Technological and Economic Development of Economy
ISSN: 2029-4913 / eISSN: 2029-4921
2023 Volume 29 Issue 6: 1657–1686
https://doi.org/10.3846/tede.2023.20214

CHINA'S HIGH-QUALITY INNOVATION DEVELOPMENT FROM AN INSTITUTIONAL PERSPECTIVE: REGIONAL DIFFERENCES AND CONVERGENCE

Ken CHENG[1], Hongwen CHEN[2], Fan ZHANG[3*], Meiyang ZHANG[4, 5]

[1]School of Economics, Xiamen University, No. 422 Siming South Road, Xiamen, 361005, China
[2]School of Tourism, Nanchang University, No. 999 Xuefu Avenue, Nanchang, Jiangxi, 330031, China
[3]The Intellectual Property Research Institute, Xiamen University, No. 422 Siming South Road, Xiamen, 361005, China
[4]School of Law and Economics, Zhongnan University of Economics and Law, No. 182 Nanhu Avenue, Wuhan, 430073, China
[5]China Intellectual Property Research Center, Zhongnan University of Economics and Law, No. 182 Nanhu Avenue, Wuhan, 430073, China

Received 17 November 2022; accepted 19 July 2023; first published online 14 November 2023

Abstract. High-quality innovation is an inevitable requirement for high-quality economic development, and an accurate grasp of the regional distribution characteristics of the level of high-quality innovation development (HQID) can better understand and simulate high-quality innovation. This paper constructs a dataset of high-value inventions based on the Chinese patent database using textual analysis methods and the criteria for High-Quality Inventions proposed by the State Intellectual Property Office, and explores inter-provincial variability and convergence by using the Theil index, σ convergence, and β convergence. This paper finds that High-Quality Inventions are significantly and positively correlated with various indicators measuring the quality and value of patents. In general, the overall level of HQID is on an upward trend with clear differences among provinces, which shows a regional unbalanced but overall rapid development. From the regional differences of HQID, the regional differences of HQID have been narrowed, mainly within the region. In terms of the convergence of HQID, σ convergence, absolute β convergence, conditional β convergence, and club convergence exist nationally and within each region, which indicates that the gap between the national and regional levels of HQID has been narrowing over time. HQID has a positive promotion effect on the relationship between HQID and economic growth, economic growth rate, and total factor productivity. High-quality innovation can improve the quality of input factors, cultivate new dynamic energy for economic development, and then promote high-quality economic development. In the context of the shift of IP work from pursuing quantity to improving quality, the scientific understanding of high-quality innovation, the development status, and the differences of regional innovation high-quality development is of great significance for improving innovation quality and efficiency, and effectively supporting high-quality economic development.

Keiwords: high-quality innovation development, High-Quality Inventions, Theil index, σ convergence, β convergence, club convergence, PVAR model.

JEL Classification: O30, R11, O12.

---

*Corresponding author. E-mail: *zhangfan94@stu.xmu.edu.cn*

Introduction

As a driving force for economic growth and social advancement, innovation plays an important role (Grossman & Helpman, 1991; Aghion & Howitt, 1992; Acemoglu & Akcigit, 2012). Through its population, capital, and institutional dividends, China's economy has achieved high growth rates since the reform and opening up. As a result of the gradual release of the dividend, the factor-driven development path is unsustainable, and innovation has become an increasingly important thrust of economic development (Zheng et al., 2009; Wei et al., 2017; Tian, 2019). China's R&D investment increased from 0.90% in 2000 to 2.23% in 2019, which indicates that China's investment in innovation has increased continuously over the past two decades. Nevertheless, innovation output is primarily "strategic innovation" (Jin et al., 2019; Qin & Xiong, 2022), lacking "substantive innovation" (Long & Wang, 2018) in line with high-quality development requirements, as well as having yet to master core technologies in strategic emerging industries.

Patents can objectively measure the performance of scientific and technological output, are an important aspect reflecting a country's innovation activities at the macro and micro levels, and play a decisive role in the improvement of a country's independent innovation capacity and economic growth (Hu & Jefferson, 2009). As a result, patent-related measures are considered important indicators of the level of innovation. In previous studies, the number of patent applications and grants has long been used as a measure of innovation performance (Griliches, 1998; Hall & Harhoff, 2012). In recent years, as the institutional and market environments increased the requirements for innovation quality, the literature has paid attention to exploiting patent characteristics such as the number of patent forward citations, the number of patent claims, and the number of patent families to measure innovation quality (Lerner et al., 2011). However, are these patent characteristics a reasonable measure of innovation performance? This issue has been heatedly debated in the academia, and no conclusion has been reached. In the past, the lack of objective, authoritative criteria made developing a measure of the level of high-quality innovation development (HQID) difficult. The Outline of the 14th Five-Year Plan and the Outline of Building a Country with Strong Intellectual Property Rights (2021–2035) introduced the indicator of "high-value invention patents per 10,000 people" for the first time, replacing the indicator of "invention patents per 10,000 people" during the 12th and 13th Five-Year Plans, respectively, which provides a new measure for studying high-quality innovation.[1] Thus, this paper first compares this indicator with commonly used standards in the past literature and uses this new measure to estimate the level of regional innovation quality development more reasonably.

The concept of regional innovation refers to a region's overall innovation capacity or all its innovation achievements in terms of all R&D activities and research projects (Asheim & Gertler, 2006; Zhang, 2021). The existing measures of regional innovation are divided into two categories, indirect measurement, which assesses the level of regional innovation based on the efficiency of R&D innovation (Li, 2009; Kim et al., 2011; Chen & Guan, 2012; Xu et al., 2022), and direct measurement, in which patents are more commonly used in the literature to measure the level of regional innovation (Acs et al., 2002; Li et al., 2014;

---

[1] An extended discourse on the interrelation between patents and innovation is available in the Appendix.

Jiang et al., 2022). As an important aspect of regional innovation activities, patents filed in a certain region objectively measure its scientific and technological output at the macro and micro levels, playing a crucial role in regional innovation capacity and economic growth (Hu & Jefferson, 2009; Moser, 2013; Akcigit et al., 2016; Acemoglu et al., 2018; Zacchia, 2019). The majority of studies measuring regional innovation levels use the number of patent filings (Wang et al., 2016; Hong et al., 2019; Zeng et al., 2019; Yang et al., 2021) without considering patent quality (Bai, 2013). Only a few studies have examined patent quality in terms of forwarding citations (Huang et al., 2020; Jiang et al., 2022), patent breadth (Gu, 2022), and claims (Dang & Motohashi, 2015), but the above indicators also present limitations, especially when the patent features are aggregated at the regional level. This situation is manifested in three aspects: First, an evident time lag is observed in the number of patent forward citations, and direct summation brings truncation problems. Second, uncertainty exists in the relationship between the number of patent claims and innovation quality, which is not a simple linear positive correlation. Third, the regional composition of industries and technology fields and inventor characteristics also have a significant heterogeneous effect on these indicators. Patent filing propensity and patent citation propensity vary greatly across industries and technology fields, and inventor characteristics between regions also have a great effect on characteristics such as forward citations, patent width, and patent claims. Thus, directly aggregating patent characteristics at the regional level for cross-industry and technology field comparisons can bring serious bias to the results. Accordingly, reasonable metrics for measuring the quality of regional innovation in China has long been lacking.

An accurate description and scientific measurement of high-quality innovation are urgently needed to drive high-quality economic development. Previously, the development pattern of regional innovation quality was difficult to measure due to the lack of objective, authoritative standards. The change in innovation orientation resulted in the State Intellectual Property Office (SIPO) and the 14th Five-Year Plan outline five dimensions for determining High-Quality Invention Patents. Based on the Chinese patent database, this paper constructs a high-value invention patent database using textual analysis based on the criteria for determining high-value invention patents proposed in the 14th Five-Year Plan, adding to the existing literature on indicators of China's innovation quality. This paper also analyzes Chinese innovation quality development based on regional differences and convergence using the Theil index and spatial measures to provide a basis for understanding China's innovation quality development.

This paper's primary goal is to capture realistic measurement, further bridging the gap in research on regional innovation differences and convergence about the measurement and decomposition of HQID and its inequality in the context of China. First, a new definition named High-Quality Inventions issued by the SIPO is adopted as an innovation ability assessment index based on the specific requirements, including the industry the patent belongs to, the patent family, the patent maintenance, the patent transactions, and the patent awarded to examine regional innovation development more thoroughly and reasonably. To the best of our knowledge, this is the first paper that evaluates the High-Quality Inventions issued by the SIPO and uses this criterion to measure the degree of regional innovation in China. Second, to understand the convergence and specific mechanisms of different factors of technological innovation in eastern, central, and western China, this paper adopts a dynamic perspective, using the Theil index and multiple spatial measures to analyze the regional differences and convergence of regional innovation and exploiting the Panel Vector Autoregression (PVAR) model to explore the relationship between HQID and industrial structure upgrade and economic growth, elucidating and illuminating some arguments and discrepancies of earlier studies. Thus, this paper deepens our understanding of regional high-quality innovation and provides recommendations for policymakers on how to narrow the regional innovation and growth gaps.

The remainder of this paper is organized as follows. Section 1 provides a methodology introducing the measurement of high-quality innovation and discrepancy measures. Section 2 presents the results of indicator measurements. Section 3 analyzes the regional convergence of high-quality development of innovation in China. The last Section concludes the paper with a discussion of policy implications.

1. Methods

On March 29, 2021, the SIPO for the first time defined High-Quality Inventions, which need to satisfy at least one of five requirements: (1) patents in strategic emerging industries, (2) patents with overseas patent family, (3) patents with a maintenance period of more than 10 years, (4) inventions with a higher pledged financing amount, and (5) inventions with the National Science and Technology Award or the China Patent Award. Moreover, the 14th Five-Year Plan for the entire country and each province mentions better protection and incentives for high-value patents and incorporates "owning high-value invention patents" as a primary indicator of economic progress and social development. As for the three types of patents, namely, inventions, utilities, and designs, in China's patent system, only inventions are subject to substantive examination, whereas utilities and designs can be granted after formal examination. Thus, according to the existing literature, inventions represent substantive innovation, whereas utilities and designs represent strategic innovation. Therefore, our focus is mainly on inventions with the highest technological content and the greatest innovation contribution. By defining high-value invention patents, this paper assesses the level of high-quality innovation nationwide and by region, and examines regional differences in HQID, which sheds new light on understanding high-quality innovation and is crucial to promoting HQID.

1.1. Measurement of regional high-quality innovation

This paper utilizes patent data obtained manually from the China Intellectual Property Office's patent search website, which contains information on all invention patents applied with the SIPO between 1992 and 2016, with December 2016 as the cut-off date for observation. These data provide information regarding the characteristics and status of the patents from the time of application, including application number, application date, priority date, disclosure number, disclosure date, grant date, expiration date, International Patent Classification (IPC) number, applicant, applicant country, applicant province, applicant city, applicant detailed address, inventor, patent family, and legal status information.

To determine whether a patent is high quality, the SIPO's high-quality innovation definition is applied using the following specific steps: (1) The patent data are divided into three categories depending on the type of patent, namely, inventions, utilities, and designs. As this paper focuses on Chinese high-quality innovation, the scope of consideration is limited to inventions granted to Chinese innovators. (2) Whether a patent belongs to a certain strategic emerging industry is determined by matching the "Strategic Emerging Industries Classification and International Patent Classification Reference Relationship Table (2021) (Trial)" with the IPC number of the patent. (3) According to the patent family information, the application number of the patent family is analyzed, the distribution countries of the patent family is determined, and whether the patent has an overseas patent family is verified. (4) Based on the grant date and expiration date of the patent, whether its maintenance period exceeds 10 years is determined. (5) The legal status information of the patent contains information regarding its pledge. Based on the patent application number and legal status information, the patent pledge information is extracted using textual analysis. (6) The patents that have received the China Patent Award during the period 1992–2016 based on the information provided by the SIPO are manually obtained. Therefore, a complete database of high-value patents is obtained and includes patent application number, applicant province, applicant city, grant status (dummy), strategic emerging industry it belongs to (dummy), overseas patent family (dummy), if maintenance period exceeds 10 years (dummy), pledge information (dummy), the National Science and Technology Awards or China Patent Awards (dummy), and high-value invention (dummy).

To assess the quantity and proportion of high-value inventions granted in province i in year t, the High-Quality Inventions data are aggregated at the province-year level, as depicted in Equation (1). This study examines the extent of high-quality innovation across provinces by comparing the percentage of patents awarded for high-value inventions.

$$hpatent_{i,t} = \frac{\sum_{p=1}^{n} I_{i,p,t}\left[\left(I_{i,p,t}\left(SEI\right)+I_{i,p,t}\left(family\right)+I_{i,p,t}\left(renewal\right)+I_{i,p,t}\left(pledge\right)+I_{i,p,t}\left(prize\right)\right)>0\right]}{patent_{i,t}}, \quad (1)$$

In this context, $hpatent_{i,t}$ denotes the percentage of high-value invention patents granted in province i in year t, while $patent_{i,t}$ refers to the total number of invention patents granted in province i in year t. We employ an indicator function to ascertain whether an invention patent p, granted in province i in year t, meets the criteria for a high-value invention. Subsequently, we calculate the sum of patents fulfilling the high-value invention requirements, i.e., the number of high-value invention patents granted in province i in year t.

1.2. SIPO High-Quality Inventions

How is the definition of High-Quality Inventions issued by the SIPO evaluated? Various patent characteristics of High-Quality Inventions are compared with those of other inventions to examine whether High-Quality Inventions indeed have high quality. To provide a comparison with the patent quality measures used in the existing literature, 14 patent quality measures are selected.

First, value is obtained from the PatSnap patent value assessment model (https://www.patsnap.com), which combines 25 dimensions of patent characteristics and global patent operation transaction data for professional patent value assessment. Patent value has a positive relationship with patent quality, i.e., the higher the patent value is, the higher the patent quality (Hall et al., 2005; Kogan et al., 2017). Claims are the scope of right protection of a patent, and pages are the number of pages of a patent application. These two indicators are often used to measure the scope and boundary of the claims of a technical solution (Lanjouw & Schankerman, 2004; Harhoff, 2016; Marco et al., 2019). Family members are the scale of the patent family reflecting the IPR layout of a patent, and family countries are the number of countries involved in the patent layout. The index related to the patent family shows the market scope of the patent. The larger the scale of the patent family is, the broader market distribution of the patent, so that the patent has higher quality and profitability (Harhoff et al., 2003; Squicciarini et al., 2013; Higham et al., 2021). The number of inventors refers to the human capital involved in developing the patent. Generally, the higher the number of inventors is, the higher the technical difficulty and complexity contained in the patent (Trajtenberg et al., 2009; Mann & Underweiser, 2012). PCT (dummy) refers to whether the patent has been internationally filed, and the PCT is generally considered to be of higher quality (Boeing & Mueller, 2019; Zhao, 2022). Firm applicant refers to whether an enterprise applicant exists among the patent applicants. Compared with other types of patentees, enterprises are less constrained to invest in R&D in the process of research and development, and thus, the higher the quality of the patent. Breadth refers to the number of different classification numbers to which the patent belongs. The more classification numbers a patent belongs to, the higher the quality of the patent (Gu, 2022). The number of forward citations is the most commonly used indicator in measuring the quality of innovation (Jaffe et al., 1993; Shu et al., 2022). When comparing the citations of different patents, the window period to decrease the problem of truncation must be considered. Table 1 shows that the quality of High-Quality Inventions is significantly higher than that of other inventions in the comparison of these indicators. Second, licensing and assignment reflect the market demand for patents (Galasso et al., 2013; Figueroa & Serrano, 2019), which is also an aspect of innovation quality. Whether it is licensed or assigned, the market demand for High-Quality Inventions is higher than the market demand for other inventions on average.

The above results indicate that High-Quality Inventions are significantly and positively correlated with various indicators measuring the quality and value of patents. Therefore, the definition of High-Quality Inventions issued by the SIPO is a reasonable standard for measuring patent quality. In the following, the regional high-quality innovation in China is measured and analyzed based on this new indicator.

1.3. Measurement of Theil index and its decomposition

This paper uses the treatments of Mao and Ma (2021) and Ying et al. (2021) to examine the regional differences in the development of innovation quality in China and their sources to reveal these regional differences. The Theil index is used to break down the overall differences in innovation quality development into intra-regional and inter-regional differences. The specific decomposition formula is as follows.

Table 1. Comparison of ordinary inventions and high-quality inventions

Variables	Mean	Mean	Diff.
	Ordinary Inventions (Obs. 452374)	High-Quality Inventions (Obs. 886609)	
Value	6.827	7.275	–0.448***
Claims	5.072	6.016	–0.945***
Pages	9.196	10.757	–1.561***
Family members	2.021	2.297	–0.276***
Family countries	0.997	1.163	–0.166***
Inventors	3.429	3.716	–0.287***
PCT (dummy)	0.050	0.063	–0.013***
Firm applicant (dummy)	0.514	0.556	–0.043***
Breadth	2.387	2.458	–0.071***
Forward citations in 3 years	1.019	1.281	–0.262***
Forward citations in 5 years	1.456	1.830	–0.374***
license	0.024	0.026	–0.002***
Assign	0.104	0.107	–0.003***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

$$T = \frac{1}{n}\sum\nolimits_{i=1}^{n}\left(\frac{hpatent_i}{ave\_hpatent}\times\ln\frac{hpatent_i}{ave\_hpatent}\right); \tag{2}$$

$$T_j = \frac{1}{n_j}\sum\nolimits_{i=1}^{n_j}\left(\frac{hpatent_{ij}}{ave\_hpatent_j}\times ln\frac{hpatent_{ij}}{ave\_hpatent_j}\right); \tag{3}$$

$$T = T_w + T_b = \sum\nolimits_{j=1}^{3}\left(\frac{n_j}{n}\times\frac{ave\_hpatent_j}{ave\_hpatent}\times T_j\right) + \sum\nolimits_{j=1}^{3}\left(\frac{n_j}{n}\times\frac{ave\_hpatent_j}{ave\_hpatent}\times\ln\frac{ave\_hpatent_j}{ave\_hpatent}\right). \tag{4}$$

Consistent with Section 1.1, we assess the extent of high-quality innovation across provinces by examining the percentage of patents awarded for high-value inventions. In Equation (2), T denotes the average difference in high-quality innovation, i represents a province, n represents the number of provinces in the country, $hpatent_i$ indicates the level of high-quality innovation in province i, and $ave\_hpatent$ denotes the national average value of high-quality innovation. The Theil index value ranges between [0, 1]; the smaller the value, the lesser the difference in HQID. In Equation (3), T_j represents the overall difference in the Theil index of HQID levels among the three regions (j = 1, 2, 3), and n_j signifies the number of provinces in the eastern, central, and western regions. The innovation quality development level for province i in region j is represented by the $hpatent_{ij}$ value, while the average innovation quality development level in region j is denoted by the $ave\_hpatent_j$ value. Equation (4) further decomposes the Theil index of high-quality innovation levels into the Theil index of intra-regional variation, T_w and the Theil index of inter-regional variation, T_b.

1.4. Convergence mechanism

(1) σ convergence. In the context of this paper, σ convergence is the deviation of innovation quality development from the average level among regions showing a gradual decrease over time. As stated in Lv et al. (2021), Kowalski (2022), and Xu et al. (2022), the coefficient of variation is used as a measurement method, and the indicator is constructed, as shown in Equation (5):

$$\sum = \frac{\sqrt{\left[\sum_{p}^{n_j}\left(hpatent_{i,j,t} - \overline{hpatent_{i,t}}\right)^2\right] \Big/ n_j}}{\overline{hpatent_{i,t}}}, \tag{5}$$

where j refers to the region of China, which includes east, central, and west; i refers to the province of China, which includes 31 provinces in mainland China; t refers to the year, 1992 to 2016, n_j refers to the number of provinces covered by region j; $hpatent_{i,j,t}$ indicates the percentage of high-value inventions in region j in year t; $hpatent_{i,t}$ represents the average number of high-value inventions in region j in year t. The coefficient of variation, as determined by the ratio of the standard deviation to the mean of the share of high-value inventions in region j in year t, is the ratio of the standard deviation to the mean of the proportion of high-value inventions in region j in year t, which measures the dispersion of the level of quality development of innovation in each province i region j in year t. If σ becomes gradually smaller with year, the dispersion degree of the level of HQID in each province i region j becomes gradually smaller, resulting in a trend of convergence to the mean.

(2) β convergence. β convergence refers to the fact that regions with a lower level of initial high-quality innovation have a faster growth rate compared with regions with a higher initial level of high-quality innovations. When the regional level of high-quality innovation shows β convergence, the level of high-quality innovation of relatively lagging regions continues to approach the level of high-quality innovation of relatively leading regions and maintain the same growth rate. According to Barro and Sala-i-Martin (1992) as well as Mankiw et al. (1992), β convergence has two types, namely, absolute β convergence, and conditional β convergence. Absolute β convergence occurs when the development level of high-quality innovation within each region gradually converges to the same level over time without considering confounding factors such as economic development, scientific and technological talent, and R&D investment. This situation is evident from the significant negative correlation between the growth rate and the initial level of high-quality innovation. Meanwhile, this study posits that the level of high-quality innovation development in provinces may exhibit varying degrees of spatial dependence. Consequently, a spatial panel Durbin model was introduced for β convergence analysis, as depicted in Equation (6):

$$\ln\left(\frac{hpatent_{i,t+1}}{hpatent_{i,t}}\right) = \alpha + \beta \ln\left(hpatent_{i,t}\right) + \rho W_{ij} \ln\left(\frac{hpatent_{i,t+1}}{hpatent_{i,t}}\right) +$$

$$\gamma W_{ij} \ln\left(hpatent_{i,t}\right) + \mu_i + \gamma_t + \varepsilon_{i,t}, \tag{6}$$

In this equation, $\ln\left(\frac{hpatent_{i,t+1}}{hpatent_{i,t}}\right)$ represents the growth rate of innovation quality development for the *i* province at period $t + 1$, where $hpatent_{i,t}$ and $hpatent_{i,t+1}$ indicate the innovation quality development indices at periods t and $t + 1$, respectively. β serves as the convergence coefficient, with $\beta < 0$ implying a convergence trend in provincial innovation quality development, and the opposite signifying divergence. ρ denotes the spatial autoregressive coefficient, reflecting the influence of the growth rate of innovation and high-quality development levels in neighboring provinces on the region, while γ represents the impact of innovation and high-quality development in neighboring provinces. The province fixed effect μ_i on the right-hand side controls for a variety of unobservable factors at the province level that remains the same over time, such as culture, and geographical location. The year fixed effect γ_t is a measure of the impact of a variety of macroeconomic factors at the year level, such as institutional changes and economic conditions. $\varepsilon_{i,t}$ signifies the disturbance terms, following an independent identical distribution. The spatial weight matrix is defined as W_{ij}, and this study adopts the inverse of the square of the geographical distance as the spatial weight, implying that greater geographical distance results in a weaker linkage of digital financial development, and vice versa, as illustrated below.

Drawing from the existing literature, a conditional beta convergence model is constructed, as displayed in Equation (7), using panel data that take into account variables potentially affecting regional innovation quality development.

$$\ln\left(\frac{hpatent_{i,t+1}}{hpatent_{i,t}}\right) = \alpha + \beta \ln\left(hpatent_{i,t}\right) + \rho W_{ij} \ln\left(\frac{hpatent_{i,t+1}}{hpatent_{i,t}}\right) +$$

$$\gamma W_{ij} \ln\left(hpatent_{i,t}\right) + col_{i,t} + rd_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}. \tag{7}$$

In comparison to the absolute β convergence model, the conditional β convergence model includes the per capita GDP of province *i* in year *t* ($pgdp_{i,t}$), the number of colleges ($col_{i,t}$), and the investment in R&D by industrial enterprises above a certain scale ($rd_{i,t}$). The remaining settings are consistent with the previous model. Therefore, the significance of the absolute β convergence model and conditional β convergence model can be inferred from the significant negative coefficient of the core explanatory variables, suggesting that regional HQID exhibits absolute convergence. A significant positive coefficient implies a dispersion trend in the level of regional HQID.

1.5. PVAR model

The PVAR model is used to examine the interaction between HQID and industrial structure upgrading and economic growth. This paper analyzes the effect of HQID on economic growth and industrial structure upgrade. As an extension of the VAR model, the PVAR model is expressed mathematically as follows:

$$y_{i,t} = \alpha_i + \beta_0 + \sum_{j=1}^{p} \beta_j y_{i,t-j} + v_{i,t} + \mu_{i,t}. \tag{8}$$

In Equation (8), $y_{i,t}$ is a vector containing endogenous variables, namely, the level of innovation quality development. α_i serves as a variable that reflects the heterogeneity of individuals. To reflect possible common shocks at different cross-sections at the same point in time, $\upsilon_{i,t}$ is used to reflect individual time effects to capture the common shocks that may be experienced at different cross-sections at the same point in time. $\mu_{i,t}$ is a random disturbance term that is assumed to follow the normal distribution. As a measure of industrial structure upgrade, the ratio of tertiary industry output to secondary industry output is compiled from the CEIC database. For economic growth, the GDP growth rate is used to measure the size of economic growth, which is compiled from the CEIC database, whereas total factor productivity is calculated using stochastic frontier analysis to measure the quality of economic growth, which is calculated from the EPS database, referencing the study of Battese and Coelli (1992).

2. Analysis of regional differences in high-quality innovation in China

2.1. Measurement results

Table 2 shows the majority of provinces have a level of high-quality innovations greater than 0.5 throughout the period in relation to the magnitude of the mean value of innovation of high quality. Accordingly, the largest mean value is in the east (Beijing = 0.715), and the smallest one is in the west (Qinghai = 0.414), indicating a greater level of development in the innovation of high quality. Furthermore, 1992–2016 is divided into four time periods according to the main periods of development and improvement of Chinese patent protection. Throughout the period between the enactment of the patent law in 1984 to 2016, China amended the law three times, namely, in 1992, 2000, and 2008, to improve the protection of intellectual property rights and foster technological innovation continuously. Specifically, in the first period (1992–2000), Gansu has the largest mean value of 0.738, and Qinghai has the smallest with 0.266. In the second period (2001–2008), Shanghai has the largest mean value, whereas Inner Mongolia has the smallest mean value at 0.423. In the third period (2009–2016), Guangdong has the largest mean value with 0.759, whereas Tibet has the smallest mean value with 0.493. In terms of the trend of the mean values, comparing the first and second periods, 16 provinces, nearly half, exhibit an increase in the mean value of innovation quality development water. Comparing the second and third periods, the mean value of innovation quality development water increased in nearly two-thirds of the provinces. The average value of innovation quality development level always increases across eight provinces collectively.

Based on the magnitude of the coefficient of variation at the time level, Tibet has the largest coefficient of variation with 0.457, whereas Liaoning has the smallest coefficient of 0.065. In the first period, Qinghai has the largest coefficient of variation of 0.768, and Beijing has the smallest coefficient of variation of 0.048. In the second period, the largest coefficient of variation is 0.399 in Tibet, and the smallest is 0.054 in Shanghai. In the third period, the

Table 2. Results of measuring the level of high-quality innovation by province

Province	Average value				Time-level coefficient of variation			
	1992–2000	2001–2008	2009–2016	1992–2016	1992–2000	2001–2008	2009–2016	1992–2016
Shanghai	0.650	0.753	0.722	0.706	0.125	0.054	0.019	0.098
Beijing	0.659	0.749	0.745	0.715	0.048	0.082	0.023	0.081
Tianjin	0.617	0.604	0.620	0.614	0.097	0.084	0.055	0.079
Shandong	0.579	0.567	0.555	0.567	0.076	0.072	0.043	0.066
Guangdong	0.619	0.723	0.759	0.697	0.083	0.094	0.017	0.112
Jiangsu	0.586	0.663	0.628	0.624	0.088	0.080	0.026	0.085
Hebei	0.521	0.527	0.589	0.544	0.185	0.091	0.061	0.131
Zhejiang	0.556	0.590	0.575	0.573	0.078	0.072	0.035	0.067
Hainan	0.576	0.531	0.689	0.600	0.611	0.317	0.112	0.371
Fujian	0.571	0.638	0.637	0.613	0.164	0.104	0.025	0.119
Liaoning	0.630	0.616	0.624	0.624	0.080	0.077	0.027	0.065
Jilin	0.641	0.627	0.639	0.636	0.138	0.117	0.055	0.106
Anhui	0.588	0.578	0.573	0.580	0.184	0.090	0.027	0.120
Shanxi	0.536	0.599	0.574	0.568	0.128	0.108	0.046	0.107
Jiangxi	0.490	0.456	0.554	0.500	0.207	0.134	0.139	0.178
Henan	0.509	0.458	0.556	0.508	0.130	0.093	0.081	0.127
Hubei	0.614	0.671	0.687	0.656	0.110	0.083	0.035	0.092
Hunan	0.525	0.592	0.641	0.584	0.185	0.120	0.032	0.145
Heilongjiang	0.522	0.533	0.636	0.562	0.159	0.133	0.031	0.144
Yunnan	0.578	0.607	0.589	0.591	0.174	0.134	0.043	0.127
Inner Mongolia	0.521	0.423	0.505	0.484	0.320	0.137	0.140	0.241
Sichuan	0.637	0.633	0.659	0.643	0.116	0.098	0.030	0.088
Ningxia	0.579	0.559	0.585	0.574	0.145	0.208	0.157	0.166
Guangxi	0.520	0.527	0.553	0.533	0.280	0.089	0.090	0.175
Xinjiang	0.566	0.545	0.609	0.573	0.216	0.154	0.072	0.159
Gansu	0.738	0.654	0.610	0.670	0.225	0.086	0.043	0.172
Tibet	0.563	0.676	0.493	0.575	0.759	0.399	0.281	0.457
Guizhou	0.658	0.549	0.562	0.593	0.210	0.252	0.119	0.212
Chongqing	0.623	0.613	0.613	0.617	0.186	0.137	0.031	0.132
Shaanxi	0.610	0.616	0.657	0.627	0.200	0.126	0.027	0.136
Qinghai	0.266	0.496	0.497	0.414	0.768	0.121	0.216	0.426

largest coefficient of variation is 0.281, and the smallest is 0.017 in Guangdong. Comparing the first and second periods, only four provinces, namely, Ningxia, Guizhou, Beijing, and Guangdong, display increase in the coefficient of variation, whereas other provinces show a decrease. Based on the whole period, no province always has an increasing coefficient of variation of innovation quality development level at the time level. As the coefficient of variation here reflects primarily the fluctuation in the innovation high-quality level of a particular province over time, the above results suggest that the degree of fluctuation in the level of high-quality innovation is slowing down over time for most provinces. As previously reported, since the establishment of the reform goals of the socialist market economy system, the level of innovation quality development in most Chinese provinces has increased and volatility has decreased.

Moreover, analysis is conducted from the perspective of three major regions, namely, eastern, central, and western regions (Ghazinoory et al., 2014). Figure 1 shows that the mean value for the eastern region has been the largest in the long term, whereas the mean value for the western region has been the smallest since 2004. The trend of change exhibits two rounds of rising and then falling mean values in the three regions, with 2006 as the dividing point, and the changes are closer in the second round. The mean value of the opening and closing values for the eastern region in 1992 is 0.579, the mean value for the central region is 0.602, and the mean value for the western region is 0.609. As of 2016, the eastern region has a mean value of 0.657, the central region has a mean value of 0.628, and the western region has a mean value of 0.624. The result suggests that the three major regions' end-of-period values are greater than their beginning values despite two rounds of decreases. The above results show that HQID has a greater degree of variability, and the differences between regions are more pronounced.

2.2. Theil index decomposition

The Theil index is an aggregated indicator, so this paper concentrates on the national level and three major regional levels, where overall variance analysis, intra-regional variance analysis, and inter-regional variance analysis are included at the national level, whereas overall variance analysis is included at the three major regional levels.

Figure 2(a) illustrates the decomposition results of the level of HQID at the national level. Intra-regional variance is always greater than inter-regional variance, but the difference between the two becomes smaller over time. As of the start of the period, the intra-regional variance was 0.0255, accounting for 99.05%, and the inter-regional variance was 0.0002, accounting for about 0.95%. At the end of the period, the intra-regional variance was 0.0027, shrinking to 90.74%, and the inter-regional variance was 0.0003, increasing to 9.26%. Generally, intra-regional variation is the primary contributor to overall variation, and its trend is closer to the overall trend. The trend of change shows that at the first and second stages, the overall difference in innovation quality development level fluctuates clearly, showing multiple rounds of rising and then falling trends. However, at the third stage, the difference in innovation quality development level becomes less volatile, particularly at the later stage, displaying a decreasing trend. The overall regional differences in innovation quality development have decreased when combined with the previous definition of the Theil index. Considering that intra-regional differences reflect regional differences between provinces within a region, whereas inter-regional differences reflect regional differences among major regions, the above results indicate a marked difference between provinces within a region and relatively small differences between the three major regions.

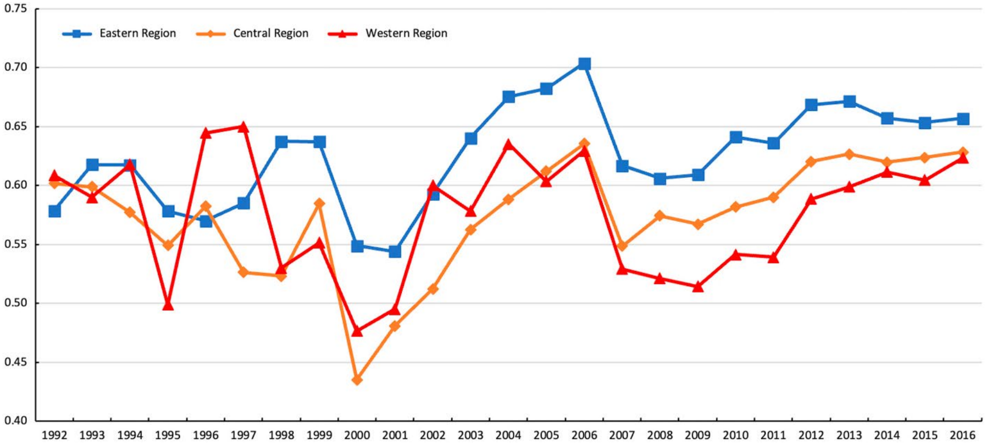
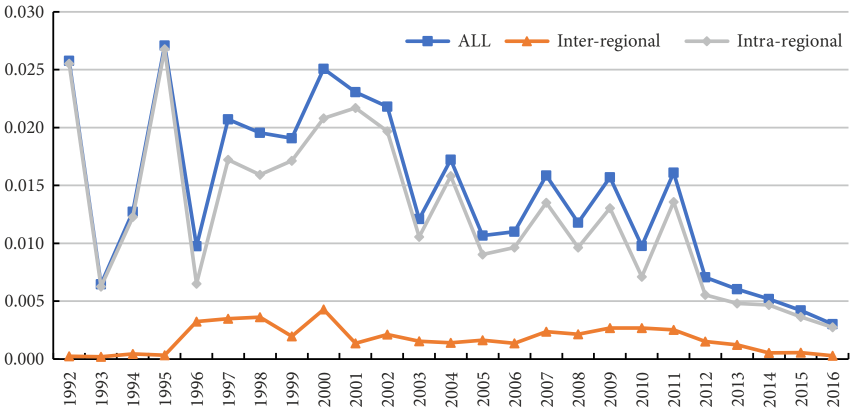


Figure 1. Results of measuring the level of high-quality innovation by region

a) At the national level



b) At the sub-regional level

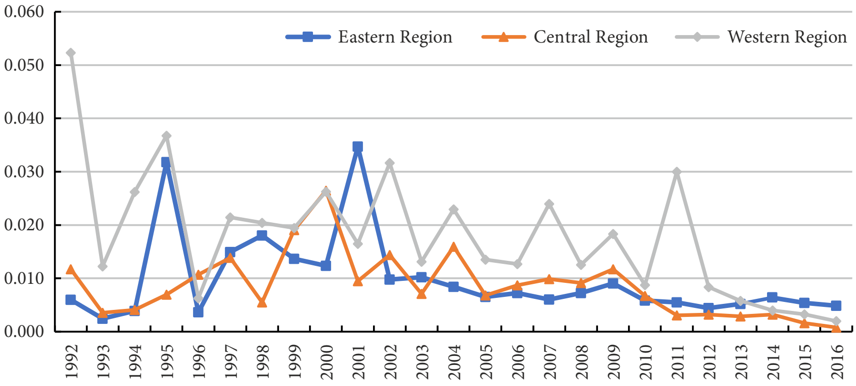


Figure 2. Results of measuring the level of high-quality innovation

As a result of the differences between the sub-regional levels of HQID, as indicated by Figure 2(b), no region always shows the maximum or minimum differences. The maximum value occurs most frequently in the western region, and the minimum value occurs most frequently in the eastern region. According to the magnitude of the opening and closing values, the overall difference indices in 1992 for HQID in the eastern, central, and western regions are 0.0060, 0.0117, and 0.0523, respectively. In 2016, the overall difference indices of the three major regions are 0.0049, 0.0008, and 0.0020, respectively, and their overall differences decrease. Combining the trend of change and the change of overall difference at the national level, the three major regions do not demonstrate stable trends of change in innovation and high-quality development, and the trend of change in the western region is similar to the national level, which is the major factor leading to the change of overall difference at the national level. In addition, taking Figures 2 and 1 as a whole, the higher the level of innovation quality development is, the smaller the internal differences, whereas the lower the level is, the larger the internal differences.

As a result of decomposing the Theil index, the analysis results indicate that regional differences in HQID have decreased primarily due to the reduction of intra-regional differences. Regional differences are dominated by intra-regional differences, i.e., the regional differences stem primarily from differences between provinces within a region. Western regions dominate the regional differences in HQID at the subregional level. Traditionally, the western region has relied heavily on external funding, excessive investment, shortcomings in science and technology, talent and other factors, and insufficient innovation capacity for its development. Further, compared with the first two stages, regional differences at the third stage are significantly reduced, i.e., the level of innovation quality development is more convergent in different regions, which indicates that regional differences in innovation quality development are gradually diminishing. The next step in our analysis is to determine regional convergence.

3. Results

3.1. σ-convergence test

Figure 3 illustrates the evolution of the convergence between the level of innovation and the development of high quality in each region of the country. From 1992 to 2016, the gap between the level of HQID in each region of the country has shown a sharp fluctuation but a steady decline trend.

Table 3 shows the convergence coefficients at the national and sub-regional levels are calculated based on the σ convergence test. At the national level, a sharp fluctuation is observed from 1992 to 2000, which is followed by a steady downward trend. In the sample interval, the average annual decline rate of the σ convergence coefficient is 1.47%, which indicates that differences in the level of innovation and high-quality development among regions in China have gradually narrowed over time. σ convergence is noted in the coefficients of variation of innovation high-quality development levels across all three regions at the regional level despite increasing fluctuations in some years. A large gap is in the level of high-quality innovation among provinces in the eastern region, whereas a small gap is in the level of high-quality innovation among provinces in the central region.

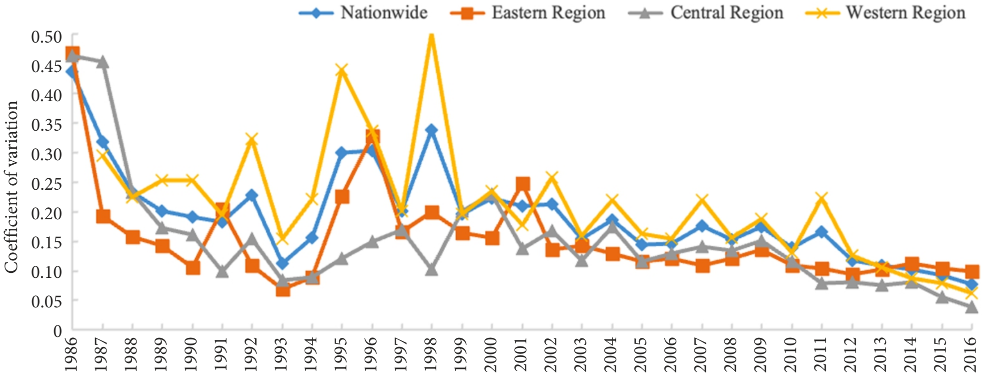


Figure 3. Trends of σ convergence for the high-quality innovation by region

Table 3. σ convergence coefficients for high-quality innovation by region, 1992–2016

Year	Nationwide	Eastern Region	Central Region	Western Region
1992	0.229	0.109	0.155	0.323
1993	0.112	0.070	0.085	0.155
1994	0.157	0.088	0.090	0.222
1995	0.300	0.226	0.120	0.441
1996	0.304	0.329	0.149	0.337
1997	0.202	0.166	0.169	0.202
1998	0.338	0.200	0.103	0.502
1999	0.196	0.165	0.201	0.196
2000	0.224	0.156	0.229	0.235
2001	0.209	0.248	0.138	0.179
2002	0.212	0.136	0.168	0.258
2003	0.154	0.142	0.118	0.160
2004	0.186	0.129	0.175	0.220
2005	0.145	0.115	0.116	0.162
2006	0.146	0.120	0.129	0.155
2007	0.176	0.109	0.142	0.220
2008	0.153	0.122	0.135	0.157
2009	0.175	0.136	0.151	0.188
2010	0.139	0.109	0.115	0.131
2011	0.166	0.105	0.079	0.224
2012	0.118	0.095	0.081	0.127
2013	0.109	0.102	0.076	0.105
2014	0.102	0.113	0.081	0.087
2015	0.092	0.105	0.056	0.080
2016	0.078	0.099	0.040	0.063

3.2. β-convergence test

Based on the above model, Equation (6), this paper evaluates the absolute convergence mechanism for the level of innovation quality development by using spatial panel Durbin model. Table 1 presents the results of the β absolute convergence test. The β values of the overall national, eastern, central, and western regions are significantly negative at the 1% level, which indicates β absolute convergence at the level of innovative, high-quality development of the nation and regions.

Table 4. Results of absolute β convergence test for the level of high-quality innovation by region in China

Region	National	East	Middle	West
Models	SDM	SDM	SDM	SDM
β	−0.974***	−0.917***	−0.708***	−1.043***
	(0.049)	(0.088)	(0.104)	(0.078)
ρ	−0.713***	−0.787***	−0.276**	−0.947***
	(0.179)	(0.172)	(0.139)	(0.198)
γ	−0.716***	−0.508	0.359	−0.802**
	(0.328)	(0.479)	(0.274)	(0.437)
Province	Yes	Yes	Yes	Yes
Fixed effects				
Year	Yes	Yes	Yes	Yes
Fixed effects				
R^2	0.321	0.326	0.198	0.390
Log-L	933.136	378.571	277.305	329.083
Hausman	148.403***	538.741***	98.916***	115.710***
Observations	750	275	200	275

Note: (1) Standard errors in parentheses, clustered to the province level; (2) ***, **, and* indicate significance at the 1%, 5%, and 10% levels, respectively.

This paper also tests whether β conditional convergence exists at the level of innovative high-quality development in each region based on model Equation (7), considering the degree to which each region has developed economically, scientifically, and technologically, and R&D input. Table 5 shows the regression results. β convergence coefficients for the whole country and each region are all negative at least at a 1% significance level based on SDM estimation. As a result, β conditional convergence is observed in HQID for the nation and the regions after accounting for time-level changes at the province level, province fixed effects, and year fixed effects.

Table 5. Results of conditional β convergence test for the level of high-quality innovation by region in China

Region	National	East	Middle	West
Models	SDM	SDM	SDM	SDM
β	-0.971^{***}	-0.974^{***}	-1.043^{***}	-1.071^{***}
	(0.049)	(0.949)	(0.123)	(0.080)
ρ	-0.791^{***}	−0.777	-0.331^{***}	-1.005^{***}
	(0.182)	(0.174)	(0.139)	(0.200)
γ	-0.712^{***}	−0.510	0.059	-0.911^{**}
	(0.328)	(0.524)	(0.315)	(0.469)
Control variables	Yes	Yes	Yes	Yes
Province Fixed effects	Yes	Yes	Yes	Yes
Year Fixed effects	Yes	Yes	Yes	Yes
R^2	0.321	0.401	0.271	0.441
Log-L	933.136	394.576	288.306	333.993
Hausman	329.121^{***}	707.834^{***}	737.146^{***}	112.552^{***}
Observations	750	275	200	275

Note: (1) Standard errors in parentheses, clustered to the province level; (2) ***, **, and* indicate significance at the 1%, 5%, and 10% levels, respectively.

3.3. Club convergence test

The Moran scatter plot is used to classify 31 Chinese provinces according to the level of HQID in each province in 2016. The 31 Chinese provinces are divided into four groups, as shown in Table 6. In the provinces classified into the same group, the level of high-quality innovations has similar properties geographically, indicating the possibility of club convergence within the group. Club convergence tests are conducted through regressions based on the clustered division of the level of high-quality innovation of each Chinese province in 2016.

The regression model is consistent with the above β absolute convergence, and this paper uses the ordinary least squares and two-way fixed effect models to test the convergence of the national and regional levels of innovation quality development, respectively. Table 7 reports the results of the club convergence test. Regardless of the inclusion of province and year fixed effects, the β values of the four regions, namely, H-H, L-H, L-L, and H-L, are significantly negative at the 1% level, which indicates club convergence in the level of regional HQID.

Table 6. Cluster group of high-quality innovation by province in 2016

Clustering grouping	H-H	L-H	L-L	H-L
High-quality innovation development level	Beijing, Guangdong, Hubei, Tianjin, Chongqing, Liaoning, Jilin, Shaanxi	Guizhou, Inner Mongolia, Hebei, Yunnan, Xinjiang, Shanxi, Heilongjiang	Ningxia, Henan, Jiangxi, Guangxi, Qinghai, Tibet, Anhui, Gansu	Shanghai, Sichuan, Jiangsu, Fujian, Hainan, Zhejiang, Hunan, Shandong

Table 7. Results of club convergence test for the level of high-quality innovation by region in China

Region	H-H		L-H		L-L		H-L	
Models	OLS	FE	OLS	FE	OLS	FE	OLS	FE
β	-0.575^{***}	-1.057^{***}	-0.926^{***}	-1.156^{***}	-0.845^{**}	-1.137^{***}	-0.906^{***}	-1.242^{***}
	(0.136)	(0.142)	(0.147)	(0.143)	(0.266)	(0.248)	(0.190)	(0.059)
Province Fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Year Fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
R^2	0.171	0.171	0.600	0.299	0.577	0.304	0.477	0.171
Observations	184	184	184	161	161	176	176	184

Note: (1) Standard errors in parentheses, clustered to the province level; (2)***,**, and* indicate significance at the 1%, 5%, and 10% levels, respectively.

Accordingly, the national and regional levels of high-quality innovations exhibit convergence in the σ convergence test and the β convergence test for the following reasons: (1) The continuous improvement of China's intellectual property protection system in the context of innovation-driven development has led to a gradual increase in the levels of scientific and technological innovation in many regions, which have benefited from intellectual property protection institutional arrangements. In addition to improving regional innovation and high-quality development, this will lead to a narrowing of regional gaps through "new track overtaking." To promote coordinated regional development, China places great value on a series of strategic deployments that encourage each region to utilize their comparative advantages according to local conditions and strengthen cooperation and innovation among regions, thereby further narrowing the gap between regional HQID.

4. HQID and industrial structure upgrade and economic growth

The relationship between the level of HQID and the upgrade of industrial structure and economic growth is analyzed by employing the dynamic impact analysis method of the PVAR model. PVAR model analysis must be preceded by a series of corresponding tests. Testing the stability of the data is necessary to determine whether a unit root exists. Levin-Lin-Chu (LLC) test and Fisher Augmented Dickey-Fuller (ADF) test are used to test the unit root of the panel data in this paper.

Using the unit root test of both panel data and rejecting the original hypothesis, Table 8 indicates that the level of HQID, index of industrial structure upgrade, economic growth rate, and total factor productivity are all stationary and pass the unit root test.

A test for optimal lag order is conducted, where the optimal lag order occurs when the corresponding test value is the smallest. Table 9 shows that the optimal lag order for the PVAR model corresponding to the level of innovation high-quality development and the level of industrial structure upgrade is order 2; Order 1 is the optimal lag order for the PVAR model in terms of the level of innovation high-quality development and economic growth rate; Using order 3 of lag to correspond to innovative high-quality development level and total factor productivity is optimal for the PVAR model.

Table 8. Results of unit root test of variables

	inno	indstr	gdp	tfp
LLC	0.000	0.000	0.000	0.000
Fisher ADF	0.000	0.000	0.023	0.000

Note: The original hypothesis for all unit root tests: "A unit root exists in the original data." Reported are the P values corresponding to the unit root test of the mean.

Table 9. Optimal lag order test results

inno & indstr	MBIC	MAIC	MQIC
1	–29.447	22.785	2.412
2	–32.004***	2.817	–10.765***
3	–15.615	1.795***	–4.996
inno & gdp	MBIC	MAIC	MQIC
1	–45.837***	–0.654***	–18.699***
2	–28.696	1.426	–10.604
3	–6.988	8.073	2.059
inno & tfp	MBIC	MAIC	MQIC
1	101.443	147.669	129.265
2	–17.731***	13.087	0.818
3	–9.473	5.935***	–0.199***

Note: *** indicates the optimal lag order.

Table 10 shows the optimal lag order determines the degrees of freedom involved in the Granger causality test. At the 10% level, HQID is the Granger causal cause of the industrial structure upgrade index, whereas the industrial structure upgrade index is not a Granger causal cause of HQID. Both HQIDs have a mutual Granger causal relationship with economic growth. A reciprocal Granger causality exists between the level of HQID and the rate of economic growth.

Table 10. Granger causality test

	Result Variables	Original hypothesis	Degree of freedom	P-value
inno & indstr	inno	indstr is not inno's Granger reason	2	0.205
	indstr	inno is not indstr's Granger reason	2	0.004
inno & gdp	inno	GDP is not inno's Granger reason	1	0.003
	GDP	inno is not GDP's Granger reason	1	0.002
inno & tfp	inno	tfp is not inno's Granger reason	3	0.000
	tfp	inno is not tfp's Granger reason	3	0.000

This paper examines the interaction between HQID and industrial structure upgrade. Figure 4 shows that the level of high-quality innovation shocks and industrial structure upgrade shocks cause themselves to fluctuate primarily upward, and both effects are significant. Over the period under examination, HQID and economic growth fluctuate upward and converge to an equilibrium value. The level of HQID fluctuates widely among them. Economic growth and the level of innovation and high-quality development have strong inertia. In addition, the interaction between the level of HQID and the upgrade of the industrial structure is analyzed. Figure 4 shows that the industrial structure upgrade index fluctuates upward due to the level of HQID, and this effect is significant, resulting in convergence to an equilibrium value during the period under investigation. Similarly, the index of industrial structure upgrade leads to an upward fluctuation in the level of HQID, with the effect being significant, converging to the equilibrium value during the period under examination. These results indicate that raising the level of innovation quality development can promote the updating of industrial structure in a sustainable manner.

In this paper, the interaction between innovation quality development and economic growth is examined. Figure 5 shows the level of high-quality innovation shocks and economic growth shocks lead to predominantly upward fluctuations, and both effects are significant. The level of high-quality innovation enters the downward fluctuation in period 4, while the economic growth enters the upward fluctuation, and both reach equilibrium during the examination period. Fluctuation is greater in terms of innovation quality development. HQID and economic growth have a strong inertia, as indicated by this result. The interaction between the level of innovation quality development and the level of economic growth is further examined. Figure 5 shows the level of HQID results in economic growth fluctuating upward. This effect is significant, and convergent to the equilibrium value throughout the paper. By contrast, economic growth shocks cause the level of HQID to always fluctuate downward. A significant effect is seen during the examination period, and it converges to the equilibrium value. Thus, increasing the level of innovation quality development promotes economic growth, and the promotion effect is long term.

This paper examines the relationship between the level of HQID and total factor productivity. Figure 6 shows that when it comes to the effect of the shock on itself, the HQID shock always causes itself to fluctuate upward. It is significant and converges to the equilibrium value during the period under consideration. However, the total factor productivity shock fluctuates upward and downward alternately. A significant effect, which does not converge to the equilibrium value during the period under study, is observed. Consequently, this result indicates strong inertia in the level of HQID. How HQID interacts with total factor productivity is further examined. Figure 6 shows that the effect of the level of high-quality innovation shock results in continuous upward fluctuations in total factor productivity. A significant effect is observed, and it does not converge to the equilibrium value in the period under analysis. The level of HQID is also affected by shocks to total factor productivity. The effect is significant and does not converge to the equilibrium value during the examination period. The level of high-quality innovation shock has a greater influence on total factor productivity in terms of magnitude. Based on the above results, the development of innovations contributes to the overall increase in productivity, and this effect is sustainable.

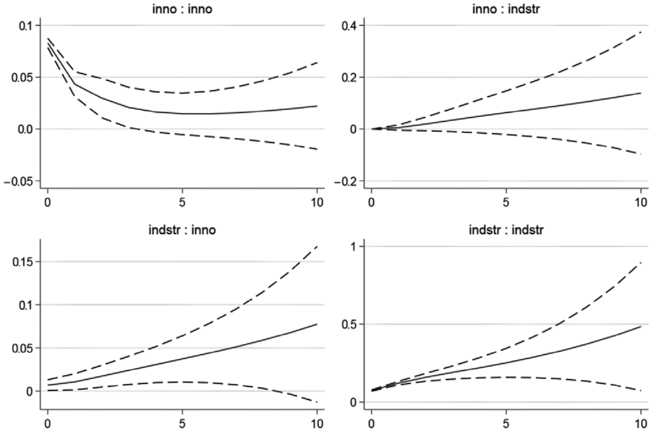


Figure 4. High-quality innovation and industrial structure upgrade

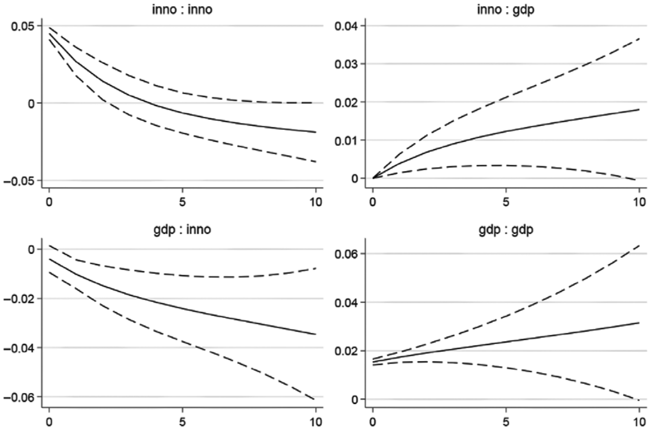


Figure 5. High-quality innovation and economic growth rate

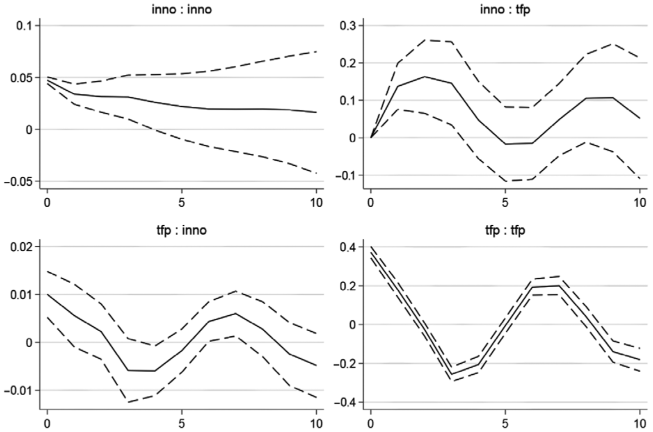


Figure 6. High-quality innovation and total factor productivity

The PVAR model results show that the level of HQID is positively correlated with the industrial structure upgrade index, economic growth rate, and total factor productivity, which indicates that high-quality innovation contributes significantly to economic growth. High-quality innovation is considered a driving force for economic development, resulting in improved input factors, the accumulation of factors, the upgrade of industrial structure, the cultivation of dynamic energy for economic growth, and the promotion of high-quality economic growth.

Conclusions and recommendations

Innovation is the key to achieving high-quality economic development. This paper uses Chinese patent data to screen out samples of high-value invention patents based on the criteria for determining high-value invention patents proposed in the 14th Five-Year Plan and obtains the index of the proportion of High-Quality Invention patents in each province after processing, thereby analyzing the development of high-quality innovation and revealing the law that governs Chinese innovation quality development. The main conclusions are as follows.

First, in terms of HQID, the overall level is on an upward trend, but differences among provinces are evident, indicating that China's HQID is unbalanced regionally, but it is generally experiencing rapid development. Although the eastern region has been at a high level for a long time overall for the development of innovative high quality, the development of innovative high quality in the three major regions is divided by the revision of patent law at various stages. HQID in the eastern region is faster at the second stage compared with the first stage, and HQID in the central and western regions is faster at the third stage compared with the second stage, indicating that the overall development of innovative high-quality in the eastern region is better, and the development of innovative high quality in the central and western regions has been rapid in recent years.

Second, regional differences in innovation quality development, primarily within a region, have been narrowing. The western region dominates the regional differences in innovation quality development at the subregional level. In addition to the time stage, the regional differences at the third stage are significantly reduced compared with the first two stages, indicating a convergence in HQID in different regions in recent years and a narrowing of differences in HQID among regions. In terms of regional convergence of HQID, the typical characteristics of σ convergence, absolute β convergence, and conditional β convergence are shown nationally and within each region. Furthermore, the phenomenon observed using the kernel density estimation method is consistent with the analysis presented above. Consequently, regional innovation quality in China exhibits a mean-reverting trend.

Third, from the relationship between innovation and high-quality development, industrial structure upgrade and economic growth, whether it is industrial structure upgrade economic growth, innovation, and high-quality development plays a positive role in promoting it, which indicates a strong interactive correlation between innovation and high-quality development, industrial structure upgrade and economic growth, and innovation and high-quality development can contribute to the shift of the powerful engine to a growth engine powered by proprietary innovation.

The following policy recommendations are derived from the above findings.

First, innovation is stimulated with intellectual property protection policies and systems. An intellectual property protection system provides the right holder with the opportunity to obtain monopoly income within a particular period, which ensures that technological innovation activities can be carried out in an orderly manner within enterprises. A reasonable, appropriate intellectual property protection can guide the optimal allocation of innovation resources in light of the increasing importance of intellectual property rights. Therefore, governments at all levels should actively implement the intellectual property index of "the number of high-value invention patents per 10,000 people" as proposed in the 14th Five-Year Plan, develop science and technology policies, and establish intellectual property protection levels to facilitate optimal resource allocation. For example, policies should support the high-quality development of the intellectual property, direct innovation resources toward strategic new industries and critical development areas for national protection of intellectual property, and ensure that patent quality is improved through the implementation of policy guidelines.

Second, regional innovation should be promoted through high-quality coordinated development. Currently, regions with higher degrees of economic development have a higher level of high-quality innovation and development, whereas regions with a lower degree of development have a lower level of high-quality innovation and development. To reduce the new regional differences brought about by innovation and high-quality development, financial capital should to promote innovation, encourage venture capital funds to be established in the western region, and increase the number of listed companies on the science and technology innovation board and venture board. Highlighting the guiding role of venture capital and breaking down capital factor barriers is essential. Moreover, policy maker can employ the concept of coordinated regional economic development, establish a multilevel inland opening platform, establish docking mechanisms for innovation platforms on the east and west sides, strengthen inter-regional cooperation, and promote two-way opening and progress between the east and west. Innovation development will be integrated into all specific work to narrow the gap between regional HQID and to establish a situation in which regional innovation and high-quality development are coordinated.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are very grateful to the anonymous reviewers and editor for their insightful comments that helped us sufficiently improve the quality of this paper. Philosophy and Social Sciences Youth Talent Cultivation and Innovation Foundation of Nanchang University funded this project under grant name "Study on collaborative governance of environmental pollution and health risks in global production networks: Theory and practice based on value chain".

References

Acemoglu, D., & Akcigit, U. (2012). Intellectual property rights policy, competition and innovation. *Journal of the European Economic Association*, *10*(1), 1–42. https://doi.org/10.1111/j.1542-4774.2011.01053.x

Acemoglu, D., Akcigit, U., Alp, H., Bloom, N., & Kerr, W. (2018). Innovation, reallocation, and growth. *American Economic Review*, *108*(11), 3450–3491. https://doi.org/10.1257/aer.20130470

Acs, Z. J., Anselin, L., & Varga, A. (2002). Patents and innovation counts as measures of regional production of new knowledge. *Research Policy*, *31*(7), 1069–1085. https://doi.org/10.1016/S0048-7333(01)00184-6

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica*, *60*(2), 323–351. https://doi.org/10.2307/2951599

Akcigit, U., Baslandze, S., & Stantcheva, S. (2016). Taxation and the international mobility of inventors. *American Economic Review*, *106*(10), 2930–2981. https://doi.org/10.1257/aer.20150237

Asheim, B. T., & Gertler, M. S. (2006). The geography of innovation: Regional innovation systems. In J. Fagerberg & D. C. Mowery (Eds.), *The Oxford handbook of innovation* (pp. 291–317). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199286805.003.0011

Bai, J. (2013). On regional innovation efficiency: Evidence from panel data of China's different provinces. *Regional Studies*, *47*(5), 773–788. https://doi.org/10.1080/00343404.2011.591784

Barro, R. J., & Sala-i-Martin, X. (1992). Convergence. *Journal of Political Economy*, *100*(2), 223–251. https://doi.org/10.1086/261816

Battese, G. E., & Coelli, T. J. (1992). Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis*, *3*(1), 153–169. https://doi.org/10.1007/BF00158774

Boeing, P., & Mueller, E. (2019). Measuring China's patent quality: Development and validation of ISR indices. *China Economic Review*, *57*, Article 101331. https://doi.org/10.1016/j.chieco.2019.101331

Chen, K., & Guan, J. (2012). Measuring the efficiency of China's regional innovation systems: Application of network Data Envelopment Analysis (DEA). *Regional Studies*, *46*(3), 355–377. https://doi.org/10.1080/00343404.2010.497479

Dang, J., & Motohashi, K. (2015). Patent statistics: A good indicator for innovation in China? Patent subsidy program impacts on patent quality. *China Economic Review*, *35*, 137–155. https://doi.org/10.1016/j.chieco.2015.03.012

Figueroa, N., & Serrano, C. J. (2019). Patent trading flows of small and large firms. *Research Policy*, *48*(7), 1601–1616. https://doi.org/10.1016/j.respol.2019.03.002

Fu, X., & Mu, R. (2014). Enhancing China's innovation performance: The policy choices. *China & World Economy*, *22*(2), 42–60. https://doi.org/10.1111/j.1749-124X.2014.12061.x

Galasso, A., Schankerman, M., & Serrano, C. J. (2013). Trading and enforcing patent rights. *The RAND Journal of Economics*, *44*(2), 275–312. https://doi.org/10.1111/1756-2171.12020

Ghazinoory, S., Riahi, P., Azar, A., & Miremadi, T. (2014). Measuring innovation performance of developing regions: Learning and catch-up in provinces of Iran. *Technological and Economic Development of Economy*, *20*(3), 507–533. https://doi.org/10.3846/20294913.2014.881433

Griliches, Z. (1998). Introduction to" R&D and Productivity: The Econometric Evidence". In *R&D and productivity: The econometric evidence* (pp. 1–14). University of Chicago Press. https://doi.org/10.7208/chicago/9780226308906.001.0001

Grossman, G. M., & Helpman, E. (1991). Trade, knowledge spillovers, and growth. *European Economic Review*, *35*(2), 517–526. https://doi.org/10.1016/0014-2921(91)90153-A

Gu, J. (2022). Spatiotemporal dynamics of the patent race: Empirical evidence from listed companies in China. *Asian Journal of Technology Innovation*, *30*(1), 106–133. https://doi.org/10.1080/19761597.2020.1830813

Hall, B. H., & Harhoff, D. (2012). Recent research on the economics of patents. *Annual Review of Economics*, *4*(1), 541–565. https://doi.org/10.1146/annurev-economics-080511-111008

Hall, B. H., Jaffe, A., & Trajtenberg, M. (2005). Market value and patent citations. *The RAND Journal of Economics*, *36*(1), 16–38. http://www.jstor.org/stable/1593752

Harhoff, D. (2016). Patent quality and examination in Europe. *American Economic Review*, *106*(5), 193–197. https://doi.org/10.1257/aer.p20161093

Harhoff, D., Scherer, F. M., & Vopel, K. (2003). Citations, family size, opposition and the value of patent rights. *Research Policy*, *32*(8), 1343–1363. https://doi.org/10.1016/S0048-7333(02)00124-5

Higham, K., de Rassenfosse, G., & Jaffe, A. B. (2021). Patent quality: Towards a systematic framework for analysis and measurement. *Research Policy*, *50*(4), Article 104215. https://doi.org/10.1016/j.respol.2021.104215

Hong, J., Zhu, R., Hou, B., & Wang, H. (2019). Academia-industry collaboration and regional innovation convergence in China. *Knowledge Management Research & Practice*, *17*(4), 396–407. https://doi.org/10.1080/14778238.2019.1589394

Hu, A. G., & Jefferson, G. H. (2009). A great wall of patents: What is behind China's recent patent explosion? *Journal of Development Economics*, *90*(1), 57–68. https://doi.org/10.1016/j.jdeveco.2008.11.004

Huang, J., Li, W., Huang, X., Wang, Y., & Guo, L. (2020). Technology and innovation in China: A patent citation-based analysis. *Science, Technology and Society*, *26*(2), 344–365. https://doi.org/10.1177/0971721820932020

Jaffe, A. B., Trajtenberg, M., & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, *108*(3), 577–598. https://doi.org/10.2307/2118401

Jiang, H., Liang, Y., & Pan, S. (2022). Foreign direct investment and regional innovation: Evidence from China. *The World Economy*, *45*(6), 1876–1909. https://doi.org/10.1111/twec.13205

Jin, P., Peng, C., & Song, M. (2019). Macroeconomic uncertainty, high-level innovation, and urban green development performance in China. *China Economic Review*, *55*, 1–18. https://doi.org/10.1016/j.chieco.2019.02.008

Kim, S. K., Lee, B. G., Park, B. S., & Oh, K. S. (2011). The effect of R&D, technology commercialization capabilities and innovation performance. *Technological and Economic Development of Economy*, *17*(4), 563–578. https://doi.org/10.3846/20294913.2011.603481

Kogan, L., Papanikolaou, D., Seru, A., & Stoffman, N. (2017). Technological innovation, resource allocation, and growth. *The Quarterly Journal of Economics*, *132*(2), 665–712. https://doi.org/10.1093/qje/qjw040

Kowalski, A. M. (2022). Innovation divide in the world economy: China's convergence towards the Triad. *Technological and Economic Development of Economy*, *28*(5), 1350–1367. https://doi.org/10.3846/tede.2022.16865

Lanjouw, J. O., & Schankerman, M. (2004). Patent quality and research productivity: Measuring innovation with multiple indicators. *The Economic Journal*, *114*(495), 441–465. https://doi.org/10.1111/j.1468-0297.2004.00216.x

Lerner, J., Sorensen, M., & Strömberg, P. E. R. (2011). Private equity and long-run investment: The case of innovation. *The Journal of Finance*, *66*(2), 445–477. https://doi.org/10.1111/j.1540-6261.2010.01639.x

Li, J., Sutherland, D., Ning, L., & Wang, Y. (2014). Firm ownership, industrial structure, and regional innovation performance in China's provinces. *Technology Analysis & Strategic Management*, *26*(9), 1001–1022. https://doi.org/10.1080/09537325.2014.943714

Li, X. (2009). China's regional innovation capacity in transition: An empirical approach. *Research Policy*, *38*(2), 338–357. https://doi.org/10.1016/j.respol.2008.12.002

Long, C. X., & Wang, J. (2018). China's patent promotion policies and its quality implications. *Science and Public Policy*, *46*(1), 91–104. https://doi.org/10.1093/scipol/scy040

Lv, C., Bian, B., Lee, C.-C., & He, Z. (2021). Regional gap and the trend of green finance development in China. *Energy Economics*, *102*, Article 105476. https://doi.org/10.1016/j.eneco.2021.105476

Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economic growth. *The Quarterly Journal of Economics*, *107*(2), 407–437. https://doi.org/10.2307/2118477

Mann, R. J., & Underweiser, M. (2012). A new look at patent quality: Relating Patent prosecution to validity. *Journal of Empirical Legal Studies*, *9*(1), 1–32. https://doi.org/10.1111/j.1740-1461.2011.01245.x

Mao, C. C., & Ma, Z. X. (2021). The analysis of the regional economic growth and the regional financial industry development difference in China is based on the theil index. *International Journal of Economics and Finance Studies*, *13*(1), 128–154.

Marco, A. C., Sarnoff, J. D., & deGrazia, C. A. W. (2019). Patent claims and patent scope. *Research Policy*, *48*(9), Article 103790. https://doi.org/10.1016/j.respol.2019.04.014

Moser, P. (2013). Patents and Innovation: Evidence from Economic History. *Journal of Economic Perspectives*, *27*(1), 23–44. https://doi.org/10.1257/jep.27.1.23

Qin, S., & Xiong, Y. (2022). Innovation strategies of Chinese new energy vehicle enterprises under the influence of non-financial policies: Effects, mechanisms and implications. *Energy Policy*, *164*, Article 112946. https://doi.org/10.1016/j.enpol.2022.112946

Shu, T., Tian, X., & Zhan, X. (2022). Patent quality, firm value, and investor underreaction: Evidence from patent examiner busyness. *Journal of Financial Economics*, *143*(3), 1043–1069. https://doi.org/10.1016/j.jfineco.2021.10.013

Squicciarini, M., Dernis, H., & Criscuolo, C. (2013). *Measuring patent quality: Indicators of technological and economic value* (OECD Science, Technology and Industry Working Papers No. 2013/03). OECD Publishing, Paris. https://doi.org/10.1787/5k4522wkw1r8-en

Tian, G. (2019). Deceleration of China's economic growth: Causes and countermeasures. *Frontiers of Economics in China*, *14*(1), 3–25.

Trajtenberg, M., Shiff, G., & Melamed, R. (2009). The "Names Game": Harnessing Inventors, patent data for economic research. *Annals of Economics and Statistics*, (93/94), 79–108. https://doi.org/10.2307/27917384

Wang, S., Fan, J., Zhao, D., & Wang, S. (2016). Regional innovation environment and innovation efficiency: The Chinese case. *Technology Analysis & Strategic Management*, 28(4), 396–410. https://doi.org/10.1080/09537325.2015.1095291

Wei, S.-J., Xie, Z., & Zhang, X. (2017). From "Made in China" to "Innovated in China": Necessity, prospect, and challenges. *Journal of Economic Perspectives*, *31*(1), 49–70. https://doi.org/10.1257/jep.31.1.49

Xu, A., Qiu, K., Jin, C., Cheng, C., & Zhu, Y. (2022). Regional innovation ability and its inequality: Measurements and dynamic decomposition. *Technological Forecasting and Social Change*, *180*, Article 121713. https://doi.org/10.1016/j.techfore.2022.121713

Yang, X., Zhang, H., Lin, S., Zhang, J., & Zeng, J. (2021). Does high-speed railway promote regional innovation growth or innovation convergence? *Technology in Society*, *64*, Article 101472. https://doi.org/10.1016/j.techsoc.2020.101472

Ying, L., Li, M., & Yang, J. (2021). Agglomeration and driving factors of regional innovation space based on intelligent manufacturing and green economy. *Environmental Technology & Innovation*, *22*, Article 101398. https://doi.org/10.1016/j.eti.2021.101398

Zacchia, P. (2019). Knowledge spillovers through networks of scientists. *The Review of Economic Studies*, *87*(4), 1989–2018. https://doi.org/10.1093/restud/rdz033

Zeng, J., Liu, Y., Wang, R., & Zhan, P. (2019). Absorptive capacity and regional innovation in China: An analysis of patent applications, 2000–2015. *Applied Spatial Analysis and Policy*, *12*(4), 1031–1049. https://doi.org/10.1007/s12061-019-09300-y

Zhang, Y. (2021). The regional disparity of influencing factors of technological innovation in China: Evidence from high-tech industry. *Technological and Economic Development of Economy*, *27*(4), 811–832. https://doi.org/10.3846/tede.2021.14828

Zhao, L. (2022). On the grant rate of patent cooperation treaty applications: Theory and evidence. *Economic Modelling*, *117*, Article 106051. https://doi.org/10.1016/j.econmod.2022.106051

Zheng, J., Bigsten, A., & Hu, A. (2009). Can China's growth be sustained? A productivity perspective. *World Development*, *37*(4), 874–888. https://doi.org/10.1016/j.worlddev.2008.07.008

APPENDIX

In the context of the Chinese system, patents are closely related to innovation for several reasons.

1. The relationship between patents and innovation activities in China

Although patents may not be a perfect proxy for innovation, they do provide a reasonable indication of innovative activities in China due to the nation's unique policies and economic environment. Some of the key factors that establish this close relationship between patents and innovation in China include the recognition of high-tech enterprises and the IPO requirements for the Science and Technology Innovation Board.

(1) Recognition of high-tech enterprises

The Chinese government has implemented policies to encourage and support the growth of high-tech enterprises, as they play a crucial role in the country's economic development and global competitiveness. To be recognized as a high-tech enterprise, a company must meet specific criteria, including a significant number of patents. This requirement reflects the importance of patents in demonstrating a firm's commitment to research, development, and innovation.

(2) IPO requirements for the Science and Technology Innovation Board

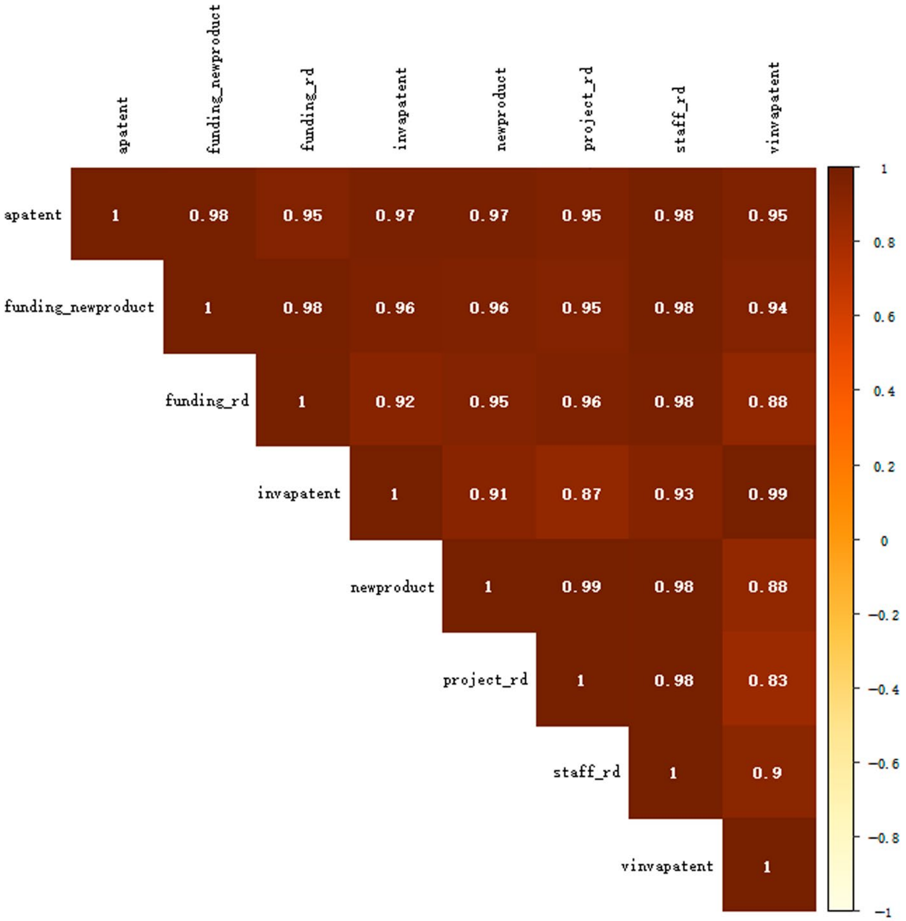
China's Science and Technology Innovation Board (also known as the STAR Market) was established to support technology-driven and innovative companies in raising capital. To be eligible for listing on the board, companies must demonstrate their innovative capabilities through a robust intellectual property portfolio, which includes patents. This requirement highlights the significance of patents in China's efforts to foster innovation and promote the growth of technology-intensive industries.

In conclusion, while patents may not be a perfect measure of innovation, they hold significant value in the Chinese context due to the government's innovation-driven development strategy and the requirements for recognition as a high-tech enterprise and listing on the Science and Technology Innovation Board. These factors contribute to the close relationship between patents and innovation in China., Therefore, it is appropriate to use patent data as a proxy for innovation activity in China.

2. The relationship between patents and other innovation indicators in China

In order to establish the relationship between patents and other indicators of innovation and to prove the feasibility of using patents to measure innovative activity, we conducted an analysis examining the correlation between corporate patents and other innovation measures, such as new products and research and experimental development activities. This analysis is based on data disclosed by the Department of Planning and Development of the State Intellectual Property Office of China.

Figure A1 below presents the results of our analysis, where: apatent represents the average number of patent applications by industrial enterprises above a designated size in each



	apatent	funding_newproduct	funding_rd	invapatent	newproduct	project_rd	staff_rd	vinvapatent
apatent	1	0.98	0.95	0.97	0.97	0.95	0.98	0.95
funding_newproduct		1	0.98	0.96	0.96	0.95	0.98	0.94
funding_rd			1	0.92	0.95	0.96	0.98	0.88
invapatent				1	0.91	0.87	0.93	0.99
newproduct					1	0.99	0.98	0.88
project_rd						1	0.98	0.83
staff_rd							1	0.9
vinvapatent								1

Figure A1. The relationship between patents and other innovation indicators in China province; invapatent represents the average number of invention patent applications by such enterprises; vinvapatent represents the average number of valid invention patents held by these enterprises; newproduct represents the average number of new product items introduced by these enterprises; funding_newproduct represents the average value of funding allocated for new product development in these enterprises; funding_rd represents the average value of R&D funding in these enterprises; project_rd represents the average number of R&D projects undertaken by these enterprises; and staff_rd represents the average value of full-time equivalent R&D staff employed by these enterprises.

Our analysis reveals that the correlation between enterprise patents and enterprise new products is greater than 0.85, while the correlation between enterprise patents and enterprise research and experimental development activities exceeds 0.8. These strong correlations suggest that patents are indeed closely related to other measures of innovation, reinforcing the validity of using patents as a proxy for innovative activity in our study. By incorporating these findings into our revised manuscript, we hope to address concerns raised by reviewers and provide further evidence supporting our choice of patents as an appropriate measure of innovation.

3. The relationship between high-value invention patents and high-quality innovation development in China

These high-value invention patents, which are in line with the regulations of the State Intellectual Property Office of China (SIPO), serve as a crucial indicator of China's innovation quality and are endorsed by the government. At a press conference on China's intellectual property work in 2022 held by the State Council, the Director General of the Department of Strategic Planning of the State Intellectual Property Office (SIPO) introduced the situation of high-value invention patents in China, agreed that high-value invention patents are an important indicator of the quality of innovation, and pointed out that in the future, the SIPO will put quality in a more prominent position, cultivate more high-value core patents, and boost high-quality economic and social development with high-quality development of intellectual property[2]. This statement underlines the importance of these patents as a measure of innovation quality in the country and supports our choice of using them in our analysis.

Furthermore, the inclusion of high-value invention patents in critical Chinese government documents, such as the 14th Five-Year Plan and the 2035 Vision outline, strengthens the relevance of these patents in the context of China's innovation landscape. These government documents set the strategic direction for China's economic and technological development, with the emphasis on high-value invention patents highlighting their role as a key component of the nation's innovation-driven growth strategy. Taking these points into consideration, our use of high-value invention patents in the article is well-justified, as they provide a meaningful and government-endorsed measure of innovation quality in China.

---

[2] http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/49421/49470/wz49472/Document/1735314/1735314.htm

4. Documentary evidence on the use of patents to measure innovation activity

Patent statistics, which contain rich and timely information on inventive activities, are increasingly utilized to analyze and measure innovations. While R&D expenditures serve as a widespread proxy for innovation input, patent statistics can measure output. This measure is more easily obtainable than other proxies for outputs, such as total factor productivity (TFP). Although patent statistics are not conceptually perfect as innovations are not always patentable or patented, they remain a reliable indicator of innovations in China. Dang and Motohashi (2015) merged patent data with industrial survey data, discovering that both patent applications and patent grants have a strong correlation with R&D expenditures. Consequently, patent statistics represent a valuable measure of innovation in China. Moreover, Wei et al. (2017) argue that innovation across all dimensions is positively correlated.

In summary, despite the acknowledged limitations of patents as a measure of innovation, substantial evidence in the economic literature supports their use in analyzing innovation activities. By incorporating this authoritative evidence into our revised manuscript, we aim to further justify our adoption of patents as a proxy for innovation.