the city level from the China City Statistical Yearbook, which has been regularly published by the Department of Urban Socioeconomic Investigation Division of the National Bureau of Statistics since 1985. This yearbook contains various statistical data, such as the population, comprehensive economy, industry, trade, education, fiscal revenue and expenditure of each city.

3.2.1. Dependent variables

This article mainly uses patents to measure innovation performance, including the total number of patents (*Patent*), the number of valid patents (*Valid patent*), the number of patent citations (*Patent citation*), and the number of valid patent citations (*Valid Patent citation*). Notably, the total number of patents in year t includes the number of valid patents, number of expired patents, and number of patents under review. The patent status (valid, expired, or pending) of each company's patents is the status when the data were crawled from the internet.[5] All patent data are derived from the IncoPat Global Patent Database.

[5] Due to data availability, the sample in this paper ranges from 2007 to 2016. The specific crawling time is May 2018.

3.2.2. Key explained variable

The core explanatory variable in this paper is broadband (*Broadband*), which is measured by the number of broadband users per 10,000 people, referring to the penetration rate of broadband internet in each year and prefecture-level city. The broadband internet user data are obtained from the Annual Report on China's Communications Statistics.

3.2.3. Control variables

Based on a study by Choi, Lee, and Williams (2011), the following control variables at the enterprise level (*FirmControl*) are included: (1) firm size is measured by the total assets of the enterprise; (2) SOE; based on the attribute classification of the Wind database, central state-owned enterprises, local state-owned enterprises and collective enterprises are defined as state-owned enterprises (SOEs), while public enterprises, foreign-funded enterprises, private enterprises and other enterprises are defined as non-state-owned enterprises; (3) employees; typically, the larger the number of enterprises, the greater the number of personnel allocated to R&D and innovation, leading to a higher patent output; (4) firm age is measured by subtracting the year of establishment from the current year; (5) leverage ratio is the ratio of a company's equity capital to its total assets, reflects a company's debt risk and may affect R&D investment; this article uses the asset-liability ratio as a measure of corporate leverage, i.e., the asset-liability ratio = total liabilities/total assets; (6) net profit is the balance of the current profit of an enterprise after deducting taxes and is the main indicator measuring the operating performance of an enterprise; and (7) business income is the total amount of money an enterprise obtains from selling goods or providing services and is an important guarantee for the enterprise to obtain profits. The above data are collected from the Wind database.

This paper also uses the following series of variables to control for city heterogeneity (*CityControl*): (1) GDP, which is the per capita GDP of cities; this variable measures the level of regional economic development; since a high level of economic development implies high internet penetration and a strong technological innovation ability, including this variable helps alleviate the problem of omitted variables; (2) industrial structure; this paper uses the proportion of the output value of the secondary industry in the output value of all industries to measure the industrial structure; (3) FDI refers to foreign direct investment and reflects the openness of a city; the more open an area, the more likely it is to come into contact with new ideas, technologies and innovation output; and (4) financial pressure, which is measured by the ratio of fiscal expenditure to fiscal revenue; the higher the ratio, the greater the fiscal pressure. The prefecture-level city data are obtained from the 2008–2017 China City Statistical Yearbooks.

3.2.4. Other variables

Our instrumental variable is the Herfindahl index of the telecommunications market (*HHI 2003*), which represents the telecom market concentration in each region in 2003.[6] The data are derived from the statistical yearbooks and reports of the Ministry of Information Industry (MII). Regarding the predetermined variable used in the analysis of the exogenous nature of the instrumental variable, the market index data are obtained from the "NERI index of marketization of China's provinces" constructed by China's National Economic Research Institute. Openness is measured by the proportion of total imports and exports (domestic destinations) to the GDP, and the degree of nationalization is the proportion of the state-owned economy in fixed asset investment. These data are derived from the China Statistical Yearbook 2003 and author accounting. Fiscal decentralization includes fiscal revenue decentralization and fiscal expenditure decentralization.[7] The relevant data are derived from the China Statistical Yearbook and China City Statistical Yearbook. The age of the secretary of the municipal party committee and the major data are mainly derived from government work reports on the websites of prefecture-level city governments, local yearbooks, and public websites. In addition, the data used in the mechanism analysis and heterogeneity analysis include the number of R&D staff, personal patents, R&D risk, R&D expenses, financing constraints, bank loans, high-tech enterprises, inventor-intensive companies, southeastern coastal regions, invention patents, design patents, and utility model patents. Among these variables, the patent-related data are derived from the IncoPat Global Patent Database. Except for the bank loan data, which is derived from the China Stock Market and Accounting Research (CSMAR) database, the remaining enterprise-level data are derived from the Wind database and our own calculations.[8]

Due to data availability and the impact of the data quality on the research results, the data are cleaned before the empirical study as follows: (1) the samples specifically processed as ST or *ST during the sample period are deleted; if a listed company in China loses money for two consecutive years, it is subjected to special treatment, abbreviated as ST; if companies lose money for three consecutive years, they are given a delisting risk warning, marked as *ST; these types of companies are not comparable to normal listed companies; (2) financial companies are excluded; compared with other listed companies, banks, securities firms, insurance companies and other financial industries adopt different accounting standards and report preparation methods; and (3) the data from and before the listing year are deleted. It is generally believed that the profitability, solvency, operating capacity, and growth capacity of a company after listing may undergo major changes. The listing year is a part of a transitional period for companies. In addition, to reduce the het-

[6] The specific calculation formula is $HHI_{2003} + S_1^2 + S_2^2 + S_3^2 + S_4^2 + S_5^2$, where S_{1-5} represents the market share of China Telecom, China Mobile, China Unicom, China Netcom, and other enterprises in each province.

[7] Fiscal revenue decentralization and fiscal expenditure decentralization are measured by the per capita fiscal revenue of prefecture-level cities/(per capita fiscal revenue of prefecture-level cities + per capita provincial fiscal revenue + per capita central fiscal revenue) and per capita fiscal expenditure of prefecture-level city/(per capita fiscal expenditure of prefecture-level city + per capita provincial fiscal expenditure + per capita central fiscal expenditure), respectively.

[8] Due to space constraints, the descriptive statistical results of these predetermined variables and the data used in the mechanism analysis and heterogeneity analysis are all reported in the Appendix (see Table A1-A2).

eroscedasticity of the model estimation and reflect the elasticity of innovation to internet development, this paper adopts the natural logarithm of all non-ratio variables. In particular, regarding data with a zero value, such as patent data and operating income, this article adds a 1 to the real value and then adopts the natural logarithm. Regarding variables with negative values, such as net profit, this article uses inverse hyperbolic sine (IHS) transformation.[9]

Table 1 and Table 2 report the variable definitions and summary statistics of the main variables used in this paper. Except for the instrumental variable (*HHI 2003*) being in the logarithmic form and *SOE* being a 0–1 dummy variable, all other variables are the results of adopting the logarithm of the original value and then subtracting the logarithm in 2007 from the logarithm in 2015. Table 2 shows that the average value of the total number of patents is 0.651, implying that the average number of patents filed by enterprises in 2015 is approximately 91.74% higher than the number in 2007,[10] reflecting the rapid development of the innovation achievements of Chinese enterprises. The average values of the number of valid patents, patent citations, and valid patent citations are 0.758, −0.123, and 0.024, respectively. Using the above method, it can be calculated that the various indicators in 2015 increased by 113.40%, −11.57%, and 2.43%, respectively, compared with those in 2007. When patent holders fail to pay the patent maintenance fees on time or take the initiative to declare in writing that the patented technology is worthless, the patent becomes invalid. Obviously, early patents have a higher probability of invalidation; thus, the gap between the number of valid patents in 2007 and that in 2015 is higher than the gap between the total number of patents. Regarding the number of patent citations, the closer the publication time is to the statistical time point, the lower the citation frequency (Jaffe & Trajtenberg, 1999), which is also the main reason why the number of patent citations in 2015 was 11.57% lower than that in 2007. The average value of broadband internet is 1.139, indicating that compared to 2007, the number of broadband internet users per 10,000 people in each region increased by 212.36% in 2015. This finding shows the rapid development of the internet in China.

4. Empirical results

4.1. Basic results

4.1.1. OLS Model

Based on model (3), columns (1) to (3) of Table 3 report the estimated results of the first-difference regression. The explained variable is the total number of patents, reflecting the quantity of patents. Column (1) contains only the basic characteristics of the firm, such as the size of the firm, the nature of the firm, the number of employees, and the firm age. Column (2) adds the financial indicators of the firm, such as leverage, net profit, and operating income. Column (3) further adds city-level control variables, such as the GDP per capita, industrial structure, foreign direct investment, and fiscal pressure. With the addition of different control variables, broadband internet significantly promotes corporate patents at least at the 95% confidence level. After controlling for the control variables at the firm and city levels, the results show that for every 1% increase in the popularity of broadband internet, the number of enterprise patents increases by an average of approximately 0.418%.

Columns (4) to (6) of Table 3 report the impact of broadband internet on the quality of corporate patents. The explanatory variables in each column are the number of valid patents, patent citations and valid patent citations. The first is the impact of the popularity of the internet on the valid patents of enterprises. The so-called valid patent refers to a patent that is still in a valid state after the patent application is authorized. Patents that last for a long time are usually patents with a high technical level and economic value or core patents. The regression results shown in column (4) illustrate that for every 1% increase in broadband internet penetration, the average number of valid patents of listed companies increases by approximately 0.561%. The second is the impact of internet popularization on the number of corporate patent citations. The number of citations of patents is an important indicator reflecting the quality of patents. A high number of citations indicates a great level of influence. The results shown in column (5) illustrate that for every 1% increase in broadband internet penetration, the average number of corporate patent citations increases by approximately 0.348%. Finally, we discuss the impact of the popularity of the internet on the number of valid patent citations of enterprises. Column (6) shows that for every 1% increase in broadband internet penetration, the number of valid patent citations of listed companies increases by 0.353%.

4.1.2. 2SLS Model

To alleviate the endogeneity problem, this paper uses the change in market concentration caused by the North–South separation reform of Telecom as an instrumental variable for further regressions. Table 4 reports the instrumental variable regression results. Column (5) reports the regression results of the first stage, with a coefficient of −3.981 and a significance level of 1%, indicating that for every 1% increase in market competition (or a 1% decrease in market concentration), the popularity of broadband internet increases by 3.981%. This result further shows that our instrumental variable satisfies the relevance condition. Regarding the weak instrumental variable test, the Kleibergen–Paap Wald rk F-statistic is 43.725, which is significantly larger than the conventional critical value of 10, indicating that there is no weak instrumental variable problem. In addition, to further verify the effectiveness of the instrumental variable, we report the reduced form regression of the impact of the telecom market concentration on the patent quantity and quality (see Appendix Table A3). The results show that the regression coefficients of the telecom market concentration are between −3.038 and −5.968 and are all significant at the 1% level. We can conclude that the North–South telecom separation has a significant

[9] The IHS transformation can be expressed as $IHS(x) = log\left(x + \sqrt{1 + x^2}\right)$, where x is the variable of interest, and IHS(x) is the final transformed version.

[10] The specific conversion formula is 100*[exp(0.651)-1] ≈ 91.74%.

Table 1
Description of the main variables.

Variables	Description
Patent	Total number of patents
Valid patent	Number of valid patents
Patent citation	Number of patent citations
Valid patent citation	Number of valid patent citations
Broadband	Broadband internet penetration rate, number of broadband users per 10,000 people
Firm size	Firm size, measured by the total assets
SOE	Nature of firm, state-owned enterprises (yes = 1, no = 0)
Employee	Number of employees
Firm age	Firm age
Leverage	Leverage ratio, using the ratio of the total liabilities to the total assets
Net profit	Net profit
Business income	Business income
GDP	GDP per capita
Industrial structure	Industrial structure, the secondary industry accounts for the proportion of the three major industries
FDI	Foreign direct investment
Financial pressure	Fiscal pressure, fiscal expenditure divided by fiscal revenue
HHI 2003	Concentration of the telecommunications market, Herfindahl index in 2003

Table 2
Summary statistics of the main variables.

Variables	N	Mean	Min	Max	Median	Std
Patent	1096	0.651	−4.898	6.848	0	1.445
Valid patent	1096	0.758	−4.466	6.475	0	1.436
Patent citation	1096	−0.123	−5.969	5.638	0	1.221
Valid patent citation	1096	0.024	−5.545	5.371	0	1.052
Broadband	1096	1.139	0.243	4.046	1.229	0.452
Firm size	1096	1.052	−3.997	7.219	0.994	0.998
SOE	1096	0.591	0	1	1	0.492
Employee	1096	0.511	−4.053	6.467	0.387	1.157
Firm age	1096	0.543	0.244	1.299	0.511	0.144
Leverage	1096	−0.110	−6.323	2.233	−0.036	0.632
Net profit	1096	−0.469	−18.75	14.30	0.530	5.178
Business income	1096	0.841	−3.818	8.783	0.777	1.211
GDP	1096	0.812	0.358	1.587	0.791	0.255
Industrial structure	1096	−5.373	−20.090	16.380	−7.090	6.784
FDI	1096	0.753	−2.473	4.192	0.846	0.851
Financial pressure	1096	−0.054	−0.386	0.391	−0.059	0.110
HHI 2003	1096	−0.966	−1.079	−0.870	−0.976	0.055

Notes: 1. Except for the instrumental variable (*HHI 2003*) being in the logarithmic form and *SOE* being a 0–1 dummy variable, all other variables are the results of adopting the logarithm of the original value and then subtracting the logarithm in 2007 from the logarithm in 2015. 2. Source: IncoPat Global Patent Database, Wind database, Annual Report on China's Communications Statistics, China City Statistical Yearbook, and the statistical yearbooks and reports of the Ministry of Information Industry (MII).

Table 3
The impact of broadband internet on corporate patents (OLS).

	Quantity			Quality		
	Patent			Valid patent	Patent citation	Valid patent citation
	(1)	(2)	(3)	(4)	(5)	(6)
Broadband	0.260**	0.258**	0.418***	0.561***	0.348***	0.353***
	(0.125)	(0.127)	(0.141)	(0.137)	(0.111)	(0.090)
Observations	1096	1096	1096	1096	1096	1096
Adjusted R-squared	0.036	0.038	0.045	0.048	0.017	0.016
Firm basic characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Firm financial indicators	No	Yes	Yes	Yes	Yes	Yes
City control variables	No	No	Yes	Yes	Yes	Yes

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. Columns (1) to (3) use the number of patents to measure the quantity of corporate innovation. Columns (4) to (6) use the number of valid patents, patent citations and valid patent citations to measure the quality of corporate innovation. All coefficients represent OLS regression results after adopting the logarithm and first-difference. Firm basic characteristics include *Firm size*, *SOE*, *Employee*, and *Firm age*. *Leverage*, *Net profit*, and *Business income* are firm financial indicators. City control variables include *GDP*, *Industrial structure*, *FDI*, and *Financial pressure*.

Table 4
The impact of broadband internet on corporate patents (2SLS).

	Second Stage				First Stage
	Patent	Valid patent	Patent citation	Valid patent citation	Broadband
	(1)	(2)	(3)	(4)	(5)
Broadband	1.395***	1.499***	0.920***	0.763***	
	(0.483)	(0.482)	(0.349)	(0.272)	
HHI 2003					−3.981***
					(1.310)
Observations	1096	1096	1096	1096	1096
Adjusted R-squared	−0.015	−0.008	−0.012	−0.004	0.439
Firm control variables	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes
KP F-statistic	43.725	43.725	43.725	43.725	–

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. Columns (1) to (4) show the results of the second stage of the two-stage least squares method, and the explanatory variables are the number of patents, valid patents, patent citations and valid patent citations. Column (5) shows the results of the first stage of the two-stage least squares method, and the explanatory variable is the number of broadband users per 10,000 people. Except for the instrumental variable (*HHI 2003*) being in the logarithmic form and *SOE* being a 0–1 dummy variable, all other variables are the results of adopting the logarithm of the original value and then subtracting the logarithm in 2007 from the logarithm in 2015. The KP F-statistic is the Kleibergen–Paap Wald rk F-statistic for weak identification in the first stage. Firm control variables include both firm basic attributes (*Firm size, SOE, Employee*, and *Firm age*) and firm financial indicators (*Leverage, Net profit*, and *Business income*). City control variables have the same definition as those reported in Table 3 (the same below).

impact on patent innovation,which indirectly indicates that the North–South telecom separation has a good instrumental variable nature.

From the perspective of the second-stage regression coefficients, columns (1) to (4) show that the increase in the popularity of broadband internet is at the level of 1%, which significantly increases the total number of patents, valid patents, patent citations and valid patent citations of enterprises. Specifically, for every 1% increase in the broadband internet penetration rate, the total number of patents increases by 1.395%. The average number of patents in our sample is 32.468, which is equivalent to an increase of 0.453 patents per enterprise. Furthermore, based on the estimation results of the Chinese patent value by Zhang, Lv, and Zhou (2014),[11] we can estimate that the market value is approximately 87.547 million yuan.[12] In addition, for every 1% increase in broadband internet, the valid patents, patent citations and valid patent citations of enterprises will increase by 1.395%, 1.499%, 0.920% and 0.763%, respectively. The regression coefficient is larger than the long-differences result under the OLS model as reported in Table 3. The possible reasons are as follows. First, the instrumental variable estimation only generates estimates of the local average treatment effect for compliers (Angrist & Pischke, 2008). In this paper, these compliers refer to the sample group whose broadband internet penetration will rise with the increase in market competition after the North–South separation of telecommunications. Therefore, the instrumental variable estimator can exceed the conventional OLS estimator if the intervention affects a subgroup with a relatively high marginal return to broadband internet. Second, some uncontrollable missing variables that are positively (negatively) correlated with broadband internet but negatively (positively) correlated with corporate innovation exist, such as the investment preferences of local governments. Local governments that attach great importance to the construction of information infrastructure will invest a large amount of funds in infrastructure construction, such as optical fiber broadband, and formulate preferential policies, which will inevitably affect transfer payments, such as innovation subsidies for enterprises. In addition, in the current information age, the development of real estate within cities will drive broadband internet connections, and housing price appreciation may also inhibit innovation (Rong, Wang, & Gong, 2016). Due to the lack of an accurate measurement of local government investment preferences and the changing real estate market, these factors are included in the error term, which, in turn, leads to an underestimation of the OLS results. Through the above analysis, it can be found that the actual effect of broadband internet could be underestimated if the endogeneity problem is not considered. Therefore, this article uses the regression result of the instrumental variable as a benchmark.

4.2. Robustness test

To ensure the robustness of the estimation results, a series of robustness tests are carried out as described in this section. First, we test the robustness of the model specification. After using the first-difference model, we use the change in market concentration caused by the impact of the telecom North–South separation reform as an instrumental variable to reflect the long-term impact of broadband infrastructure—but at the expense of the sample size. Therefore, this paper multiplies the HHI by the year dummy variable as a new

[11] Zhang et al. (2014) estimated that the average patent values in the fields of electrical engineering, instruments, chemistry and pharmaceutical, process engineering and special equipment, mechanical engineering, and consumptions in China from 2001 to 2007 were 60,963, 68,106, 65,451, 72,195, 72,504, and 68,997, respectively. We calculate that the average value of these patents is 68,036 yuan (in 2012 RMB).

[12] In 2015, there were 2841 listed companies in China. Therefore, the market value caused by a 1% increase in broadband internet is approximately 32.468*1.395%*2841*68036/1000000 ≈ 87.547 million yuan.

instrumental variable and applies this variable to the panel regression model from 2007 to 2016. The regression results are reported in Table 5. Columns (3) to (6) show that the coefficients of the total number of patents, the number of valid patents, the number of patent citations and the number of valid patent citations are very close to the instrumental variable results under the first-difference model, further verifying that the first-difference model adopted in this paper does not introduce a large deviation due to the loss of sample size.

Second, the robustness of the regression results is verified by adjusting the variable measurement, screening samples, and adopting different regression models. (1) One approach is to change the logarithmic transformation of the core variables. There are many 0 values in the corporate patent data. This paper mainly used the regression result of adding 1 to the original value and adopting the natural logarithm. To avoid the impact of direct logarithm transformation on the results, this paper also uses IHS transformation as mentioned above for a robustness test, and the regression results are reported in Table 6. Columns (1) to (4) of Table 6 show that for every 1% increase in internet penetration, the total number of patents, number of valid patents, number of patent citations and number of valid patent citations of enterprises increase by 1.621%, 0.840%, 0.653% and 0.509%, respectively. There is minimal difference from the benchmark result coefficient. (2) The second approach is to replace the measurement method of the patent data. Column (1) of Table 7 reports the results obtained using the number of patents per capita as the explanatory variable.[13] The results show that for every 1% increase in the number of broadband internet users, the number of patents per capita of enterprises increases by 0.011%. (3) The third approach is to carry out robustness tests by screening samples. Column (2) reports the regression results after deleting the enterprise with 0 patents in 2015. Here, the regression coefficient is 1.393, which is very close to the benchmark regression result of 1.395, further indicating that the zero value processing method of the benchmark regression does not introduce significant deviation. In column (3), excluding the samples from first-tier cities, such as Beijing, Shanghai, Guangzhou and Shenzhen, the regression results are still significant, and the coefficient increases, indicating that the internet may have a stronger effect on small cities with less broadband infrastructure coverage. (4) The fourth approach is to change the ending year of the first-difference model to 2014 and 2016, and the results are reported in columns (4) and (5). The effect of broadband internet on enterprise technological innovation is still robust. (5) Finally, the counting model is adopted. Since the numbers of patents of listed companies are non-negative integers, Poisson regression is often used to analyze such counting data. However, one limitation of Poisson regression is the assumption that its expectation and variance are equal, i.e., equidispersion; however, in reality, the data variance is often greater than the expectation. Therefore, negative binomial regression is often used for further verification (Peterson, 1999). Columns (6) and (7) report the results of the Poisson regression and negative binomial regression, respectively. In these two types of counting models, the meaning of the semi-elastic coefficient is consistent with the full elastic coefficient of the OLS model, indicating that for every 1% increase in the popularity of broadband internet, the average number of corporate patents increases by approximately 1.648% and 1.627%, which is only slightly higher than the regression coefficient of the OLS.[14]

Furthermore, we discuss the exogeneity of the instrumental variable. This article is based on the North–South separation reform of telecommunications implemented by the State Council of the People's Republic of China. However, some time-varying economic or political characteristics in various regions may still affect the concentration of the telecommunications market and are related to corporate innovation, which may cause bias in the estimation results. Therefore, in addition to the per capita GDP of prefecture-level cities, industrial structure, foreign direct investment and financial pressure controlled in the benchmark regression, this paper also further controls for other provincial or municipal characteristic variables in 2002. The results are reported in Table 8. Column (1) shows the benchmark results after using the instrumental variable. Column (2) adds the marketization index, degree of openness and nationalization of each province. Column (3) adds fiscal decentralization indicators, including fiscal revenue decentralization and fiscal expenditure decentralization. Column (4) further adds the characteristics of the leaders of prefecture-level cities, referring to Kunrong and Gang (2020), using the age of the municipal party secretary and the mayor as a measure of pro-competition government. The regression results show that except for the age of the municipal party secretary, the coefficients of all variables are not significant, suggesting that in addition to the political characteristics, the characteristics of various regions in 2002 does not affect the concentration of the telecommunication market in 2003. In addition, even if political characteristics affect the exogeneity of the instrumental variable, the basic regression results are still significant after adding control variables. Columns (5) to (7) successively report the regression results obtained after adding the control variables of various provinces and prefecture-level cities. The explanatory variables are the number of valid patents, the number of patent citations, and the number of valid patent citations, and the regression results are all maintained robustly.

5. Further discussion

5.1. Mechanism analysis

Internet development can alleviate information asymmetries, accelerate knowledge spillover, reduce transaction costs (Bellou, 2015; Bojnec & Ferto, 2010; Hitsch, Hortaçsu, & Ariely, 2010; Koutroumpis, 2009; Kuhn & Skuterud, 2004; Zheng, Duan, & Ward, 2019), and ultimately affect corporate innovation. In this paper, we further divide the role of the internet's influence on corporate innovation into the following three aspects: innovation ability, innovation willingness, and innovation support (see Fig. 3).

[13] The robustness tests shown in Table 6 mainly report the results of the total number of patents. The results of the number of valid patents, patent citations, and valid patent citations are still robust. Due to space limitations, the results are not repeated in the main text.

[14] After the first-difference, some observations have negative values (i.e., the number of patents applied in 2015 is less than that in 2007), which is not suitable for the counting model. Therefore, we delete the negative values and continue the counting model regression.

Table 5
Regression results of the full sample (IV*year dummy).

	Patent	Patent	Patent	Valid patent	Patent citation	Valid patent citation
	(1)	(2)	(3)	(4)	(5)	(6)
Broadband	1.492**	1.815**	1.621**	1.501**	0.920**	0.769**
	(0.664)	(0.904)	(0.782)	(0.706)	(0.423)	(0.351)
Observations	17,813	17,813	17,813	17,813	17,813	17,813
Adjusted R-squared	−0.352	−0.418	−0.018	−0.021	0.040	0.046
Firm control variables	No	Yes	Yes	Yes	Yes	Yes
City control variables	No	No	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	16.203	14.229	23.041	23.041	23.041	23.041

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. The sample period is from 2007 to 2016, and the instrumental variable is the *HHI 2003* * year dummy.

Table 6
Robustness test I (IHS transformation).

	Second Stage (IHS)				First Stage
	Patent	Valid patent	Patent citation	Valid patent citation	Broadband
	(1)	(2)	(3)	(4)	(5)
Broadband	1.621***	0.840***	0.653***	0.509***	
	(0.563)	(0.267)	(0.241)	(0.179)	
HHI 2003					−3.981***
					(1.310)
Observations	1096	1096	1096	1096	1096
Adjusted R-squared	−0.018	0.001	−0.027	−0.007	0.439
Firm control variables	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes
KP F-statistic	43.725	43.725	43.725	43.725	–

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. All dependent variables are transformed by inverse hyperbolic sine (IHS) transformation.

Table 7
Robustness test II.

	Patents per capita	0 patents removed	No first-tier cities	2007 and 2014	2007 and 2016	Poisson	Negative binomial
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Broadband	0.011*	1.393**	2.410***	1.782***	1.877**	1.648**	1.627***
	(0.006)	(0.611)	(0.927)	(0.669)	(0.859)	(0.739)	(0.363)
Observations	1096	488	851	1099	1092	993	993
Adjusted R-squared	−0.001	0.029	−0.112	−0.068	−0.149	–	–
Firm control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	43.725	39.150	22.545	50.395	26.828	–	–

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. Columns (1)–(5) employ the same model as in Table 4, and columns (6) and (7) adopt Poisson regression and negative binomial regression, respectively. The dependent variable in column (1) is patents per capita. The dependent variable in columns (2)–(5) is the logarithmic form of patents in 2015 minus the value in 2007, while the dependent variable in columns (6) and (7) is calculated by the actual number of patents in 2015 minus the value in 2007. Columns (2)–(5) use different subsamples as a robustness test. Column (2) includes a sample of companies with 0 patents in 2015 removed, and column (3) excludes samples from first-tier cities, such as Beijing, Shanghai, Guangzhou and Shenzhen. The samples used in column (4) are 2007 and 2014, and the samples used in column (5) are 2007 and 2016.

First, broadband internet affects corporate innovation capability. Innovation ability in this paper is mainly measured from the perspectives of R&D personnel and innovation efficiency. Numerous existing studies show that R&D personnel input is an essential factor affecting knowledge output (Chang, Fu, Low, & Zhang, 2015; He & Tian, 2018) because talent is the subject of innovation activities. Through the internet, enterprises can easily release a large amount of recruitment information and then hire more R&D personnel at lower costs. The R&D personnel data are derived from the Wind database.[15] Column (1) of Table 9 shows that broadband

[15] Regarding missing data, the observation value from the year closest to the missing value is used.

Table 8
Exogenous analysis.

	Patent	Patent	Patent	Patent	Valid patent	Patent citation	Valid patent citation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Broadband	1.395***	1.378***	1.310***	1.765***	1.786***	1.098**	0.766**
	(0.483)	(0.427)	(0.403)	(0.547)	(0.587)	(0.431)	(0.339)
Market index		−0.024	−0.040	0.016	0.044	−0.076	−0.054
		(0.095)	(0.097)	(0.116)	(0.113)	(0.079)	(0.061)
Openness		0.330	0.305	0.276	0.172	0.125	0.061
		(0.226)	(0.215)	(0.252)	(0.262)	(0.168)	(0.135)
Nationalization		0.312	0.039	1.818	2.109	0.092	−0.185
		(1.810)	(1.815)	(2.273)	(2.275)	(1.547)	(1.135)
Fiscal revenue			0.516	0.093	−0.283	−0.168	−0.578
Decentralization			(0.882)	(1.001)	(1.003)	(0.782)	(0.582)
Fiscal expenditure			0.074	0.780	1.226	0.653	1.001
Decentralization			(0.948)	(1.111)	(1.124)	(0.892)	(0.632)
Secretary age				2.214**	1.887**	1.390*	0.676
				(0.879)	(0.935)	(0.771)	(0.588)
Mayor age				0.332	0.346	0.281	0.379
				(1.007)	(1.010)	(0.641)	(0.472)
Observations	1096	1095	1095	1095	1095	1095	1095
Adjusted R-squared	−0.015	−0.011	−0.004	−0.036	−0.024	−0.021	−0.000
Firm control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	43.725	61.846	68.218	38.846	38.846	38.846	38.846

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level.

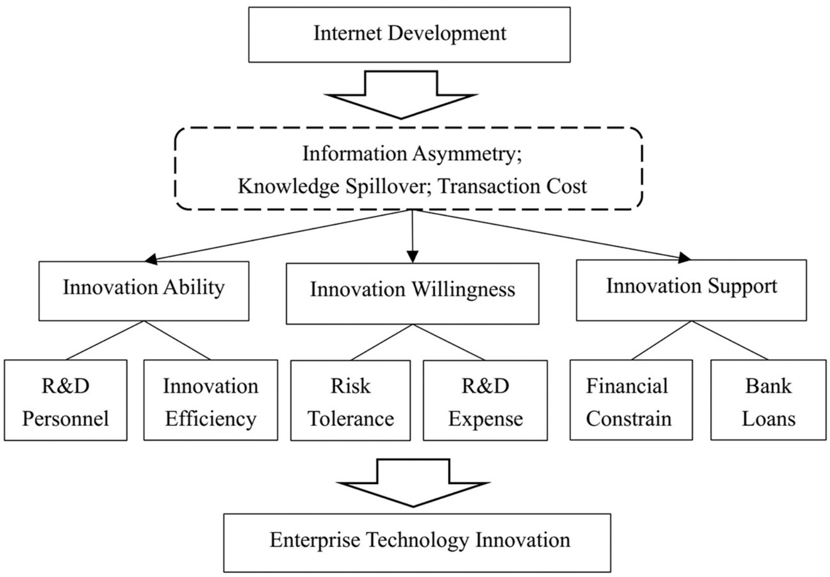

Fig. 3. The mechanism of the impact of internet development on enterprise technological innovation.

internet significantly increases the number of corporate R&D personnel. In addition, the internet facilitates information search, promotes interaction between researchers and accelerates knowledge spillover, which can improve the innovation efficiency of R&D personnel. We measure innovation efficiency by the change in personal patents. This paper matches the patent inventors of listed companies in 2007 and 2015. In total, 2831 inventors have patent applications in both years. The inventors' data are derived from the IncoPat Global Patent Database. Column (2) shows that for every 1% increase in broadband internet, local personal patents increase by an average of 0.661%, indicating that broadband internet improves the innovation efficiency of inventors.

Second, broadband internet affects enterprises' willingness to innovate. According to the theory of planned behavior in the behavioral science literature, attitude, subjective norms, and perceptual control jointly determine the willingness of behavior, and willingness, in turn, determines behavior (Ajzen, 1991; Armitage & Conner, 2010). Specifically, R&D willingness or motivation has significant impacts on innovation output (Sauermann & Cohen, 2010). Ordinarily, after information is unblocked, uncertainty is

Table 9
Mechanism analysis.

	Ability		Willingness		Support	
	Number of R&D staff	Personal patent	R&D risk	R&D expense	Financing constraint	Bank loans
	(1)	(2)	(3)	(4)	(5)	(6)
Broadband	0.773*	0.661*	0.866***	0.753*	−0.066**	1.259*
	(0.457)	(0.374)	(0.330)	(0.442)	(0.031)	(0.709)
Observations	886	2831	1096	793	1096	1096
Adjusted R-squared	0.057	0.064	0.199	0.092	0.327	−0.044
Firm control variables	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	37.387	19.729	43.725	42.035	43.725	43.725

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. The dependent variables in columns (1) to (6) are the number of R&D staff, personnel patents, R&D risk, R&D expenses, financing constraints, and bank loans.

reduced, and risk expectations are reduced, which can improve risk tolerance and, thus, enhance the innovation output of enterprises. Based on Mukherjee, Singh, and Žaldokas (2017), the standard deviation of patent citations is used as a proxy indicator of patent R&D risk. A large standard deviation of patent citations indicates a high risk. The results shown in column (3) of Table 9 illustrate that for every 1% increase in broadband internet penetration, the standard deviation of the patent citations of listed companies increases by approximately 0.866% on average, indicating that the internet increases corporations' affordability of risk. In addition, we use R&D expenses as a measure of enterprises' willingness to innovate. Column (4) of Table 9 shows that after the increase in broadband internet penetration, the R&D funds that enterprises are willing to invest also significantly increase.

Furthermore, this article explores the impact of the internet on innovation support. This article mainly considers innovation support for enterprises from the perspective of financing. The incomplete market caused by information asymmetry leads enterprises to face the problem of financing constraints and then abandon innovative projects with a high risk, long cycles and large capital demand (Aboody & Lev, 2000; Fazzari & Athey, 1987). The development of the internet has a substantial impact on corporate financing. On the one hand, internet-based big data, cloud computing, and various network platforms assisting enterprises in financing have rapidly developed, providing a considerable development space for reducing transaction costs and expanding the scope of financial services. On the other hand, the development of information technology also facilitates the disclosure of enterprise information and strengthens the interaction between enterprise management and investors (Elliott, Grant, Hobson, & Asay, 2020), which is more conducive for enterprises to obtain venture capital. In particular, the rapid development of internet finance with the popularity of the internet has greatly facilitated corporate fundraising and turnover, thereby alleviating financing constraints and providing material guarantees for corporate patent innovation. Following Hadlock and Pierce (2010), this article uses the financial constraint index to measure the relative degree of financial constraint of a company.[16] Column (5) of Table 9 shows that the coefficient before the core explanatory variable is −0.066 and is significant at the 95% confidence level, indicating that broadband internet significantly reduces corporate financing constraints, which is also consistent with our analysis above. In addition, bank credit or loans are integral to the external source of enterprise funds, which is also an essential guarantee for corporate innovation (Amore, Schneider, & Žaldokas, 2013; Dou & Xu, 2021). Therefore, we further test whether broadband internet affects enterprise innovation by increasing bank loans. The regression results confirm our inference as shown in column (6) of Table 9.

5.2. Heterogeneity analysis

To further verify the mechanism underlying the effect of broadband internet on corporate innovation and explore the heterogeneity of its effect, this paper is also concerned with different enterprise types, patent types, and industry categories. First, we attempt to explore the impact of the popularization of broadband internet on different types of enterprises. The regression results are reported in Appendix Table A4,[17] and Fig. 4 plots the coefficients of each regression. The specific analysis process is as follows. (1) This article distinguishes high-tech companies from non-high-tech companies. Based on the measurable quantitative indicators in the Administrative Measures for the Recognition of High-tech Enterprises (Guo Ke Fa Huo [2008] No. 172) jointly issued by China's Ministry of

[16] The formula used to calculate the financial constraint index is $SA = (-0.737^{*} Size) + (0.043^{*} Size^{2}) - (0.040^{*}Age)$. Among them, Size represents the logarithmic value of a company's total assets, and Age is the age of the company. The calculated SA index is a negative value, and the larger the absolute value, the lower the financing constraint.

[17] Following a reviewer's suggestions, we use the interaction item to double-check whether the differences between every two groups are statistically significant. As shown in Appendix Table A5, the results remain robust.

Science and Technology, Ministry of Finance and State Administration of Taxation, our samples are divided into high-tech enterprises and non-high-tech enterprises.[18] The results provided in Fig. 4 show that internet popularization mainly promotes the technological innovation of high-tech enterprises and has no significant impact on non-high-tech enterprises. A possible reason is that the internet can introduce more knowledge spillovers in knowledge-intensive enterprises. (2) Regarding enterprise inventors, we first count the number of inventors of each listed company in the sample period and then divide this number according to the median number of inventors. A company with a higher number of inventors than the median is called an inventor-intensive company. Fig. 4 shows that broadband internet mainly promotes corporate innovation with dense inventors but has no significant effect on enterprises with few inventors. This result proves once again that the spillover effect in knowledge-intensive enterprises is stronger and indicates that there is a scale effect of the promotion of broadband internet on corporate innovation. (3) Regarding the ownership of enterprises, Fig. 4 shows that the penetration of broadband internet significantly enhances the technological innovation of state-owned enterprises, but the result is not significant among non-state-owned enterprises. A possible explanation is that state-owned enterprises find it easier or can obtain bank loans at lower interest rates than private enterprises (Song, Storesletten, & Zilibotti, 2011). Therefore, when the internet plays a role in alleviating information asymmetry and reducing transaction costs, the innovation incentive of state-owned enterprises is stronger. (4) The sample is also divided according to the region in which the enterprise is located. In this paper, the samples are divided into the southeastern coastal region and the non-southeastern coastal region. The southeastern coastal region is the most economically dynamic area in China and mainly includes Jiangsu, Shanghai, Zhejiang, Fujian and Guangdong. The other 26 provinces of the 31 Chinese mainland provinces are non-southeastern coastal regions. As shown in Fig. 4, broadband internet mainly acts in non-southeastern regions. The reason may be that the transportation and internet infrastructures in the non-southeastern coastal region of China are significantly weaker.[19] Therefore, according to the principle of diminishing marginal returns, the effect of broadband internet popularization on alleviating information asymmetry and reducing transaction costs is more apparent.

Second, this paper further explores the impact of the popularization of broadband internet on different types of patents. The regression coefficients of the internet on invention patents, design patents, and utility model patents and their 10% confidence intervals are illustrated in Fig. 5 (columns (1) to (3) of Appendix Table A7 also report the regression results). The popularization of broadband internet has a significant positive impact on invention patents and utility model patents but no significant impact on design patents. Since the quality of invention patents is the highest among all three types of patents, the results suggest that internet penetration significantly promotes corporate patent quality.

Finally, this paper also explores the heterogeneity of the impact of the internet on listed companies in different industries. According to the industry classification in the Wind database, listed companies are divided into the following eight categories[20]: industry, materials, optional consumption, daily consumption, information technology, utilities, medical care and energy. The Wind industry classification standard is an industry classification standard introduced by Wind information to meet the needs of market investment research after widely learning from the industry classification standards of domestic and foreign securities markets and considering the characteristics of China's securities market. Fig. 6 illustrates the regression coefficients and 10% confidence intervals by industry. We can conclude that broadband internet mainly promotes enterprise innovation in the fields of industry, materials and optional consumption and has no significant impact on the other types of enterprises. Of course, the non-significant coefficient of the core variables may also be due to the small sample, especially in the energy industry, which only includes 36 enterprises (see column (8) of Appendix Table A8).

6. Conclusion

Based on the microdata from 1096 listed companies and the internet macrodata for prefecture-level cities, this paper empirically explores the impact of broadband internet on the technological innovation of local listed companies. This paper also uses the changes in market concentration caused by the North–South separation of telecommunications in 2002 as an instrumental variable. After testing the robustness of the model specification, replacing the patent data measurement, screening the samples, adjusting the year of the first-difference model, adopting counting models, and further considering the exogeneity of the instrumental variable, the regression results remain robust. On this basis, this article further explores the mechanism through which broadband internet promotes enterprise innovation based on the following three aspects: enterprise innovation ability, innovation willingness and innovation support. Finally, this research also analyzes the heterogeneity of enterprises from the perspectives of the technological level, ownership type, region, and industry category of enterprises. The main research conclusions are as follows.

First, broadband internet significantly promotes the technological innovation of enterprises, and the total number of patents, the number of valid patents, the number of patent citations, and the number of valid patent citations significantly increase. Second, broadband internet affects enterprise technological innovation through the following three channels: innovation capability,

[18] To be recognized as a high-tech enterprise, the ratio of the total R&D expenses to the total sales income in the past three fiscal years should meet the following requirements: for companies with sales income less than 50 million yuan (inclusive), the ratio must not be less than 6%; for companies with sales revenue of 50 million yuan to 200 million yuan (inclusive), the ratio must not be less than 4%; and for companies with sales revenue greater than 200 million yuan (inclusive), the ratio must not be less than 3%.

[19] Appendix Table A6 shows the ranking of China's major telecom industry indicators in 2015. We can conclude that the top provinces in terms of the various indicators are primarily located in the southeast coastal areas.

[20] There are 10 primary classifications of Wind industry. According to the above, the financial industry is excluded. Since there are only 2 listed telecom companies in the sample, the telecom industry is also excluded. Finally, 8 industries are included in the heterogeneity analysis.

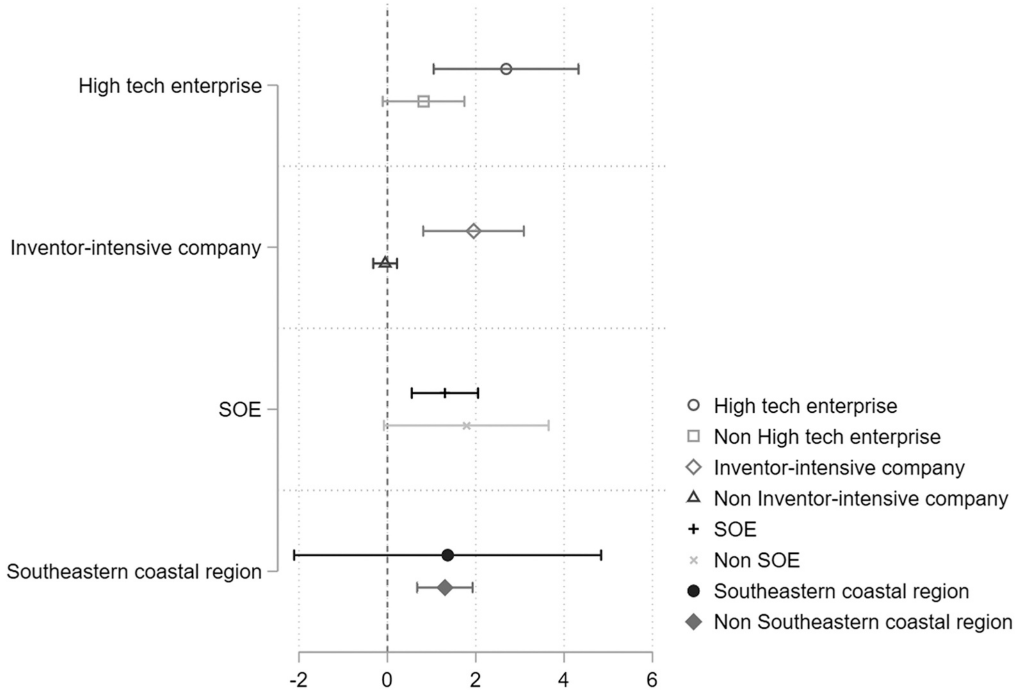

Fig. 4. Heterogeneity of enterprises of different types in different regions.
Notes: The center icon represents the estimated result of the instrumental variable, and the solid line represents the 90% confidence interval.

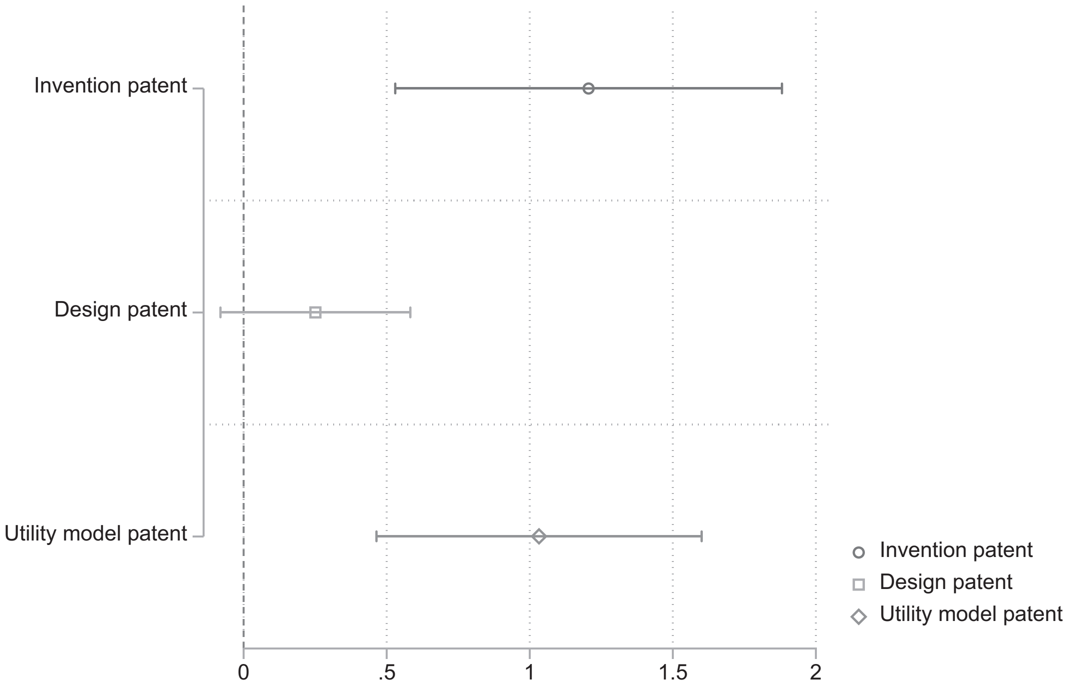

Fig. 5. Heterogeneity of patent types.
Notes: 1. The center icon represents the estimated result of the instrumental variable, and the solid line represents the 90% confidence interval. 2. The dependent variables are invention patents, design patents, and utility model patents.

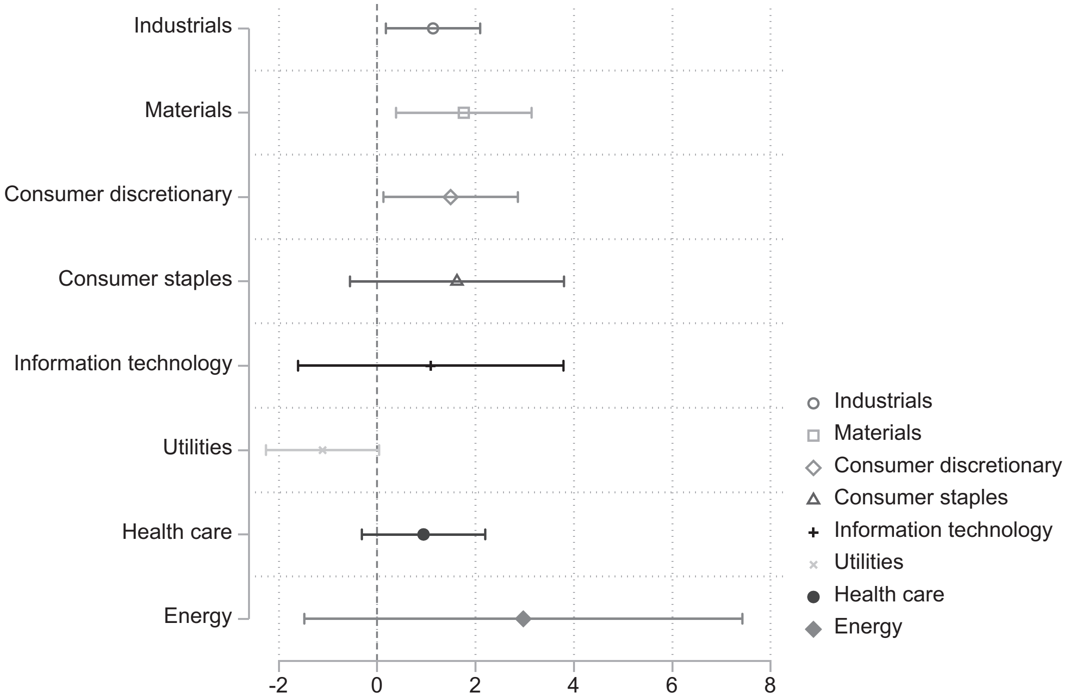

Fig. 6. Heterogeneity of industry types.
Notes: 1. The center icon represents the estimated result of the instrumental variable, and the solid line represents the 90% confidence interval. 2. The dependent variable is the total number of patents. 3. The sample sizes in the eight rows, i.e., the number of enterprises in the corresponding industry, from top to bottom, are 268, 222, 228, 80, 95, 70, 95, and 36.

innovation willingness, and innovation support. Specifically, regarding corporations' innovation capability, the development of broadband internet has a positive effect on corporate R&D personnel and improves the innovation efficiency of inventors. In addition, the internet enhances corporate risk tolerance and R&D investment willingness for innovation. The final channel is innovation support, and the internet eases corporate financing constraint problems and benefits enterprises by enabling them to obtain more bank loans. Third, the impact of broadband internet on different types of patents is heterogeneous. Specifically, the popularization of broadband internet promotes the growth of invention patents and utility model patents but has no significant impact on design patents. The impact of the internet on the technological innovation of different types of enterprises also differs. Specifically, the internet mainly promotes the technological innovation of high-tech enterprises, inventor-intensive companies, and state-owned enterprises and mainly promotes the technological innovation of enterprises in the non-southeastern coastal region of China. From the perspective of industry categories, the effects are mainly concentrated in the industry, materials and optional consumption fields.

China's innovation and development have changed daily in recent years. On the one hand, an increasing number of studies have explored the factors influencing innovation from the perspective of "tangible" transportation infrastructure, such as highways, street network density, and high-speed railways, but ignored the critical role of "intangible" internet infrastructure in innovation and development. On the other hand, internet companies, such as Tencent, Alibaba, Meituan, and Pinduoduo, have developed rapidly, extensively promoting China's economy's rapid development. Internet infrastructure is a fundamental guarantee for the survival and development of internet companies. The rapid growth of broadband internet can promote technological innovation and have important implications for the transformation of corporate business models and the promotion of mobile payments. Therefore, it is particularly critical to focus on the impact of the "invisible" internet on corporate innovation. The heterogeneity analysis in this article shows that the internet mainly impacts invention patents and the non-southeastern coastal regions of China, which are less developed, effectively alleviating the problems of low patent quality and uneven regional development in China. Therefore, advancing the construction of broadband internet infrastructure is conducive to the high-quality development of China's economy. In addition, this study has vital reference significance for the economic development of other developing countries, especially for innovation-driven development.

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Appendix A. Appendix

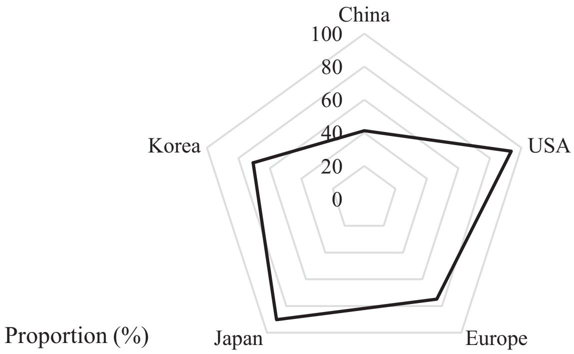

Fig. A1. Proportion of invention patents of the total number of patents.

Notes: 1. The solid black line represents the proportion of invention patents of the total number of patents in major countries or regions in 2015. 2. Source: own calculations based on the IncoPat Global Patent Database.

Table A1
Description of variables not included in the baseline regression.

Variables	Description
Market index	Marketization index of each province in 2002
Openness	Openness of provinces in 2002
Nationalization	The degree of nationalization of provinces in 2002
Fiscal revenue decentralization	Decentralization of the fiscal revenue of prefecture-level cities in 2002
Fiscal expenditure decentralization	Decentralization of the fiscal expenditure of prefecture-level cities in 2002
Secretary age	Age of municipal party secretary in 2002
Mayor age	Mayor's age in 2002
Number of R&D staff	Number of R&D staff
Personal patent	Number of patent applications by the same inventor in each year
R&D risk	R&D risk, standard deviation of patent citations
R&D expense	R&D expense
Financing constraint	Financing constraints , SA index = $(-0.737^* \text{ Size}) + (0.043^* \text{ Size}^2) - (0.040^*\text{Age})$
Bank loans	The total amount of loans from banks, including short-term and long-term loans
High-tech enterprise	High-tech enterprises (yes = 1, no = 0)
Inventor-intensive company	Enterprises with a higher number of inventors than the median (yes = 1, no = 0)
Southeastern coastal region	Enterprises located in the southeastern coastal region of China (yes = 1, no = 0)
Invention patent	Number of invention patents
Design patent	Number of design patents
Utility model patent	Number of utility model patents

Table A2
Summary statistics of the variables not included in the baseline regression.

Variables	N	Mean	Min	Max	Median	Std
Market index	1095	6.265	2.45	8.63	6.23	1.781
Openness	1095	0.501	0.05	1.585	0.355	0.488
Nationalization	1095	0.415	0.303	0.658	0.412	0.09
Fiscal revenue decentralization	1095	0.505	0.068	0.74	0.519	0.13
Fiscal expenditure decentralization	1095	0.539	0.179	0.775	0.538	0.111
Secretary age	1095	3.972	3.611	4.159	3.97	0.118
Mayor age	1095	3.941	3.611	4.143	3.932	0.097
Number of R&D staff	886	5.303	0	10.36	5.493	1.731
Personal patent	2831	0.19	−3.258	3.961	0	0.866
R&D risk	1096	−0.832	−4.369	3.991	−0.433	1.573
R&D expense	793	1.641	−1.363	5.194	1.434	1.601
Financing constraint	1096	−0.345	−3.187	1.195	−0.333	0.187
Bank loans	1096	0.491	−9.126	10.690	0.757	2.770
High-tech enterprise	778	0.406	0	1	0	0.491
Inventor-intensive company	1096	0.501	0	1	1	0.5
Southeastern coastal region	1096	0.387	0	1	0	0.487
Invention patent	1096	0.547	−4.159	6.42	0	1.238
Design patent	1096	0.088	−4.382	6.526	0	0.758
Utility model patent	1096	0.503	−4.394	6.68	0	1.175

Notes: 1. The predetermined variables (*Market index, Openness, Nationalization, Fiscal revenue decentralization, Fiscal expenditure decentralization, Secretary age,* and *Mayor age*) are shown in the logarithmic form. The variables used in the mechanism analysis (*Number of R&D staff, Personal patent, R&D risk, R&D expense, Financing constraint,* and *Bank loans*) are the results of adopting the logarithm of the original value and then subtracting the logarithm in 2007 from the logarithm in 2015. The other grouping variables used in the heterogeneity analysis (*High-tech enterprise, Inventor-intensive company, SOE,* and *Southeastern coastal region*) are 0–1 dummy variables. 2. Source: IncoPat Global Patent Database, Wind database, China Stock Market and Accounting Research (CSMAR) database, NERI index of marketization of China's provinces, China Statistical Yearbook, China City Statistical Yearbook, government work reports on the websites of prefecture-level city governments, local yearbooks, and public websites.

Table A3
Reduced form of the instrumental variable regression.

	Patent	Valid patent	Patent citation	Valid patent citation
	(1)	(2)	(3)	(4)
Panel A: logarithm				
HHI_2003	−5.552***	−5.968***	−3.662***	−3.038***
	(1.415)	(1.581)	(1.297)	(1.117)
Observations	1096	1096	1096	1096
Adjusted R-squared	0.050	0.047	0.016	0.010
Panel B: IHS transformation				
HHI_2003	−6.454***	−3.346***	−2.599***	−2.026***
	(1.626)	(0.880)	(0.820)	(0.708)
Observations	1096	1096	1096	1096
Adjusted R-squared	0.050	0.049	0.019	0.012
Firm control variables	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. Panel A shows the reduced form of the instrumental variable regression shown in columns (1) to (4) of Table 4. Panel B shows the reduced form of the instrumental variable regression shown in columns (1) to (4) of Table 5.

Table A4
Heterogeneity of enterprises of different types in different regions.

	High-tech enterprises		Inventor-intensive companies		SOEs		Southeastern coastal region	
	YES	NO	YES	NO	YES	NO	YES	NO
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Broadband	2.688***	0.818	1.951***	−0.051	1.301***	1.787	1.364	1.301***
	(0.997)	(0.562)	(0.693)	(0.163)	(0.456)	(1.133)	(2.112)	(0.380)
Observations	316	462	549	547	648	448	424	672
Adjusted R-squared	−0.115	0.037	−0.013	−0.005	0.005	−0.106	−0.001	0.000
Firm control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	22.805	35.934	37.99	25.203	63.236	8.004	2.095	55.352

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. This table reports the heterogeneous impact of broadband internet on enterprise innovation from the perspectives of the technology level (columns (1) and (2)), inventor-intensity (columns (3) and (4)), ownership (columns (5) and (6)), and location (columns (7) and (8)).

Table A5
Heterogeneity of enterprises of different types in different regions (robustness check).

	(1)	(2)	(3)	(4)
VARIABLES	Patent	Patent	Patent	Patent
Broadband	1.481***	0.383	1.253***	1.483***
	(0.437)	(0.331)	(0.344)	(0.343)
Broadband×	0.244**			
High-tech enterprises	(0.109)			
Broadband×		1.012***		
Inventor-intensive companies		(0.082)		
Broadband×			0.162**	
SOE			(0.080)	
Broadband×				−0.220*
Southeastern coastal region				(0.118)
Observations	778	1096	1096	1096
Adjusted R-squared	0.006	0.171	−0.010	−0.019
Controls	Yes	Yes	Yes	Yes
KP F-statistic	20.814	21.227	22.049	23.222

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. *Controls* include the grouping variable in each intersection item and firm- and city-level control variables. This table reports the heterogeneous impact of broadband internet on enterprise innovation from the perspectives of the technology level (column (1)), inventor-intensity (column (2)), ownership (column (3)), and location (column (4)).

Table A6
Ranking of major indicators of China's telecom industry in 2015 (top 10).

Ranking	Province	Popularization rate of the internet (%)	Province	Broadband subscribers Internet ports (10,000 ports)	Province	Length of optical cable Lines (km)
1	Beijing	76.5	**Zhejiang**	4768.9	**Jiangsu**	2,511,543
2	**Shanghai**	73.1	**Guangdong**	4765.5	**Zhejiang**	2,072,207
3	**Guangdong**	72.4	**Jiangsu**	4697.3	**Guangdong**	1,645,703
4	**Fujian**	69.6	Shandong	4003.4	Sichuan	1,617,009
5	**Zhejiang**	65.3	Henan	3241.9	Shandong	1,371,672
6	Tianjin	63.0	Sichuan	3117.9	Henan	1,231,505
7	Liaoning	62.2	Hebei	2948.5	Hunan	1,076,349
8	**Jiangsu**	55.5	Liaoning	2710.8	Hebei	1,031,586
9	Xinjiang	54.9	**Fujian**	2335.3	Anhui	972,903
10	Qinghai	54.5	Anhui	2211.5	Hubei	930,329
Ranking	Province	Base Stations of Mobile Telephones (10000)	Province	Popularization Rate of the Telephone (sets/100 persons)	Province	Popularization Rate of Fixed Line Telephones (sets/100 persons)
1	**Guangdong**	42.2	Beijing	217.9	Beijing	36.2
2	**Zhejiang**	32.7	**Shanghai**	162.7	**Shanghai**	33.0
3	**Jiangsu**	32.5	**Guangdong**	159.3	**Zhejiang**	26.6
4	Shandong	28.4	**Zhejiang**	158.1	**Guangdong**	25.9
5	Henan	25.0	**Fujian**	131.4	**Jiangsu**	24.7
6	Sichuan	24.9	**Jiangsu**	125.0	Liaoning	23.7
7	Hebei	19.2	Liaoning	121.5	**Fujian**	23.2
8	**Fujian**	18.7	Hainan	116.9	Tianjin	22.2
9	Hunan	17.7	Shaanxi	113.1	Xinjiang	21.2
10	Hubei	17.5	Jilin	112.0	Jilin	20.8

Notes: 1. All 31 mainland Chinese provinces are included in the rankings. Limited by space, only the top ten provinces are reported for each telecom index. In addition, the five provinces (Jiangsu, Zhejiang, Shanghai, Fujian and Guangdong) in the southeast coast of China are in bold type. 2. The Popularization Rate of the Telephone indicator includes both fixed and mobile phones. 3. The data are derived from the China Statistical Yearbook 2016.

Table A7
Heterogeneity of patent types.

	Invention patent	Design patent	Utility model patent
	(1)	(2)	(3)
Broadband	1.205***	0.250	1.032***
	(0.411)	(0.202)	(0.345)
Observations	1096	1096	1096
Adjusted R-squared	−0.002	−0.015	−0.011
Firm control variables	Yes	Yes	Yes
City control variables	Yes	Yes	Yes
KP F-statistic	43.725	43.725	43.725

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. The dependent variables in columns (1), (2), and (3) are invention patents, design patents, and utility model patents, respectively.

Table A8
Heterogeneity of industry types.

	Dependent variable: Patent							
	Industrials	Materials	Consumer discretionary	Consumer staples	Information technology	Utilities	Health care	Energy
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Broadband	1.135*	1.761**	1.493*	1.622	1.088	−1.112	0.941	2.971
	(0.583)	(0.838)	(0.831)	(1.323)	(1.641)	(0.699)	(0.763)	(2.708)
Observations	268	222	228	80	95	70	95	36
Adjusted R-squared	0.057	−0.118	−0.011	−0.056	−0.184	0.116	−0.026	−0.557
Firm control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
KP F-statistic	8.851	8.106	6.964	6.396	3.525	5.955	15.673	2.728

Notes: *, * *, and * * * indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are reported in parentheses and are clustered at the city level. This table shows the regression results of subsamples based on different industries.

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